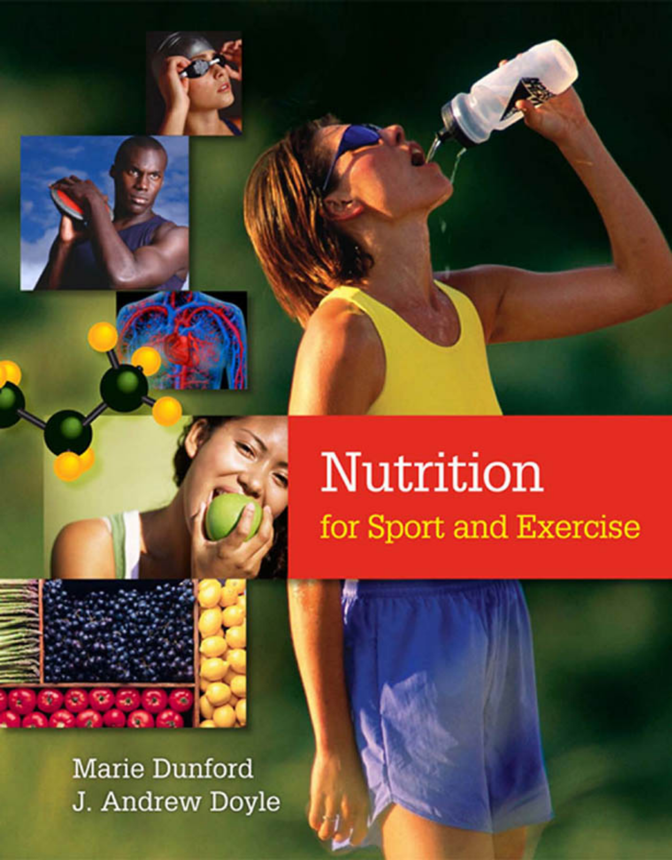

Nutrition
for Sport and Exercise

Marie Dunford
J. Andrew Doyle

Common Conversion Factors

Energy Conversions

1 kilocalorie (kcal)	=	4.184 kilojoules
1 calorie (cal)	=	4.184 joules (J)
1 kilocalorie (kcal)	=	1,000 calories or 4,184 joules
1 Calorie (C)	=	1,000 calories or 4,184 joules
1 kilojoule (kJ)	=	1,000 joules

Volume Conversions

1 teaspoon (tsp or t)	=	4.93 (~5) milliliters (ml)
1 tablespoon (tbsp or T)	=	14.8 (~15) milliliters (ml) or 3 tsp
1 fluid ounce (fl oz)	=	29.6 (~30) milliliters (ml) or 2 T
1 cup	=	236.6 (~240) ml or 8 fl oz or 16 T
1 pint (pt)	=	473.2 (~470) ml or 16 fl oz or 2 cups
1 quart (qt)	=	946.4 (~950) ml or 32 fl oz or 4 cups
1 gallon (gal)	=	3.79 liters (L) or 64 fl oz or 8 cups
1 liter (L)	=	1,000 milliliters (ml)

Mass Conversions

1 ounce (oz)	=	28.3 grams (g)
1 gram (g)	=	1,000 milligrams (mg)
1 milligram (mg)	=	1,000 micrograms (mcg or µg)
1 microgram (mcg or µg)	=	0.001 milligrams (mg)
1 pound (lb)	=	0.45 kilograms (kg) or 454 g or 16 oz
1 kilogram (kg)	=	2.2 pounds (lb) or 1,000 g

Length Conversions

1 inch (in)	=	2.54 centimeters (cm)
1 foot (ft)	=	30.48 centimeters (cm)
1 yard (yd)	=	0.9 meters (m)
1 meter (m)	=	39.37 inches (in)
1 mile (mi)	=	1.6 kilometers (km)
1 kilometer (km)	=	1,000 meters (m)

Temperature Conversions

1 degree Celsius (ºC)	=	33.8 degrees Fahrenheit (ºF)
Celsius (ºC) to Fahrenheit (ºF)	=	Multiply temperature in ºC by 9; Divide the answer by 5; Add 32

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Former Professor and Chair
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Georgia State University

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Dedication

To my husband, Greg, who for 30 years has always kept his promises.

MGD

To my wife, Colleen, and my sons, Patrick and Jackson—the sources of my joy and happiness.

JAD

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Brief Contents

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Preface

Sports nutrition is a natural marriage of two fields: nutrition and exercise physiology. These complementary academic disciplines enable us to understand the energy expenditure that is required by exercise and sport, and the energy intake that is vital to support these activities. Exercise challenges the human body to respond and adapt, and proper nutrition supports these processes. While all people can benefit from proper nutrition and exercise, athletes must pay careful attention to both. Training and nutrition are key elements of excellent athletic performance.

Nutrition for Sport and Exercise is designed primarily as a college-level text for upper division courses in sports nutrition. It carefully illustrates the links between exercise; the increased demand for nutrients as a result of training; the translation of nutrient goals to specific plans for the appropriate amount and type of foods, beverages, and/or supplements; and, the ultimate goal, excellent performance. First and foremost, this book is scientifically sound and evidence-based, but it is also filled with practical nutrition information and designed so faculty can teach from the text.

To understand sports nutrition, students must understand both nutrition and exercise physiology. For example, carbohydrates are found in food and are used by the body to fuel exercise. The type and amount of carbohydrates in foods are "nutrition" issues. The influences of exercise intensity and duration on carbohydrate usage are "exercise physiology" issues. Sports nutrition requires an understanding and integration of these issues because the timing of carbohydrate intake or the amount needed to delay the onset of fatigue involves both nutrition and exercise physiology. The goal of this book is to integrate the principles of nutrition and exercise physiology in a well-organized sports nutrition text.

THE PLAN OF THE TEXT

Chapter 1, *Introduction to Sports Nutrition,* sets the stage. Broad terms such as *athlete* and *exercise* are defined, and basic training and sports nutrition principles are outlined. The intensity and duration of exercise training and the unique demands of competition affect nutrition requirements and food intake. Many recreational athletes require only a good basic diet. Nearly all athletes have questions about supplements, and the first chapter discusses basic information about and a process for evaluating dietary supplements.

The first chapter also emphasizes the science behind sports nutrition recommendations. From the beginning students should recognize that the recommendations made throughout the text are evidence-based. As part of the critical thinking process, future chapters will reinforce some of the basic concepts introduced in the initial chapter, such as the strength of the scientific evidence, research design, and consensus opinion. A unique feature of this chapter is the information on scope of practice of dietitians, exercise physiologists, athletic trainers, strength and conditioning coaches, and other sports-related professionals. As with any integrated discipline, no one profession "owns" sports nutrition. However, extent of professional training and licensure can help students understand practice boundaries and when to refer to someone with the appropriate expertise, professional training, and/or credentials.

Chapters 2 and 3 cover energy concepts. Extensive teaching experience has convinced the authors that students more easily understand the difficult area of energy if it is broken into two parts. The first part (*Defining and Measuring Energy*) introduces general energy concepts—what energy is and how it is measured by direct and indirect calorimetry. This leads to a discussion of energy balance and an explanation of factors that affect it, such as resting metabolic rate, physical activity, and food intake.

Once that foundation is established, then students can more easily understand the specific energy systems needed to fuel exercise of varying intensities as presented in Chapter 3, *Energy Systems and Exercise*. The focus of the chapter is an explanation of the three major energy systems used to replenish ATP—creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation. Oxygen consumption, fuel utilization, and the Respiratory Exchange Ratio are described, and the safety and effectiveness of creatine supplements are reviewed.

Chapters 4, 5, and 6 cover three energy-containing nutrients—*Carbohydrates*, *Proteins,* and *Fats*. These topics are at the heart of sports nutrition. Each chapter begins with a description of digestion, absorption, and metabolism and explains each as a source of energy based on the intensity and duration of exercise. Current recommendations for athletes are outlined and the effects of inadequate intake on training and performance are discussed. Type, amount, and timing are important nutrition concepts, and these chapters end with a focus on the translation of current recommendations to appropriate food and beverage choices.

Similar to Chapters 4 through 6, Chapters 7 through 9 are nutrient-focused. *Water and Electrolytes* are covered first, followed by *Vitamins* and *Minerals*. These chapters feature a holistic approach. For example, Chapter 7 begins with an overview of water and electrolytes but emphasizes the effect that exercise has on fluid and electrolyte balance by examining water and electrolyte loss and intake during training and competition. The recommendations for replenishment of water and electrolytes are a logical extension of understanding fluid homeostasis.

To avoid the encyclopedic approach that can overwhelm students with detailed information about vitamin and minerals, Chapters 8 and 9 are organized according to function. In the case of vitamins, their major roles in energy metabolism, antioxidant protection, and red blood cell function are explained. The mineral chapter is organized according to bone, blood, and immune system function and emphasizes calcium, iron, and zinc, respectively. Each chapter also discusses adequate intake and the potential for clinical and subclinical deficiencies and toxicities. Vitamin- and mineral-rich foods, fortified foods, and supplement sources are covered with special attention paid to the perceived need for supplementation by athletes.

After a solid foundation in principles of sports nutrition has been laid, the text moves into comprehensive diet planning. Chapter 10 is entitled *Diet Planning: Food First, Supplements Second* and helps students take the science-based nutrient recommendations made in the previous chapters and translate them into daily food choices, including food and fluid intake prior to, during, and after exercise. Nutrition periodization, a plan for matching dietary intake to the demands imposed by training, is emphasized. This chapter also contains information about caffeine, alcohol, and dietary supplements. Supplements are a complicated issue requiring an understanding of legality, ethics, safety, and effectiveness, and practitioners will have little credibility with athletes if they simply dismiss their use. Exploring the issues surrounding dietary supplements helps students become better critical thinkers.

No sports nutrition book would be complete without a chapter on body composition. Chapter 11, *Weight and Body Composition,* is realistic—it considers measurement techniques, error of measurement, interpretation of body composition results, and the relationship of body composition and weight to performance. The chapter begins with a review of methods for determining body composition and the advantages and disadvantages of each. The role of training and nutrition in increasing muscle mass and decreasing body fat is explained. Minimum and target body weights, based on a body composition that promotes health, are discussed for sports in which making weight or achieving a certain appearance is important. Muscle building and weight loss supplements are also covered.

While the focus in most of the chapters is on the trained athlete, Chapter 12 gives ample coverage to diet and exercise for lifelong fitness and health and their roles in preventing or delaying chronic disease. Many students dream of working with elite athletes, but in reality most will work with many people who are recreational athletes or are untrained, have relatively low fitness levels, eat poorly, and want to lose weight. This chapter addresses the issue of declining physical activity associated with aging and uses scenarios of former athletes to highlight chronic diseases such as obesity, type 2 diabetes, heart disease, metabolic syndrome, osteoporosis, and lifestyle-related cancers.

The final chapter covers disordered eating and exercise patterns in athletes. The book's philosophy throughout is that normal eating is flexible and that food is eaten for fuel and for fun. However, disordered eating and life-threatening eating disorders can touch the lives of anyone who works with athletes, and these problems cannot be ignored. This chapter follows the progression of eating and activity patterns from "normal" to disordered to severely dysfunctional, and explains the interrelated elements of the Female Athlete Triad.

Nutrition for Sport and Exercise is a blend of nutrition and exercise physiology and both scientific and practical information. It differs from other books on the market because it is targeted to upper division students only (not graduate students) and fully integrates both fields of study. It is not an exercise physiology book with nutrition as an afterthought or a nutrition book with superficial explanations of core exercise physiology principles. The authors, a registered dietitian and an exercise physiologist, have more than 30 years of classroom experience in sports nutrition and have used that experience to create a text that, we believe, meets the needs of both nutrition and exercise science majors.

SUPPLEMENTAL RESOURCES

Instructor's CD-ROM. This CD-ROM includes Instructor Manual and Test Bank resources and PowerPoint® presentations to accompany every chapter of the text.

- Instructor's Manual with Test Bank. This contains objectives, chapter outlines, instructor activities, and discussion questions. The Test Bank consists of multiple-choice, true-false, fill-in, and essay questions.
- PowerPoint® Presentation. This tool contains lecture slides to correspond with every chapter

of the text; also included are figures and art from the text. Chapter Objectives are featured at the beginning of each chapter.

- ExamView®—Computerized Testing. Create, deliver, and customize tests and study guides (both print and online) in minutes with this easy-to-use assessment and tutorial system. ExamView offers both a Quick Test Wizard and an Online Test Wizard that guide you step-by-step through the process of creating tests, while its unique capability allows you to see the test you are creating on the screen exactly as it will print or display online.

Website (http://thomsonedu.com/health) When you adopt *Nutrition for Sport and Exercise,* you and your students will have access to a rich array of teaching and learning resources that you won't find anywhere else. This site features student and instructor resources for this text, including self-quizzes, Web links, suggested online readings, and discussion forums—as well as downloadable supplementary resources, for instructors. You will also find an online catalog of Wadsworth's health, fitness, wellness, and physical education books and supplements.

Diet Analysis+ for Exercise and Health Science, Version 1.0 We have updated Diet Analysis+, the market-leading diet assessment program for Nutrition, to make it more useful for Exercise and Health Science courses. The user can easily create a personalized profile based on height, weight, age, sex, and activity level, including additional features to measure body frame, BMI, girth in centimeters, skinfold in millimeters, and exercise and resting heart rates. Its dynamic interface makes it easy to track calories, carbohydrates, fiber, proteins, fats, vitamins, and minerals in foods, as well as determine whether nutrient needs are being met. A new table is included to highlight nutrients obtained from dietary supplements.

Walk4life Elite Model Pedometer This pedometer tracks steps, elapsed time, distance, and calories expended. The pedometer includes an extra large digital display with a hinged protective cover, and comes with instructions outlining how to use the tool most effectively. It can be used as part of an in-class activity or as a tool to increase awareness and encourage students to simply track their steps and walk toward better fitness. This is a valuable resource for everyone *and* at $10.50 when bundled with the text, this pedometer is a deal!

ACKNOWLEDGEMENTS

From initial conceptualization to final product, this book required several years and the efforts and inspiration of many people. The authors would like to thank those people, both together and individually, who have either directly or indirectly helped make this book a reality.

Many thanks to all of the people at Thomson Learning and associated companies who were able to take all our words and ideas and turn them into the professional work you see here. It takes an astonishing number of talented and creative people to produce a book like this and we want to personally thank them all.

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We are particularly appreciative of those who reviewed the manuscript. Their time, effort, and suggestions have helped make this a much better book. We appreciate your insights and your suggestions.

REVIEWERS

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In addition to our appreciation of the work done by our editorial and production teams, each of us wishes to express special thanks as follows:

MGD: This book actually began in the 1980's, although I didn't know it at the time, when some insightful faculty at California State University, Fresno supported the development of a new course—Nutrition and the Athlete. The course evolved over the many years that I taught it, in large part due to feedback from students, and I would like to thank them for challenging me to be a better teacher. I also met Andy Doyle during this time, a fellow member of the faculty, who is a wonderful co-author. I thank him for adding his considerable expertise to this book, bringing the best out in me, and always maintaining his sense of humor.

It takes many years to write a textbook and it is such an arduous task that it would not be possible without support from family, friends, and colleagues. There are too many to mention by name but I am most appreciative to all who have encouraged me over the course of my career.

JAD: I would like to thank Marie for inviting me to join her in this project. This book was not only her idea, it would not have happened without her patience, persistence, discipline, and good humor. My mother, Ann Lundquist, and my sister, Liz Doyle have always been supportive of my education and my career, and I would like to thank them for their love and support. Many thanks are due to the students who have been an integral part of my courses and research over the years. In particular, I'd like to thank Michael Green and Ben Corona for their research assistance on this book, and Rob Skinner for the many conversations we've had in which he has shared his ideas and experience in sports nutrition. Finally, I would like to thank the faculty and staff of the Department of Kinesiology and Health at Georgia State University for their patience and support.

Marie Dunford, Ph.D., R.D.
Former Professor and Chair
Department of Food Science and Nutrition
California State University, Fresno

J. Andrew Doyle, Ph.D.
Associate Professor and Chair
Department of Kinesiology and Health
Georgia State University

About the Authors

Marie Dunford, Ph.D., R.D. has been involved in sports nutrition since the mid-1980's. In 1985, while a faculty member at California State University, Fresno, she created the curriculum for an upper division course entitled, Nutrition and the Athlete. She taught the course for a total of 16 years during which time she interacted with thousands of student-athletes. This direct exposure to nutrition and exercise science majors and NCAA Division I athletes, helped her to develop an understanding of how students learn and the sports nutrition topics that are the most difficult for students to master. Since leaving the university, Dr. Dunford has written numerous online sports nutrition courses for nutrition and exercise professionals. She is an active member of SCAN, the Sports, Cardiovascular and Wellness Nutritionists, a dietetic practice group of the American Dietetic Association, and a member of the American College of Sports Medicine. Dr. Dunford is the editor of the 4th edition of Sports Nutrition: A Practice Manual for Professionals (2006). She is an avid recreational tennis player.

J. Andrew Doyle, Ph.D. is an Associate Professor of Exercise Physiology in the Department of Kinesiology and Health at Georgia State University where he serves as the Department Chair. He received a B.S. in Zoology from Clemson University, a M.S. in Exercise Science from Georgia State University, and his doctorate in Exercise Physiology from the Ohio State University. He has taught exercise physiology, exercise testing and fitness assessment, and exercise programming, at the undergraduate and graduate levels for nearly 20 years. His research interests include carbohydrate metabolism and exercise and the role of physical activity, exercise and fitness in health. He has conducted, published, and presented numerous research studies with cyclists, runners, and triathletes, and has extensive experience testing elite athletes from cycling, running, gymnastics, rowing, canoe and kayak, and basketball. Dr. Doyle currently serves on the Science and Education Committee for USA Cycling.

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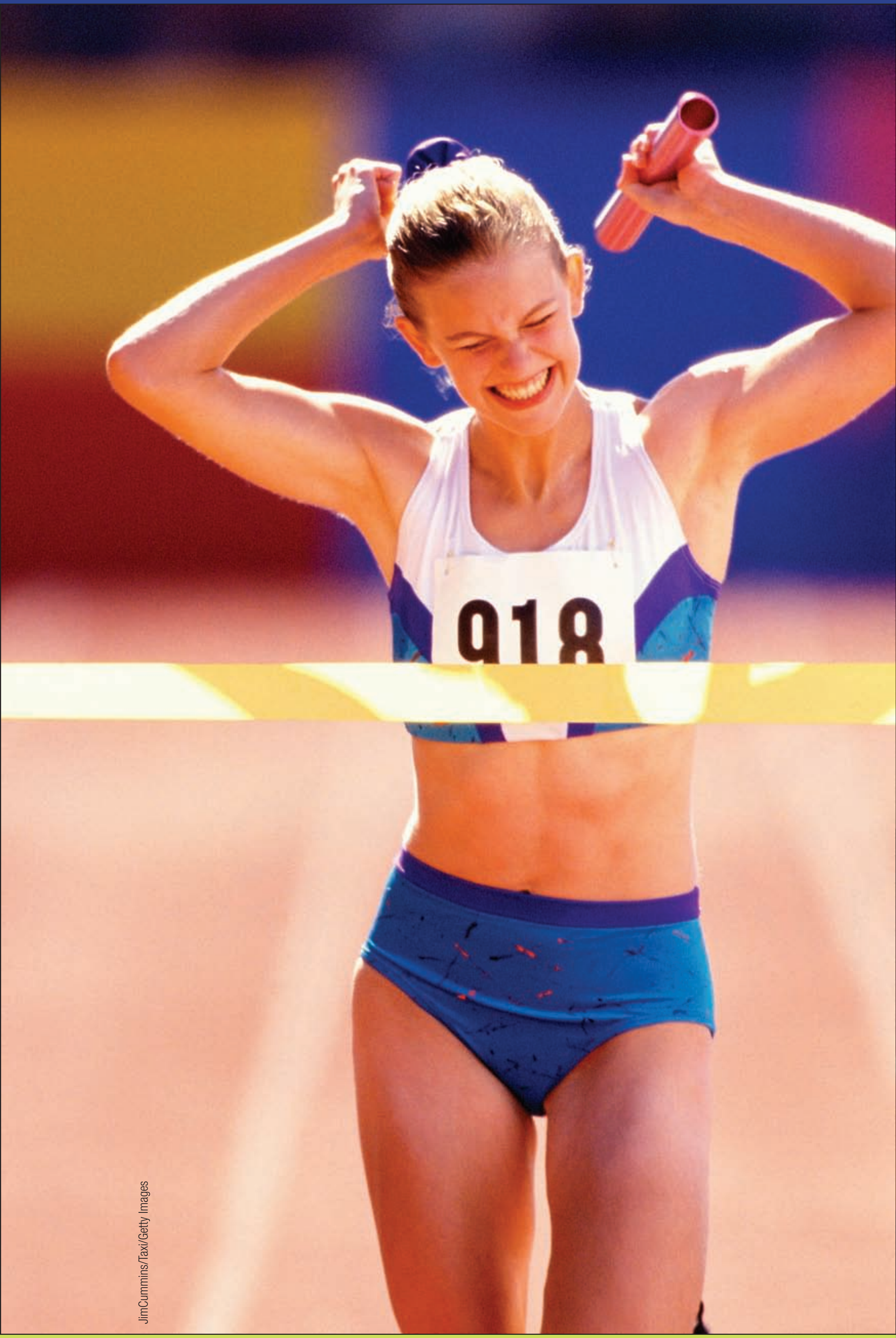
1 Introduction to Sports Nutrition



JimCummins/Taxi/Getty Images

Learning Objectives

1. Define key terms such as exercise physiology, nutrition, physical activity, exercise and sport.
2. List and explain basic training and sports nutrition goals.
3. Identify basic nutrition standards and guidelines and indicate when these guidelines are applicable to athletes.
4. Discuss the purity, legality, ethics, safety, and effectiveness of dietary supplements.
5. Distinguish between types of research studies, weak and strong research designs, and correlation and causation.
6. Explain the importance of using recommendations based upon current scientific evidence (i.e., evidence-based), and ways that research results may be misinterpreted.
7. Discuss the role of the Internet in finding sports nutrition research and information.
8. Compare and contrast the academic training and experience necessary to obtain various exercise and nutrition certifications.

Pre-Test Assessing Current Knowledge of Sports Nutrition

Read the following statements and decide if each is true or false.

1. An athlete's diet is a modification of the general nutrition guidelines made for healthy adults.
2. Nutrition periodization refers to a nutrition plan that is developed to match an athlete's training program.
3. In the United States, dietary supplements are regulated in the same way as over-the-counter medications.
4. The scientific aspect of sports nutrition is developing very quickly and quantum leaps are being made in knowledge of sports nutrition.
5. To legally use the title of sports nutritionist in the United States, a person must have a bachelor's degree in nutrition.

Welcome to the exciting world of sports nutrition. This relatively new field is a blend of nutrition and exercise physiology. These fields are complementary academic disciplines that help us to understand the energy expenditure that is required by exercise and sport, and the energy and nutrient intake that is vital to support excellent **training** and performance. Exercise challenges the human body to respond and adapt, and proper nutrition supports these processes. Training and nutrition are keys to athletic performance at any level.

The Olympics motto is *Citius, Altius, Fortius,* Latin for "swifter, higher, stronger." To achieve the highest level of success, athletes must be genetically endowed, and they must train optimally to meet their genetic potential. Proper nutrition supports the demands of training. To run faster, jump higher, and be stronger, athletes must use genetics, training, and nutrition to their advantage.

Exercise physiology is the science of the response and adaptation of bodily systems to the challenge imposed by movement—physical activity, exercise, and sport. Nutrition is the science of the ingestion, digestion, absorption, and metabolism of nutrients and their biochemical functions. First, and foremost, these disciplines are based on sound scientific evidence. But there is also an art to applying scientific principles to humans. For example, scientists identify nutrients found in food that are needed by the body, but food is sometimes eaten just because it tastes delicious or smells good. Exercise physiologists know from well-controlled research studies that the size and strength of athletes' muscles can be increased with overload training, but choosing the appropriate exercises, the number of sets and repetitions, the amount of resistance, the rest intervals, and the exercise frequency for optimal response by each individual athlete is as much of an art as a science.

Sports nutrition is the integration and application of scientifically based nutrition and exercise physiology principles that support and enhance performance. These principles also help athletes attain and maintain good health. Because sports nutrition is a relatively young field, there is more research to be done and much more to be learned, presenting an exciting opportunity for exercise science and nutrition-oriented students.

Training, Nutrition, and the Athlete

WHAT IS AN ATHLETE?

The word *athlete* describes a person who participates in a sport. Using that definition, Tiger Woods, a collegiate golfer, and a weekend golfer are all athletes. Clearly there are differences among these three golfers. One difference is skill and another is training. Elite athletes, like Tiger Woods, are exceptionally skilled and dedicated to their training regimes. Their lives are planned around their training and competition schedules because athletic competition is their profession. Collegiate athletes are also trained athletes, although the level of their training is probably less than that of their professional counterparts. Dedication to training is important because proper training is necessary to improve and maintain performance. Many people are recreational athletes. Some of them are former competitive athletes who continue to train, albeit at a lower level, to remain competitive within their age group in masters events. However, many recreational athletes train little, if at all. They participate in sports to be physically active, to maintain a healthy lifestyle, and for enjoyment.

DEFINING PHYSICAL ACTIVITY, EXERCISE, AND SPORT

Physical activity is bodily movement that results in an increase in **energy** expenditure above resting

REUTERS/Robert Galbraith/Landov

AP Photo/St. Joseph News

Steve Cole/Digital Vision/Getty Images

Anyone who participates in a sport can be called an athlete. As a means of distinction, the terms elite, well trained, and recreational athlete are often used.

levels. Examples can include activities of daily living such as bathing, walking the dog, raking leaves, or carrying bags of groceries. Exercise and sport are very specific types of physical activity. Exercise has been defined as "physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is the key" (Caspersen, Powell, and Christensen, 1985). For example, running is a specific type of physical activity that is often done regularly by people who hope to improve their cardiovascular fitness. Sports can be thought of as competitive physical activities. Track, cross country, or road running (e.g., marathon) are examples of running as a sport.

Exercise may be described an **aerobic** or **anaerobic.** Aerobic means "with oxygen" and is used in reference to exercise or activity that primarily uses the oxygen-dependent energy system—oxidative phosphorylation (see Chapter 3). These types of activities can be sustained for a prolonged period of time and are referred to as endurance activities. Those who engage in them are referred to as endurance athletes. Anaerobic means "without oxygen" and is used in reference to exercise that primarily uses one or both of the energy systems that are not dependent on oxygen—creatine phosphate or anaerobic glycolysis (see Chapter 3). These types of activities are short in duration and high in exercise **intensity.** Athletes in high intensity, short duration sports are often called strength athletes. Although few sports are truly anaerobic and weight lifting to strengthen muscles is usually a part of an endurance athlete's training, "strength" and "endurance" athletes are terms that are commonly used.

THE IMPORTANCE OF TRAINING AND NUTRITION

The long-time columnist, book author, and running philosopher George Sheehan (1980) once wrote that everyone is an athlete; only some of us are not in training. Athletes improve their sports performance through skill development and training. Skill development is enhanced through practice and instruction or coaching. Success in many sports is directly related to fitness levels, achieved by sport-specific training. For example, to be successful, competitive distance runners must have a high level of **cardiovascular fitness,** which is developed through following a rigorous running training program.

Training: A planned program of exercise with the goal of improving or maintaining athletic performance.

Sports nutrition: The application of nutrition and exercise physiology principles to support and enhance training.

Energy: The capacity to do work. In the context of dietary intake, defined as the caloric content of a food or beverage.

Aerobic: "With oxygen." Used in reference to exercise that primarily uses the oxygen-dependent energy system, oxidative phosphorylation.

Anaerobic: "Without oxygen." Used in reference to exercise that primarily uses one or both of the energy systems that are not dependent on oxygen, creatine phosphate or anaerobic glycolysis.

Intensity: The absolute or relative difficulty of physical activity or exercise.

Cardiovascular fitness: Ability to perform endurance-type activities, determined by the heart's ability to provide a sufficient amount of oxygen-laden blood to exercising muscles and the ability of those muscles to take up and use the oxygen.


Altrendo Images/Getty Images

AP Photo/Sang Tan

Although each participates in the same sport, the training and nutritional needs of recreational and elite athletes are very different.

As advances in exercise and sports science have become more widely recognized and adopted, athletes from a wide variety of sports have begun to use improved physical conditioning as a way to further improve their performance. Even athletes in sports such as golf and car racing have begun physical training as a strategy to improve personal performance. Physical training to improve specific components of fitness must be taken into account when considering nutritional needs, such as total energy and carbohydrate intakes. Nutrition supports training and good health, two factors that are essential to excellent performance.

While nutrition by itself is important, it may have the greatest performance impact by allowing athletes to train consistently. Proper nutrition during the recovery period is essential for replenishing nutrient stores depleted during training, for example, muscle **glycogen.** Inadequate replenishment of energy, **fluid, carbohydrates, proteins,** and/or **vitamins** and **minerals** limits the potential for full recovery after training. Limited recovery can result in **fatigue** during the next training session, and consistent lack of nutritional replenishment can lead to chronic fatigue (Maughan, 2002).

Athletes perceive that nutrition is important, but they sometimes fail to realize that it is a factor that needs daily attention. They can get so focused on one small aspect of their diet that they neglect their comprehensive daily nutrition requirements. For example, athletes may concentrate on the best precompetition meal, but if they fail to address their day-to-day nutrition needs, then their training will suffer. Inadequate training that is a result of inadequate nutrient replenishment is much more detrimental to performance than the precompetition meal is beneficial to performance (Maughan, 2002).

TRAINING AND NUTRITION GOALS

The main goal for any athlete is to improve performance. Improvements in sport performance can come as a result of many factors: skill enhancement, psychological changes, specialized equipment and clothing, or physiological improvements due to training. All aspects of training should support this primary goal of improving performance. General training goals are listed below:

- Improving performance
- Improving specific components of fitness
- Avoiding injury and overtraining
- Achieving top performance for selected events (i.e., peaking)

Long-term nutrition goals are formulated to support training, provide adequate recovery, maintain the immune system, and support overall health. Athletes who train hard deplete nutrient stores and are at risk for frequent and repeated infections. Short-term nutrition goals are often focused on specific strategies for nutritional intake prior to and during competition. Some of these goals are listed below (Maughan, 2002).

Long-term sports nutrition goals:

- Adequate energy intake to meet the energy demands of training
- Adequate replenishment of muscle and liver glycogen with dietary carbohydrates
- Adequate protein intake for growth and repair of tissue, particularly muscle
- Adequate overall diet (e.g., proteins, antioxidant vitamins) to maintain a healthy immune system
- Adequate hydration

Short-term sports nutrition goals:

- Consumption of food and beverages to delay fatigue during training and competition
- Minimization of dehydration and **hypohydration** during exercise
- Utilization of dietary strategies known to be beneficial for performance, such as precompetition meal, caffeine intake, or carbohydrate loading

What's the point? The primary goal of training is to improve performance. Proper nutrition supports training, recovery, and good health.

BASIC TRAINING AND NUTRITION PRINCIPLES

As the athlete trains, the body responds to the individual exercise sessions and gradually adapts over time. The nature and degree of the adaptation(s) depends upon the type of training the athlete does, and follows general principles derived from the results of many research studies. Most of the basic training principles have dietary corollaries. Training periodization is a well-accepted concept; nutrition periodization has been a more recent development (Seebohar, 2004).

The Principle of Progressive Overload. Adaptation occurs as a result of a stimulus that stresses the body. The stimulus must be of sufficient magnitude to cause enough stress to warrant longer-term changes by the body. Stimulus of this magnitude is called **overload.** If exposed to an overload stimulus repeatedly, the body will adapt over time to that level of stimulus. For further adaptation to occur, the overload stimulus must be progressively increased.

For example, in order for the biceps muscles to get stronger, an athlete must perform a weight-lifting exercise like an arm curl. The muscles will not get stronger curling the weight of a pencil, rather, the weight must be heavy enough to achieve overload. Once the muscles have adapted to that weight, they will not get any stronger until the overload stimulus is progressively increased (i.e., the weight is increased further).

The Principle of Individuality. While general training principles apply to all people, individuals may respond and adapt slightly differently, even when exposed to the same training stimulus. Two similar athletes that follow the same strength-training program will both improve their strength, but it is likely that the amount and rate of change in strength will be slightly different. People do not respond in precisely the same way or time frame, so individual differences must be taken into account when considering an athlete's training program.

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An overload stimulus, such as an arm curl, is required for the biceps muscles to get stronger.

The Principle of Specificity. The type of physiological responses and eventual adaptations will be specific to the type of stimulus and stress imposed on the body. In the most general sense, aerobic exercise will result primarily in cardiovascular adaptations and strength training will result in neuromuscular adaptations. Adaptations can be more subtle and specific, such as the effect intensity and duration of aerobic exercise may have on changes in energy system pathways such as carbohydrate and fat metabolism (see Chapters 4 and 6). One of the primary goals of sports nutrition is to support training, so nutrition recommendations for athletes must be specific to their sport or training focus. Dietary recommendations for those who train primarily for strength and power are different from recommendations for athletes who train primarily for endurance.

Glycogen: Storage form of glucose in the liver and muscle.

Fluid: Water or a liquid that contains mostly water.

Carbohydrates: One of the six classes of nutrients; sugars and starches.

Proteins: One of the six classes of nutrients; made up of amino acids.

Vitamin: An essential nutrient needed in small quantities to assist in metabolic processes.

Mineral: An inorganic element (e.g., calcium, iron).

Fatigue: Decreased capacity to do mental or physical work.

Hypohydration: An insufficient amount of water; below the normal state of hydration.

Overload: An exercise stimulus that is of sufficient magnitude to cause enough stress to warrant long-term changes by the body.

Liquidlibrary/Jupiter Images

A dietitian can help an athlete develop a diet plan that is well matched to the demands of training.

The Principle of Hard/Easy. The stimulus part of training receives the most attention, but often neglected are the rest and recovery that are required for the adaptation to occur. Training programs are usually designed so that hard physical efforts are followed by training sessions with less physical stress to allow for the rest necessary for optimal adaptation. These training principles have applications to nutrition. After hard training sessions where muscle glycogen is nearly depleted, athletes recognize that they must eat a large amount of carbohydrates to replenish the carbohydrate-depleted muscles. The amount of muscle glycogen used during an easy workout is much less. While carbohydrate intake is still important after an easy workout, the amount of carbohydrates needed to replenish muscle is not as great.

The Principle of Periodization. Adhering to the principle of **specificity,** training programs are also often arranged in time periods according to the specific adaptation that is sought. For example, competitive long distance runners may spend a portion of their yearly training time concentrating on running longer distances to improve their maximal aerobic capacity and endurance, and another portion of their training time running shorter distances at higher intensity to improve their speed. Within this principle of **periodization,** training programs are generally arranged according to different time periods:

Macrocycle: A macrocycle is an overall time period that begins at the onset of training and includes the time leading up to a specific athletic goal, such as an important competition. For an athlete seeking to peak at the annual national championships, the macrocycle may be a calendar year. A macrocycle may be longer (e.g., four years for an athlete concentrating on the Olympics) or shorter (e.g., six months for a distance runner training for a springtime marathon), depending upon the specific competitive goals of the athlete.

Mesocycle: A macrocycle is subdivided into time frames called mesocycles, each having a specific training purpose. As with the macrocycle, the mesocycles may be of varying lengths of time, depending upon the athlete's goals, but typically are weeks or months in duration. The competitive distance runner may have a mesocycle focused on improving aerobic capacity and endurance and another mesocycle focused on improving speed.

Microcycle: Each mesocycle is made up of repeated time intervals called microcycles. Microcycles are often designed to coincide with the weekly calendar, but can vary from the standard seven-day week, depending upon the athlete's specific needs. Weekly training mileage for the competitive distance runner is an example of a microcycle.

Training periodization involves changing the intensity, **volume,** and specificity of training to achieve specific goals. It is imperative that a parallel nutrition plan, known as **nutrition periodization,** be developed to support the various training cycles. If the training macrocycle is one year, athletes should also have an annual nutrition plan. Each mesocycle will have specific nutrition goals as well. For example, weight loss by the endurance athlete is usually planned to take place during the active recovery ("off-season") period and early in the preparation period so a restricted-calorie diet can be avoided during high-volume training periods or during the competitive season. During each microcycle refinements are made to dietary intake (Seebohar, 2004).

Figure 1.1 illustrates the concept of nutrition periodization. In this example of a male collegiate 800-m runner, energy, carbohydrate, protein, and fat intakes change over the course of the year (i.e., the macrocycle) to match training and body composition goals. The training and nutrition goals of each mesocycle vary. During the early months of the preparation period (September through October) the primary focus is on aerobic training. This athlete also wants to decrease five pounds of body fat that has been gained during the active recovery period ("off-season"). Energy (calorie) and carbohydrate intakes must be sufficient to support training, but energy intake must be reduced from baseline so that some of the energy needed is provided from stored fat. The second part of the preparation period (November through January) focuses on maintaining aerobic fitness, increasing strength and power, and technique. This athlete also

Preparation		Competition		Transition	
General Training	Specific Training	"Preseason"	Racing Season	Active Recovery ("off-season")	
75% aerobic and 25% anaerobic training	50% aerobic and 50% anaerobic training	60% aerobic and 40% anaerobic training	25% aerobic and 75% anaerobic training	None	100% aerobic
Body composition goal: Reduce 5 lb fat	Increase muscle mass by 3–5 lb	Maintain the increased muscle mass	Maintain body composition	Small loss of muscle mass and small increase in body fat is acceptable to the athlete. Weight may be 8–10 lb greater than during racing season.	
Sept, Oct	Nov, Dec, Jan	Feb, Mar, Apr	May, June	July	Aug
Energy intake: Slight reduction of usual caloric intake for slow loss of body fat	Increase caloric intake to support muscle growth and increased volume of training	Match caloric intake with caloric expenditure (e.g., 45 kcal/kg)	Match caloric intake with caloric expenditure	If caloric intake is not reduced, body fat will increase	If caloric intake is excessive, body fat will increase
Nutrient focus: Adequate carbohydrates to support training; fat intake may be reduced to limit caloric intake	Sufficient energy, and carbohydrate, protein, and fat intakes to build muscle and support high-volume training	Consume ~6–7 g CHO/kg, ~1.4 g protein/kg and ~1.0 g fat/kg (~55–62% CHO, ~12–15% protein, ~23–33% fat)	Sufficient CHO daily to replenish muscle glycogen; adequate energy intake	Nutritious diet that meets the Dietary Guidelines	

Figure 1.1 A training and nutrition periodization plan for a male collegiate 800 m runner.

Legend: lb = pound; kcal = kilocalorie (energy); kg = kilogram body weight; g = gram; CHO = carbohydrate

Note: Aerobic training refers to exercise that primarily uses the oxygen-dependent energy systems; anaerobic training refers to exercise that primarily uses energy systems that are not oxygen dependent.

wants to increase muscle mass by three to five pounds. The volume of training is increased and is equally divided between aerobic (e.g., running) and anaerobic (e.g., high-repetition lifting and **plyometric** exercise) activities. Proper energy, carbohydrate, protein, and fat intakes are needed to support both his training and body composition goals.

During the precompetition period (February through April), most of the training takes place on the track. Training is approximately 40 percent anaerobic and 60 percent aerobic. Weight lifting is decreased because the goal is maintenance of gained muscle rather than a continued increase in muscle mass. There is an emphasis on plyometric training and an alternating schedule—Monday, Wednesday, and Friday feature hard workouts while Tuesday and Thursday involve easy recovery runs as the athlete prepares for competition on Saturday. During the competitive season (May through mid-June), more emphasis is placed on anaerobic training (~75 percent) and less on aerobic training (~25 percent). Almost all of the training is on the track and the athlete does no weight lifting. Friday is a rest and travel day in preparation for racing on Saturday. The active recovery period ("off-season") is split into two periods. For about three weeks (mid-June to early July), the athlete does no training, in an effort to recuperate from many months of training and competition. Through most of July and August the focus is on moderate-duration, low-intensity running. Energy expenditure in the active recovery period is the

Specificity: A training principle that stresses muscle in a manner similar to which they are to perform.

Periodization: Dividing a block of time into distinct periods. When applied to athletics, the creation of time periods with distinct training goals and a nutrition plan to support the training necessary to meet those goals.

Macrocycle: An athlete's overall training period; often one year but may be longer or shorter.

Mesocycle: Subdivision of the macrocycle; usually many weeks or a few months.

Microcycle: Subdivision of the mesocycle and the smallest subdivision of the macrocycle; usually seven days but may be longer or shorter.

Volume: An amount; when applied to exercise training, a term referring to the amount of exercise usually determined by the frequency and duration of activity.

Nutrition periodization: Creating a nutrition plan to support training that has been divided into distinct periods of time.

Plyometric: A specialized type of athletic training that involves powerful, explosive movements. These movements are preceded by rapid stretching of the muscles or muscle groups that are used in the subsequent movement.

lowest of the entire year and the runner will need to reduce food intake to match reduced expenditure to prevent weight gain as body fat.

The Principle of Disuse. Just as the body adapts positively in response to training stress, it can adapt negatively, or **atrophy** if stress is insufficient or absent. Gradual erosion of physiological capacity over time is often observed in individuals as a result of sedentary lifestyles. Athletes that have improved function through training can experience the loss of function, either intentionally for short periods (e.g., resting during the "off-season") or unintentionally due to forced inactivity from injury. This is the physiological equivalent of the term "Use it, or lose it."

The most obvious dietary example is body weight. One of the reasons that many people fail to maintain their weight loss is that they do not continue a post-weight loss dietary and exercise program. Athletes who have a defined "off-season" must adjust their dietary intake to reflect their lower level of training and exercise or they risk gaining unwanted weight and body fat.

BASIC NUTRITION STANDARDS AND GUIDELINES

Sports nutrition principles are based on sound general nutrition principles that have been modified to reflect the demands of training and competition. General guidelines help all people, including athletes, to achieve optimal nutritional health. An optimal diet is one in which there are neither deficiencies nor excesses.

The early focus of nutrition research was on the amount and type of nutrients needed to prevent deficiencies. Once nutrient deficiency diseases were well understood the research focus changed to the amount and type of nutrients that help prevent chronic diseases. A chronic disease is one that progresses slowly, such as heart disease or osteoporosis (i.e., loss of bone mineral density). These diseases are a reflection of long-term, not short-term, nutrient intake. Keeping in mind the need to prevent nutrient deficiencies as well as nutrient excesses, guidelines have been established for energy (calories), **macronutrients** (i.e., carbohydrates, proteins, and fats), **fiber,** vitamins, minerals, **electrolytes** (e.g., sodium, potassium), and water. These guidelines are known as the **Dietary Reference Intakes** (Institute of Medicine, 1997–2004).

Dietary Reference Intakes (DRI). The Dietary Reference Intakes (DRI) is a standard used to assess and plan diets for individuals and groups (Institute of Medicine, 2006 and 2001). The DRI expands on and replaces the 1989 Recommended Dietary Allowances (RDA) and the Recommended Nutrient Intakes (RNI) of Canada. The DRI is a general term that includes four types of reference values—Recommended Dietary Allowances, Adequate Intake, Estimated Average Requirement, and Tolerable Upper Intake Level. These terms are defined in Figure 1.2.

The DRI are based on the Recommended Dietary Allowance whenever possible (i.e., when enough research has been conducted). When an RDA cannot be determined, the Adequate Intake (AI) becomes the reference value for the DRI. The AI is not as scientifically strong since it is based on estimates or approximations derived from scientific research. The Dietary Reference Intakes and the reference value used for each vitamin and mineral are found on the inside gatefold of this textbook. Values for other nutrients are found in Appendix A. The use of the term *RDA* has caused some confusion. For many years, the RDA was the standard, but now is one of the reference values used to compile the DRI, the current standard.

Athletes in training may wonder how the DRI apply to them since they were developed for the general population. Since the goal of the DRI is to guard against both nutrient inadequacies and excesses, athletes use the DRI to assess the adequacy of their current diets and to plan nutritious diets. For example, there is little evidence that athletes need vitamins and minerals in amounts greater than the DRI (Volpe, 2005). On the other hand, some of the DRI, such as the estimated energy requirement or the need for water intake, may not be appropriate to use with athletes in training because athletes' energy and fluid needs may be greater than those of the general population. In such cases other standards and guidelines are used.

Dietary Guidelines for Americans. The Dietary Guidelines for Americans (2005) are published every five years by the Department of Health and Human Services and the Department of Agriculture. The purpose of the Dietary Guidelines is to provide dietary and exercise advice to Americans over the age of two that will promote health and reduce the risk for chronic diseases. The Dietary Guidelines' topics and key recommendations are listed in Figure 1.3.

Athletes may wonder how the Dietary Guidelines apply to them since they were developed for the general population. Most of the dietary recommendations do apply, such as getting adequate nutrients within calorie needs and eating fiber-rich fruits, vegetables, and whole grains to meet carbohydrate needs. But some of the recommendations may not apply. For example, for those athletes who lose large amounts of sodium in sweat, limiting sodium intake to 2,300 mg daily may be detrimental. Athletes engaged in regular training will usually easily meet and exceed the physical activity recommendations contained in the Dietary Guidelines. However, some athletes concentrating on sports involving very specific components of fitness

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(e.g., muscular strength for weight lifting or bodybuilding) may need to be conscious of including other components of fitness (e.g., cardiovascular exercise) necessary for long-term health. The Dietary Guidelines are a good starting point for people who want to improve their health and fitness. The general nutrition principles can then be modified to fit the demands of training.

MyPyramid. The release of the 2005 Dietary Guidelines resulted in an update in the graphic known as the Food Guide Pyramid. Now called *MyPyramid,* this graphic reflects the principles outlined in the Dietary Guidelines and is a food guidance system that can be used to teach consumers about basic nutrition. MyPyramid retains the pyramid shape but adds exercise to the graphic and uses color to categorize the food groups. Although the Food Guide Pyramid was widely recognized by Americans, its messages were not always understood and were not often followed. Health, nutrition, and exercise professionals must explain the messages that are embedded in the MyPyramid graphic if this graphic is to be more successful than its predecessor in changing health behaviors.

MyPyramid is designed to convey several general messages: physical activity, variety, proportionality, moderation, gradual improvement, and personalization as shown in Figure 1.4. Physical activity, which was not included in the original Food Guide Pyramid, is represented by a figure climbing steps. This is symbolic of the need for daily physical activity. The colored bands represent variety, with each band depicting a different food group. The size of the band suggests how much food should be chosen from that group in proportion to the other groups. For example, the largest band is orange, which represents grains. The message is that grains should be the largest proportion of food in the total diet. The yellow band, which represents oils, is the smallest band. Moderation is depicted by the narrowing of the bands from

Atrophy: A wasting or decrease in organ or tissue size.

Macronutrient: Any essential nutrient needed in large quantities (e.g., carbohydrates, proteins, and fats).

Fiber: A component of food that resists digestion (e.g., pectin, cellulose).

Electrolyte: A substance in solution that conducts an electrical current (e.g., sodium, potassium).

Dietary Reference Intakes (DRI): Standard for essential nutrients and other components of food needed by a healthy individual.

Dietary Guidelines for Americans, 2005

Adequate Nutrients within Calorie Needs

Consume a variety of nutrient-dense foods and beverages within and among the basic food groups while choosing foods that limit the intake of saturated and trans fats, cholesterol, added sugars, salt, and alcohol.

Meet recommended intakes within energy needs by adopting a balanced eating pattern, such as the USDA Food Guide or the DASH Eating Plan (see Appendix B).

Weight Management

To maintain body weight in a healthy range, balance calories from foods and beverages with calories expended.

To prevent gradual weight gain over time, make small decreases in food and beverage calories and increase physical activity.

Physical Activity

Engage in regular physical activity and reduce sedentary activities to promote health, psychological well-being, and a healthy body weight.

- To reduce the risk of chronic disease in adulthood: Engage in at least 30 minutes of moderate-intensity physical activity, above usual activity, at work or home on most days of the week.
- For most people, greater health benefits can be obtained by engaging in physical activity of more vigorous intensity or longer duration.
- To help manage body weight and prevent gradual, unhealthy body weight gain in adulthood: Engage in approximately 60 minutes of moderate- to vigorous-intensity activity on most days of the week while not exceeding caloric intake requirements.
- To sustain weight loss in adulthood: Participate in at least 60 to 90 minutes of daily moderate-intensity physical activity while not exceeding caloric intake requirements. Some people may need to consult with a healthcare provider before participating in this level of activity.

Achieve physical fitness by including cardiovascular conditioning, stretching exercises for flexibility, and resistance exercise or calisthenics for muscle strength and endurance.

Food Groups to Encourage

Consume a sufficient amount of fruits and vegetables while staying within energy needs. Two cups of fruit and 2½ cups of vegetables per day are recommended for a reference 2,000-calorie intake, with higher or lower amounts depending on the calorie level.

Choose a variety of fruits and vegetables each day. In particular, select from all five vegetable subgroups (dark green, orange, legumes, starchy vegetables, and other vegetables) several times a week.

Consume three or more ounce-equivalents of whole-grain products per day, with the rest of the recommended grains coming from enriched or whole-grain products. In general, at least half the grains should come from whole grains.

Consume 3 cups per day of fat-free or low-fat milk or equivalent milk products.

Fats

Consume less than 10% of calories from saturated fatty acids and less than 300 mg/day of cholesterol, and keep trans fatty acid consumption as low as possible.

Keep total fat intake between 20 to 35% of calories, with most fats coming from sources of polyunsaturated and monounsaturated fatty acids, such as fish, nuts, and vegetable oils.

When selecting and preparing meat, poultry, dry beans, and milk or milk products, make choices that are lean, low fat, or fat free.

Limit intake of fats and oils high in saturated and/or trans fatty acids, and choose products low in such fats and oils.

Carbohydrates

Choose fiber-rich fruits, vegetables, and whole grains often.

Choose and prepare foods and beverages with little added sugars or caloric sweeteners, such as amounts suggested by the USDA Food Guide and the DASH Eating Plan.

Reduce the incidence of dental caries by practicing good oral hygiene and consuming sugar- and starch-containing foods and beverages less frequently.

Sodium and Potassium

Consume less than 2,300 mg (approximately 1 tsp of salt) of sodium per day.

Choose and prepare foods with little salt. At the same time, consume potassium-rich foods, such as fruits and vegetables.

Alcoholic Beverages

Those who choose to drink alcoholic beverages should do so sensibly and in moderation—defined as the consumption of up to one drink per day for women and up to two drinks per day for men.

Alcoholic beverage should not be consumed by some individuals, including those who cannot restrict their alcohol intake, women of childbearing age who may become pregnant, pregnant and lactating women, children and adolescents, individuals taking medications that can interact with alcohol, and those with specific medical conditions.

Alcoholic beverages should be avoided by individuals engaging in activities that require attention, skill, or coordination, such as driving or operating machinery.

Food Safety

To avoid microbial foodborne illness:

- Clean hands, food contact surfaces, and fruits and vegetables. Meat and poultry should *not* be washed or rinsed.
- Separate raw, cooked, and ready-to-eat foods while shopping, preparing, or storing foods.
- Cook foods to a safe temperature to kill microorganisms.
- Chill (refrigerate) perishable food promptly and defrost foods properly.
- Avoid raw (unpasteurized) milk or any products made from unpasteurized milk, raw or partially cooked eggs, or foods containing raw eggs, raw or undercooked meat and poultry, unpasteurized juices, and raw sprouts.

U.S. Department of Agriculture and U.S. Department of Health and Human Services, Dietary Guidelines for Americans, 6th ed. www.healthierus.gov/dietaryguidelines/

Figure 1.3 Dietary Guidelines for Americans, 2005

the bottom to the top of the pyramid. The foods at the bottom of each group (except oils) represent those foods with little solid fat or sugar. As the band narrows, the foods in that group contain more fat and sugar. The slogan is *steps to a healthier you,* a phrase that suggests that improvement will be gradual. Finally, the pyramid may be personalized by going to the website, MyPyramid.gov.

Without viewing additional materials, consumers receive only the general messages depicted by the MyPyramid graphic. A miniposter, shown in Figure 1.5, lists the principles outlined in the 2005 Dietary Guidelines. By going to the MyPyramid.gov website, consumers can find out the amount of calories they need daily based on their age, sex, and physical activity. They can also download one of 12 worksheets that best matches their caloric needs, ranging from 1,000 to 3,200 calories (www.MyPyramid.gov/professionals/food_tracking_wksht.html). The amount of food suggested from each food group for each of the 12 calorie levels can be found in Appendix C. It is hoped that these tools will help consumers to better understand and follow the messages of the MyPyramid graphic.

Other Meal Planning Systems. MyPyramid groups together foods that are similar in macronutrient content.

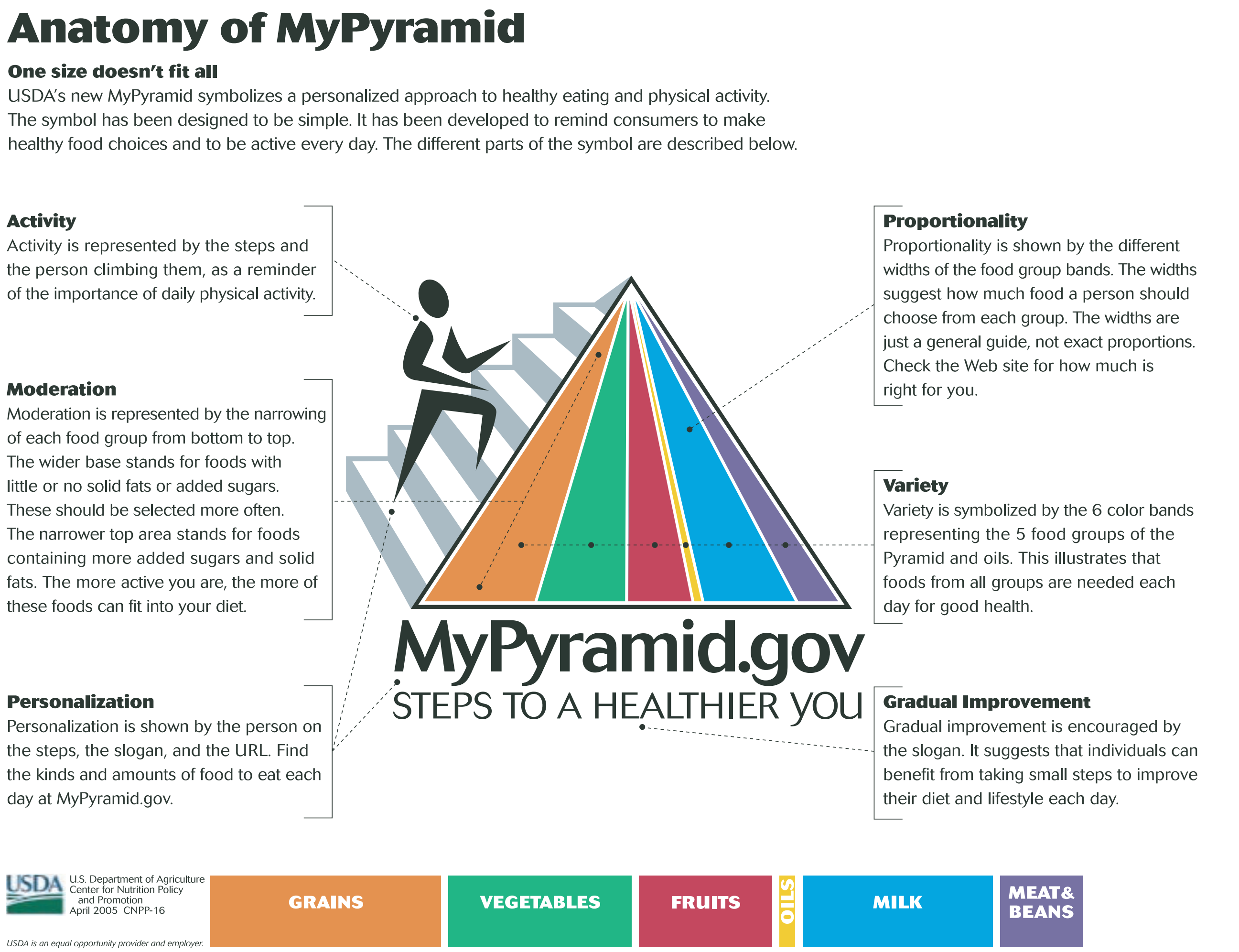

Figure 1.4 MyPyramid with General Messages Explained

Likewise, the Food Exchange System, often referred to as the exchange lists, categorizes foods based on their carbohydrate, protein, and fat contents (American Diabetes and Dietetic Associations, 2003). There are three groups—carbohydrate, meat and meat substitutes, and fat—with the carbohydrate and meat groups containing several subgroups. The foods on each list can be "exchanged" for another food on the same list because each has approximately the same macronutrient content for the portion size listed (Wheeler, 2003). For example, one small banana (~4 oz) has approximately 15 g of carbohydrates and 60 calories (kcal), about the same as one small orange.

However, foods are broadly categorized according to macronutrient content and there can be substantial **micronutrient** (i.e., vitamin and mineral) differences between foods on the same list. For example, an orange is an excellent source of vitamin C (~70 mg) while a banana has little (~10 mg). The starch list contains whole wheat and white bread, foods with equivalent amounts of carbohydrates, proteins, and fats. However, whole wheat bread is a nutritionally superior food to white bread because of the fiber and trace mineral contents. Additionally, each food listed does not have the same portion size. On the fat exchange list, the portion size for avocado is 2 tablespoons while the portion size for oil is considerably smaller, 1 teaspoon. The Food Exchange System is found in Appendix D.

Another method that some athletes use is carbohydrate counting. The amount of carbohydrates needed daily is determined and then distributed throughout the day in meals and snacks. Although carbohydrate intake is emphasized to ensure adequate muscle glycogen for training, it is part of a larger plan that considers daily energy (calorie), protein, fat, and alcohol intakes.

Micronutrient: Any essential nutrient needed in small quantities; vitamins and minerals.

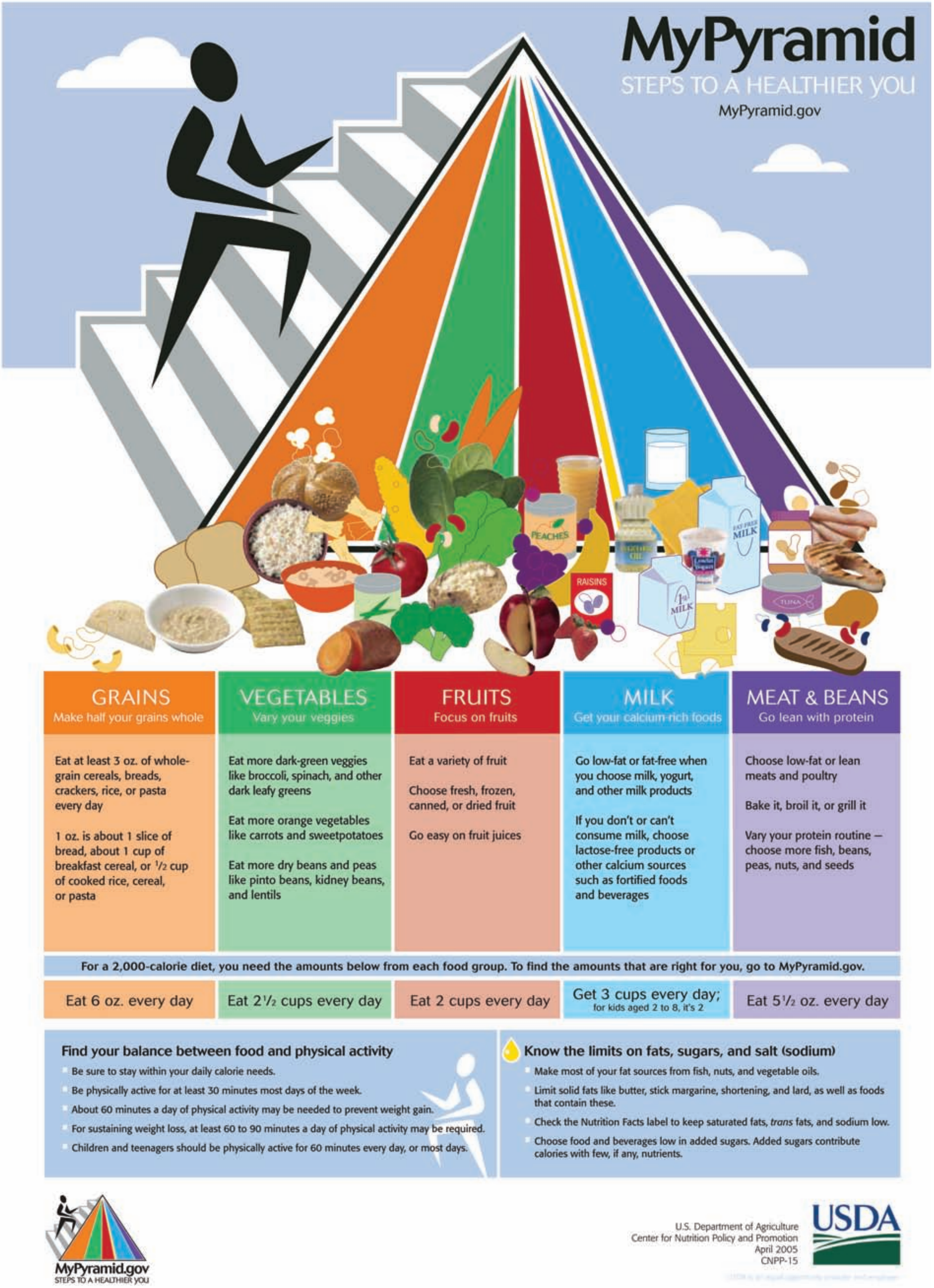

Figure 1.5 MyPyramid Miniposter

A meal planning system is useful, especially when athletes are learning about the nutrient content of foods and beginning to plan a diet that supports training. Over time, athletes typically want more precise information about the nutrient content of food and this leads to use of nutrient analysis software, such as the dietary analysis program that accompanies this textbook.

What's the point? Although not developed specifically for athletes, the Dietary Guidelines, MyPyramid, and the exchange lists are tools that can be used by athletes to develop a nutritionally sound diet plan. They are especially useful for athletes who are just learning about nutrition and for recreational athletes who engage in little training.

BASIC SPORTS NUTRITION GUIDELINES

Sports nutrition recommendations build upon and refine basic nutrition guidelines. Athletes need to understand and apply general nutrition principles before making modifications to reflect their training and sport-specific nutrient demands. Ultimately, sports nutrition recommendations are fine-tuned and are as precise as possible to closely meet the demands of training and competition and reflect the needs of the individual athlete. Here is a brief overview of some key sports nutrition recommendations (American Dietetic Association et al., 2000; Burke et al., 2001).

Energy: An adequate amount of energy is needed to support training. Appropriate amounts of food should be consumed daily to avoid long-term energy deficits or excesses. Adjustments to energy intake for the purpose of attaining a body weight or body composition goal should be made slowly and started early enough in the training mesocycle so as not to interfere with training or performance.

Carbohydrates: An intake of 5 to 10 grams (g) of carbohydrates per kilogram (kg) of body weight per day is recommended. The daily amount needed depends on the sport, type of training, gender, and need for carbohydrate loading. Timing is also important and recommendations for carbohydrate intake before, during, and after exercise are made. The use of the **glycemic index (GI)** may assist athletes in fine-tuning their carbohydrate intake.

Proteins: An intake of 1.2 to 1.7 g of protein per kg of body weight per day is generally recommended. This recommendation assumes that energy intake is adequate. The daily amount of proteins needed depends on the sport and type of training. Timing of protein intake is also important. For example, postexercise protein ingestion aids in muscle protein resynthesis.

Fats: After determining carbohydrate and protein needs, the remainder of the energy intake is typically from fats, although adult athletes may include a small amount of alcohol. Trained athletes generally consume 1.0 to 2.0 g of fat per kg of body weight per day (Seebohar, 2005). Extremely low-fat diets can be detrimental to health and performance.

Vitamins and minerals: Athletes should meet the DRI for all vitamins and minerals. The DRI can be met if energy intake is adequate and foods consumed are **nutrient dense** (i.e., abundant nutrients in relation to caloric content). Any recommendation for vitamin or mineral supplementation should be based on an analysis of the athlete's usual diet.

Fluid: Athletes should balance fluid intake with fluid loss. A number of factors must be considered, including the sweat rate of the athlete and environmental conditions such as temperature, humidity, and altitude.

In addition to the above recommendations, there are a number of other critical areas that involve diet. Attaining and maintaining a body composition that enhances performance is important. Some athletes focus on scale weight since weight may be a sport participation criterion, but attaining a particular weight should be done in a healthy manner. **Disordered eating** (i.e., abnormal eating patterns) and **eating disorders,** such as anorexia or bulimia, are concerns for individual athletes as well as teammates, coaches, parents, and anyone else who works with athletes.

Athletes need a tremendous amount of information about dietary supplements, since the decision to use them should be based on safety, effectiveness, potency, purity, legality, and ethics. Proper food and beverage intake before, during, and after exercise can enhance training and performance while improper intake can be detrimental. All of these issues are covered in depth in the chapters of this text. With so many details to consider, some athletes find that they begin to follow a rigid daily diet. The key is to meet nutrient needs and support training and performance while maintaining dietary flexibility. Athletes need to keep their diet in perspective: Food is needed to fuel the body and the soul (see Keeping It in Perspective).

Adhering to a very rigid eating plan can lead to social isolation and can be a sign of compulsive behavior, both of which can create problems for athletes. Some find themselves eating the same foods every day and the joy of eating is diminished. The key is to have a flexible eating plan that is nutritious and includes a variety of foods. Flexibility usually results in short-term over- and under-eating, but long-term weight stability, proper nutrition, and enjoyment of eating.

Flexible eating is not the same as unplanned eating. Sports nutrition is complicated and the failure to plan a nutritious diet often results in poor nutrient intake, which may hamper performance and undermine long-term health. But eating according to a rigid schedule is a problem, too. Food is for fuel and fun, and athletes must find the right balance.

DIETARY SUPPLEMENTS

Athletes typically have as many questions about dietary supplements as they have about diet. Supplementation is a complicated topic and athletes as well as the professionals who work with them, need correct, unbiased information before making any decisions. Regulation of dietary supplements in the United States is minimal. In fact, dietary supplements could contain banned substances that may result in disqualification, suspension, or other penalties for athletes. The safety and effectiveness of most dietary supplements have not been scientifically tested, although a few supplements, such as creatine, have been widely studied. This section provides an introduction to the topic of dietary supplements. Specific supplements will be discussed in later chapters.

Dietary Supplement Health and Education Act. The Dietary Supplement Health and Education Act (DSHEA), passed in 1994, provides a legal definition for the term *dietary supplement* in the United States. A dietary supplement is defined as a "vitamin, mineral, herb, botanical, amino acid, metabolite, constituent, extract, or a combination of any of these ingredients" (Food and Drug Administration, 1994). This legislation also provides labeling guidelines but does not ensure safety or effectiveness. In mid 2007, quality standards were mandated by the FDA. It also places supplements that have very different functions and safety profiles in the same category. For example, prior to 1994, botanicals and herbs were considered neither a food nor a drug; the passage of the DSHEA classified them as dietary supplements (Dunford, 2003).

Because the legal definition for a dietary supplement is so broad, it may be helpful to further divide this vast category into three subcategories: 1) vitamins, minerals, and amino acids, 2) botanicals, and 3) herbals. Vitamins, minerals, and amino acids are all nutrients that are also found in food. Most of these compounds have an established standard for how much is needed by humans (i.e., DRI) and some have a Tolerable Upper Intake Level established, the highest level taken daily

How to choose? Dietary supplements line the shelves in grocery and drug stores in the United States.

Glycemic index (GI): A method of categorizing carbohydrate-containing foods based on the body's blood glucose response after carbohydrates ingestion, digestion, and absorption. The index is based on scores up to 100.

Fats: One of the six classes of nutrients; most often found in food as three fatty acids attached to glycerol (i.e., triglyceride).

Nutrient dense: A food containing a relatively high amount of nutrients compared to the caloric content.

Disordered eating: A deviation from normal eating but not as severe as an eating disorder.

Eating disorders: A substantial deviation from normal eating, which meets established diagnostic criteria (e.g., anorexia nervosa, bulimia nervosa, anorexia athletica).

KEEPING IT IN PERSPECTIVE

Food Is for Fuel and Fun

Many athletes follow rigorous training programs. To support such training, diet planning becomes very important because food provides the fuel and nutrients that are needed to train hard. Endurance and ultraendurance athletes must carefully plan their food and beverage intake before, during, and after training and competition or they risk running out of fuel and becoming hypohydrated. This need for constant, nutritious food and drink sometimes means that athletes get very rigid about their dietary intake. Rigid meal planning might meet the scientific requirements of nutrition, but it falls short when it comes to the art of eating, which also involves pleasure and enjoyment. In other words, sometimes athletes need to eat food just for fun.

NSF International

When this certification appears on a dietary supplement it means that it is produced using good manufacturing practices.

that is not likely to cause a health problem. Botanicals are typically compounds that have been extracted from foods and concentrated. These supplements have a link to both food (i.e., original source) and medications (i.e., concentrated dose). For example, garlic contains allicin, a biologically active ingredient that may influence blood cholesterol concentration, and garlic supplements are sold as a concentrated source of allicin. The majority of the most widely used herbal supplements in the United States (e.g., ginkgo biloba, St. John's wort, echinacea, saw palmetto) do not contain nutrients found in food. In fact, these herbal products are typically being used as alternative medications. Although the DSHEA prohibits claims that herbal products can treat, prevent, diagnose, or cure a specific disease, such claims are made frequently, especially when these supplements are marketed via the Internet (Morris & Avorn, 2003).

These three subcategories can be useful when evaluating dietary supplements. Since vitamins, minerals, and amino acids are found in foods that the athlete currently consumes, a logical first step is to evaluate current dietary intake to determine if any nutrient deficiencies exist. Botanical supplements raise more questions because the amount may be greater than that obtained from the diet. Additionally, **Good Manufacturing Practices (GMP)** must be used to ensure that the active ingredient is standardized (i.e., the same amount appears in each pill or tablet) and the supplement is pure (i.e., has not been intentionally or unintentionally contaminated). Herbal supplements should also be scrutinized for evidence of safety, effectiveness, purity, and potency, and comparisons should be made to over-the-counter and prescription medications if the supplement is being used as an alternative medication. Clearly, a process involving critical thinking is needed to make wise supplement decisions (Dunford, 2003).

Good Manufacturing Practices (GMP): Quality control procedures for the manufacture of products ingested by humans to ensure quality and purity.

Potency and Purity of Active Ingredients. Until mid-2007, the DSHEA did not require the amount of an active ingredient in a dietary supplement to be standardized, or the use of good manufacturing practices, so quality ranged from excellent to poor. Gurley, Gardner, and Hubbard (2000) tested the ephedrine (ephedra) content of 20 dietary supplements and compared it to the amount listed on the label. Half of the supplements varied by more than 20 percent, including one that contained none and one that contained 150 percent of the amount stated. Botanical and herbal supplements need standardization because the amount of active ingredient in the herb or plant varies substantially, depending on the harvest and manufacturing conditions.

In the same study, the authors detected five dietary supplements that contained norpseudoephedrine, a controlled substance (i.e., drug). Some dietary supplements do contain substances banned by sports governing bodies, and athletes are subject to disqualification even if the banned substances are not listed on the label and were consumed unintentionally. The contamination of dietary supplements prompted the National Football League (NFL) and its players association (NFLPA) to begin a supplement certification program in 2004. Under this program, dietary supplement manufacturers can be certified by an independent testing organization, NSF International, and players can be confident that the labels are accurate and the dietary supplements do not contain any banned substances such as anabolic steroids, androstenedione, and ephedra (www.nsf.org/business/nfl_nflpa/index.asp).

Quackery. Quackery is the practice of making false claims about health-related products, and some dietary supplements fall under this category. It is very difficult to combat quackery, but some resources are listed in the sidebar (see The Internet Café). Many dietary supplements are sold using multilevel marketing (MLM), and unscrupulous distributors may exaggerate their value because they will be financially rewarded if sales increase. Consumers can reduce their risk for being a victim of quackery by critically evaluating products before purchasing them. One method for evaluating dietary supplements is shown in the Spotlight on Supplements: Evaluating Dietary Supplements feature.

The Internet Café

Where Do I Find Information about Quackery?

The following websites are devoted to combating health misinformation, fraud, and quackery:

National Council against Health Fraud (NCAHF): A private, nonprofit, voluntary health agency. **www.ncahf.org**

Quackwatch: Nonprofit organization of volunteers and expert advisors founded in 1969 by Stephen Barrett, M.D. **www.quackwatch.org**

Understanding and Evaluating Scientific Evidence

Although sports nutrition is a fairly new academic discipline, there have always been recommendations made to athletes about foods that could enhance athletic performance. Ancient Roman athletes were encouraged to eat meat before competing. One ancient Greek athlete is reported to have eaten dried figs to enhance training. There are reports that marathon runners in the 1908 Olympics drank cognac (brandy) to improve performance (Grandjean, 1997). The teenage running phenomenon, Mary Decker (Slaney), surprised the sports world in the 1970s when she reported that she ate a plate of spaghetti noodles the night before a race. Such practices may be suggested to athletes because of their real or perceived benefits by individuals who excelled in their sports. Obviously, some of these practices, such as drinking alcohol during a marathon, are no longer recommended, but others, such as a high-carbohydrate meal the night before a competition, have stood the test of time.

Today, sports nutrition recommendations are **evidence based.** Evidence-based practice is the review and use of scientific research to determine the most effective outcome. The scientific evidence plays a central role, although clinical judgment and the athlete's personal preferences and values must also be considered. Because research findings are fundamental in forming recommendations, the quality of the research is very important (Gray & Gray, 2002).

TYPES OF RESEARCH STUDIES

Most research studies fall into one of three categories: case studies, epidemiological studies, or experimental

Evidence-based recommendations: Recommendations based on scientific studies that document effectiveness.

SPOTLIGHT ON SUPPLEMENTS

Evaluating Dietary Supplements

Evaluating dietary supplements requires a systematic, multistep process of gathering, weighing, and judging information. In other words, it requires critical thinking.

Gathering Information

Subjective information: product information and claims found in brochures, advertisements, or on websites.

Objective information: 1) ingredients and amount (dose) found on the label (assume that this is correct information, but in some cases it may not be), 2) physiological and biochemical roles of active ingredients (can be found in physiology, exercise physiology, or biochemistry books), 3) peer-reviewed research articles, and 4) banned substance list from the appropriate sports governing body.

Weighing Information

Objective information is more credible than subjective information. Consider the strength of the body of scientific literature. Note when information is consistent from several objective sources. Be cautious of information obtained only from subjective sources such as advertising. The primary goals of an advertisement are to highlight the advantages of the product and increase sales, not to provide unbiased educational information.

Judging Information

Questions that need to be answered include:

1. Is it legal and ethical?
2. Is it safe? If so, at what dose (amount) and under what conditions?
3. Is it effective? If so, what are the characteristics of the groups in which effectiveness was shown (e.g., age, gender, training, presence of obesity, nutritional status, etc.) and do they reflect the characteristics of the person who would consume the supplement?
4. What is not known?
5. Are the claims true and stated in the correct context, true but overstated, or false?
6. Is the quality of the supplement certified? Can the athlete be reasonably confident that the supplement does not contain a banned substance?

Andy Doyle

An experimental study of carbohydrate consumption and endurance cycling performance.

studies. **Case studies** are observational records. They provide information about an individual in a particular situation. Gathering information is an important first step because it helps researchers to form hypotheses, but case studies are the weakest of all scientific findings.

Epidemiological studies help to determine the distribution of health-related events in specific populations. Such studies highlight nutrition and exercise patterns and help to show associations and **correlations.** These studies are stronger than case studies because large groups of people are studied and data are statistically analyzed. However, these are observational studies and they lack control of all the variables.

The strongest studies are **experimental studies.** These studies follow strict protocols and control most variables except the ones being studied. This is how cause-and-effect relationships are established. One example of each type of study is reviewed here.

Cox and colleagues (2003) published a case study of the training, fitness, and nutritional intake of a musher (sled dog driver) during the Iditarod, a 1,049-mile dog-sled race in Alaska in March. They reported changes in aerobic capacity, energy intake, energy expenditure, weight, and hydration status of a 49-year-old female during the 12-day race. These are important observations but they do not provide a scientific basis for making any recommendations to other mushers or ultraendurance athletes who perform under similar conditions.

The relationship between physical activity or physical fitness levels and improved health is well known as a result of a number of epidemiological studies. A notable example is the large well-designed study of Blair et al. (1989) from the Institute for Aerobic Research. In a study that included over 13,000 subjects, the authors showed that there was a strong relationship between aerobic fitness and decreased all-cause **mortality,** primarily from decreased premature mortality from cardiovascular disease and cancer.

An experimental study that has become a "classic" in sports nutrition was conducted by Coyle et al. (1983) to determine if drinking a carbohydrate beverage helped endurance cycling performance. Well-trained cyclists rode to exhaustion on two occasions, once while drinking a beverage containing carbohydrates and once while drinking a **placebo.** Although muscle glycogen utilization was no different when consuming the carbohydrate drink, blood glucose was maintained, a high rate of carbohydrate oxidation was also maintained, and the cyclists were able to ride at the prescribed intensity for an additional hour before becoming exhausted. This study showed that there was a cause-and-effect relationship between consuming a carbohydrate-containing beverage and the ability to cycle for a longer period of time.

RESEARCH DESIGN AND METHODS

The hallmark of good scientific research is the use of strong research design and methodology. Well-designed studies reduce bias and help to ensure accurate results. The strongest research protocol is a randomized, double-blind, placebo-controlled, crossover study performed on humans. It may include a familiarization trial. The number of subjects in the study should be as large as possible and their characteristics (e.g., age, fitness, training, health status) should be similar.

Randomization is part of the subject selection process. It is usually difficult to study 100 percent of the population of interest, so a sample is chosen. Randomization tries to ensure that all people in the study population will have the same chance of being selected for the sample. The study subjects are also randomly assigned to either the treatment or the placebo group. The placebo group receives an inactive substance that resembles the treatment in every way possible. A double-blind study is one in which neither the researchers nor the study participants know which group they are in or which treatment they are receiving. In a crossover study, subjects will be in both the treatment and placebo groups. For example, if four trials were scheduled, subjects would receive the treatment in two of the trials. For the other two trials they would "cross over" and be in the placebo group.

Randomized double-blind, placebo-controlled study designs help to reduce bias, which can lead to inaccurate results and erroneous conclusions. If subjects aren't randomized, then selection bias will be present. Think about what might happen if researchers knew that the subjects were in the treatment group. They might subtly influence the participants to ensure that the treatment works. If the subjects knew that they were receiving a treatment, they may try to perform better.

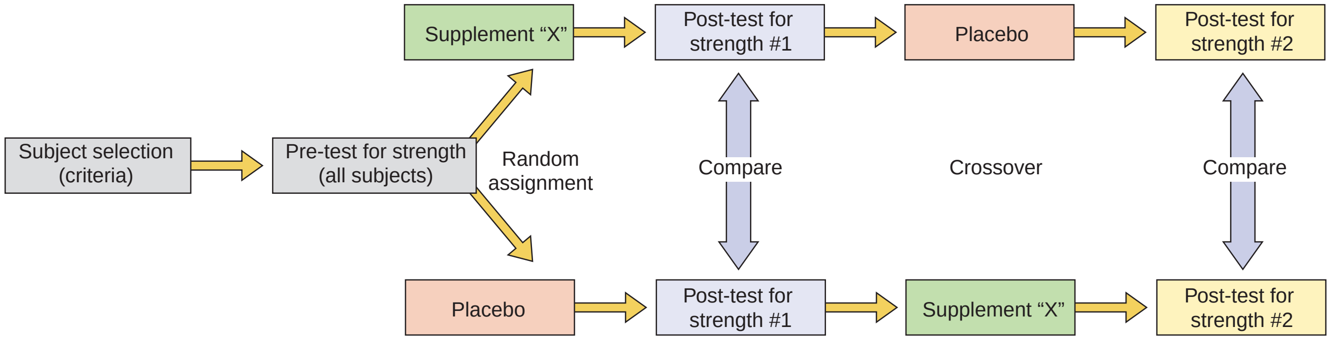

Figure 1.6 Research Design

A research design for an experimental study to determine if the consumption of Supplement “X” improves strength. Appropriate subject selection criteria are established and a pre-test measure of strength is determined for all subjects in the study. Subjects are then randomly assigned to either the experimental (Supplement “X”) group or the control (placebo) group. After consuming the supplement or placebo, a post-test of strength is determined. Subjects then cross over into the opposite group and consume either the placebo or Supplement “X,” and a second post-test of strength is performed. Results of the strength tests after consuming Supplement “X” or the placebo are compared.

Before data are gathered, subjects should complete a familiarization trial. This is critical in studies where the subjects' performance is being measured. Consider a study held in an exercise physiology lab on a stationary bicycle. If subjects are not familiar with the bike or other laboratory equipment, their performance might not be as fast during the first trial. A familiarization trial gives the subjects a chance to practice on equipment and also understand what is expected of them (e.g., length of time in the lab, intensity of exercise). When data collection begins, unfamiliarity with equipment or the study protocol should not be a factor.

The strongest results come from studies in which data are obtained from both an experimental (treatment) and a control (nontreatment/placebo) group. Most of the time, the treatment and **control groups** comprise different people. In a crossover design, subjects are in both groups so they serve as their own controls. For example, a study may be designed to have subjects perform four trials. In the first and fourth trials, the subject is in the **experimental group** and receives a treatment (e.g., a carbohydrate-containing beverage). In the second and third trials, the subject is in the control group and receives a placebo (e.g., an artificially sweetened beverage that contains no carbohydrates). The results for each person can be directly compared because each subject received both the treatment and the placebo. Crossover studies are advantageous, but researchers must be careful to account for any carry-over effects. For example, the effect of creatine loading may last for a month or more while bicarbonate loading may only show effects for a day or two. When designing a crossover study, ample time must be allowed before the next phase of testing begins. An example of a research design for an experimental study is shown in Figure 1.6.

Strong research design and methodology is fundamental to unbiased and accurate scientific information. The recommendations made to athletes are only as strong as the research studies on which those recommendations are based. But how does a person who does not conduct research know if a research study is well designed and accurate? One safeguard is the peer review process.

PEER REVIEW OF SCIENTIFIC RESEARCH

Every scientific study should be peer-reviewed, which means that it is scrutinized by a group of similarly trained professionals (peers) before publication. The peer-review

Case study: An analysis of a person or a particular situation.

Epidemiology: The study of health-related events in a population.

Correlation: A relationship between variables. Does not imply that one causes the other.

Experimental study: A research experiment that tests a specific question or hypothesis.

Mortality: Death; the number of deaths in a population.

Placebo: An inactive substance.

Control group: The subjects in a scientific experiment that do not receive a treatment or who receive a placebo. Also known as a nontreatment or placebo group. Subjects in the control group mirror the characteristics of the subjects in the experimental group so the groups can be compared.

Experimental group: The subjects in a scientific experiment that receive a treatment or intervention; also known as a treatment group.

process begins when the editor of the publication receives a written manuscript from the researchers. The researchers' names are removed and the manuscript is sent to two or more reviewers. They carefully read the study protocol, review the data, and evaluate the authors' conclusions. If the study design and methodology are not scientifically sound, the peer reviewers will recommend that it not be published. If the method is sound, they will make suggestions to ensure clarity and accuracy in reporting the data and drawing conclusions, which the authors will incorporate into a revised manuscript. The revised manuscript is reviewed by the editor and then scheduled for publication. Like the scientific studies, the peer review process should be blind—researchers should not know who reviewed the article and reviewers should not know who conducted the research and wrote the article.

Readers can have confidence in the quality of an article in a peer-reviewed journal. The peer-review process should be a rigorous one. Journals that have the strongest peer-review processes have the best reputations. Examples of peer-reviewed journals that publish sports nutrition-related articles are listed in Figure 1.7.

American Journal of Clinical Nutrition

European Journal of Applied Physiology

International Journal of Sports Medicine

International Journal of Sport Nutrition and Exercise Metabolism

Journal of the American Dietetic Association

Journal of the American Medical Association

Journal of Applied Physiology

Medicine and Science in Sports and Exercise

Sports Medicine (reviews)

Figure 1.7 Examples of Peer-reviewed Journals

LEVELS OF EVIDENCE AND GRADES OF RECOMMENDATIONS

The most conclusive evidence comes from studies that are randomized, double-blind, placebo-controlled, and published in peer-reviewed journals. The results of such studies should be given greater weight than results from other study designs or those published in non-peer-reviewed journals. But even the results of the best-designed study cannot stand alone. Reproducible results are an important part of the scientific process. Recommendations must be based on the cumulative body of scientific literature and not on the results of one study. Just as the strength of each study must be established, the quality of the body of literature must also be determined. This process involves levels of evidence and grades of recommendations.

Level of evidence refers to the relative strength or weakness of the current collective body of scientific research. The strongest evidence comes from a review of all the randomized controlled trials. Such reviews compare the results of high-quality research studies. Many of these reviews involve meta-analysis, a statistical method of comparison. Articles reviewing the collective body of scientific research give rise to the strongest recommendations.

As noted previously, sports nutrition is a relatively young scientific field, so abundant, high-quality research is lacking in many areas. Practitioners must make recommendations based on the current body of literature, knowing full well the limitations of the current scientific knowledge. Grading the scientific evidence is important because it indicates the relative strength and quality of the body of scientific research. Four grades, designated either by Roman numerals or by letters, are generally accepted as described below.

Grade I (Level A): The conclusions are supported by good evidence, known as a rich body of data. The evidence is based on consistent results of well-designed, large randomized research studies. Confidence in the accuracy of these studies is high.

Grade II (Level B): The conclusions are supported by fair evidence, known as a limited body of data. The evidence is less convincing either because the results of well-designed studies are inconsistent or the results are consistent but obtained from a limited number of randomly controlled trials or studies with weaker designs.

Grade III (Level C): The conclusions are supported by limited evidence. Confidence in the results of the research studies is limited by their size and design (e.g., nonrandomized trials or observational studies) or by the size of the cumulative body of literature that consists of a small number of studies.

Grade IV (Level D): The conclusions are supported by expert opinion, known as panel consensus judgment, as a result of the review of the body of experimental research. This category includes recommendations made by sports nutrition experts based on their clinical experience (Myers, Pritchett, and Johnson, 2001; National Heart, Lung and Blood Institute evidence categories).

In a perfect world, Grade I (Level A) evidence would be available to answer all questions regarding the nutrition and training needs of athletes. But in many cases, recommendations are supported by only fair or limited evidence. In some cases, expert opinion is relied upon until more research can be conducted. Although dietary supplements are widely

The Advertising Archives

Many ads for dietary supplements include testimonials by elite athletes.

used by athletes, the scientific evidence available may be limited or nonexistent in many cases. Lack of scientific research makes it difficult to evaluate claims regarding safety and effectiveness. When making sports nutrition, training, or dietary supplement recommendations to athletes, it is important to indicate the relative strength of the research or the absence of scientific studies.

Anecdotal Evidence. Anecdotes are personal accounts of an incident or event and are frequently used as a basis for testimonials. Anecdotal evidence is based on the experiences of one person and then stated as if it had been scientifically proven. Often anecdotal evidence is cited to show that the current recommendations are not correct. Anecdotal evidence is not necessarily false (it may be proven in the future), but it should not be used as proof.

Anecdotal evidence and testimonials are often used to market dietary supplements. For example, a well-known athlete may appear in a supplement advertisement and endorse the product. It is not illegal to include endorsements in advertisements, but it is deceptive if the consumer is led to believe that the endorsement is made voluntarily when the person is being paid to promote the product. The Federal Trade Commission (FTC) is responsible for regulating the advertisement of dietary supplements and more information can be found at (www.ftc.gov/).

What's the point? The strength of any scientific recommendation depends on the quality of the research conducted.

DRAWING APPROPRIATE CONCLUSIONS FROM SCIENTIFIC STUDIES

One scientific study does little by itself to answer critical questions about sports nutrition issues. As shown above, it is both the quality and quantity of scientific research that allows practitioners to make sound nutrition and training recommendations to athletes. Critical thinking skills are needed to correctly interpret scientific research and properly communicate their results to athletes. Here are some issues that need special attention when drawing conclusions from scientific studies.

Distinguish between Correlation and Causation. One of the fundamental differences between epidemiological and experimental studies is the establishment of **causation.** Epidemiological studies can only establish a correlation (i.e., that a relationship exists between two variables, and the strength of that relationship). It takes experimental research to establish causation—that the variable studied produces a particular effect. It is very

Causation: One variable causes an effect. Also known as causality.

THE EXPERTS IN. . .

Exercise Physiology and Sports Nutrition

To students who are taking a first course in exercise physiology or nutrition, it might seem unfathomable that they may one day become the experts in these fields. In fact, today's experts were once students in introductory courses and some of today's students will be the cutting edge researchers of the future. In subsequent chapters of this textbook, one or more of today's experts will be highlighted. These men and women from all over the world have become experts because of their hard work, curiosity, and dedication to advancing knowledge in their chosen fields. They are real people who are recognized by their peers for their knowledge and experience. In time, one of those experts may be you.

Andy Doyle

Jacky Naegelen/Reuters/Corbis

Does the laboratory research study accurately reflect the demands or strategy of a competitive event?

important in both written and oral communications that professionals do not use the word *causes* if in fact the study or the body of research only shows an association or correlation. For example, epidemiological studies clearly show that people with lower aerobic fitness levels have an increased risk of premature death, particularly from cardiovascular disease and cancer (Blair et al., 1989; Laukkanen et al., 2001). This knowledge is based upon the strong inverse relationship between fitness levels and premature all-cause mortality. So it is correct to say that there is an association between aerobic fitness levels and premature death. However, based upon this type of research, it is not valid to suggest that low fitness levels cause premature death.

Understand the Importance of Replicating Results. Recommendations should not be made based on the results of one research study. Preliminary studies, many of which are performed in very small study populations, often produce surprising results, but many of these studies are never replicated. Unfortunately, the results of single studies are often widely reported as "news" by the media and then become falsely established as fact.

Extrapolate Results of Scientific Research with Caution, If at All. Extrapolation takes known facts and observations about one study population and applies them to other populations. This can lead to erroneous conclusions because only the original study population was tested directly. In the area of sports nutrition there are many ways that data may be extrapolated, including animals to humans, males to females, adults to adolescents, or children and younger adults to older ones. Sports nutritionists work with athletes of all levels, from recreational to elite, and must carefully consider the validity of extrapolating research results to these populations. For example, a dietary intervention or manipulation that shows positive results in a sedentary population with diabetes may not be applicable to well-trained runners. Other factors that are powerful influences and should be extrapolated with caution, if at all, are the presence or absence of training, the type of sport, laboratory or field conditions, and competition or practice conditions.

Interpret Results Correctly. The results of research studies are often misinterpreted or applied to an inappropriate population. Professionals must be able to evaluate the results of research studies, and be able to recognize when recommendations are being made in an inappropriate way. One important consideration is to evaluate the characteristics of the subject population studied and to determine if the results observed in this group can reasonably be expected in other groups. Many studies of specific sport or exercise performance have used physically active college students as subjects; results of these studies should be considered with great caution when making recommendations to other groups, such as highly trained athletes. Many sports nutritionists and physiologists that work with elite athletes will only use the results of studies that have used highly trained athletes that are similar to their client population.

Another important consideration in evaluating research results is how closely the laboratory experimental design mimics the "real" demands of the athletic event. Scientists study athletes in the laboratory so that they can carefully control as many experimental conditions as possible. In studying endurance performance, it is common to use "time to exhaustion" protocols in which athletes run or ride at a fixed exercise intensity until they are no longer able to maintain the required pace. While these types of protocols are useful for studying metabolic responses during these types of activities, they do not reflect the demands or strategy of a real race, and may therefore be less useful for predicting performance.

Focus on Cumulative Results and Consensus. There is much excitement when a new study is published, especially when the results contradict current sports nutrition recommendations or long-held theories. But startling breakthroughs are the exception, not the rule. Cumulative data, not single studies, are the basis for sound recommendations. It is imperative that any new study be considered within the context of the current body of research.

While some topics may be subject to healthy debate among experts, many topics have good scientific agreement, known as **consensus.** One of the best ways to know the consensus opinion is to read review articles or position statements. Review articles help students to understand the body of literature on a particular topic. These articles also help practitioners put the results of new research studies in the proper context and remain up to date with the current body of research.For example, Burke, Kiens, and Ivy (2004) published an article on carbohydrates and fats for training and recovery in which the authors reviewed the scientific literature on post-exercise glycogen storage published between 1991 and 2003. Such articles consider the cumulative body of scientific evidence over a long period of time and help students and practitioners become familiar with the consensus opinion.

Recognize the Slow Evolution of the Body of Scientific Knowledge. Occasionally, landmark research studies are published that increase knowledge in a particular field in a quantum leap (e.g., Watson and Crick elucidating the structure of DNA). However, for the most part, knowledge in scientific areas such as sports nutrition increases gradually as additional research studies are completed and evaluated in the context of the existing research. The process can move slowly, as it takes time for research studies to be proposed, funded, completed, published, and evaluated by the scientific community. At times it may seem to be a slow and cumbersome process. However, a deliberate, evaluative approach is an important safeguard for the integrity of the information. The scientific process is similar to building a brick wall; it takes time and must be done one brick at a time, but if done correctly, the end product has considerable strength.

CONSUMER EXPOSURE TO SCIENTIFIC STUDIES

In the past, only other scientists read articles published in scientific journals. Today, results of scientific studies are widely reported in the print and visual media. Athletes may hear results of a research study before the journal is received and read by professionals. Consumers like to hear about new studies, but few consumers can interpret the research or put the newest results in the proper context. The role of the professional is threefold: 1) provide sound science-based information, 2) recognize and correct misinformation, and 3) address the effects of misinformation (Wansink & American Dietetic Association, 2006).

Surveys suggest that the primary source of nutrition information for consumers is the media. The top two media sources are television and magazines, with newspapers a distant third. All of these media routinely report the results of research studies. Athletes are also consumers, so these sources are likely popular with athletes too. In addition to media sources, studies of collegiate athletes suggest that nutrition information is also obtained from fellow athletes, friends, family members, coaches, strength and conditioning coordinators, and certified athletic trainers (Froiland et al., 2004; Jacobson, Sobonya, and Ransone, 2001).

The Internet is a popular source for nutrition, excercise, and health information, but it is not clear how people utilize the information obtained.

One of the problems with the coverage of scientific studies in the media is that preliminary research data are reported. Preliminary data often raise more questions than they answer and such data are not considered sound until replicated. Additionally, research results may not be put in the larger context of the known body of literature on the subject. Other concerns are that cause and effect are reported or inferred when an association or correlation was actually found. Distinctions between probability and certainty are rarely made (Wansink & American Dietetic Association, 2006).

The results of research studies are frequently used as a marketing tool, some of them prior to being reviewed and published in peer-reviewed journals, and some from unpublished studies. Clever advertising copy can make it appear that there is a direct link between scientific research and the product being sold, as shown in Spotlight on Supplements: Use of Scientific Studies as a Marketing Tool. Testimonials from athletes, a form of anecdotal not scientific evidence, are widely used to sell sports nutrition products.

USE OF THE INTERNET FOR NUTRITION, EXERCISE, AND HEALTH-RELATED INFORMATION

The Internet is a major source of information about health, exercise, and nutrition. It is estimated that 40 to

Consensus: General agreement among members of a group.

70 percent of all people who access the Internet look for health-related information (Baker et al., 2003; Klurfeld, 2000). Diet and nutrition are popular topics among people of all ages, including adolescents (Skinner et al., 2003) and college students (Hanauer et al., 2004).

While many consumers are accessing health information on the Internet, the impact of that information is not known. A systematic review of all Internet health information studies from 1995 to 2001 (Bessel et al., 2002) found that consumers widely used the Internet to find health information, but such information had no effect on outcomes such as knowledge, change in health status, or utilization of the health-care system. It appears that people are looking for information on the Internet, but what they do with that information once they obtain it is not clear.

The Internet has been described as a democracy of information since access is freely available. Consumers and professionals need excellent critical thinking skills to place health, nutrition, and exercise information found on the Internet in its proper context. Health-care professionals are concerned about the amount of misinformation present and the degree of commercial exploitation that accompanies educational information. Some information is false and may harm consumers. Other information is biased and limited to facts that support products and services that are being sold on the same website. Some information is balanced and reliable but still may have a commercial slant since most websites are commercial enterprises (Klurfeld, 2000).

Morris and Avorn (2003) reported on the content of websites devoted to herbal dietary supplements. Of the 443 websites analyzed, 76 percent (338 websites) sold or were linked to sites that sold the products. Approximately 80 percent of the retail websites made one or more health claims and the majority (55 percent) claimed that the product could treat, prevent, diagnose, or cure a specific disease, although such statements are prohibited under the Dietary Supplement Health and Education Act. Internet information about dietary supplements is widespread and easily accessible but not well regulated. Some reliable sources of diet, exercise, and health related information are listed in The Internet Café sidebar.

USE OF THE INTERNET FOR FINDING SCIENTIFIC INFORMATION ABOUT SPORTS NUTRITION

The Internet is an appealing vehicle for finding scientific information about sports nutrition because of its speed and scope. However, the sheer amount of information can be overwhelming. Most libraries have developed research guidelines to help users understand and access electronic databases. One of the largest is Pubmed, which contains more than 16 million scientific citations for biomedical articles from MEDLINE, the National Library of Medicine online database (www.pubmed.gov). Some of the scientific articles are freely accessible for downloading while others are linked to the journal's website and are available for a fee.

SPOTLIGHT ON SUPPLEMENTS

Use of Scientific Studies as a Marketing Tool

The picture on the supplement bottle was eye-catching. A good-looking couple were running down the beach. He was shirtless, which highlighted his impressive upper body muscle mass. She had a tight-fitting white sundress, a perfect figure, and long blond hair. The supplement was advertised as a nutritional means to control weight. The accompanying materials were also impressive. Two research studies were called into evidence. The first indicated that those who took the supplement had a much greater weight loss than those who were given a placebo. The second study was cited as evidence that taking the supplement could boost energy. The results of these studies were reduced to a single sentence prominently displayed in the advertising—University studies show that this supplement helps people lose weight and feel less fatigued. A closer look at the studies (something most consumers cannot do) tells a more complete story. In the first study, the 14 obese subjects were all consuming a liquid diet of 1,000 Calories daily. They were living in an experimental research ward where they had no access to food other than the liquid diet. While the women receiving the supplement did lose more weight than the ones not receiving it, they were still obese at the end of the 21-day study period.

The second study involved a different population—20- to 30-year-old males. The eight subjects did not receive a calorie-restricted diet. The exercise that the study subjects performed was on a stationary bike in the laboratory. Those who received the supplement experienced less fatigue than those who did not.

These studies were published in peer-reviewed journals and their results are an important contribution to the body of literature about this particular compound. But small study populations and tightly controlled food and exercise conditions limit their applicability outside the laboratory setting. Using these studies to sell supplements to the general population is stretching the scientific literature beyond its application limits. The study citations give the supplement more scientific credibility than it deserves. It is safe to say that consumers will not look like the man or woman in the picture by just taking this supplement.

The Internet Café

Where do I find reliable information about diet, exercise, and health?

Although there are many reliable websites, those listed here are government agencies or professional organizations.

Healthfinder: A guide to reliable health information sponsored by the Office of Disease Prevention and Health Promotion. **www.healthfinder.gov**

MedlinePlus®: Trusted health information sponsored by the National Library of Medicine and the National Institutes of Health. **www.medlineplus.com**

Nutrition.gov: "Smart Nutrition Starts Here" sponsored by the National Agricultural Library and the U.S. Department of Agriculture. **www.nutrition.gov**

American College of Sports Medicine: Professional organization whose mission is to advance health through science, education, and medicine has resources for the general public at **www.acsm.org**

American Dietetic Association: Professional organization committed to helping people enjoy healthy lives through good nutrition. Food and nutrition information for consumers can be found at **www.eatright.org**

Scope of Practice

Who is qualified to make nutrition and training recommendations to athletes? Because health, nutrition, and exercise are interrelated, the lines between these disciplines are sometimes blurry and there is some overlap among various practitioners. **Scope-of-practice** definitions help establish professional boundaries by outlining the skills, responsibilities, and accepted activities of practitioners. Such definitions take into account academic training and professional knowledge and experiences. Certifications and licenses are one way to formally define scope of practice, but not all health, exercise, and nutrition practitioners are formally licensed and some certifications are voluntary. In some states, scope of practice may be legally defined.

Scope of practice protects both consumers and practitioners. Consumers can be assured that practitioners have been properly trained and are qualified to practice. Likewise, practitioners are aware of their professional boundaries and can avoid areas in which they do not have appropriate training and skills. When a client's needs fall outside a practitioner's scope of practice, the appropriate response is to acknowledge these limits and make a referral to a qualified practitioner. Practitioners may be professionally and personally liable if they work outside their scope of practice and their clients are harmed. Most health-care professionals,

© Rachel Epstein/The Image Works

A trainer shows an athlete how to check her pulse.

such as medical doctors (MD) and nurses (RN), are licensed, usually by the state in which they practice. Registered dietitians (RD) and Registered Clinical Exercise Physiologists (RCEP) are certified. These licenses and certifications require at least a bachelor's degree, clinical experience, and successful completion of a written exam. In some cases higher degrees and more training are needed—RCEPs must complete a master's degree in exercise science, exercise physiology, or kinesiology and MDs must complete medical school and postgraduate training such as internships and residencies.

Other certifications are available in the exercise field. For example, the American College of Sports Medicine (ACSM) certifies Exercise Specialists, Health/Fitness Instructors, and Personal Trainers. The academic preparation of each is different. Exercise Specialists must have a bachelor's degree in an allied health field, such as exercise physiology, physical therapy, or nursing. Health and Fitness Instructors must have an associate's or bachelor's degree in any number of allied health fields, while a Personal Trainer must have a high school degree or the equivalent to be certified. Because academic training is different, scope of practice is also different. Brief explanations of these exercise certifications can be found in Figure 1.8.

In addition to those already mentioned, other practitioners such as certified strength and conditioning specialists (CSCS) and certified athletic trainers (ATC), may work closely with athletes. The CSCS is a certification by The National Strength and Conditioning Association, which tests and certifies individuals who can design and implement safe and effective strength and conditioning programs. To be eligible, a candidate must have a bachelor's or chiropractic degree or be enrolled as a senior at an accredited college or university and have a current CPR certification. Certified athletic trainers (ATC) are

Scope of practice: Legal scope of work based on academic training, knowledge, and experience.

The ACSM Certified Personal Trainer™ (CPT) is a fitness professional involved in developing and implementing an individualized approach to exercise leadership in healthy populations and/or those individuals with medical clearance to exercise.

The ACSM Health/Fitness Instructor® (HFI) is a degreed health and fitness professional qualified to assess, design, and implement individual and group exercise and fitness programs for apparently healthy individuals and individuals with medically controlled diseases.

The ACSM Exercise Specialist® is a health-care professional certified by the ACSM to deliver a variety of exercise assessment, training, rehabilitation, risk factor identification, and lifestyle management services to individuals with or at risk for cardiovascular, pulmonary, and metabolic disease(s).

The ACSM Registered Clinical Exercise Physiologist® is an allied health professional who works in the application of exercise and physical activity for those clinical and pathological situations in which exercise it has been shown to provide therapeutic or functional benefit. Patients for whom services are appropriate may include, but not be limited to, those with cardiovascular, pulmonary, metabolic, immunological, inflammatory, orthopedic, and neuromuscular diseases and conditions.

Figure 1.8 Examples of Exercise Specialist Certifications

allied health-care professionals that provide for risk management and injury prevention, acute care of injury and illness, assessment and evaluation of injury, and who conduct therapeutic modalities and exercise. To be eligible for certification, candidates must have a degree from an accredited college or university athletic training program that includes both academic and clinical requirements.

Registered dietitians (RD) are food and nutrition experts. They must earn a bachelor's degree with specialized dietetics courses, complete 6 to 12 months of supervised practice, and pass a national exam. In addition to the RD, which is a national certification, dietitians may also be subject to state licensure laws. Registered dietitians have clinical training, counseling experience, and a solid background in nutrition assessment. Excellent assessment and counseling skills are needed to identify and counsel clients with disordered eating issues or eating disorders (Clark, 2000).

In many states, anyone can legally give general nutrition advice, but only certain practitioners can give medical nutrition therapy (MNT). MNT is nutrition advice that is intended to prevent, treat, or cure a

Commission on Dietetic Registration (CDR)

This logo indicates the individual is a registered dietitian who is board certified in sports dietetics.

disease or disorder. MNT requires extensive training and usually falls under the scope of practice of physicians, registered dietitians, and those with master's degrees in clinical nutrition.

Nutritionist refers to someone who has studied nutrition. It is a very general term and academic training can range from marginal to rigorous. For example, one online university certifies nutritionists after they complete just six online courses and pass an exam. Contrast that academic training with a person with a master's degree in nutrition science. A science-based bachelor's degree is a prerequisite and the master's degree requires at least two years of coursework and research study in the area of nutrition. When the term *nutritionist* is used, consumers should inquire about the practitioner's academic background.

Certification of sports nutritionists is in its infancy. A Board Certified Specialist in Sports Dietetics (CSSD) is a registered dietitian who has specialized knowledge and experiences in sports nutrition. To be eligible to take the board certification exam the individual must be a registered dietitian (RD) for a minimum of two years with at least 1,500 hours of sports nutrition experience in the past five years. Registered dietitians must possess a bachelor's degree and coursework in dietetics, complete a supervised practice program (internship), pass a national exam, and meet continuing professional educational requirements. More information can be found at www.eatright.org.

The International Society of Sports Nutrition offers the CISSN (Certified Sports Nutritionist from the International Society of Sports Nutrition). This certification requires the individual to possess a four-year undergraduate degree in exercise science, kinesiology, physical education, nutrition, biology, or related biological science **or** be a certified strength and conditioning specialist (CSCS). However, there is an alternative pathway that does not require a four-year degree and is based on five years of experience and possession of two other certifications. The CISSN requires successful completion of the CISSN certification exam. More information can be found at www.sportsnutritionsociety.org/site/cissn.php.

Many professional organizations have clear statements regarding scope of practice. Practitioners must recognize the limitations of their training, skills, and knowledge. Many practitioners have basic but not advanced knowledge of nutrition and physical fitness. In such cases professional organizations often suggest using and promoting only general nutrition and exercise materials that are in the public domain. Public domain documents can be freely copied and distributed. There are excellent public domain general nutrition and fitness materials produced by federal government agencies and large health-oriented organizations such as the American Heart Association. The Dietary Guidelines for Americans (2005), MyPyramid, and ACSM's position statements are examples. The use of public domain general nutrition and exercise materials is unlikely to cause harm, and consumers receive consistent health-related messages from professionals.

Specific nutrition and training recommendations for athletes should be made by practitioners who are qualified to do so. To most effectively help athletes and to avoid potentially harming them, it is important to know and respect professional boundaries and to make referrals to other qualified professionals.

What's the point? Certifications vary widely in their requirements. Many exercise and nutrition-related certifications do not require a four-year degree.

Summary

Sports nutrition combines the scientific disciplines of exercise physiology and nutrition. The ultimate goal is improved performance, which involves both skill development and training. Proper nutrition helps to support training and recovery as well as good health. Sports nutrition principles are based on sound general nutrition principles that have been modified to reflect the demands of training and competition. Dietary supplements are widely advertised to athletes but are not well regulated in the United States. Athletes must take into account the legality, ethics, purity, safety, and effectiveness of the dietary supplement.

Sports nutrition recommendations should be **evidence based.** The most conclusive evidence comes from studies that are randomized, double-blind, **placebo-controlled**, and published in peer-reviewed journals. The results of research studies are often misinterpreted or misapplied. The role of the professional is to provide sound science-based information and to correct erroneous information. Athletes are subject to much misinformation, especially concerning dietary supplements.

Practitioners must understand and respect the limitations of their training, skills, and knowledge. **Scope of practice** definitions help establish professional boundaries and protect athletes and practitioners. A referral should be made when an athlete's needs fall outside a practitioner's scope of practice. Many people who work with athletes are certified or licensed. Some certifications are rigorous but others are not.

Post-Test: Reassessing Knowledge of Sports Nutrition

Now that you have more knowledge about sports nutrition, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. An athlete's diet is a modification of the general nutrition guidelines made for healthy adults.
2. Nutrition periodization refers to a nutrition plan that is developed to match an athlete's training program.
3. In the United States, dietary supplements are regulated in the same way as over-the-counter medications.
4. The scientific aspect of sports nutrition is developing very quickly and quantum leaps are being made in knowledge of sports nutrition.
5. To legally use the title of sports nutritionist in the United States, a person must have a bachelor's degree in nutrition.

Review Questions

1. What is sports nutrition?
2. What are the general goals of training and the short- and long-term nutrition goals that may improve performance?
3. In what ways do basic nutrition principles parallel basic training principles?
4. Explain the ways in which the Dietary Supplement Health and Education Act regulates dietary supplements in the United States. In what ways are dietary supplements not well regulated?
5. Why is the Internet both advantageous and disadvantageous for obtaining health-related and sports nutrition information?
6. What are the advantages of experimental research? What are the limitations of epidemiological research and case studies?
7. What are the elements of research design that give strength to a scientific study?

8. Who is qualified to make nutrition and training recommendations to athletes?
9. What is scope of practice?
10. What are the roles of exercise physiologists, sports dietitians, athletic trainers, and strength and conditioning specialists? When do these roles overlap and when are they distinct?

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2 Defining and Measuring Energy

Learning Objectives

1. Define and explain bio-energetics, ATP, calorie, kilocalorie, and other energy-related terms.
2. Explain the concept of conservation of energy and how this concept applies to energy utilization in the body.
3. Identify the primary source of energy in the body and explain how it is used by muscle during exercise.
4. Explain the resynthesis of ATP, including the role of en-zymes, and name the major energy systems involved.
5. Explain how the energy con-tent of food and how energy expenditure are measured directly and indirectly, and how estimates can be made more accurate.
6. List and explain the compo-nents of the energy balance equation.
7. Explain resting metabolic rate, the factors that influ-ence it, and how it is mea-sured or predicted in athletes and nonathletes.
8. Explain the impact of physical activity on energy expenditure.
9. Calculate an estimated energy requirement for a 24-hour period using a simple formula.

Pre-Test Assessing Current Knowledge of Energy

Read the following statements and decide if each is true or false.

1. The body creates energy from the food that is consumed.
2. The scientific unit of measure of energy is the calorie.
3. A person's resting metabolic rate can change in response to a variety of factors such as age, food intake, or environmental temperature.
4. Physical activity is responsible for the largest amount of energy expended during the day for the average adult in the United States.
5. The energy source used by all cells in the body is adenosine triphosphate (ATP).

For the body to remain viable and to function properly, thousands of physiological and biochemical processes must be carried out on a daily basis. Each requires **energy.** A relatively large amount of energy is needed just to sustain life throughout the day. Physical activity, exercise, and sport require energy beyond that needed for daily subsistence. Where do humans get the energy for these activities? The simple answer is food. **Bioenergetics,** the process of converting food into biologically useful forms of energy, is the focus of the next two chapters.

Energy is such a large topic that it can quickly become overwhelming, so the discussion of energy is covered in two chapters in this textbook. This chapter will focus on the introductory concepts of energy primarily, defining and measuring it, and energy balance, "Energy in = Energy out." On one side of the energy balance equation is energy intake in the form of food (i.e., "energy in"). On the other side of the energy balance equation is energy expenditure (i.e., "energy out"), primarily from resting metabolism and physical activity, exercise, and sport. Chapter 3 will cover the energy systems that are used to fuel the body at rest and during exercise.

Energy and Energy Concepts

BASIC ENERGY CONCEPTS

Energy is difficult to define, but simply stated, it is the ability to perform work. Energy exists in different forms: atomic, chemical, electrical, mechanical, radiant, and thermal. It is easy to think of a wide variety of tasks that need to be performed in the body that require work and, therefore, energy. Examples include:

- Chemical work (e.g., storage of carbohydrates by forming glycogen for later use)
- Electrical work (e.g., maintenance of the distribution of ions across cell membranes)
- Mechanical work (e.g., **force production** by muscle)
- Transportation work (e.g., circulation of blood throughout the body to deliver oxygen, nutrients, and other compounds to tissues)

To understand the various energy systems in the body, it is necessary to understand some basic concepts of energy. An important concept, commonly known as the law of "Conservation of Energy," is the First Law of Thermodynamics, which states, "Within a closed system, energy is neither created nor destroyed." It can, however, be transformed from one form of energy to another. An old-fashioned steam locomotive is an excellent example of how thermal, or heat energy, is transformed into mechanical energy to drive the locomotive wheels (see Figure 2.1).

AP Photo/Chris Gardner

© Jeff Greenberg/PhotoEdit

Figure 2.1 Conversion of Thermal (heat) Energy to Mechanical Energy

Male cyclist weighing 150 pounds (68.2 kg) riding on a cycle ergometer at 180 Watts (for perspective, riding at a power output of 180 Watts would be a moderate-to-hard training pace for a recreational cyclist, and a relatively easy pace for a well-trained competitive cyclist).

Exercise oxygen consumption = 36.0 ml/kg/min or 2.455 L/min

Resting oxygen consumption = 3.5 ml/kg/min

Conversion factors (see Conversion Tables in the front of the book)

1 Watt = 0.0143 kcal/min

5 kcal = 1 L oxygen

1 L = 1,000 ml

External work performed:

180 Watts × 0.0143 kcal/min = 2.574 kcal/min

Total energy expended during exercise:

36.0 ml/kg/min × 1000 ml/L = 0.036 L/kg/min

0.036 L/kg/min × 68.2 kg = 2.455 L/min

2.455 L/min × 5 kcal/L = 12.28 kcal/min

Energy expended (above resting):

36.0 ml/kg/min – 3.5 ml/kg/min = 32.5 ml/kg/min

32.5 ml/kg/min × 1,000 ml/L = 0.0325 L/kg/min

0.0325 L/kg/min × 68.2 kg = 2.217 L/min

2.217 L/min × 5 kcal/L = 11.08 kcal/min

Efficiency = External Work ÷ Energy Expended

Efficiency = (2.574 kcal/min ÷ 11.08 kcal/min) × 100 = 23.2%

Every minute this person cycles at this intensity, he expends 11.08 kilocalories of energy, but accomplishes only 2.574 kilocalories of external work.

Figure 2.2 Example of Energy Efficiency During Exercise

Legend: kg = kilogram; ml = milliliter; min = minute; L = liter; kcal = kilocalorie

How does the First Law of Thermodynamics apply to the human body and the study of sports nutrition? Humans do not create energy or lose energy; rather, they have a variety of processes that are used to transfer energy from one form to another for use by the body. Energy is consumed in the form of food and transformed into different chemical forms that can be used immediately or stored for later use.

Humans are relatively inefficient in the process of energy conversion, at least compared to machines. Electric motors and steam turbine engines can convert approximately 85 percent of electrical or thermal energy to mechanical work. However, biological systems are much less efficient, directing a much lower percentage of available energy to the performance of useful work. For example, when one is using muscle for exercise, all of the energy expended is not used for force production, but a large amount of the energy is transferred to heat. This is why muscle and body temperature rise during exercise.

Bicycling is an excellent physical activity to study the energy efficiency of human exercise. First, with the use of a precision cycle ergometer, the amount of work performed can be accurately measured. Second, because of the mechanical design of the gearing, cycling on a bicycle or cycle ergometer is at the upper end of the efficiency range for a human to perform work. As seen in the example in Figure 2.2, exercising on a cycle ergometer results in only approximately 25 percent of the energy expended being converted to useful work. Bicycling is one of the more energy-efficient activities for humans; other activities such as walking, running, and swimming are even less energy efficient.

Energy: The ability to perform work.

Bioenergetics: The process of converting food into biologically useful forms of energy.

Force production: The generation of tension by contracting muscle.

Figure 2.3 An Example of Potential Energy and Kinetic Energy

Water stored in a reservoir behind a dam is an example of potential energy. The force of the moving water released from the dam is an example of kinetic energy.

Storing and Releasing Energy. Energy can exist in a state of **potential energy** when it is being stored for future use. As stored (potential) energy is released to perform some type of work, it is referred to as **kinetic energy.** The water captured in a reservoir behind a dam has a tremendous amount of potential energy as shown in Figure 2.3. If water is allowed to flow through pipelines in the dam to turbines, the kinetic energy of the moving water turns the blades of the turbines, which then drives a generator to produce electricity. A hydroelectric dam (Figure 2.4) is an excellent example of 1) storing energy in a potential state to be used later (water in the reservoir), and 2) the conversion of energy from one form to another useful form of energy (the mechanical energy of the moving water and the spinning turbine to electrical energy).

These same concepts can be applied to energy processes in the body. Carbohydrates consumed by an athlete can be stored for later use. The energy contained in carbohydrate foods can be stored in muscle as glycogen (i.e., a carbohydrate reservoir). Glycogen can then be used as a fuel source during exercise; its stored potential energy can be converted to chemical energy (i.e., ATP), which can be used by muscles for force production.

There are processes and reactions that store energy and ones that release energy. Those that store energy are referred to as **endergonic** reactions; those that release energy are referred to as **exergonic** reactions. The setting and use of a mousetrap illustrates the complementary processes of endergonic and exergonic reactions in a mechanical fashion as illustrated in Figure 2.5. In

Image not available due to copyright restrictions

(a) Input of energy required. (b) Storing energy as potential energy. (c) Release of energy—kinetic energy.

Figure 2.5 A Mechanical Example of Endergonic and Exergonic Processes

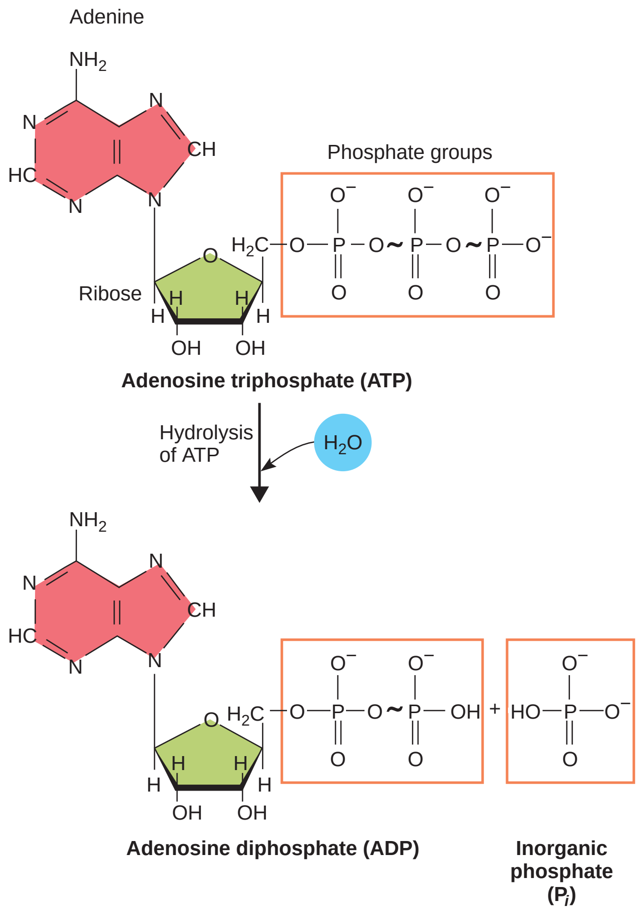

Figure 2.6 Adenosine Triphosphate (ATP) and Adenosine Diphosphate (ADP)

The energy currency of all living things, ATP consists of adenine, ribose, and three phosphate groups. The hydrolysis of ATP, an exergonic reaction, yields ADP and inorganic phosphate. The black wavy lines indicate unstable bonds. These bonds allow the phosphates to be transferred to other molecules, making them more reactive.

order for the mousetrap to be useful, the spring trap must be set. To set the trap, the wire bail must be forced back into position against the spring and locked into place, which requires the input of energy. This is the endergonic portion of the process; energy is put into the process and can be stored for later use. Once the mousetrap is set, it can be used immediately, or it might be placed somewhere in the house where it can perform its useful task at any time over the next few hours, days, or weeks. When the device is triggered, the energy that has been stored in the spring is released, causing the wire bail to snap. This is the energy releasing, or exergonic, part of the process.

The mousetrap is a mechanical example of the storage and release of energy; this same process can occur in chemical reactions. Some chemical reactions require the input of energy, but that energy can be stored for later use. Other chemical reactions can release the energy, which can then be used to power activities such as muscle contraction. Many of the chemical reactions that store and release energy in the body utilize chemical compounds called **high-energy phosphates.**

HIGH-ENERGY PHOSPHATES

The primary example of a chemical compound used in reactions in the body that can store and release energy is **adenosine triphosphate (ATP).** Adenosine triphosphate is a high-energy phosphate compound, a chemical that can store energy in its phosphate bonds. A protein molecule (adenine) combines with a sugar molecule (ribose) to form adenosine, which then has three phosphate groups attached, thus, the name adenosine triphosphate (see Figure 2.6). Energy is released from ATP in a very rapid one-step chemical reaction when a phosphate

Potential energy: Stored energy.

Kinetic energy: Energy of motion.

Endergonic: Chemical reactions that store energy.

Exergonic: Chemical reactions that release energy.

High-energy phosphate: A chemical compound that stores energy in its phosphate bonds.

Adenosine triphosphate (ATP): A chemical compound that provides most of the energy to cells.

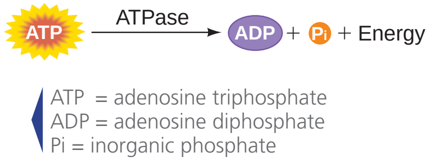

Figure 2.7 Breakdown of ATP and Release of Energy

group is removed. The catalyst for the reaction is the enzyme ATPase. As shown in Figure 2.7, ATP is broken down to yield **adenosine diphosphate (ADP),** inorganic phosphate (Pi), and energy. The role of enzymes in catalyzing reactions is explained in Spotlight on Enrichment: The Role of Enzymes.

Use of ATP by Muscle. Adenosine triphosphate is the source of energy that is common to all cells in the body. It is often referred to as the common energy currency, much like the Euro has become the common currency of most countries in the European Union. While ATP is used by all cells of the body, the use of ATP by skeletal muscle is of major interest for those engaged in activity, exercise, and sport.

Any physical activity requires energy expenditure beyond what is needed at rest. As the intensity of the activity increases, the energy that is necessary to support that activity increases as well. Exercise or sports activities may require a large total amount of energy (e.g., marathon running) or may require a very high **rate** of energy expenditure (e.g., sprinting or weight lifting).

For skeletal muscles to produce force, the globular heads of the thick contractile protein, myosin, must form attachments (crossbridges) with the thin contractile protein, actin (see Figure 2.8). Once this crossbridge is formed, the myosin heads swivel in a power stroke similar to a rower pulling on an oar. This power stroke causes the actin strands to be pulled so that they slide over the myosin filaments, creating tension or force. This is known as the Sliding Filament Theory of muscle contraction. After the contraction- or force-producing phase, the myosin heads must detach and reset, allowing relaxation of the muscle and preparation for the next contraction.

Where does the energy come from for muscles to produce force for exercise? The direct source of energy for force production and relaxation of muscle comes from ATP. Molecules of ATP are stored directly on the myosin head at the site where energy is needed for force production. When ATP is split (hydrolyzed), the energy released from the phosphate bonds puts the myosin heads in an energized state in which they are capable of forming a crossbridge with actin and performing a power stroke. In order to prevent rigor or sustained contraction of the muscle, and allow relaxation, ATP must be reloaded on the myosin head, which allows it to detach from the actin. Therefore, ATP is crucial for both the force production and relaxation of skeletal muscle.

As an athlete exercises, muscles are using ATP as the direct source of energy. One can picture how a high

Adenosine diphosphate (ADP): A chemical compound formed by the breakdown of ATP to release energy.

Rate: Speed.

Static: Not moving or changing.

SPOTLIGHT ON ENRICHMENT

The Role of Enzymes

Many chemical reactions in the body are catalyzed by enzymes. Enzymes are protein structures that speed up chemical reactions, primarily by lowering the energy required to activate the chemical reaction. Enzymes do not change the chemical compounds or the outcome of the reaction; they just allow the reaction to proceed more rapidly. Enzymes themselves are not **static,** but can change their activity or the degree to which they influence the speed of the reactions that they catalyze. A number of factors can influence enzymatic activity; two of the most common are temperature and pH.

If enzymes are warmed slightly, their activity increases. Exercise results in an increase in muscle temperature, which in turn results in an increase in enzymatic activity for those chemical reactions that support the exercise. Excessive changes in temperature, however, can reduce enzymatic activity. Excessive heating causes an enzyme to be broken down or denatured; it is literally cooked. Cooling an enzyme reduces the activity to the point that the enzyme cannot affect the rate of the chemical reaction. Enzymes also have an optimal pH range, and too much acidity or alkalinity can reduce their activity and slow the reaction.

Enzymes may also have different isoforms, slightly different versions of the enzyme for specific areas or functions in the body. For example, the enzyme ATPase catalyzes the breakdown of ATP to release energy for use by cells. When this enzyme is found in skeletal muscle, the enzyme is a specific isoform, called myosin ATPase. In this way, enzymes can be "optimized" to work in specific situations such as muscle when large amounts of energy may be needed very quickly for exercise.

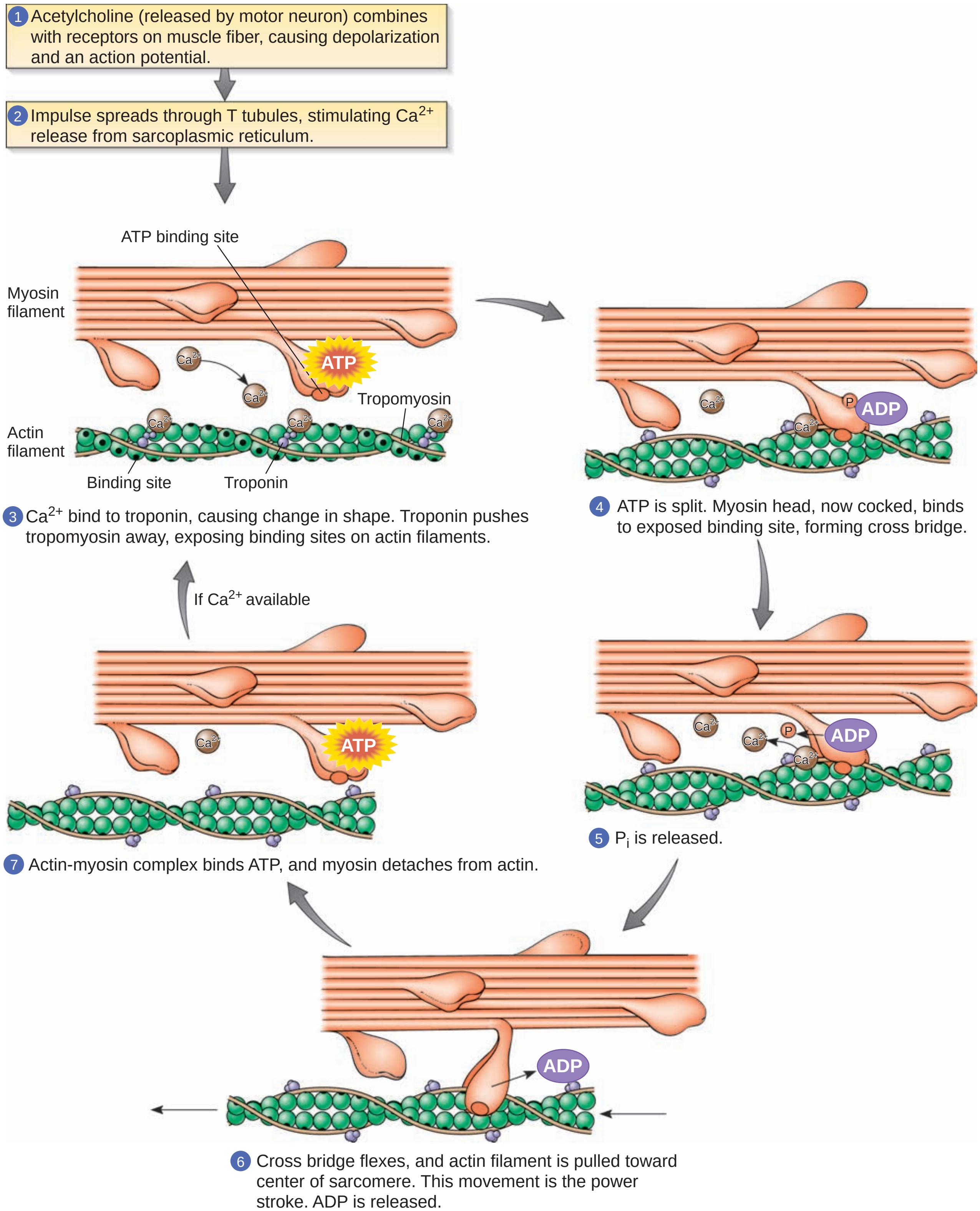

Figure 2.8 Model of Muscle Contraction

Contraction results when actin filaments slide toward the center of individual sarcomeres of a myofibril. After Step 7, the cycle repeats from Step 4.

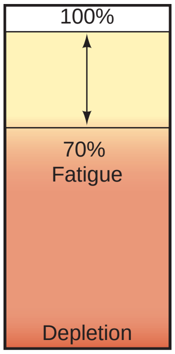

Figure 2.9 ATP Concentrations in Muscle During Very-High-Intensity Exercise

ATP concentration may fall to 70–75% of original levels, but fatigue will soon occur. ATP does NOT approach depletion in muscle cells during voluntary exercise.

rate of ATP utilization might result in a rapidly declining concentration of ATP in the muscle, potentially leading to complete depletion if the exercise is intense enough or lasts long enough. Research studies show, however, that ATP concentrations in exercising muscle rarely drop more than 20 to 30 percent, even during the highest exercise intensity that an athlete can voluntarily perform (Hirvonen et al., 1987; see Figure 2.9). Once the ATP concentration in an exercising muscle is reduced to this degree, the force production ability of the muscle is reduced and the muscle starts to fatigue.

The response of ATP concentration in the muscle to exercise reveals two things: 1) a relatively large proportion of the ATP stored in the muscle is not able to be used for force production, even during very high intensity exercise and 2) the ATP that is used to provide energy for muscle force is replaced very rapidly.

Resynthesis of ATP. After ATP is broken down to provide energy, it must be resynthesized for use again in the future. This process is known as **rephosphorylation,** an endergonic reaction requiring an input of energy. In this reaction, phosphate (Pi) is chemically joined to ADP to produce ATP (see Figure 2.10).

The body utilizes several different energy systems to rephosphorylate ADP (i.e., to resynthesize ATP). The major energy systems used during exercise are the creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation energy systems (see Figure 2.11). These energy systems will be discussed in detail in Chapter 3.

What's the point? ATP is the direct source of energy that the body uses to perform any function. Food provides that energy, but it must be biochemically transformed to ATP.

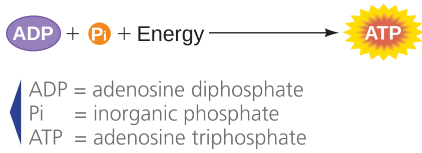

Figure 2.10 Rephosphorylation of ADP

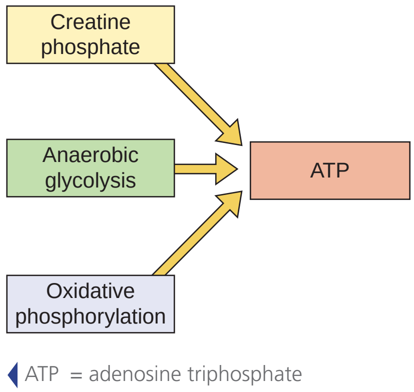

Figure 2.11 The Three Energy Systems that Replenish ATP

Measuring Energy

Energy is not only hard to define; it is also difficult to measure. There are a variety of techniques used to measure energy, and different units are used to express energy, adding to the confusion. The scientific community has adopted a standardized system of weights and measures that is based on metric measurements and is known as the International System of Units (SI units). In the United States, most people outside the scientific community are familiar with and use the term calorie, a unit of energy measurement that is not the designated SI unit for energy.

The unit of measure for energy in SI units is the **joule (J),** named for British physicist James Prescott Joule (1818–1889). The technical definition of a joule is the work done by a force of 1 Newton acting to move an object 1 meter, or 1 Newton-meter. This is a definition of mechanical energy, which is better suited to physicists and scientists working with physical rather than biological systems. However, Joule was renowned for a series of innovative and meticulous experiments that demonstrated the equivalence between mechanical energy and thermal (heat) energy. Therefore, one of the acceptable and practical ways to study and discuss energy is in terms of heat, which is particularly appropriate for bioenergetics.

In nutrition and exercise physiology, energy is often expressed in calories, an expression of thermal energy. One **calorie** (lowercase *c*), is the heat required to raise the temperature of 1 gram (g) of water by 1ºC,

Table 2.1 Energy Units and Equivalents

Energy Units and Equivalents	
1 calorie (cal)	= 4.184 joules (J)
1 kilocalorie (kcal)	= 1,000 calories
1 kilocalorie	= 4,184 joules
1 Calorie (C)	= 1,000 calories
1 Calorie	= 4,184 joules
1 kilojoule (kJ)	= 1,000 joules
1 kilocalorie	= 4.184 kilojoules

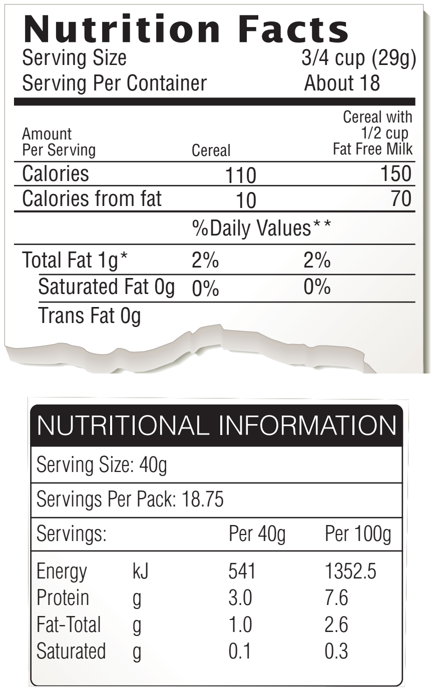

Figure 2.12 Energy measurements used on food labels in the United States and Australia.

Labels in the United States use the term *Calories,* but most countries in the world use kilojoules (kJ).

and is equal to 4.184 joules. This is a small amount of energy, so when discussing the energy content of food or the energy expenditure of physical activities, it is more practical to express energy in larger units. Usually the terms **Calorie** (uppercase *C*) and **kilocalorie (kcal)** are used. One kilocalorie is equal to 1,000 calories, the energy required to raise the temperature of 1 kilogram or 1 liter of water 1°C.

Throughout this book the term kilocalorie will be used. Food labels in the United States use Calorie as the unit of measure. Keep in mind that kilocalorie and Calorie are equivalent units. However, kilocalorie and Calorie are not terms that most Americans are familiar with. In everyday language and in nonscientific writing the word *calorie* (lowercase *c*) is used. Although not technically correct, *calorie* is often used interchangeably with Calorie and kilocalorie.

Most scientific journals require that energy be expressed as an SI unit, which is the joule. Once again, because a joule is a relatively small amount of energy, the unit **kilojoule (kJ),** which is equal to 1,000 joules, is used because it is a more practical measure when discussing large amounts of energy intake or expenditure. To convert kilojoules to kilocalories, divide kJ by 4.2 kcal/kJ. For example, a food intake of 8,400 kJ is equivalent to 2,000 kcal. Table 2.1 lists energy units and their equivalents. Figure 2.12 uses food labels from the United States and Australia to illustrate the different units of measure used to express the energy value of food.

MEASUREMENT OF ENERGY IN FOOD

Only one factor accounts for the "energy in" side of the energy balance equation: food. Most people are familiar with the concept that the energy content of food is its caloric content. How does one measure the energy content of food? The caloric content of food is determined through a process of calorimetry, during which food samples are burned and the resulting liberation of heat energy is precisely measured as a change in temperature. Because the thermal energy of the food is directly measured, this process is referred to as **direct calorimetry.**

Direct calorimetry analysis of food involves a bomb **calorimeter** (see Figure 2.13), a device that determines energy by the amount of heat produced. The "bomb" is

Rephosphorylation: Reestablishing a chemical phosphate bond, as in adenosine diphosphate (ADP) reestablishing a third phosphate bond to become adenosine triphosphate (ATP).

Joule (J): The International System of Units (SI) way to express energy; specifically, the work done by a force of 1 Newton acting to move an object 1 meter, or 1 Newton-meter. 1 calorie is equal to 4.184 joules.

calorie: The amount of heat energy required to raise the temperature of 1 gram of water by 1°C.

Calorie: The amount of heat energy required to raise the temperature of 1 kilogram or 1 liter of water 1°C. Equal to 1,000 calories.

Kilocalorie (kcal): A unit of expression of energy, equal to 1,000 calories (see calorie).

Kilojoule (kJ): A unit of expression of energy equal to 1,000 joules (see Joule).

Direct calorimetry: A scientific method of determining energy content of food or energy expenditure by measuring changes in thermal or heat energy.

Calorimeter: A device that measures energy content of food or energy expenditure.

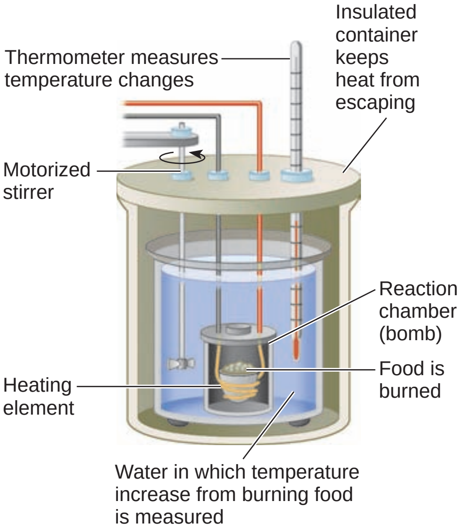

Figure 2.13 Bomb calorimeter for determining the energy content of food.

Table 2.2 Energy Content of Carbohydrates, Fats, Proteins, and Alcohol

	Bomb Calorimeter (kcal/g)	Human Calorimeter (kcal/g)
Carbohydrates	4.2	4.2
Fats	9.4	9.4
Proteins	5.7	4.2
Alcohol	7.0	7.0*

Legend: kcal/g = kilocalorie per gram

*Under normal circumstances. However, when alcohol is a high percentage of total caloric intake, some of the energy is not available to the body.

a metal container in which the food sample is burned in a pressurized, pure oxygen atmosphere. It is constructed to withstand high temperature and pressure, and is surrounded by a water bath that is insulated from outside temperature changes. As the food sample burns, the temperature change in the surrounding water bath is recorded with a sensitive thermometer and determines the thermal energy of the food.

Caloric Content of Carbohydrates, Fats, Proteins, and Alcohol. Using direct calorimetry, the average caloric content of a wide variety of foods has been determined. When the amount of carbohydrates, fats, proteins, and alcohol in a food is known, the *approximate* caloric (energy) value can be calculated. The average energy values for each are listed in Table 2.2. Notice there are two columns of values, one for a bomb calorimeter and one for a human calorimeter (i.e., the body). The human calorimeter refers to the amount of energy a person can utilize from the food. The values are the same for carbohydrates and fats, but differ for proteins and may differ for alcohol.

Carbohydrate foods contain approximately 4.2 kilocalories of energy per gram (kcal/g) of food, while fats contain ~9.4 kcal/g. When burned completely in a bomb calorimeter, protein foods yield, on average, 5.7 kcal/g. However, when proteins are metabolized in the body (the human calorimeter), the full potential energy of these foods is not available because nitrogen, an important constituent of proteins, is not metabolized but is excreted. Therefore, when proteins are metabolized in the body the average caloric value is estimated to be 4.2 kcal/g (World Health Organization, 1991).

Alcohol (ethanol) yields approximately 7.0 kcal/g when burned in a bomb calorimeter. Under normal circumstances, the human calorimeter value is the same as the bomb calorimeter. For all practical purposes this value is used to estimate the caloric value of alcohol. However, when alcohol intake represents a large percentage of total caloric intake, some of the energy in the alcohol is not available to the body, resulting in alcohol yielding less than 7 kcal/g. This is most likely a result of damaged mitochondria in liver cells, an undesirable health circumstance (Lieber, 2003).

From a practical perspective, the values for carbohydrates and proteins (4.2 kcal/g) and fats (9.4 kcal/g) are too cumbersome, so they are rounded to the nearest whole number. That is why the energy content of carbohydrates and proteins is estimated to be 4 kcal/g and the energy content of fats is estimated at 9 kcal/g. For example, 1 tablespoon of oil has 14 grams of fat, or approximately 126 kcal (14 g × 9 kcal/g). That estimate is slightly low compared to the 131.6 kcal that is calculated if the more precise figure of 9.4 kcal/g is used. However, all the values obtained are just estimates and the error introduced by using the rounded off numbers is considered small and acceptable. At best, the amount of energy in food can only be estimated; the true energy value—when the potential energy from food is converted to useful forms of energy in the body—cannot be directly measured.

This difficulty in determining the "exact" caloric content of any food illustrates the imprecision and potential problems with strict "calorie counting" as a weight loss strategy. The caloric content of an individual food, a combination of foods in a meal, or the total amount of food consumed in a day can only be estimated. Tracking energy intake over weeks and months is especially difficult. Relatively small differences in energy intake exert influence and bring about change in body composition (e.g., body fat loss or gain) but over relatively long periods of time. The person who diligently counts calories may calculate the amount of body fat that should be lost in a given time period, but this may be counterproductive. If caloric intake is underestimated and body fat is not lost according to "schedule," then the individual may conclude that the weight loss diet is not effective. In fact, counting calories gives the dieter a false sense of precision and an erroneous time frame for the loss of body fat. Although estimates of the amount of energy consumed daily can be useful, the precise caloric content of the foods consumed cannot be determined.

MEASUREMENT OF ENERGY EXPENDITURE

There are a variety of ways to measure the amount of energy expended— "energy out." However, since people are active, free-living beings, it can be difficult to obtain measures of energy expenditure. The basic methods of measuring the energy expended by an individual are covered here. Some of the most accurate measurement techniques have limited use with athletes because of their impracticality.

Direct Calorimetry. As the body utilizes the potential energy contained in food, a large portion of that energy is converted to heat energy. The amount of heat that is produced is proportional to the amount of energy expended; this heat energy can be measured as a change in temperature. Therefore, energy expenditure in humans and small animals can be determined by the principle of direct calorimetry in a process roughly similar to the determination of the energy content of food.

In the late 1700s, the French chemist Antoine Lavoisier developed a direct calorimeter in which he measured the amount of water produced by ice melting from an animal's body heat. The energy expenditure of the animal was determined from the amount of heat required to melt a measured quantity of ice. Over time, more sophisticated calorimeters have been developed, similar in principle to the bomb calorimeters used to measure the energy in food, except that they have been built large enough to completely enclose a human. Heat emitted from the human subject is recorded as a temperature change in an insulated water layer. In the late 1800s and early 1900s Atwater and colleagues (1899, 1905) conducted a series of elegant and precise metabolic experiments in which they used direct (and indirect) calorimetry to elucidate the metabolic effects of diet and exercise and the balance of energy intake and energy expenditure. Direct calorimetry is still used today but for research purposes only.

Indirect Calorimetry. Another of Lavoisier's important discoveries was the relationship of **oxygen consumption** (O_2) and **carbon dioxide production** (CO_2) to energy expenditure and heat production. As the body's energy expenditure increases, the use of oxygen and the production of carbon dioxide by the aerobic energy system (see Chapter 3) increase proportionately. If the oxygen consumption and carbon dioxide production is measured, then the amount of energy expended can be calculated. This determination of energy expenditure by gas exchange is termed **indirect calorimetry.**

Indirect calorimetry can be used in conjunction with the direct method in room-sized calorimeters. Air is circulated through the chamber of the calorimeter, and the difference in the oxygen and carbon dioxide in the air entering and leaving the chamber is calculated, which indicates the amount of oxygen used and the amount of carbon dioxide produced. Sophisticated, room-sized calorimeters can measure both direct and indirect calorimetry (see Figure 2.14). The size and complexity of these devices make them unsuitable for measuring energy expenditure for short time intervals, particularly less than 30 minutes. They are more appropriate for the determination of energy expenditure over long periods of time of at least 24 hours and up to several days (Seale, Rumpler, and Moe, 1991).

The University of Wollongong in Australia

Figure 2.14 Whole-room calorimeter with direct and indirect calorimetry capability.

As with the energy content of food, energy expenditure is expressed as either kilocalories or kilojoules. It can be expressed as an absolute amount expended (e.g., 200 kcal or 837 kJ) or as an amount over a given time period, generally a day (e.g., 1,500 kcal/day or ~6,300 kJ/day).

While room-sized calorimeters can precisely measure temperature and changes in oxygen consumption and carbon dioxide production over long time intervals, they require a confined space for observation. Studies of exercise activities by direct calorimetry may be further complicated by relatively slow response time of the measurements and the heat produced by exercise equipment, such as a motorized treadmill or friction-braked cycle ergometer (Schoffelen et al., 1997). Room-size calorimeters are another example of

Oxygen consumption ($\dot{V}O_2$): The amount of oxygen used by the body in aerobic metabolism.

Carbon dioxide production ($\dot{V}CO_2$): The amount of carbon dioxide that is produced and eliminated by the body through the lungs.

Indirect calorimetry: A scientific method of determining energy expenditure by measuring changes in oxygen consumption and/or carbon dioxide production.

ParvoMedics TrueOne® 2400 Metabolic Measurement System

Figure 2.15 An Open-Circuit Metabolic Measurement System

Gary Granata

Figure 2.16 Measurement of Resting Metabolic Rate with Indirect Calorimetry

a measurement method best suited for research purposes. Fortunately, there are other methods that can be used to determine energy expenditure during exercise and other free-living activities.

Metabolic measurement systems measure energy expenditure through indirect calorimetry without the need to enclose the subject inside the measurement apparatus (Figure 2.15). The most commonly used systems are open circuit, in which the subject breathes in **ambient** room air and is not confined to breathing the air within a sealed environment. These computerized systems are compact and can be contained within a mobile cart, often referred to as a metabolic cart. The cart can easily be positioned beside a hospital bed for medical studies or next to a subject on a treadmill, cycle ergometer, or other type of ergometer for exercise studies. The metabolic cart has a flow meter to measure the amount of air breathed, analyzers for measuring the percentage of oxygen and carbon dioxide in the air, and computer hardware and software to perform the oxygen consumption and carbon dioxide production calculations.

A metabolic measurement system determines energy expenditure indirectly by measuring the amount of oxygen consumed and the amount of carbon dioxide produced during different activities. Oxygen consumption is converted to energy expenditure in kilocalories using conversion factors based upon the **Respiratory Exchange Ratio** (see Chapter 3). Oxygen consumption can be expressed in relative terms as the milliliters of oxygen consumed per kilogram body weight per minute (ml/kg/min). It can also be expressed as an absolute number of liters of oxygen consumed each minute (L/min). Although it varies slightly depending upon exercise intensity, on average, 1 liter of oxygen consumed is equivalent to 5 kcal of energy expended. Therefore, as shown in the previous example (see Figure 2.2), a 150-pound (68.2 kg) cyclist riding at 180 Watts, with an exercise oxygen consumption of 36.0 ml/kg/min or 2.455 L/min expends 12.28 kcal of energy each minute (2.455 L/min × 5 kcal/L = 12.28 kcal/min). Note this is an expression of *total* oxygen consumption and *total* caloric expenditure, not just the amount of energy expended above **resting oxygen consumption,** which was also shown in Figure 2.2. Measurements of energy expenditure during exercise are commonly expressed as total oxygen consumption, without subtracting the individual's resting oxygen consumption.

Metabolic carts are also commonly used in exercise physiology laboratories to determine the oxygen consumption and energy expenditure response to exercise, in some cases to determine maximal oxygen consumption ($\dot{V}O_{2max}$). Because of their rapid response times and high degree of accuracy, these devices have advantages for these purposes over a room-size calorimeter. However, full metabolic measurement systems are expensive, require trained personnel to operate, and require time for setup, cleanup, and maintenance.

A metabolic measurement system can also be used for measurements of resting oxygen consumption to determine **Resting Metabolic Rate (RMR).** These measurements are performed with a subject resting quietly in a reclining, mostly **supine** position while connected to the metabolic cart through a breathing tube with a mouthpiece, facemask, or ventilated hood (see Figure 2.16). Data are collected and averaged for time periods of 30 minutes to several hours to obtain the most accurate results.

Smaller, easier to use, and less expensive systems have been developed specifically to determine resting metabolic rate in a nonresearch setting (Figure 2.17). These devices are much more portable, their use requires less training, maintenance, and troubleshooting, and results can be obtained in less time. To obtain the most accurate results, subjects should follow the

Microlige USA, Inc.

Figure 2.17 A Simplified Portable System for Measuring Resting Metabolic Rate

To obtain the most accurate measure of resting metabolic rate in healthy adults, before beginning an indirect calorimetry procedure, the subject should:

- Fast at least 5 hours after a meal or snack
- Abstain from alcohol and nicotine for at least 2 hours
- Abstain from caffeine for at least 4 hours
- Abstain from vigorous resistance exercise for at least 14 hours
- Abstain from moderate aerobic or anaerobic exercise for at least 2 hours

C. Compher, D. Frankfield, N. Keim, and L. Roth-Yousey. Evidence Analysis Working Group (2006). Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. *Journal of the American Dietetic Association*, 106(6), 881–903.

Figure 2.18 Obtaining the most accurate estimate of resting metabolic rate by indirect calorimetry.

guidelines summarized in Figure 2.18 (Compher et al., 2006). Because of their limitations, these devices are restricted to measurements at rest; they are not valid for activity studies. Studies have shown that these devices provide a more accurate determination of RMR than commonly used **prediction equations** (e.g., Harris-Benedict) yet do not provide the same degree of accuracy as the full metabolic measurement systems (Melanson et al., 2004; Nieman, Trone, and Austin, 2003).

Although the metabolic measurement systems are much smaller and more portable than the room-size calorimeters, there is a limit to their portability and their use requires the subject to be tethered to the equipment by a breathing tube. There is, therefore, a limitation in using these systems for many sports, exercise activities,

Viasys Respiratory Care

Figure 2.19 A Portable Metabolic Measurement System

and other free-living activities. Advancements in technology have led to the development of small, fully portable versions of metabolic measurement systems that can be carried by an individual in a backpack or vest and can be used to measure energy expenditure during a wide range of activities (see Figure 2.19). These devices can either store data for later analysis or transmit the information instantly by telemetry (radio waves) to a receiver attached to a computer for calculation. As the technology and resulting accuracy and reliability of portable metabolic systems improve, the energy expended by athletes in a wide variety of activities can be more accurately determined (Macfarlane, 2001).

Direct and indirect calorimeters are generally used to determine energy expenditure in time periods of minutes, hours, or days. The **Doubly Labeled Water (DLW)** technique allows for the indirect determination of energy expenditure over much longer periods of time (usually one to three weeks) and allows subjects to participate in their

Ambient: In the immediate surrounding area.

Respiratory Exchange Ratio: The ratio of carbon dioxide production to oxygen consumption; used to determine percentage of fat and carbohydrate metabolism.

Resting oxygen consumption: Measurement of energy expenditure while a person is awake, reclining, and inactive.

Resting Metabolic Rate (RMR): The amount of energy per unit time required by the body to maintain a nonactive but alert state.

Supine: Lying on the back with the face upward and the palms of the hands facing upward or away from the body.

Prediction equation: A statistical method that uses data from a sample population to predict the outcome for individuals not in the sample.

Doubly Labeled Water (DLW): A measurement technique for determining energy expenditure over a long time period using radioactively labeled hydrogen and oxygen.

normal, free-living activities. This method makes use of the known pathways for the elimination of hydrogen and oxygen, the two constituents of water (H_2O), from the body. Hydrogen and oxygen are eliminated as water in urine, sweat, respiratory water vapor, and other avenues. Oxygen is also eliminated as carbon dioxide (CO_2). A person who is more active and expends more energy over the observation period will consume more oxygen and will produce and eliminate more carbon dioxide than an individual with a lower energy expenditure.

The amount of hydrogen and oxygen eliminated is measured with radioactively labeled water using two safe and stable isotopes, one for oxygen and one for hydrogen (thus, the term doubly labeled water). A known amount of each of the stable isotopes, oxygen-18 (^{18}O) and deuterium (^{2}H) is mixed with water and consumed by the subject. Within a few hours the radioactively labeled water is distributed throughout the various water compartments in the body. The amount of radioactivity being eliminated as water is measured in urine samples at specified time intervals. The difference in the rates of excretion of ^{18}O and ^{2}H allows the calculation of long-term carbon dioxide production and energy expenditure. Subjects who are more physically active expend more energy, consume more oxygen, and produce and expel more carbon dioxide, thus increasing the rate of excretion of the radioactively labeled oxygen. While this method has shown good **validity** and **reliability,** the high cost of the measurement equipment and the high cost of the individual tests have prevented the widespread use of this technique of energy expenditure assessment outside research studies.

What's the point? To study energy intake or expenditure, energy must be measured. The measurements of energy are estimates because there are many limitations to measuring energy. Some of the most accurate measures are not practical to use outside research settings, but the more practical measurement systems are reasonably accurate.

Concepts of Energy Balance

So far this chapter has examined the ways in which the energy content of food and the energy expended via activity and metabolism are measured and expressed. Many of these measurement techniques are largely research related and focus on the discrete components of energy intake or energy output. Outside the research setting, practical methods that are reasonably accurate are needed to estimate energy intake and energy expenditure. In addition, these two components must be considered from the perspective of how they relate to each other—the balance of energy intake and output—rather than as distinct entities.

One of the simplest ways to illustrate the concept of energy balance as it relates to the human body is to use a balance scale, shown in Figure 2.20. On one side of the scale is energy intake in the form of food. On the other side of the scale is energy expenditure. The primary influences on energy expenditure are resting metabolism and physical activity in the form of activity, exercise, and sport. A small influence on energy expenditure is the process of digesting food.

Estimating the amount of energy (i.e., food) consumed is relatively simple and the application of that information is easy to understand. In contrast, measuring the amount of energy expended by the body is difficult and often involves complicated prediction equations and formulas. Adding to the difficulty is the use of various terms, each slightly different from the other (e.g., basal metabolic rate and resting metabolic rate). Knowledge of terminology and the concepts on which the equations are based helps dispel confusion about estimating energy expenditure. Precise terminology and detailed prediction equations are necessary for research purposes, but practitioners also need to apply energy expenditure information in a way that is easy for consumers to understand. To accomplish this goal, complicated terminology and equations have been simplified for use with individuals outside research settings.

THE EXPERTS IN. . .

Energy Measurement

Research using direct and indirect calorimetry to estimate the energy contained in food and expended by exercise spans hundreds of years and includes many groundbreaking researchers such as Antoine Lavoisier, James Prescott Joule, and Wilbur Atwater. Contemporary researchers have focused on applications of these principles to individuals and populations. One such researcher is Barbara Ainsworth, Ph.D., who has been a leader in categorizing physical activities based on the energy expended to help epidemiological researchers study physical activity in large population studies.

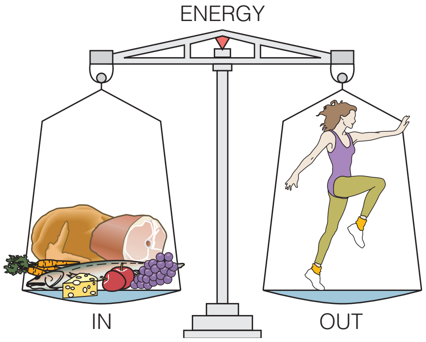

Figure 2.20 Energy Balance

When "energy in" balances with "energy out," a person's body weight is stable.

ESTIMATING DAILY ENERGY INTAKE

Daily energy intake is usually estimated by having individuals self report their food intake for one, three, or seven days by using a food diary in which they list all the foods and beverages consumed in each 24-hour period. A sample form is found in Appendix E. These foods and beverages are then entered into a computer program that estimates energy (and nutrient) intake. The greatest source of error with this method is the accurate recording of both the types and amounts of foods and beverages consumed. Recording *all* foods and beverages consumed is a tedious task. It is often difficult to estimate fluid intake. For example, athletes sip sports drinks throughout training or consume water from drinking fountains. Many people also snack frequently and may forget to record snacks in their food diaries. A major source of error is underestimating portion size (Magkos and Yannakoulia, 2003). Attention to detail in the recording stages is needed to reduce the error when estimating energy intake.

Studies of athletes have shown that food intake is underreported, thus, energy intake is underestimated (Jonnalagadda, Benardot, and Dill, 2000; Braakhuis et al., 2003; Champagne et al., 2002; Magkos and Yannakoulia, 2003). Studies that compare reported energy intake with actual energy expenditure (using doubly labeled water) suggest that individuals, including athletes, *underestimate* their energy intake by approximately 10 to 20 percent (Trabulsi and Schoeller, 2001).

Not only do athletes underreport their food intake, but they may consciously or unconsciously undereat during the period when they are keeping a food diary (Burke et al., 2001; Jonnalagadda, Benardot, and Dill, 2000). The act of writing down what is eaten often changes eating behavior. There may be a number of subtle influences and reasons why athletes underreport food intake. For example, in a study of elite female gymnasts, those who underreported their energy intake more often had a higher percent body fat than the gymnasts who more accurately reported their food intake (Jonnalagadda, Benardot, and Dill, 2000). Underreporting is not unique to females; males appear to underreport their intakes as well (Trabulsi and Schoeller, 2001).

Error can also be introduced if athletes, sports dietitians, or others erroneously enter the data into the computer (Braakhuis et al., 2003). Nutrient analysis databases are large and each food or beverage must be matched as closely as possible to those found in the database. The amount must be entered accurately, but many athletes are unfamiliar with portion sizes, especially those expressed as tablespoons or ounces. Careful attention to recording and computer-coding food and beverage intake will help to reduce the error associated with estimating energy intake. Although the methods used to assess energy intake are known to underestimate actual intake, they are helpful. Food diaries will continue to be used until better methods can be developed.

DESCRIPTION AND ESTIMATION OF ENERGY EXPENDITURE

The other side of the energy balance equation is the amount of energy expended, or "energy out." The total amount of energy required by the body over the course of a day is termed **Total Energy Expenditure (TEE).** Sometimes the term used is Total Daily Energy Expenditure (TDEE). These terms are used interchangeably and are estimates of the amount of energy expended over a 24-hour period.

Total energy expenditure is broken down into three discrete components for study and analysis—metabolism, thermic effect of food, and physical activity. Figure 2.21 illustrates the contribution of each of the three factors for a sedentary individual. On average, resting metabolism makes up approximately 70 percent of TEE, while thermic effect of food (~10 percent) and physical activity (~20 percent) are much smaller contributors. There are times when it is beneficial to calculate the individual components of total energy expenditure, particularly resting metabolic rate and energy expended from physical activities.

Validity: Ability to measure accurately what was intended to be measured.

Reliability: Ability to reproduce a measurement and/or the consistency of repeated measurements.

Total Energy Expenditure (TEE): The amount of energy that is required by the body, typically determined over the course of a 24-hour day.

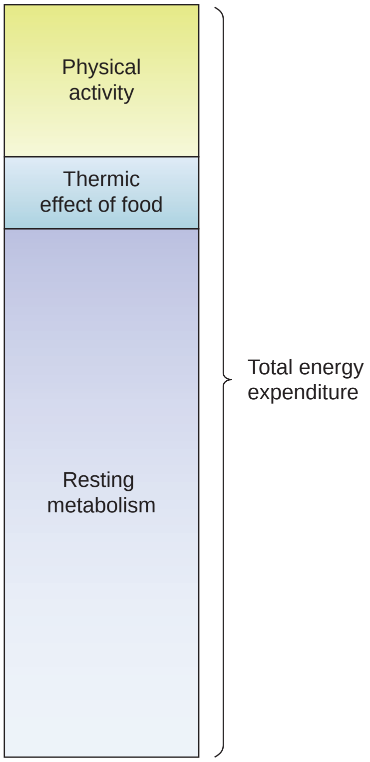

Figure 2.21 Components of Total Energy Expenditure (TEE) for a Sedentary Individual

For a sedentary individual, resting metabolism typically makes up approximately 70 percent of the day's total energy expenditure. The thermic effect of food accounts for approximately 10 percent, while the physical activity component accounts for approximately 20 percent.

However, much of the time it may be best to measure total energy expenditure or the amount of energy expended in a 24-hour period so that it can be compared to 24-hour food intake.

Basal and Resting Metabolism. The major component of TEE is basal metabolism. Basal metabolism refers to the energy necessary to keep the body alive at complete rest. Many life-sustaining body processes require energy (i.e., ATP). Breathing is an obvious one, but energy is also needed to circulate blood throughout the body, move food through the digestive system, absorb nutrients, conduct nerve signals, and maintain body temperature. In other words, basal metabolism is the minimal energy expenditure compatible with life. It is typically measured in the morning soon after waking after an overnight fast, with the person lying supine at complete rest in a temperature-controlled room. When determined under these conditions in the laboratory the measurement is referred to as **Basal Metabolic Rate (BMR).**

Most people are studied in a state of wakefulness at different times throughout the day, which requires slightly more energy than the basal level (e.g., food must be digested, body temperature must be maintained in a room where the temperature is not precisely controlled). This is referred to as resting metabolism and its measurement is known as resting metabolic rate (RMR). Although BMR and RMR are often used interchangeably, there is a slight difference between them in measurement methodology and the energy required. Resting metabolism is about 10 percent greater than basal metabolism. Nutrition and exercise professionals should take care to use the terms BMR and RMR correctly. Because the majority of a person's time is spent in an active, awake state, it is more common and accurate outside a research setting to discuss resting metabolism and resting metabolic rate. **Resting Energy Expenditure (REE)** is an equivalent term to resting metabolism and these terms are used interchangeably.

Resting metabolism comprises approximately 70 percent of a sedentary person's total daily energy expenditure, although the total amount and the percentage can vary substantially among individuals. Resting metabolism can be affected by a wide variety of factors, including age, gender, genetics, hormonal changes, body size, body composition (especially the amount of skeletal muscle), exercise, environmental temperature, altitude, food and caffeine intake, and cigarette smoking (see Table 2.3).

Table 2.3 Influences on Resting Metabolic Rate

Factor	Influence Not Under Voluntary Control	Substantial Influence, Under Some Voluntary Control	Subtle or Temporary Influence, Under Voluntary Control
Gender	X		
Genetics	X		
Age	X		
Body size (height)	X		
Thyroid hormones	X		
Starvation (self-restricted food intake)		X	
Amount of fat-free tissue		X	
Exercise			X
Environmental temperature			X
Ascending to high altitude			X
Caffeine			X

Some of these factors are under voluntary control, so resting metabolism can be altered to some degree.

Gender and genetics are two factors that influence a person's baseline RMR and cannot be changed. When males and females are compared and the differences in muscle mass are accounted for it appears that the metabolic rate of females is less than males by about 100 kcal/d (Ferraro et al., 1992). Metabolic rate tends to be similar among family members, which suggests that it is genetically influenced (Bouchard, 1989). As with any other physiological process, individuals show large variations within the normal range. Thus, some people tend to have higher metabolic rates while others have lower metabolic rates and some of this difference is probably the influence of genetics.

In the healthy individual, two factors are known to decrease RMR: 1) age and 2) starvation (e.g., famine or severe dieting). The 1 to 2 percent decline in RMR seen per decade that is a result of aging is not under voluntary control. Stopping the aging process is not an option! However, severe self-restriction of food, which unfortunately is a method some people use to lose weight, is voluntary.

A starvation state forces the body to adapt. One of the problems with the very low calorie "starvation" diets that people, including some athletes, often employ to lose weight rapidly is the reduction in resting metabolic rate that occurs as a result of a dramatically reduced energy intake. Studies have shown that a starvation state can reduce resting metabolic rate by 20 percent or more (Bray, 1969). This "famine response" can result in an individual expending many fewer kilocalories over the course of the day. Ironically, the reduction in RMR may actually impede weight loss.

Predictably, the body adapts relatively quickly to starvation (i.e., within a couple of days); RMR declines and energy expenditure is reduced. The impact of this response is to protect both fat and lean tissue from being substantially reduced. Although a substantial reduction in body fat may be the goal of an individual who adopts a "starvation diet," the physiological response is to protect against fat loss because the body has no mechanism for determining if starvation will be short-term or prolonged. Prolonged starvation can lead to death of the organism so a decline in resting metabolic rate is a survival mechanism.

Perhaps not as obvious is the body's metabolic response upon refeeding (i.e., consuming a normal amount of food after food restriction). Naïve dieters may think that RMR increases as soon as they stop the food restriction. In studies of normal weight men who were starved and then refed, RMR was still lower after 12 weeks of refeeding (Dulloo and Jacquet, 1998; Keys et al., 1950). In other words, the effects of starvation on RMR persisted even after the starvation was no longer present. Of note, the men in this very famous starvation study received 50 percent of their usual food intake.

One of the greatest influences on RMR is the amount of body mass, specifically, fat-free mass (Hulbert and Else, 2004; Leonard et al., 2002). Fat-free mass refers to all the tissues in the body that are not fat (e.g., muscle, bones, organs). Fat is a tissue with low metabolic activity. In other words, it does not take much energy to maintain fat stores **(adipose tissue).** In contrast, fat-free tissues are more metabolically active, even when the body is at rest. Remember that resting metabolism refers to the energy necessary to keep the body alive at complete rest. Thus, it is logical that the amount of fat-free mass a person has would greatly influence RMR. Studies have shown that people with more fat-free mass (measured in kg) have higher resting metabolic rates than those with less fat-free mass (Leonard et al., 2002). This holds true for both males and females and for all races. Because people can change the amount of fat-free mass by increasing the size of their skeletal muscles through strength training, body composition is a factor that can increase RMR and is under some voluntary control.

Body size can influence RMR (Hulbert and Else, 2004). One of the body's basic functions is the maintenance of body temperature and this is reflected in RMR. Those with a larger body (e.g., taller and broader) have more surface area than those with a smaller body. More body heat is lost when the surface area is larger, thus larger body size is associated with a higher RMR when compared to smaller body size.

Most of the factors discussed thus far have an enduring effect. Gender and genetics are not temporary factors, so their influence on RMR is constant. The influence of aging is progressive and permanent. Most people do not dramatically increase or decrease their fat-free mass, although it is possible to gradually increase it over time. Other factors can cause more temporary alterations in RMR. They include hormonal changes, exercise, environmental temperature, altitude, food and caffeine intake, and cigarette smoking.

Thyroid hormones influence many metabolic processes throughout the body, including fat and carbohydrate metabolism and growth. These hormones affect nearly every cell in the body and have a constant effect on resting energy expenditure. Temporary alterations occur if thyroid concentrations fall outside the normal range. When thyroid hormones are elevated above normal concentrations, RMR is abnormally high. Conversely, when

Basal Metabolic Rate (BMR): A measure of the amount of energy per unit time necessary to keep the body alive at complete rest.

Resting Energy Expenditure (REE): The amount of energy required by the body to maintain a nonactive but alert state.

Adipose tissue: Fat tissue. Made up of adipocytes (fat cells).

thyroid hormones are below normal concentrations, RMR is abnormally low. The inadequate or excessive production of thyroid hormones is a medical condition that needs treatment.

Other hormones cause temporary increases in RMR. For example, at certain times during a woman's menstrual cycle and during pregnancy, hormone concentrations (e.g., estradiol and progesterone) fluctuate and RMR may be increased. Exercise also temporarily increases some hormones (e.g., epinephrine and norepinephrine) that increase RMR. These are all temporary conditions and such hormonal changes do not permanently increase resting metabolic rate.

Variations in environment, such as temperature and altitude, can have a measurable effect on RMR. Studies of populations residing in tropic and polar environments show differences in metabolic rate, with RMR increasing when the environmental temperature gets colder. This effect also occurs with seasonal variations in temperature and when individuals travel to warmer or colder climates (Leonard et al., 2002). The range of increase is approximately 3–7 percent. Ascending to high altitudes (e.g., above 10,000 feet) also increases resting metabolic rate by an estimated 15–25 percent. This increase is transient, however, and RMR returns to the rate seen at sea level within one to three weeks (Butterfield et al., 1992; Mawson et al., 2000).

It is clear that exercise results in an increase in energy expenditure. Does exercise also result in a change in the subsequent resting metabolic rate? Unfortunately, the answer is not entirely clear. Energy expenditure is elevated in the immediate aftermath of exercise as an individual rests and recovers from the exercise bout. The level of this "postexercise energy expenditure" is dependent upon the intensity and duration of the exercise session—harder and/or longer exercise results in metabolism being elevated for a longer period of time during recovery. Although some studies have shown metabolism to be elevated for hours after exercise, most studies show a return to pre-exercise resting levels within 10 to 90 minutes (Molé, 1990). Regular chronic exercise training may also affect resting metabolic rate. The addition of exercise training by obese subjects restricting food intake results in RMR increasing, and the cessation of exercise by trained runners results in a decrease in RMR, suggesting that regular exercise training may slightly increase daily RMR. The interpretation of this research is complicated, however, by the variability in research study designs, methods, and subject populations (Molé, 1990).

Caffeine also increases RMR but for very short periods of time (i.e., up to a couple of hours) (LeBlanc et al., 1985). Cigarette smoking has a more dramatic effect and the change in RMR may be part of the reason that people who quit smoking experience a small weight gain (Perkins et al., 1989). Of course, the health risk of gaining weight is minimal compared to the risk of continuing to smoke.

While there are many factors that influence resting metabolic rate, there are only a few that are under voluntary control. Many of the factors have subtle rather than dramatic influences. Athletes would be wise to focus on the two factors they can influence that have the strongest effects. The first is to avoid declines in resting metabolic rate by avoiding severe starvation states. The second is to build and maintain muscle mass at a level that is compatible with their sport. Maintaining muscle mass is especially important as one ages because some of the decline attributed to aging is due to the loss of muscle. These two factors have a substantial and long-lasting influence on RMR.

Estimating Resting Metabolic Rate. Resting metabolic rate can be measured directly, but in many cases direct measurement is impractical. Thus, RMR is often calculated using a formula (i.e., prediction equation). The formulas were originally developed as a way to estimate energy expenditure in hospital patients (Harris and Benedict, 1919). Studies of nonhospitalized individuals showed that these same formulas could reasonably predict RMR in healthy people (Lee and Nieman, 1993). In 2005, Frankenfield, Roth-Yousey, and Compher reviewed four prediction equations (Harris-Benedict, Mifflin-St. Jeor, Owen, WHO/FAO/UNU) and found the Mifflin-St. Jeor equation to be the most appropriate equation to use with healthy Caucasian adults, both nonobese and obese. Unfortunately, not enough research has been conducted to validate these prediction equations in nonwhite populations.

Of the four equations examined, the Mifflin-St. Jeor equation most accurately predicted resting metabolic rate, typically within 10 percent of the RMR that had been determined under laboratory conditions. When used with nonobese individuals, 82 percent of the estimates are considered "accurate" with the remaining equally divided between overestimation (as much as 15 percent) and underestimation (as much as 18 percent). When used with obese individuals, the Mifflin-St. Jeor equation is considered accurate about 70 percent of the time. When inaccurate, the estimate tends to be an *underestimate* of RMR (by up to 20 percent), but in some cases RMR may be *overestimated* by 15 percent. It is important to understand that the calculations are just estimates of the amount of kilocalories required to meet resting metabolic needs (Frankenfield, Roth-Yousey, and Compher, 2005).

The example in Figure 2.22 uses the Mifflin-St. Jeor equation (Mifflin et al., 1990) to estimate the RMR of a 23-year-old Caucasian nonobese female who is 5'6" and weighs 135 pounds. All of the mathematical calculations are shown, but in most workplace settings the formula is part of a computer program that performs the calculations once the person's age, weight, and height are

Mifflin-St. Jeor Equation

Men: RMR (kcal/day) = (9.99 × wt) + (6.25 × ht) − (4.92 × age) + 5

Women: RMR (kcal/day) = (9.99 × wt) + (6.25 × ht) − (4.92 × age) − 161

Where: wt = weight (kg)

ht = height (cm)

age = age (years)

To convert weight in pounds (lb) to weight in kilograms (kg): Divide weight in lb by 2.2 lb/kg.

To convert height in feet (ft) and inches (in) to height in centimeters (cm): 1) determine total height in inches by multiplying height in feet by 12 in/ft and adding remaining inches, and 2) multiplying height in inches by 2.5 cm/in.

Example:

Estimating resting metabolic rate in a 23-year-old Caucasian nonobese female who is 5'6" and weighs 135 lb.

Step 1: Convert weight in pounds to weight in kilograms

135 lb ÷ 2.2 lb/kg = 61.36 kg

Step 2: Convert height in feet and inches to height in centimeters

5 ft × 12 in/ft = 60 in; 60 in + 6 in = 66 in

66 in × 2.5 cm/in = 165 cm

Step 3: Calculate formula

RMR (kcal/day) = (9.99 × wt) + (6.25 × ht) − (4.92 × age) − 161

RMR (kcal/day) = (9.99 × 61.36) + (6.25 × 165) − (4.92 × 23) − 161

RMR (kcal/day) = 612.99 + (6.25 × 165) − (4.92 × 23) − 161

RMR (kcal/day) = 612.99 + 1,031.25 − (4.92 × 23)− 161

RMR (kcal/day) = 612.99 + 1,031.25 − 113.16 − 161

RMR (kcal/day) = 1,644.24 − 113.16 − 161

RMR (kcal/day) = 1,531.08 − 161

RMR (kcal/day) = approximately 1,370

Figure 2.22 Using the Mifflin-St. Jeor equation to estimate resting metabolic rate.

entered. The Mifflin-St. Jeor equation estimates RMR for this individual at 1,370 kcal/d. For the purposes of this discussion, assume that this estimate is accurate but recognize that it may be underestimated by up to 18 percent (i.e., actual RMR is 1,617 kcal) or overestimated by up to 15 percent (i.e., actual RMR is 1,165 kcal).

The Mifflin-St. Jeor equation can be used with confidence with healthy Caucasian adults (the majority of whom are sedentary), but which prediction equation is best for use with athletes? Athletes represent a specialized subpopulation because they typically have a larger amount of fat-free mass (e.g., skeletal muscle) than nonathletes. The amount of skeletal muscle influences RMR because muscle tissue has a higher metabolic activity than adipose tissue. Thompson and Manore (1996) compared four equations (Harris-Benedict, Mifflin-St. Jeor, Owen, Cunningham) and found that the Cunningham equation most accurately predicted RMR in their study population, 24 male and 13 female endurance athletes. Although more research is needed, those who work with athletes, particularly endurance athletes, might use the Cunningham equation because it may better account for the higher amount of lean body mass in trained athletes.

The Cunningham equation is shown in Figure 2.23. Note that to use the Cunningham equation the athlete must have an estimate of body composition (see Chapter 11). In this example, the estimate of RMR by the Cunningham equation (1,580 kcal/d) was ~14 percent higher than the Mifflin-St. Jeor equation (1,370 kcal/d).

It may be impractical to calculate the equations discussed above, for example, when body composition, and therefore, fat-free mass (FFM) is unknown. A simple and commonly used estimate of resting

Cunningham Equation

RMR = 500 + 22 (FFM)

Where: FFM = fat-free mass (kg)

Example:

Estimating resting metabolic rate in a 23-year-old Caucasian nonobese female endurance athlete who is 5'6" and weighs 135 lb. At 20 percent body fat, she has approximately 49 kg of fat-free mass (135 lb × 0.20 = 27 lb; 135 lb − 27 lb = 108 lb; 108 lb/2.2 lb/kg = 49.1 kg)

RMR (kcal/d) = 500 + 22(FFM)

RMR (kcal/d) = 500 + 22(49.1)

RMR (kcal/d) = 500 + 1,080

RMR (kcal/d) = 1,580

Figure 2.23 Using the Cunningham equation to estimate resting metabolic rate.

Simplified Resting Metabolic Rate Formula

Men: 1 kcal per kilogram body weight per hour

Women: 0.9 kcal per kilogram body weight per hour

To convert weight in pounds (lb) to weight in kilograms (kg): Divide weight in lb by 2.2 lb/kg

Example:

Estimating resting metabolic rate in a 23-year-old Caucasian nonobese female who is 5'6" and weighs 135 lb.

Step 1: Convert weight in pounds to weight in kilograms

135 lb divided by 2.2 lb/kg = 61.36 kg

Step 2: Determine kcal used per hour

61.36 kg × 0.9 kcal/kg/hr = 55.22 kcal/h (rounded off to 55 kcal/h)

Step 3: Determine kcal used per day (24 hours)

55 kcal/h × 24 hr = 1,320 kcal per day

Figure 2.24 Using a simplified formula to estimate resting metabolic rate.

energy expenditure for men is 1 kcal per kilogram body weight per hour. For women, RMR may be estimated as 0.9 kcal per kilogram body weight per hour. Although gender and body weight are considered, this simple calculation does not account for age. The calculations, which can be done using a hand calculator, are shown in Figure 2.24. Using this simple formula, the RMR of the 23-year-old, 5'6", 135-lb female is estimated to be 1,320 kcal per day. Comparing the simple formula to the Mifflin-St. Jeor equation, the estimates differed by 50 kcal or approximately 4 percent. The simple formula produced a "ballpark" figure but it likely *underestimated* resting metabolic rate. Compared to the Cunningham equation, the simple formula *underestimated* RMR by 260 kcal or approximately 20 percent.

Until better prediction equations are developed and tested, especially in athletes, practitioners will continue to use some of the methods described above to estimate resting metabolic rate. Caution must be used in the application of the estimates obtained since RMR may be over- or underestimated by up to 20 percent. Furthermore, RMR is only one of three factors that accounts for total daily energy expenditure so it should not be overemphasized to the exclusion of the other factors.

Thermic Effect of Food (TEF). When food is consumed, it must be mechanically digested and moved through the gastrointestinal tract. Nutrients must also be absorbed and transported across cell membranes from the gut into the blood for distribution throughout the body. All of these processes require energy, and an increase in energy expenditure can be measured in a time period after a meal is consumed. This increase in energy expenditure due to food consumption is called the **Thermic Effect of Food (TEF).** The TEF can vary slightly depending upon the frequency and energy content of the meals, but generally makes up a fairly small proportion of the day's energy expenditure. Because TEF is a small part of the energy expenditure equation, the emphasis is generally on the two predominant factors, resting metabolism and physical activity.

Direct measurement of TEF can be done in a research laboratory, but there is no practical way to measure it in a nonresearch setting. In many cases, TEF is not calculated or included in estimates of total daily energy expenditure because the increase in energy expenditure occurs for only an hour or two after eating. If TEF is estimated, it is typically calculated by multiplying daily caloric intake by 10 percent. For example, if a person consumed 2,000 kcal in a 24-hour period, the amount that is attributed to TEF is 200 kcal (2,000 × 0.10). Proteins have a greater effect on TEF than carbohydrates, while the effect of fats on TEF is very small. The composition of the diet may, therefore, have a small effect on TEF, but the contribution of TEF to total daily energy expenditure is small, especially when compared to resting metabolism (Gropper, Smith, and Groff, 2005).

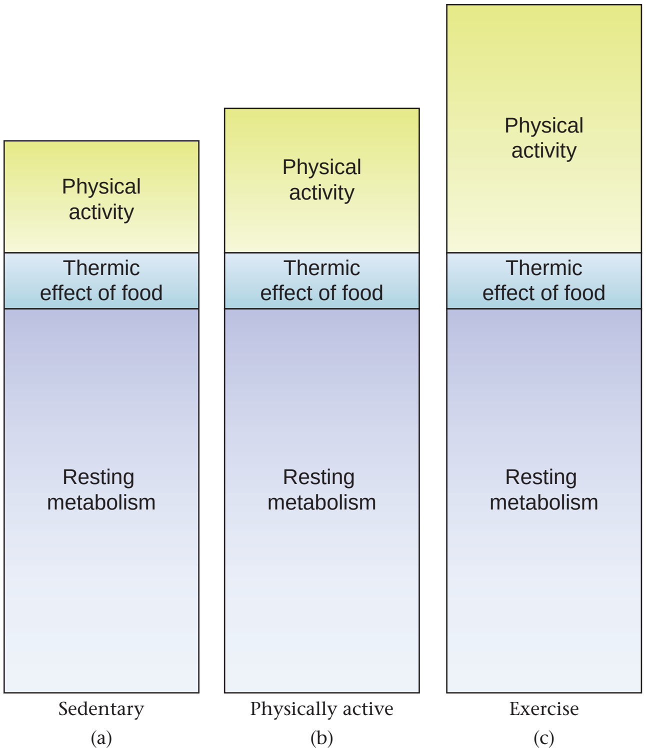

Figure 2.25 Total Energy Expenditure for Three Different Levels of Activity

(a) Sedentary; (b) Moderately physically active—active to the minimum recommended by health organizations, i.e., accumulates 30 minutes of moderate-intensity physical activity daily (e.g., walking at a moderate pace); (c) Exercise—regular moderate to vigorous activity (e.g., run/jog for 45 minutes). Daily total energy expenditure is increased if a person engages in physical activity or exercise.

Physical Activity. Any kind of physical activity requires energy expenditure above resting metabolism. **Activities of Daily Living (ADL),** such as walking or moving about (ambulation), bathing, grooming, dressing, and other personal care activities, result in modest expenditures of energy and may be the majority of energy expended as activity by sedentary people. Daily energy expenditure can be increased by voluntary physical activities such as housework, yard work, climbing stairs, or walking for transportation. Sports and exercise activities can dramatically increase energy expenditure. While physical activity may only comprise approximately 20 percent of the sedentary person's daily energy expenditure, an athlete engaged in intense training dramatically increases daily energy expenditure through exercise.

Of the three constituents of total energy expenditure—resting metabolic rate, thermic effect of food, and physical activity—the one that can be influenced most readily and to the largest extent by the individual is physical activity. Figure 2.25 shows the differences in energy expenditure due to physical activity for a person on different days when sedentary, moderately physically active, or exercising at a vigorous level. Again, this example is based on a 23-year-old nonobese female who is 5'6" and weighs 135 pounds.

On her sedentary day, only a small amount of her daily energy expenditure is a result of activity. If she increases daily physical activity to the minimum recommended by health organizations (i.e., 30 minutes daily), the physical activity portion of TEE increases by approximately 63 kcal per day. This is based upon walking at a moderate pace for 30 minutes, and represents an increase in daily energy expenditure of approximately 5 percent. If one is calorie counting, this may not appear to be much of a difference, but over time a slight energy deficit can have a noticeable effect. A difference of ~60 kcal each day could account for a change in body weight of about 1 pound every two months (assuming that food intake is the same and no other changes are made in physical activity). Incorporating 30 minutes of moderate exercise daily can lead to a small but steady weight loss of about 6 pounds per year.

The total energy expenditure of the example subject is increased more dramatically if she pursues an exercise activity at a more vigorous intensity and/or for a longer duration. For example, if she runs or jogs for 45 minutes, this activity adds approximately 300 kcal of energy expenditure to the physical activity component of her total energy expenditure. This increases her TEE by nearly 25 percent.

What about the energy requirements of extreme physical labor or very intense exercise training or competition? For relatively short periods of time, humans can participate in activities that require extreme levels of energy expenditure. An example is the Tour de France bicycle race, in which competitors race nearly 2,500 miles in stages over a three-week period. The energy demand of this race has been estimated to be in excess of 5,300 kilocalories per day (Saris et al., 1989), representing a 3,000 kcal difference in TEE from that of a sedentary person! It is thought that these extreme levels of energy expenditure can be sustained for relatively short periods (e.g., several weeks) before there are performance and health consequences.

Estimating Daily Energy Expenditure through Physical Activity. Although it is more accurate to have daily energy expenditure assessed by one of the direct or indirect calorimetry methods described previously in the chapter (e.g., whole-room calorimeter or doubly labeled water),

Thermic Effect of Food (TEF): The amount of energy required by the body to digest and absorb food.

Activities of Daily Living (ADL): Personal care activities (e.g., bathing, grooming, dressing) and the walking that is necessary for day-to-day living.

in most cases these assessments cannot be performed because of a lack of time, money, or access to the equipment. A common and practical method is to use self-reported physical activity logs or questionnaires to keep track of activities, including household, occupational, transportation, sport, exercise, and leisure (see Appendix F). Once the type and amount of activity has been determined, it can be entered into a computer program that can calculate total daily energy expenditure.

Most computer programs, including the one used with this text, allow an individual to input all physical activities for a 24-hour period. The energy values given for each activity and for the 24-hour period include the energy needed for metabolism. In other words, resting metabolic rate is not a separate calculation. From a practical point of view, it is not necessary to separate the amount of energy used to support metabolism from the amount used to support physical activity, especially when total energy expenditure is being compared to total energy intake.

The most variable aspect of daily energy expenditure is the amount of energy expended through physical activity. The same individual may have markedly different activity patterns from day to day, as well. Over a weekend, a person may have a day with a large amount of physical activity by participating in recreational sports, working in the yard, or other leisure-time activities. The next day may be largely sedentary, reading the paper, lying on the couch watching TV, and taking a nap. An athlete pursuing a "hard-easy" training program may have a day of heavy, intense training followed by a day of rest or low-intensity training. Therefore, keeping activity logs for more than one day will add to the accuracy of the assessment.

Estimating Energy Expended by a Single Physical Activity. People often want to know the amount of energy expended when they perform a specific physical activity. For example, those who work out in health clubs may ask, "How many calories do I use when I lift weights for an hour?" Or, "How many calories do I use if I walk for 30 minutes?" In these cases, the person only wants to know the energy expended by one activity, not the energy expended by all the physical activities done in a day. How is the energy expended by a single activity estimated?

One way is to enter a single activity into a computer program or online physical activity calculator, however not everyone has access to such tools. Another way is to use a reference such as the Compendium of Physical Activities (Ainsworth et al., 1993 and 2000; see Appendix G). This compendium provides a coding scheme to describe each activity, both generally (e.g., walking) and specifically (e.g., walking at 4 miles per hour). The Compendium was developed more for providing an activity classification system than as a means of determining specific energy expenditure levels, but it is sometimes used in this way. While the energy expenditure levels of many of the listed activities are based upon studies using indirect calorimetry, the amount of energy expended for a number of the activities has been estimated from activities with similar movement patterns. Therefore, caution should be used when using the energy expenditure values in the Compendium.

The Compendium expresses the energy expended in **metabolic equivalents (METs),** not kilocalories. One MET is equal to the energy expenditure of an *average* resting metabolic rate. Activity intensity expressed in METs, therefore, is a multiplication of energy expenditure at rest. For example, a task that requires 3 METs requires an energy expenditure level three times that of resting. How is this converted to the more familiar kilocalories of energy expenditure?

Returning to the example of the 23-year-old female, assume she is a sedentary person and wants to increase her daily physical activity to the minimum recommended by health organizations—30 minutes of walking at a moderate pace. If she walks at a moderate pace, the Compendium suggests a MET level of 3.3. Her resting metabolic rate has been previously determined to be ~55 kcal per hour (see Figure 2.24). At 3.3 METs she would expend approximately 181.5 kcal per hour (55 kcal/hr × 3.3). But she only walks for 30 minutes, or 0.5 hours, so she expends about 91 kcal via this activity (181.5 kcal/h × 0.5 h).

This ~91 kcal estimate represents the total energy expenditure for that 30 minutes of exercise and includes her resting energy expenditure. If she wants to know how much energy was expended just for the activity of walking, she must subtract the estimate of her resting energy rate for those 30 minutes. As mentioned above, the estimate of RMR for this woman is 55 kcal/h or 27.5 kcal for 30 minutes. By subtracting 27.5 kcal from 90.75 kcal, it can be estimated that she expended approximately 63 kcal by walking at a moderate pace for 30 minutes (90.75 kcal – 27.5 kcal = 63.25 kcal). Many charts that list the energy expended through activity or exercise include RMR, so unless RMR is accounted for, the figure *overestimates* the amount of energy expended via the movement alone.

Athletes, coaches, and trainers often use heart rate as an indication of exercise intensity, and therefore as an indirect prediction of energy expenditure. Heart rate is easy to measure, either with an electronic heart rate monitor or using the fingertips and a watch to count the pulse rate. It provides a reflection of energy expenditure because heart rate has a mostly linear relationship with oxygen consumption. The specific relationship of heart rate to oxygen consumption is highly individualized, however, and standardized heart rates cannot be used accurately to predict energy expenditure. For example, one person exercising at a heart rate of 120 beats per minute (bpm) might be expending 180 kcal per hour, while another person at that same rate of energy expenditure might have a heart rate of 130 bpm.

The Internet Café

Where do I find information about estimating energy intake and expenditure?

Shape Up America! has three online calculators available to estimate energy intake and expenditure: Physical activity calculator **(www.shapeup.org/interactive/phys1.php),** resting metabolic rate calculator **(www.shapeup.org/interactive/rmr1.php),** and meal and snack calculator **(www.shapeup.org/interactive/msc1.php).**

Shape Up America! is a nonprofit organization committed to raising awareness of obesity as a health issue. The calculators are part of the effort to educate people about attaining and maintaining a healthy body weight throughout life.

24-HOUR ESTIMATED ENERGY REQUIREMENT

Energy balance is simply defined as "Energy in = Energy out." It is important to be able to estimate how much energy is being consumed, how much is being expended, and how these two estimates compare, but as this chapter has shown, it is difficult to measure energy. Most nutritional analysis computer programs will calculate an **Estimated Energy Requirement (EER),** which is the average dietary energy intake that will maintain energy balance. EER is based on age, gender, weight, height, and physical activity, all of which are self-reported. Determining EER helps to answer the often-asked question: "How many calories do I need to consume each day?"

The answer to that question depends, to a large degree, on activity level. Computerized nutritional analysis programs ask the user to designate a category that best reflects usual physical activity (e.g., sedentary, light, moderate, heavy, exceptional activity) and uses that and other information to calculate EER. However, not everyone has access to or time to enter information into the computer. Thus, a very simple method has been developed to estimate daily energy intake in adult males and nonpregnant females based on gender, weight in kilograms, and level of physical activity (see Table 2.4). This very simple estimate is the least accurate way to estimate an individual's daily energy requirement; however, it is often used because of its simplicity. It is truly a "ballpark" figure.

It is estimated that sedentary people use about 30 kilocalories of energy per kilogram body weight daily. For example, a 110-lb (50-kg) sedentary female may not need more than 1,500 kcal daily to maintain energy balance (30 kcal/kg × 50 kg = 1,500 kcal). A sedentary 165-lb (75-kg) male is estimated to need about 2,325 kcal per day to maintain energy balance (31 kcal/kg × 75 kg = 2,325 kcal). As Table 2.4 and Figure 2.25 clearly show, as activity increases, the amount of energy expended increases. Those who are lightly active, generally defined as activities of daily living plus walking two miles a day or the equivalent, need between 35 (women) and 38 (men) kcal/kg/d. Moderate, heavy, and exceptional activity take into account an increasing intensity and/or duration of activity, and the estimate of the amount of energy needed

Metabolic equivalent (MET): Level of energy expenditure equal to that measured at rest. 1 MET = 3.5 ml/kg/min of oxygen consumption.

Estimated Energy Requirement (EER): The estimated amount of energy that needs to be consumed to maintain the body's energy balance.

KEEPING IT IN PERSPECTIVE

Food = Fuel = Exercise

The word *energy* typically has a positive connotation. It denotes both power and vigor and is the opposite of fatigue. The body uses energy, in the form of ATP, to fuel all of its activities from sleep to vigorous exercise. Without the consumption of food and the transformation of the energy contained in that food into biologically useful energy, life would not be possible. Curiously, the measure of energy, or calories, often has a negative connotation. Athletes should think of energy and calories in positive terms because energy is needed to fuel activity. Many sports nutritionists use the words "energy intake" instead of "calorie intake" to help athletes understand the connection between food, fuel, and exercise.

The "energy in" side of the energy balance equation receives much attention (i.e., the amount of food eaten), but it is the "energy out" side of the equation that needs first consideration. In other words, the amount of physical activity should determine the amount of food consumed. Athletes who wish to maintain their body composition must consume enough food to match their energy expenditure. Those who wish to lose body fat must still consider daily energy output and reduce food intake somewhat, forcing the body to use some of its stored energy to fuel activity. However, too severe of an energy restriction can be counterproductive, particularly if resting metabolic rate is reduced or a high volume of training cannot be sustained. When viewed from the perspective of activity and exercise, the energy (calories) contained in food has a positive connotation. Food = fuel = exercise.

Table 2.4 Estimating Daily Energy Need

Level of Activity	Energy Expenditure—Females (kcal/kg/d)	Energy Expenditure—Males (kcal/kg/d)
Sedentary (Activities of daily living [ADL] only)	30	31
Light activity (ADL + walking two miles per day or the equivalent)	35	38
Moderate activity (ADL + moderate exercise 3 to 5 days per week)	37	41
Heavy activity (ADL + moderate to heavy exercise on most days)	44	50
Exceptional activity (ADL + intense training)	51	58

Legend: kcal/kg/d = kilocalorie per kilogram body weight per day

These "ballpark" figures can be used to quickly calculate an estimate of daily energy need, taking into account gender and activity.

Note: These estimates have generally been derived from surveys and clinical observations.

to maintain energy balance increases proportionately. While these estimates are just ballpark figures, they can help an individual quickly determine the amount of energy (i.e., caloric intake) needed each day to maintain energy balance.

Of course, not all people, including athletes, are or want to be in energy balance. The information obtained from food and activity diaries and the estimates of energy intake and expenditure that are based on these records or other methods of measuring energy expenditure will be useful information for athletes and practitioners as weight, body composition, training, and performance goals are set. The application of the concepts of "energy in" and "energy out" to maintaining or changing weight and body composition is covered later in this text, specifically in Chapters 10–12.

Summary

Energy exists in a number of forms and can be transferred from one type to another. The energy contained in food can be converted in the body to other forms of energy for immediate use or storage. The primary form of energy used by the body is in chemical form, in the high-energy phosphate compound **adenosine triphosphate (ATP).** Muscles directly use the energy from ATP to produce force for exercise and physical activity, and the purpose of the major energy systems of the body is to replenish ATP.

The energy contained in food can be measured through direct **calorimetry** by measuring the heat given off when the food is burned in a bomb calorimeter. Similarly, the energy expended by the body can be determined through direct calorimetry by measuring the heat emitted. **Energy expenditure** can also be determined indirectly by measuring oxygen consumed and carbon dioxide produced using a variety of techniques. Units of energy include **kilojoules, kilocalories,** and **Calories.**

The **energy balance** equation, "Energy in = Energy out," is one of the simplest ways to illustrate energy balance. **Food** is the only factor on the "energy in" side of the equation. The "energy out" side includes **resting metabolism, thermic effect of food,** and **physical activity.** While many factors influence resting metabolism, the two factors under voluntary control that have the strongest influence are self-starvation (e.g., severe dieting) and building and maintaining muscle mass through strength training. The thermic effect of food accounts for only a small amount of the total energy expended in a day. Physical activity is the factor on the "energy out" side that is the most variable and is under the most voluntary control.

Resting metabolic rate can be estimated by using appropriate prediction equations. Computer-based nutritional analysis programs provide reasonable estimates of the amount of energy consumed, the amount expended through physical activity, and the total amount of energy needed daily to maintain energy balance. Very simple calculations are sometimes used in practice settings. In such cases, some accuracy is sacrificed for ease of use.

Post-Test Reassessing Knowledge of Energy

Now that you have more knowledge about energy read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. The body creates energy from the food that is consumed.
2. The scientific unit of measure of energy is the calorie.
3. A person's resting metabolic rate can change in response to a variety of factors such as age, food intake, or environmental temperature.
4. Physical activity is responsible for the largest amount of energy expended during the day for the average adult in the United States.
5. The energy source used by all cells in the body is adenosine triphosphate (ATP).

Review Questions

1. What does the term *bioenergetics* mean?
2. Name at least three forms of energy.
3. What is the First Law of Thermodynamics and how does it apply to energy use by the body?
4. What is the principal energy source used by the body and how is it used by muscle to produce force?
5. Is ATP ever used up completely by exercising muscle? How does the muscle respond to reduced ATP concentrations?
6. How does the body replenish the ATP that is used?
7. What is the standard unit of measure (SI unit) for energy?
8. What are the commonly used units of measure for energy in the field of nutrition, and how do they relate to the SI unit of measure for energy?
9. How is the energy content of food determined?
10. How is energy expenditure measured by direct calorimetry?
11. What is meant by indirect calorimetry and how is energy expenditure measured by this method?
12. What is the energy balance equation? What are the three components of "energy out?"
13. What is resting metabolic rate? Which factors influence RMR? Which have the greatest influence?
14. What effect does severe food restriction have on resting metabolic rate? Why? What happens to resting metabolism after food is reintroduced? Why?
15. How accurate are prediction equations for estimating resting metabolic rate?
16. What is the most accurate way of measuring total daily energy expenditure? What are the most practical ways in a university setting? In a health and fitness club?

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3 Energy Systems and Exercise

Learning Objectives

1. Describe the characteristics of the creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation energy systems.
2. Evaluate creatine supplements based on legality, ethics, safety, and effectiveness.
3. Compare and contrast the three energy systems and give examples of physical activities, exercise, or sports in which each is the predominant energy system.
4. Outline the process of carbohydrate, fat, and protein (amino acid) oxidation.
5. Explain the response of oxygen consumption to steady-state, submaximal exercise.
6. Explain the concept of maximal oxygen consumption and become familiar with relative values of $\dot{V}O_{2max}$.
7. Explain the concept of respiratory exchange ratio and describe the process of determining the percentage of fat and carbohydrate fuel utilization.

Pre-Test: Assessing Current Knowledge of Energy Systems and Exercise

Read the following statements and decide if each is true or false.

1. The direct source of energy for force production by muscle is ATP.
2. Creatine supplements result in immediate increases in strength, speed, and power.
3. Lactate is a metabolic waste product that causes fatigue.
4. The aerobic energy system is not active during high-intensity anaerobic exercise.
5. At rest and during low levels of physical activity, fat is the preferred source of fuel for the aerobic energy system.

In the previous chapter, the high-energy phosphate compound adenosine triphosphate (ATP) was shown to be the immediate source of energy in the body for activity and exercise. This chemical compound can store potential energy in its phosphate bonds, and when broken down to ADP (adenosine diphosphate), can release energy to be used for a wide variety of tasks such as force production by muscle. ATP is found in all cells in the body, and can be thought of as the body's primary energy currency. This important energy compound is found in surprisingly small amounts in the body and can be used at very high rates in some cases, such as during high-intensity exercise. Because of the importance of ATP, the body must have ways to restore ATP after it has been used. The process of resynthesizing ATP from ADP is called rephosphorylation. This chapter reviews the three major energy systems used for rephosphorylation of ATP, the interactions of these systems, and how exercise intensity and duration influences the utilization of each energy system.

Overview of Energy Systems

REPHOSPHORYLATION OF ADP TO FORM ATP

As discussed in Chapter 2, the chemical breakdown of ATP to ADP is an exergonic reaction, that is, it releases energy (Figure 3.1). The process of rephosphorylation of ADP back to ATP therefore is an endergonic reaction; it requires the input of energy, which is then stored in the phosphate bond that is reestablished to form ATP (Figure 3.2). One objective of this chapter is to examine the various bioenergetic processes (e.g., converting food to energy in the body) used to resynthesize ATP. In other words, the focus is on the connections between food, the energy that is found in food, and the transformation of that energy into ATP, which is the body's source of energy during exercise and at rest.

Sports and exercise provide an excellent model to study the energy systems that lead to the restoration of ATP concentrations in the body. There are few situations encountered by the human body that utilize ATP at a faster rate than exercise, which in turn creates a substantial demand for rapid replacement of ATP stores. A useful schematic for picturing this process can be seen in Figure 3.3. If an individual muscle fiber is stimulated to produce force, energy is required. The direct source of energy for force production by muscle comes from splitting ATP molecules that are stored in the muscle cells. This process can occur very

Figure 3.1 Hydrolysis of ATP

ATP (adenosine triphosphate) is split chemically, leaving adenosine diphosphate (ADP) and inorganic phosphate (Pi) and releasing energy in an exergonic reaction.

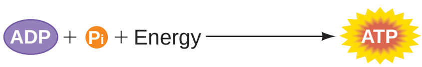


Figure 3.2 Rephosphorylation of ADP to form ATP.

An inorganic phosphate (Pi) is joined to adenosine diphosphate (ADP) to re-form ATP. This endergonic process requires the input of energy, which is then stored as potential energy in the phosphate bonds of ATP.

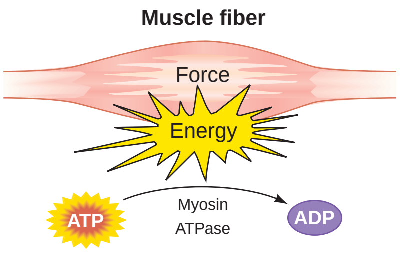
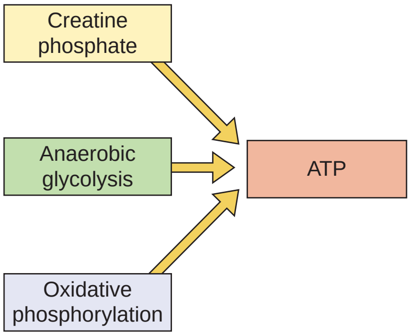


Figure 3.3 Schematic of ATP and energy use by exercising muscle.

The production of force by a muscle fiber requires energy. The direct source of energy for muscle force production comes from ATP (adenosine triphosphate), which is stored in the muscle cell. When ATP is broken down to ADP (adenosine diphosphate), energy is released and can be used for muscle contraction.



ATP = adenosine triphosphate

Figure 3.4 The three major energy systems that replenish ATP.

The purpose of the three energy systems, creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation, is to use chemical energy to re-form ATP, the direct source of energy used by cells in the body.

Table 3.1 Characteristics of the Three Energy Systems

	Speed of Action	Amount of ATP Replenished	Duration of Action
Creatine Phosphate	Very Fast	Very Small	Very Short
Anaerobic Glycolysis	Fast	Small	Short
Oxidative Phosphorylation	Very Slow	Large	Very Long

Legend: ATP = adenosine triphosphate

rapidly, particularly during high-intensity exercise when the amount of force produced by muscles is very high. Just as important as the force production phase, the muscle cells must be able to relax and prepare for the next contraction. This process requires the replenishment of ATP within the muscle. As discussed in Chapter 2, failure to replenish ATP in the muscle may result in fatigue and rigor, a persistent contracted state. How is it that ATP is replenished?

The focus of this chapter is an examination of the three major energy systems that are used to replenish ATP: the creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation energy systems (Figure 3.4). Each of the three energy systems has its advantages (e.g., speed of action, amount of energy released) and disadvantages (e.g., duration of action) as shown in Table 3.1.

A preliminary word must be said about the use and interaction of these three energy systems. Because of their characteristics (e.g., speed, duration), each energy system may be used by the body under different exercise or activity conditions. In other words, certain activities may require the use of the creatine phosphate system, while the energy demands of other activities may be met using the **aerobic,** or oxidative phosphorylation energy system. The tendency, therefore, is to think of each of these energy systems operating to the exclusion of the other systems. It is tempting to think of these systems as light switches: when during a certain activity one of the energy systems is "switched on" to support the activity, the others must therefore be switched off. This image incorrectly depicts the interaction of the energy systems.

A better analogy for the operation of the three energy systems might be a series of dimmer switches. All three are "on" all the time, but in certain situations, one of the systems may be "turned up" more than the other two. Certain exercise or sports activities may have an energy requirement that results in one of the energy systems being the predominant energy system used for that activity. The other energy systems are active, but to a lesser degree. As each energy system is described, examples of activities that *predominantly* use that source of energy will be given, but one must recognize that the other energy systems may be in use to some degree at the same time.

The Creatine Phosphate Energy System

The most prevalent high-energy phosphate in the body is ATP, but there is another high-energy phosphate compound that is stored in muscle (and other tissues)—**creatine phosphate (CrP)**. Just as with ATP, potential energy is stored within the phosphate bond of creatine phosphate, and this energy can be released when the phosphate bond is broken and the inorganic phosphate (Pi) released. Unlike ATP, however, this energy is not used directly to power muscle contraction. Instead, the energy released from the breakdown of creatine phosphate is used to rephosphorylate ADP into ATP (Figure 3.5). Thus, the creatine phosphate stored in muscle acts as a readily accessible reservoir of energy for the re-formation of ATP.

It should be noted that a number of slightly different terms and abbreviations are used interchangeably for creatine phosphate, including **phosphocreatine,** PC, PCr, and CP. In this textbook, creatine phosphate, abbreviated as CrP, will be used. Because creatine phosphate is a high-energy phosphate compound like ATP, this energy system is referred to by many sports nutrition and exercise physiology texts as a combined system, the ATP-PC energy system. As has been pointed out, ATP directly provides the energy for force production by muscle and

Aerobic: "With oxygen." Refers to an energy system that can operate only if oxygen is present.

Creatine phosphate: Organic compound that stores potential energy in its phosphate bonds.

Phosphocreatine: See creatine phosphate.

Figure 3.5 The Creatine Phosphate Energy System

Creatine phosphate is split chemically, releasing energy that is used to rephosphorylate ADP and re-form ATP, leaving unphosphorylated creatine. The reaction is catalyzed by the enzyme creatine kinase (CK).

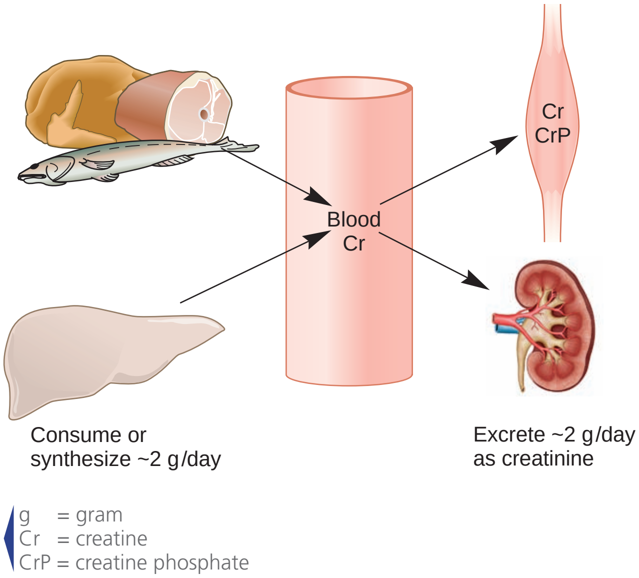


Figure 3.6 Creatine metabolism—consumption, synthesis, uptake, excretion.

For the majority of people, creatine is either consumed in the diet from meat or fish sources and/or is synthesized by the liver and other tissues. Approximately 2 g are consumed or synthesized daily (this figure assumes that creatine supplements are not taken). Creatine is distributed throughout the body in the blood and is taken up by tissues such as skeletal muscle. In muscle, approximately two-thirds is phosphorylated as creatine phosphate, while one-third remains as creatine. Approximately 2 grams per day is excreted in the urine as creatinine.

is present in such limited amounts that it may provide energy for only a few seconds of very high-intensity exercise. The role of creatine phosphate, like the two other major energy systems (anaerobic glycolysis and oxidative phosphorylation), is to replenish ATP so that it is available for muscle relaxation and subsequent force production. In this text, the term *creatine phosphate energy system* is used rather than the term *ATP-PC energy system*.

CREATINE PHOSPHATE

What Is Creatine? Creatine is an **amine,** a nitrogen containing compound similar to a protein, constructed from the amino acids arginine, glycine, and methionine. It can either be consumed in the diet via food or supplements or produced by the body. The major food sources of creatine are beef and fish. Those who eat beef and fish consume approximately 1 to 2 g of creatine daily, while nonmeat and nonfish eaters consume negligible amounts. Creatine can also be consumed as a dietary supplement, usually 3 to 5 g/day. Creatine as a supplement generally is found as creatine monohydrate in a white powdered form, which is mixed with water for consumption.

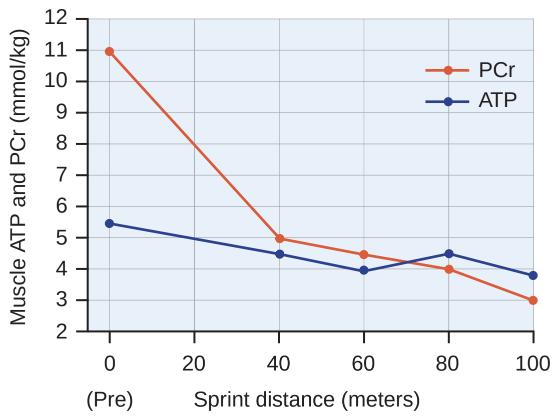
Even if creatine is not consumed directly in the diet, the liver and kidneys can synthesize it in adequate amounts if the amino acids arginine, glycine, and methionine are present in sufficient quantities (i.e., protein intake is adequate). A creatine deficiency in humans would be extremely rare.

Whether consumed or produced by the body, creatine is transported in the blood to tissues throughout the body. Tissues such as muscle will take up creatine from the blood and store it, approximately one-third as creatine (Cr) and two-thirds as creatine phosphate (CrP). Excess creatine is filtered by the kidneys and is excreted as the chemical compound **creatinine.** The body's "turnover" of creatine is approximately 2 g per day. That is, an average nonvegetarian who does not use creatine supplements will consume and/or synthesize approximately 2 g of creatine daily and the body will excrete approximately the same amount as creatinine (Figure 3.6). Since the dietary intake of creatine by a vegetarian is near or at zero, the amount of creatine in a vegetarian's body is dependent on how much the body can make. Although research is limited in this area, there is some consistent evidence that the total amount of creatine in the muscles of vegetarians is lower than for nonvegetarians (Watt, Garnham, and Snow, 2004; Burke et al., 2003). Vegetarians are not creatine deficient (they may be on the lower end of the normal range), but they do have relatively less creatine than nonvegetarians who complement the production of creatine in the body with creatine found in meat and fish.

Because creatine is an important energy source, particularly for higher-intensity exercise, strength athletes and vegetarians have attempted to manipulate the intake of creatine through supplementation. Creatine loading and supplementation will be discussed in a later section of this chapter (see Spotlight on Supplements).

THE CREATINE PHOSPHATE (CrP) ENERGY SYSTEM

As seen in Figure 3.5, creatine phosphate is broken down, releasing its energy and Pi, which is then used to rephosphorylate ADP into ATP. This is a very rapid, one-step chemical reaction, catalyzed by the enzyme **creatine kinase (CK).** If ATP concentrations in a muscle cell start to decline, the drop in ATP and the concomitant rise in ADP in the cell result in an increase in the

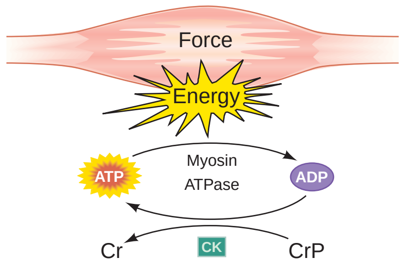


ATP = adenosine triphosphate
PCr = creatine phosphate
mmol/kg = millimoles per kilogram

Figure 3.7 Utilization of ATP and creatine phosphate in muscle during short-term, very-high-intensity exercise.

Well-trained sprinters had muscle ATP and creatine concentrations measured immediately before and after sprinting various distances to examine the use of these energy sources during very-high-intensity exercise.

Hirvonen, J., Rehunen, S., Rusko, H. & Harkonen, M. (1987). Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *European Journal of Applied Physiology and Occupational Physiology*, 56(3), 253–259.



ATP = adenosine triphosphate
ADP = adenosine diphosphate
Cr = creatine
CK = creatine kinase
CrP = creatine phosphate

Figure 3.8 Creatine Phosphate and ADP Rephosphorylation

Creatine phosphate is used to rephosphorylate ADP to re-form ATP and provide energy for exercising muscle.

activity of CK, allowing the reaction to proceed even faster. The reaction does not depend upon the presence of oxygen, so this energy system is considered to be one of the **anaerobic** ("without oxygen") energy systems. Each molecule of CrP can rephosphorylate 1 molecule of ADP to ATP, so the ratio of ATP energy produced is 1:1.

Because of the speed with which the CrP can act to replenish ATP, it is the preferred energy system during very-high-intensity exercise when ATP is utilized very rapidly. As discussed in Chapter 2, it is potentially disastrous to a muscle cell to have ATP concentrations drop to very low levels, so the muscle uses fatigue as a protective mechanism to prevent ATP depletion. When a muscle begins to fatigue, it fails to produce force at the same level or the same rate. Because it is not producing force at the same rate, the requirement for ATP declines and it is not used up as rapidly.

As with ATP, CrP is stored in finite amounts in the muscle, but unlike ATP, CrP can be used to the extent that it will decrease to very low concentrations. A normal resting level of total creatine (creatine + creatine phosphate) in muscle is approximately 120 mmol/kg (millimoles per kilogram of muscle), which can be reduced below 20 mmol/kg with very intense exercise. The term *depletion* is used, even though the muscle creatine levels do not actually drop to zero.

A number of studies have demonstrated this near depletion of CrP in muscle during high-intensity exercise, and one research study (Hirvonen et al., 1987) investigating the levels of ATP and CrP in the muscles of sprinters is illustrated here. As seen in Figure 3.7, as the sprinters ran as fast as they could for 40, 60, 80, and 100 meters, the concentration of ATP dropped approximately 20 percent in the first 40 meters and then essentially reached a plateau. While there was some modest variation in the ATP concentration over the last 60 meters, the overall concentration did not go down further than the initial 20–25 percent decline. The level of CrP, however, declined substantially throughout the high-intensity exercise, particularly within the first five seconds (i.e., ~40 meters). Very low levels of CrP in the muscle are associated with muscle fatigue. At very high intensities of exercise, it takes approximately five to 10 seconds for CrP in muscle to be depleted and fatigue to occur, so it is said that the duration of the creatine phosphate energy system is approximately five to 10 seconds.

Creatine phosphate is an important high-energy phosphate that is stored in muscle where it is readily available to replenish ATP very rapidly (Figure 3.8). Because this energy system can be used for rapid replenishment of ATP, it is the energy system that is predominately used during very-high-intensity short-duration exercise when ATP is being used very rapidly. What types of exercise or sports activities meet this description?

Creatine: An amine, a nitrogen-containing chemical compound.

Amine: An organic compound containing nitrogen, similar to a protein.

Creatinine: Waste product excreted in the urine.

Ergogenic: Ability to generate or improve work. Ergo = work, genic = formation or generation.

Creatine kinase (CK): Enzyme that catalyzes the creatine phosphate energy system.

Anaerobic: "Without oxygen." Refers to an energy system that can operate without the use of oxygen.

- Short, fast sprints, such as the 100-meter sprint in track or the 40-yard sprint in football
- Short, powerful bursts of activity such as the shot put or jumping to dunk a basketball
- Activities requiring large amounts of force, such as very heavy weight lifting, e.g., maximal effort bench press or a maximal Olympics lift such as a clean and jerk

In summary, the characteristics of the creatine phosphate energy system are:

- One chemical step
- Catalyzed by creatine kinase (CK)
- Very fast reaction
- One ATP per CrP molecule
- Five- to 10-second duration
- Anaerobic
- Fatigue associated with CrP depletion
- Predominant energy system in very-high-intensity exercise, e.g., "power" events

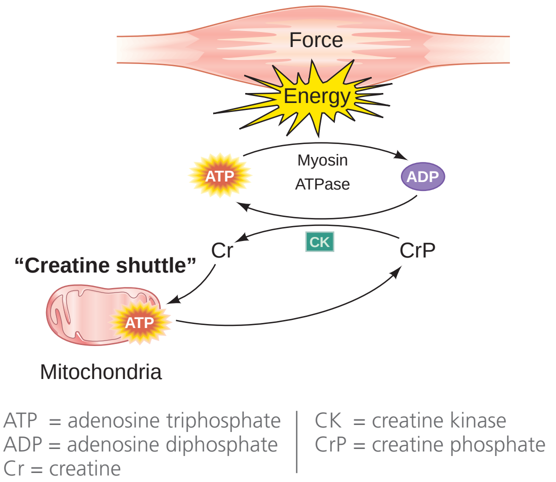


Figure 3.9 The Creatine Shuttle

Rephosphorylation of creatine to creatine phosphate via aerobic metabolism. Creatine that remains from chemically splitting creatine phosphate is rephosphorylated using energy from ATP produced aerobically in the mitochondria of the muscle. This process requires an increase in aerobic metabolism (oxidative phosphorylation) and returns creatine phosphate concentrations to normal within a minute or two.

REPHOSPHORYLATION OF CREATINE TO CREATINE PHOSPHATE

Using the same schematic depicting energy and force production by exercising muscle, Figure 3.8 shows the role of creatine phosphate in the rephosphorylation of ADP to ATP. When this reaction proceeds, one of the end products is creatine, without the phosphate group. If creatine phosphate is an important energy source, particularly for high-intensity exercise, how does the body recover its stores of creatine phosphate?

The answer lies is the realization that the creatine phosphate energy system is not completely anaerobic. The presence of oxygen is not required when CrP is used to replenish ATP. However, the recovery of CrP from creatine depends upon aerobic metabolism in the cell, in a process referred to as the Creatine Shuttle (Bessman and Carpenter, 1985). As discussed in greater detail later in this chapter, aerobic metabolism takes place within mitochondria, small organelles in cells. A series of chemical reactions requiring oxygen are continuously carried out to produce ATP within the mitochondria. Creatine molecules can use the energy from ATP produced aerobically in the mitochondria to restore creatine to creatine phosphate (Figure 3.9). Once restored, creatine phosphate is ready as a reservoir of energy for high-intensity exercise.

How long does it take for creatine to be rephosphorylated to creatine phosphate? It depends upon how much creatine phosphate was used, but it can take up to one to two minutes if the exercise has been intense and long enough to substantially deplete creatine phosphate in the muscle. Ever wonder why athletes breathe hard for a time after short duration high-intensity exercise? Because the body uses the aerobic energy system to restore creatine phosphate, it must temporarily increase oxygen intake and aerobic metabolism to meet the increased aerobic task of restoring creatine to creatine phosphate. This is another example of the integration of the body's energy systems.

The major advantage of the creatine phosphate energy system is that it is a very rapid way to replace ATP. However, it has significant disadvantages in that creatine phosphate is stored in very limited amounts in the muscle, can be depleted rapidly, and has a very short duration as an energy system. Fortunately, the body has additional energy systems to replace ATP under different circumstances.

What's the point? Very-high-intensity exercise reduces ATP rapidly. Creatine phosphate is used to rapidly replenish ATP so that exercise can continue. The amount of creatine phosphate in muscle can be manipulated to a small degree by supplementation or loading creatine in the diet, which may allow some athletes to sustain their high-intensity training for a longer period of time.

Creatine Loading and Supplementation

Creatine phosphate is an important high-energy phosphate that can be used to replenish ATP very rapidly. Its major disadvantage as an energy system, however, is its limited supply in muscle: it can be depleted relatively quickly during very-high-intensity exercise. It is not unexpected that athletes competing in events that rely heavily upon this energy source would try to improve their performance by increasing the amount of creatine phosphate available to the muscle (ACSM, 2000).

How can the muscle's supply of creatine phosphate be increased above normal levels? Muscle creatine and creatine phosphate concentrations can be increased by approximately 20 percent by consuming creatine supplements (Hultman et al., 1996). Creatine loading is a strategy used to accomplish this increase in a short period of time by consuming a large amount of creatine (20 to 25 g per day) in supplement form over a period of five to six days. The Hultman et al. study also showed that a similar 20 percent increase in muscle creatine phosphate concentrations could be achieved by supplementing the diet with smaller amounts of a creatine supplement (3 g per day) over a longer period of time (one month). It should be pointed out that some athletes respond to creatine supplements with substantial increases in muscle creatine concentrations while others have small increases and some are nonresponders. This is likely explained by the amount of creatine in the muscle prior to supplementation. In one study, both vegetarians and nonvegetarians increased the amount of creatine in muscles after five days of creatine supplementation, but the vegetarians saw relatively larger increases (76 percent increase) than nonvegetarians (36 percent increase) because they had lower levels prior to the supplementation (Watt, Garnham, and Snow, 2004).

Increasing the amount of creatine phosphate in the muscle is similar in concept to increasing the size of the gas tank in a race car. Will increasing the size of the fuel tank necessarily allow the race car to go faster? Will increasing the size of the creatine "gas tank" in the muscle immediately make the athlete faster or more powerful? Merely increasing the size of the gas tank won't make the race car go faster. It will however, allow the car to maintain its top speed for a longer period of time. This appears to be the long-term benefit of creatine loading or supplementation for the strength and power athlete.

There is insufficient evidence to suggest that creatine loading or supplementation results in an immediate increase in an athlete's strength, speed, or power or that it has a direct effect on performance for most athletes. While many creatine studies show an **ergogenic** effect for a variety of athletes, a performance effect has only been shown for weight lifters (Volek and Rawson, 2004). The studies do suggest that creatine loading or supplementation allows an athlete to train harder, for example, by completing more weight lifting repetitions (Volek et al., 1999). The increase in the training stimulus over time allows the athlete to potentially become stronger, faster, or more powerful but only in weight lifters is it directly related to performance. In the case of runners, the weight gain that accompanies creatine supplementation could have a detrimental effect on performance (Volek and Rawson, 2004; Volek et al., 1999).

Creatine supplementation increases intracellular water in the muscle, which may stimulate muscle glycogen storage. Increases in intracellular water also influence protein metabolism. These effects are intriguing but more studies are needed to determine the effect creatine supplementation has on either glycogen storage or muscle protein synthesis or breakdown (Volek and Rawson, 2004; Branch, 2003).

The safety of creatine supplementation has always been subject to much debate, but currently available research suggests that creatine supplementation is safe. When creatine supplements first became popular, it was widely reported in the press that they caused dehydration, muscle cramps, and, possibly, kidney damage. There is no scientific evidence that creatine supplementation causes dehydration or muscle cramps. Studies have also shown that creatine supplements do not adversely affect kidney or liver function, hormone levels, lipids, or sperm count and mobility (Crowe, O'Connor, and Lukins, 2003; Mayhew, Mayhew, and Ware, 2002; Schilling et al., 2001; Poortmans and Francaux, 2000). One clinical sign of kidney damage is excess creatinine in the urine. Because excess creatine is eliminated in the form of creatinine, urinary creatinine concentrations may be elevated after creatine loading, but studies have shown these levels to rise only to the high end of the normal range (Poortmans and Francaux, 2000). Some athletes may experience some minor side effects with supplements, such as gastrointestinal upset or cramps.

Creatine Supplementation Recommendations:

- Application is very specific to strength and power activities.
- Creatine is not a "magic pill"—only effective in conjunction with vigorous training.
- Response may be related to initial creatine levels.
- Do not use if kidney disease or dysfunction is present.
- Supplement dose is typically 3 to 5 grams per day.
- Loading dose is typically 20 to 25 grams per day in four to five doses for five to seven days.
- Loading is not necessary unless time urgent.
- Consume with carbohydrates to enhance uptake.
- Be well hydrated.
- Document any adverse effects and reevaluate use.

The Anaerobic Glycolysis Energy System

Anaerobic glycolysis is the process of taking carbohydrate in the body and putting it through a series of chemical reactions that release enough energy to rephosphorylate ADP and re-form ATP (Figure 3.10). The final product of this series of chemical reactions is often referred to as lactic acid, so this energy system is often called the lactic acid system. In reality, lactic acid is a weak acid and under normal conditions in the body is rapidly **dissociated,** separating into the **lactate** molecule and a hydrogen ion (H^+). It would therefore be more accurate to use the term lactate energy system; however, in exercise physiology the term anaerobic glycolysis is also widely used. In this text, the term anaerobic glycolysis energy system is used to identify the biochemical pathways involving the conversion of glucose to lactate in contracting muscle under anaerobic conditions. The term glycolysis, not anaerobic glycolysis, is used in most biochemistry textbooks.

Carbohydrates will be covered in much greater detail in Chapter 4, but a summary is needed at this point as background for understanding anaerobic glycolysis. Virtually all carbohydrates consumed are converted to and used as **glucose,** or are stored as **glycogen** in the muscle and liver for later use. Glycogen is a large molecule composed of many glucose molecules linked together. **Glycolysis** is the breakdown of glucose through a specific series of chemical steps to rephosphorylate ADP and form ATP. When the starting point is glycogen, the process is called **glycogenolysis** (lysis means to separate).

The complete process of glycolysis involves 18 chemical reactions but only 12 chemical compounds, because six reactions are repeated or duplicated. The glycolytic pathway begins with glucose and ends with lactate and the chemical compounds in this pathway are called glycolytic intermediates. Each chemical step is catalyzed by an enzyme. When a series of chemical reactions are catalyzed by enzymes, one of the enzymes is considered to be the **rate-limiting enzyme.** In other words, there is an enzyme that controls the speed of all the reactions in the same way that the overall speed of an assembly line is governed by the speed of the slowest worker. The rate-limiting enzyme for glycolysis is **phosphofructokinase (PFK),** which catalyzes the third step. If the activity of PFK increases, the entire reaction speeds up and if PFK activity decreases, the entire reaction slows down. As mentioned in Chapter 2, the activity of enzymes can be affected by temperature and pH, among other factors. For example, if the environment becomes too acidic, the activity of PFK will decline, slowing the entire glycolytic reaction, and ultimately slowing the rate of ATP replacement. The activity of PFK is dramatically increased, however, by a drop in the concentration of ATP and the concomitant rise in ADP concentration—this is an important signal that ATP is being used up and must be replenished.

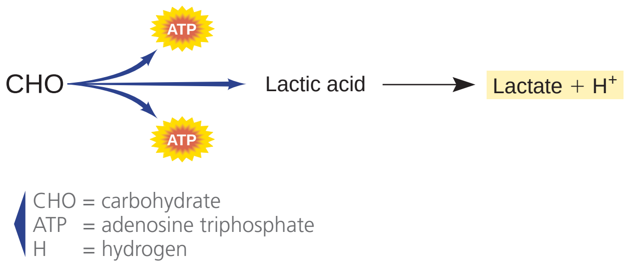


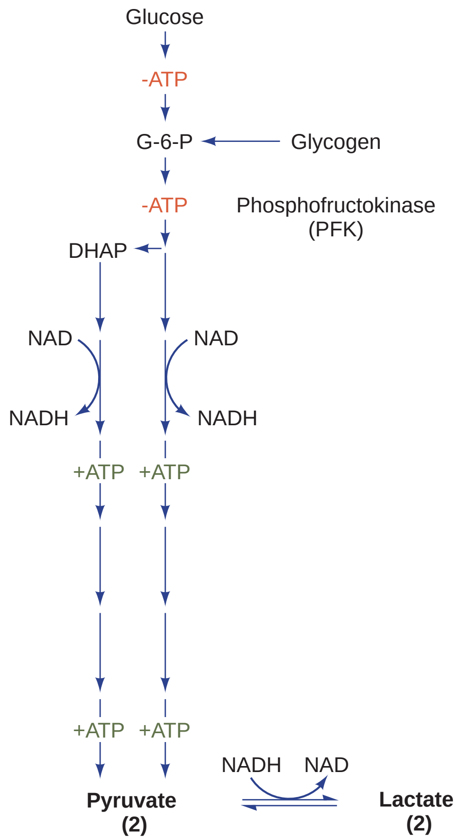
Figure 3.10 Anaerobic Glycolysis

Carbohydrates in the form of glucose are broken down through a series of chemical reactions that result in a net formation of ATP. The final product, lactate, is an important metabolic compound.

Oxygen is not required for these chemical reactions to proceed, so glycolysis is one of the anaerobic energy systems. Knowledge of the details of glycolysis is important for a thorough understanding of sports nutrition, but at this point in the discussion the important details and concepts have been condensed as represented in Figure 3.11. For now, the simplified schematic will be used to develop an understanding of the fundamental concepts of glycolysis. A more detailed description of anaerobic glycolysis can be seen in Figure 3.12, which illustrates the specific chemical reactions that occur.

Beginning with glucose, two out of the first three reactions require the utilization of an ATP, that is, they require the input of energy for the reaction to proceed. In the first step, energy and a phosphate group from an ATP is added to glucose to form glucose-6-phosphate (G-6-P), one of the notable glycolytic intermediate compounds. Glucose is a compound that contains six carbon molecules and in the fourth step it is split into two 3-carbon molecules. After a side step reaction to DHAP (dihydroxyacetone phosphate) the 3-carbon molecules are identical, so the remaining reactions of glycolysis are duplicated. In the sixth chemical reaction, sufficient energy is released to rephosphorylate ADP into ATP. This is one of the reactions that is repeated, so two ATP are produced at this point. In the ninth reaction the same thing occurs, so two additional ATP are produced. The result of this ninth reaction is the production of **pyruvate,** an important intermediate compound. In anaerobic glycolysis, pyruvate then proceeds through the final chemical reaction to lactate. Glycolysis produces four ATP but two ATP are used in the process, so the final (net) ATP production from anaerobic glycolysis is two ATP.

In Figure 3.11, notice that if the beginning point of the reaction is glycogen, the pathway skips the first reaction that requires the use of an ATP, and the reaction beginning with glycogen goes directly to glucose-6-phosphate.



G-6-P = glucose-6-phosphate
ATP = adenosine triphosphate
NAD = nicotinamide adenine dinucleotide
NADH = reduced form of NAD

Figure 3.11 Schematic of Anaerobic Glycolysis

Glucose proceeds through a series of 18 chemical steps, six of which are repeated, ending as lactic acid or lactate. In the initial steps, energy in the form of two ATP is needed to allow the reaction to proceed, and sufficient energy is released in subsequent chemical reactions to re-form four ATP. When the process begins with stored glycogen, it is called glycogenolysis and it proceeds from the point of G-6-P.

Therefore, when glycogenolysis (i.e., the breakdown of glycogen) is used instead of glycolysis (i.e., the breakdown of glucose), four ATP are produced and only one is used in the process, so the final or net ATP production is three ATP. Glycogenolysis is obviously more energetically efficient, and in fact, exercising muscle will generally use stored glycogen in preference to glucose because the energy yield is higher. This helps during exercise, but the ATP that is not used when glycogen is broken down during exercise is used eventually when glucose is stored as glycogen during rest or recovery.

Given the number of chemical steps, it is readily apparent that anaerobic glycolysis will produce ATP more slowly than the one-step creatine phosphate system. Anaerobic glycolysis is a relatively fast-acting energy system, however, and becomes the preferred or predominant system to supply energy during high-intensity or repeated exercise lasting approximately one to two minutes. The overall speed of glycolysis and the subsequent rate of ATP replenishment are primarily governed by the activity of PFK, the rate-limiting enzyme. The body has a considerable amount of carbohydrate energy in the form of blood glucose and muscle glycogen, so unlike the creatine phosphate system, the anaerobic glycolytic energy system is rarely limited by depleted energy stores.

The major disadvantage of this energy system is the increasing acidity (i.e., decline in pH) within the muscle cell that occurs when anaerobic glycolysis is used at a high rate, as occurs during moderately high to high-intensity exercise. Because the acidity is a result of a very high rate of metabolism it is referred to as **metabolic acidosis.** If this acidosis occurs in exercising muscle, the drop in pH can result in the decrease in activity of key metabolic enzymes and can interfere directly with the process of force production, resulting in muscle fatigue. When exercising at high intensity, this metabolic acidosis results in muscle fatigue in approximately one to two minutes, so the duration of this energy system is said to be one to two minutes.

Anaerobic glycolysis utilizes only carbohydrate as a fuel source, and can replace ATP rapidly during moderately high to high-intensity exercise. It begins to function at the onset of high-intensity exercise, but becomes the predominant energy system after five to ten seconds when the creatine phosphate energy system begins to reach its limit. To return to the light controller analogy, after five to ten seconds the dimmer switch is turned down on the CrP energy system and turned up

Anaerobic glycolysis: A series of chemical steps that break down glucose without the use of oxygen to rephosphorylate ADP to ATP.

Dissociate: The breakdown of a compound into simpler components, such as molecules, atoms or ions.

Lactate: The metabolic end product of anaerobic glycolysis.

Glucose: A sugar found in food and in the blood.

Glycogen: Storage form for carbohydrates in the body; a series of glucose molecules linked together.

Glycolysis: Metabolic breakdown of glucose.

Glycogenolysis: Metabolic breakdown of glycogen.

Rate-limiting enzyme: In a series of chemical reactions, the enzyme that influences the rate of the entire series of reactions by changes in its activity.

Phosphofructokinase (PFK): The rate-limiting enzyme for glycolysis.

Pyruvate: Chemical compound that is an important intermediate of glycolysis.

Metabolic acidosis: Decrease in pH associated with high-intensity exercise and the use of the anaerobic glycolysis energy system.

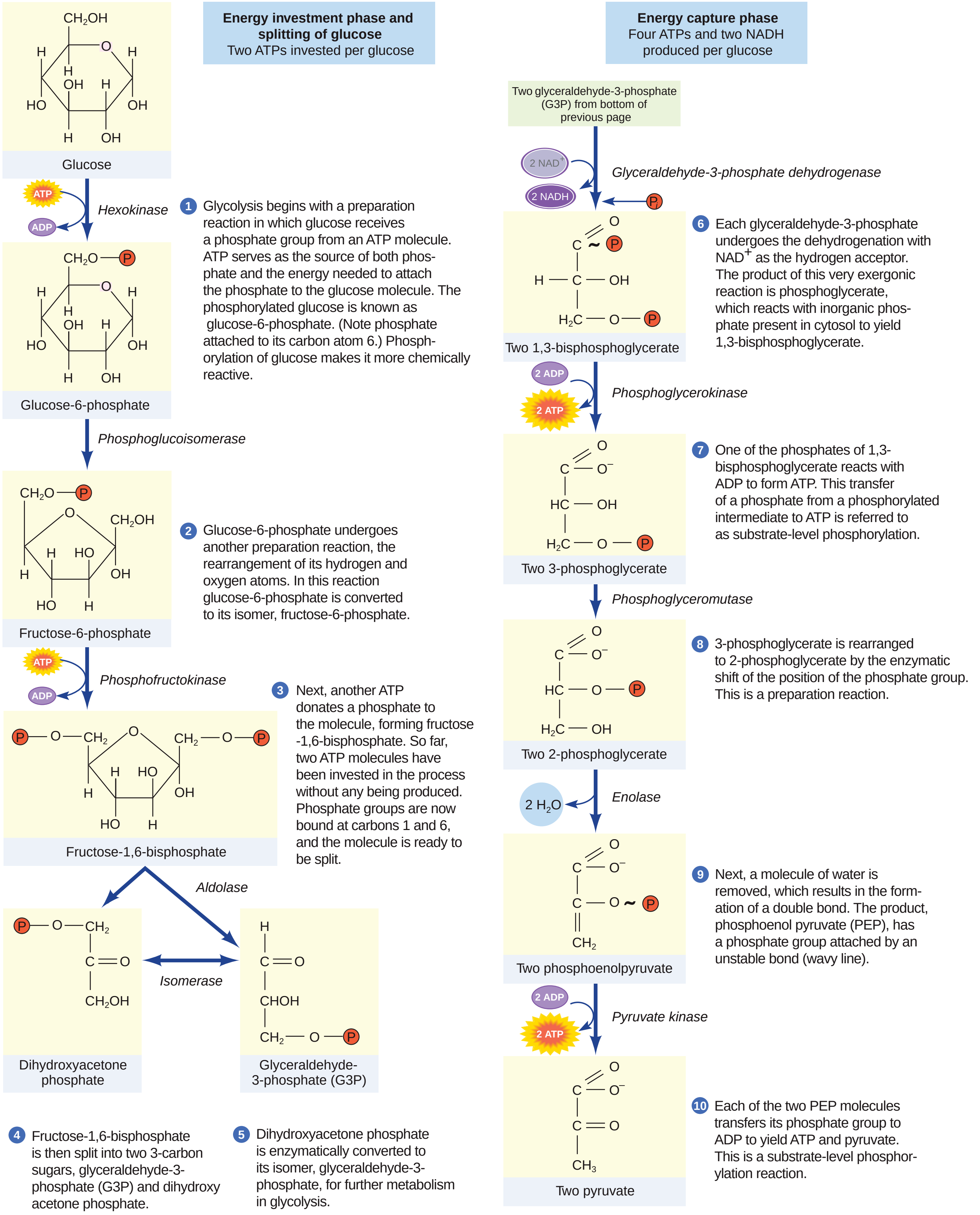


Figure 3.12 A Detailed View of Anaerobic Glycolysis

on the anaerobic glycolysis energy system. If used continuously at a high rate, anaerobic glycolysis remains the predominant energy system for one to two minutes, or longer if the activity is intermittent. What types of exercise or activities meet this description?

- Long sprints such as the 400-meter sprint in track
- Repeated high-intensity sprints such as the intermittent sprints by a soccer or basketball player
- Repeated high-force activities such as 10 to 15 repetitions of weight lifting
- Regular, repeated intervals such as 50- to 100-meter swimming intervals

To summarize the characteristics of the anaerobic glycolytic energy system:

- 18 Chemical steps/reactions, six are repeated
- 12 Chemical compounds, 11 enzymes
- Rate-limiting enzyme phosphofructokinase (PFK)
- Fast, but not as fast as the creatine phosphate (CrP) system
- Two ATP produced via glucose, three ATP produced via glycogen
- Anaerobic
- One- to two-minute duration
- Fatigue associated with decreased pH (metabolic acidosis)
- Predominant energy system in high-intensity exercise, e.g., sustained, repeated sprints

LACTATE REMOVAL AND OXIDATION

When anaerobic glycolysis is utilized as an energy system, the concentration of glucose or glycogen declines and the concentration of lactate increases within the cell. What happens to this metabolic by-product? Previously, lactate had been thought of as a metabolic “waste product,” something that “poisons” the muscle. However, an important distinction must be made between the lactate molecule and the acidity that is associated with high-intensity exercise when glycolysis is used as the predominant energy system. The body has several processes to buffer acidity, but the body’s buffering capacity may be overwhelmed by acidosis that occurs during high-intensity exercise. This acidity may result in an impairment of cell processes. Therefore, the acidity associated with high-intensity exercise may be detrimental to the cells, but far from being a waste product, the lactate molecule is used by cells in the body as an important fuel source (Gladden, 2004).

Notice in Figure 3.11 that the reaction between pyruvate and lactate is a two-way reaction: that is, pyruvate can be converted to lactate, but when concentrations of lactate are high, lactate can also be converted to pyruvate. This is especially important in highly aerobic cells (e.g., muscle, liver), as pyruvate can be taken into mitochondria and metabolized aerobically to produce ATP. In Figure 3.11, pyruvate is identified as a key glycolytic intermediate compound because it represents an important metabolic crossroad. Pyruvate can be metabolized either anaerobically (converted to lactate) or aerobically (taken into a mitochondria and sent through oxidative phosphorylation). Therefore, highly aerobic tissues in the body (e.g., liver, heart muscle, slow-twitch muscle fibers) can take up lactate molecules and use them as a fuel source to produce ATP via aerobic metabolism.

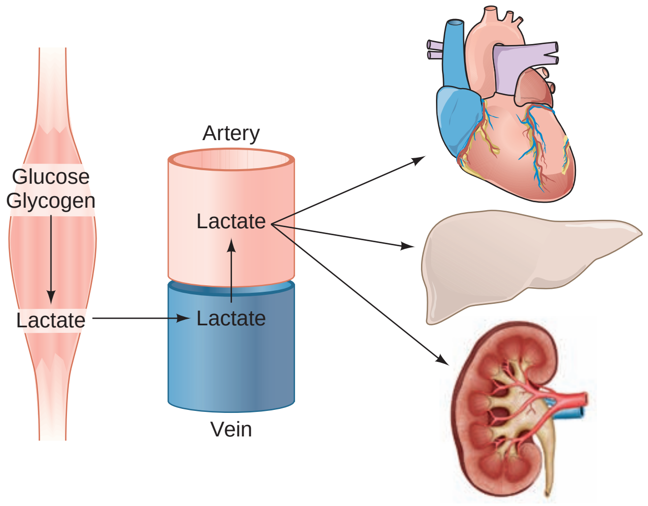


Figure 3.13 The Fate of Lactate

Lactate is transported out of exercising muscle into the venous circulation and is then distributed throughout the body via the arterial circulation. Highly aerobic tissues such as heart, liver, and kidney can remove lactate from the blood and use it as an energy source in aerobic metabolism.

When lactate is produced in cells, such as those in exercising muscle, the increase in lactate concentration results in the movement of lactate molecules out of the cell and into the blood. Once in the blood, lactate molecules can be distributed throughout the body where they can be taken up by other highly aerobic tissues (e.g., heart, liver, kidney) and metabolized aerobically (see Figure 3.13). The more lactate that needs to be oxidized, the more aerobic metabolism must be increased to accomplish this task. Just as the creatine phosphate system is not completely anaerobic, neither is the anaerobic glycolysis energy system. Anaerobic glycolysis relies upon the aerobic energy system to metabolize lactate, the final product of glycolysis. This is another example of the integration of the body’s energy systems.

In addition to aerobic metabolism of lactate for energy, the body can use lactate in other ways. The necessary enzymes are not present in muscle to take lactate through the chemical reactions to make glucose (i.e., gluconeogenesis). This process is referred to as the Cori cycle and must take place in the liver, which does have the necessary enzymes. During exercise, lactate that is produced by exercising muscle can be transported to the liver, used to create glucose, which is then released from the liver into the blood, helping to maintain blood glucose concentration and providing carbohydrates to other cells in the body.

The major advantages of the anaerobic glycolysis energy system are the relatively fast ATP production, the reliance upon a fuel source that is present in large amounts (glucose and glycogen), and the potential usefulness of lactate, its end product. The major disadvantage is the relatively short duration of this energy system due to the metabolic acidosis associated with its use at a high rate.

What's the point? Anaerobic glycolysis produces ATP relatively rapidly for one to two minutes by metabolizing glucose and glycogen in the absence of oxygen. Instead of being a waste product that poisons muscle, the lactate that is produced can be used by the liver to manufacture glucose or used by highly aerobic cells for energy.

The Oxidative Phosphorylation Energy System

The major limitation of the two anaerobic energy systems is their relatively short duration of action, on the order of seconds or minutes. The aerobic energy

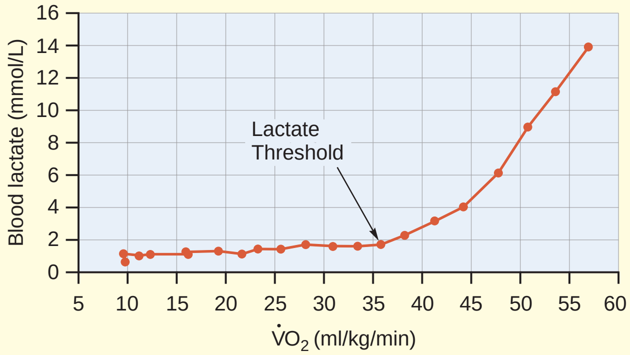
SPOTLIGHT ON ENRICHMENT

Lactate Threshold

Lactate can be produced by exercising muscle and is transported into the blood where it is often monitored by exercise physiologists as an indication of exercise intensity. As exercise increases in intensity, there is usually little increase in the concentration of lactate in the blood initially. Once the intensity reaches a certain level, however, the amount of lactate in the blood begins to increase dramatically. This point of sudden increase is called the Lactate Threshold (LT) and is illustrated in Figure 3.14.

This point of exercise intensity is often erroneously referred to as the Anaerobic Threshold (AT), with the explanation that this is the point of exercise intensity where aerobic metabolism is insufficient and anaerobic glycolysis suddenly becomes active, producing lactate. However, lactate is produced at lower levels of exercise intensity in small amounts, but the lactate concentration in blood does not increase because lactate is being removed from the blood by highly aerobic tissues and oxidized as fast as the exercising muscles are releasing lactate into the blood. The lactate threshold more accurately represents the level of exercise intensity in which lactate production has increased to the point where it has overwhelmed the body's lactate removal mechanisms. Although the term *Anaerobic Threshold* has achieved widespread usage, it should be eliminated in favor of the more accurate term *Lactate Threshold*. Another acceptable term is *Ventilation Threshold (VT),* if this point of exercise intensity is determined using measures of breathing instead of taking blood samples and measuring for lactate.

What is the practical significance of the LT? It has been associated with an exercise intensity that can be sustained for long periods during endurance exercise. For example, LT correlates highly with the race pace for a distance runner: a pace too much faster results in fatigue and poor results, while a pace too much slower results in less than optimal performance.



mmol/L = millimoles per liter
$\dot{V}O_2$ = oxygen consumption
ml/kg/min = milliliters oxygen per kilogram body weight per minute

Figure 3.14 The Concept of the Lactate Threshold

As exercise intensity and oxygen consumption increase, initially, the concentration of blood lactate does not change much, indicating lactate is being removed from as fast as it is being transported into the blood. At a certain point of exercise intensity, however, the production of lactate exceeds its rate of removal, and the lactate concentration continually climbs. This point is referred to as the Lactate Threshold.

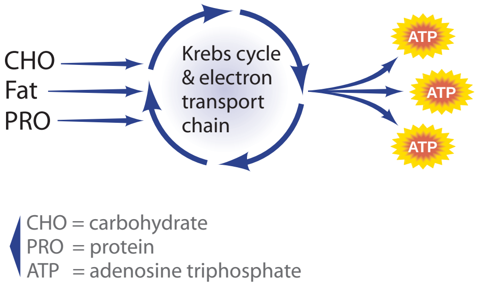


Figure 3.15 Oxidative Phosphorylation

Carbohydrates, fats, and proteins are broken down through a series of chemical reactions that result in a net formation of ATP. The final step requires oxygen, making this the aerobic energy system.

system, known as **oxidative phosphorylation,** is the energy system that can be used to supply ATP on a virtually limitless basis, as long as oxygen and sources of fuel are available. Oxidative phosphorylation is a process by which carbohydrates, fats, or proteins can be metabolized through a series of chemical reactions to release the energy necessary to rephosphorylate ADP to ATP (Figure 3.15).

The oxidative phosphorylation process, which takes place in the mitochondria, is made up of three major phases. In the first phase, carbohydrates, fats, and proteins are prepared to be metabolized aerobically. The second major phase is the **Krebs cycle,** also known as the tricarboxylic acid (TCA) cycle or the citric acid cycle. The Krebs cycle produces a very limited amount of ATP directly, so its primary function is to oxidize, or remove electrons from, the compounds produced from the breakdown of carbohydrates, fats, and proteins. The electrons removed in the Krebs cycle are used in the final phase, the **electron transport chain.** Electrons are passed through a series of chemical reactions, which release energy to rephosphorylate ADP into ATP. As the electrons pass through the electron transport chain, the final electron acceptor is oxygen, making this the aerobic energy system.

Even more so than anaerobic glycolysis, oxidative phosphorylation is a complex series of chemical reactions involving many steps, intermediates, enzymes, and cofactors. In fact, if the starting point is glucose, complete aerobic metabolism involves 124 steps, 30 chemical compounds, and 27 enzymes. Compare that to glycolysis, where the starting point is also glucose, but the process involves only 18 steps, 12 chemical compounds, and 11 enzymes. It is not just the number of steps, compounds, or enzymes that makes aerobic metabolism complicated. Once the reaction progresses to pyruvate, the pyruvate molecules must be transported into mitochondria for oxidative phosphorylation to proceed. In addition, oxygen must be transported from the lungs via the blood and through the muscle cells into the mitochondria to be available to pick up the electrons. Once again, a detailed knowledge of this metabolic pathway is important for a thorough understanding of sports nutrition and can be seen in a subsequent section, but the basics of oxidative phosphorylation have been condensed and represented in Figure 3.16.

Refer to Figure 3.16 and follow the steps of oxidative phosphorylation as glucose (carbohydrates) is completely metabolized aerobically. Glycolysis has already been discussed from the perspective of anaerobic glycolysis in which glucose proceeds to pyruvate and on to lactate. In aerobic metabolism, glycolysis prepares glucose and glycogenolysis prepares glycogen for aerobic metabolism by producing pyruvate, which is shuttled into the mitochondria for the second phase of oxidative phosphorylation. Later in this chapter the preparation of fats and proteins for aerobic metabolism will be discussed. At this point the discussion of glucose will continue with an explanation of the second phase of aerobic metabolism, the Krebs cycle.

KREBS CYCLE

Once glucose (or glycogen) has been broken down into pyruvate, the pyruvate molecules are shuttled into one of many mitochondria in a typical muscle cell. Remember that for each glucose molecule metabolized, two pyruvate molecules are formed by glycolysis, and therefore two "turns" of the Krebs cycle can be completed. While a high-energy phosphate (guanosine triphosphate [GTP]) is produced by the Krebs cycle, the major function of the Krebs cycle is to oxidize, or remove, electrons from the compounds going through the cycle for later use in the electron transport chain.

Once in the mitochondria, pyruvate is converted to another important intermediate compound, **acetyl CoA,** as shown in Figure 3.16. In this process a molecule of carbon dioxide is created, the first of three for each complete turn of the Krebs cycle. One can begin to see the production of carbon dioxide that goes along with the utilization of oxygen in aerobic metabolism.

The Krebs cycle is a series of 10 chemical reactions that begin with acetyl CoA (a two-carbon compound) joining with **oxaloacetate** (four carbons) to

Oxidative phosphorylation: The aerobic energy system.

Krebs cycle: A series of oxidation-reduction reactions used to metabolize carbohydrates, fats, and proteins.

Electron transport chain: A series of electron-passing reactions that provides energy for ATP formation.

Acetyl CoA: A chemical compound that is an important entry point into the Krebs cycle.

Oxaloacetate: Chemical compound that is one of the intermediate compounds in the Krebs cycle.

form a six-carbon compound, **citric acid** (see Figure 3.17 for greater detail of the Krebs cycle). For this reason, the Krebs cycle is often referred to as the citric acid cycle. The rate-limiting enzyme for this series of reactions is **isocitrate dehydrogenase (IDH).** During the course of the series of reactions, two carbons are lost due to the formation of two carbon dioxide molecules. The reactions eventually return to the four-carbon oxaloacetate, which is then available to combine with another acetyl CoA—a repeating cycle of chemical reactions.

Beginning with pyruvate, six **oxidation-reduction** reactions take place for each turn of the Krebs cycle. An aspect of chemical reactions that was not previously discussed even though it occurs in glycolysis is oxidation-reduction reactions. Some chemical compounds need to have electrons removed in order to be transformed chemically to another compound. The process of giving up electrons is called **oxidation,** and the compound that has electrons removed has been **oxidized.** The process of accepting electrons is called **reduction,** and the compounds that receive the electrons have been **reduced.** When electrons are removed they can be destructive if allowed to remain free within the cell. Therefore, oxidation-reduction reactions are coupled. That is, when one compound needs to give up electrons and is oxidized, another compound simultaneously accepts electrons and is reduced. The two most common electron-accepting compounds are **nicotinamide adenine dinucleotide (NAD)** (see Figure 3.18) and **flavin adenine dinucleotide (FAD).** Although most electrons are coupled in oxidation-reduction reactions, some can remain free within a cell and they may form damaging chemicals called **free radicals** (see Spotlight on Enrichment: Free Radicals).

Citrate/citric acid: Chemical compound that is one of the intermediate compounds in the Krebs cycle; the first compound formed in the Krebs cycle by the combination of oxaloacetate and acetyl CoA.

Isocitrate dehydrogenase (IDH): The rate-limiting enzyme for the series of chemical reactions in the Krebs cycle.

Oxidation-reduction: The giving up of (oxidation) and acceptance of (reduction) electrons in chemical reactions; these reactions typically occur in pairs.

Oxidize/oxidation: Chemical process of giving up electrons.

Reduce/reduction: Chemical process of accepting electrons.

Nicotinamide adenine dinucleotide (NAD): Molecule involved in energy metabolism that contains a derivative of the vitamin niacin.

Flavin adenine dinucleotide (FAD): A molecule involved in energy metabolism that contains a derivative of the vitamin riboflavin (vitamin B_2).

Free radical: A highly reactive molecule with an unpaired electron. Also known as reactive oxygen species (ROS).

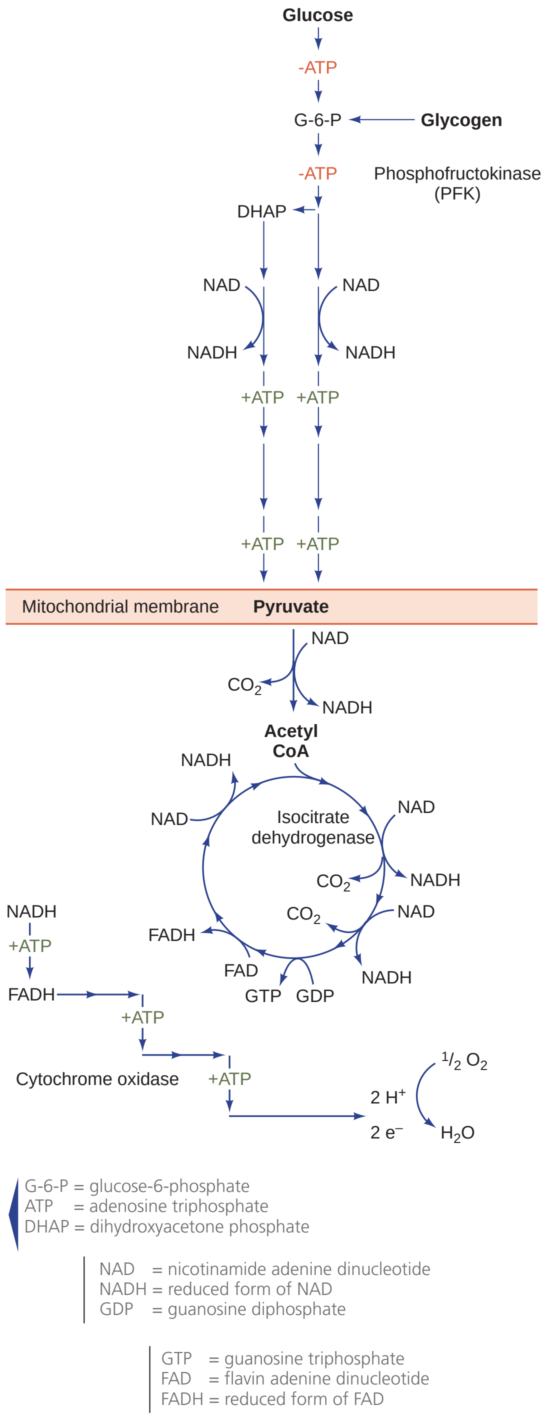


Figure 3.16 Schematic of glycolysis, Krebs cycle, and electron transport chain of oxidative phosphorylation.

Glucose follows the steps of glycolysis, except that rather than being converted to lactate, pyruvate is transported into a mitochondrion for aerobic metabolism. Pyruvate goes through the Krebs cycle, a series of chemical reactions that oxidize, or remove, the electrons from the intermediate compounds in the process. The electrons are transported to the electron transport chain where they participate in a series of reactions that release sufficient energy to rephosphorylate ADP to ATP. Oxygen is the final electron acceptor and forms water.

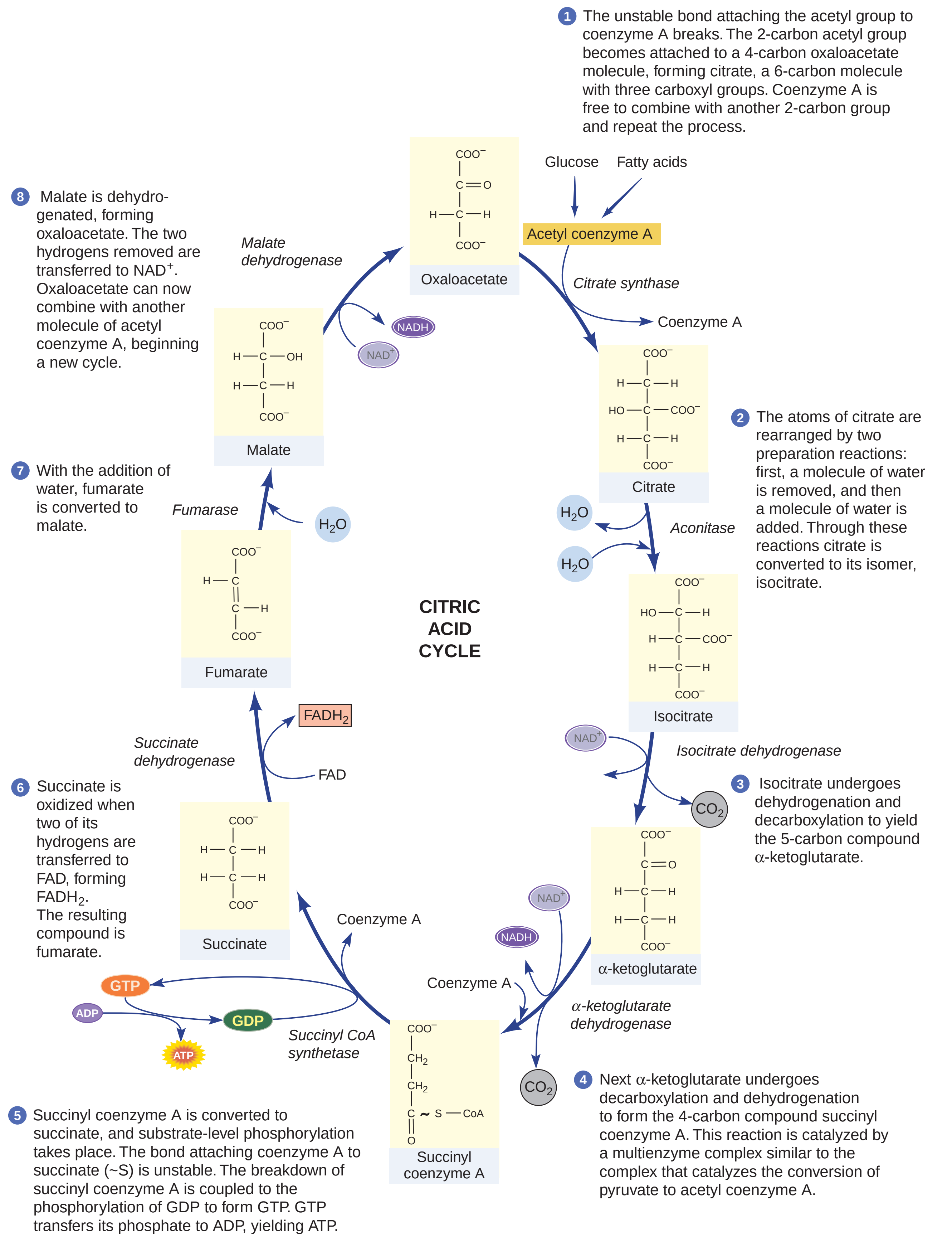
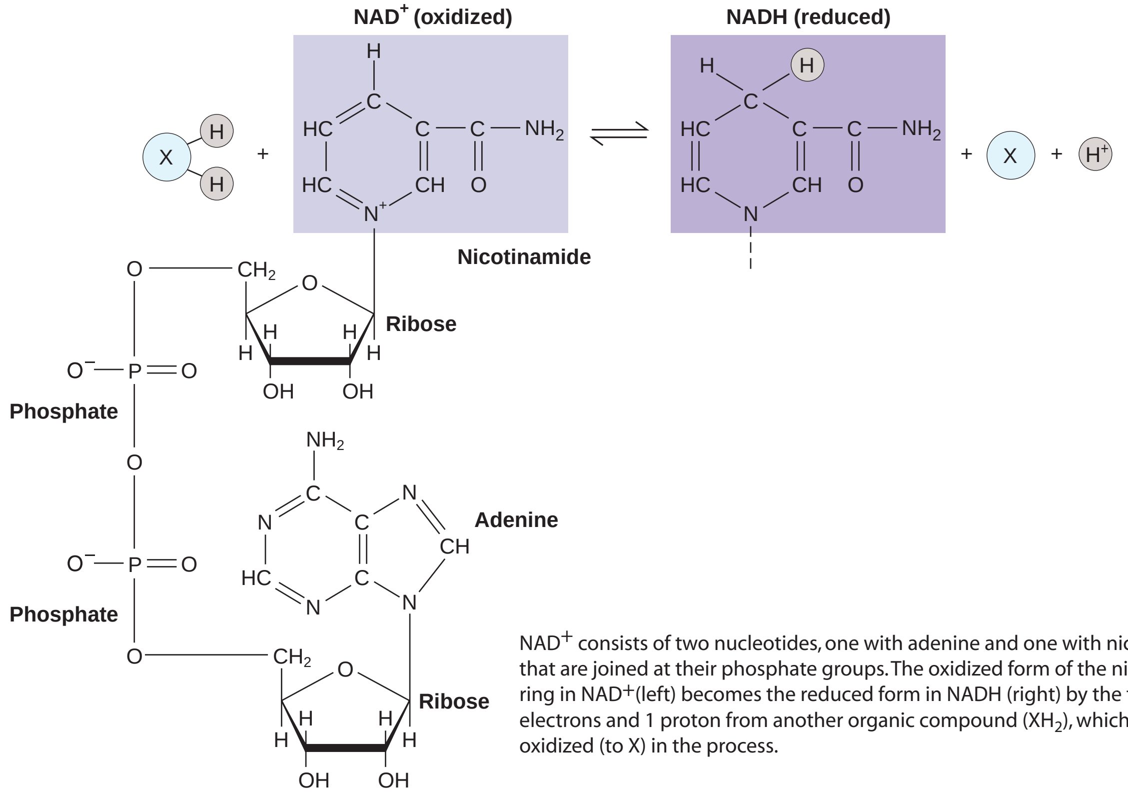


Figure 3.17 A Detailed View of the Krebs Cycle



NAD^+ consists of two nucleotides, one with adenine and one with nicotinamide, that are joined at their phosphate groups. The oxidized form of the nicotinamide ring in NAD^+ (left) becomes the reduced form in NADH (right) by the transfer of 2 electrons and 1 proton from another organic compound (XH_2), which becomes oxidized (to X) in the process.

Figure 3.18 NAD and the Transfer of Electrons

One of the Krebs cycle reactions is exergonic and releases enough energy to produce a high-energy phosphate compound, **guanosine triphosphate (GTP),** which is then used to form an ATP. In four of the oxidation-reduction reactions NAD is the electron acceptor, and in one FAD is the electron acceptor. The vitamins niacin (i.e., nicotinic acid and nicotinamide) and riboflavin are major components of NAD and FAD, respectively. NAD and FAD shuttle the electrons to the final major component of oxidative phosphorylation, the electron transport chain.

ELECTRON TRANSPORT CHAIN

The electron transport chain is yet another series of chemical reactions that take place within the inner membrane of the mitochondria (Figure 3.19). Electrons are passed along a series of complexes containing

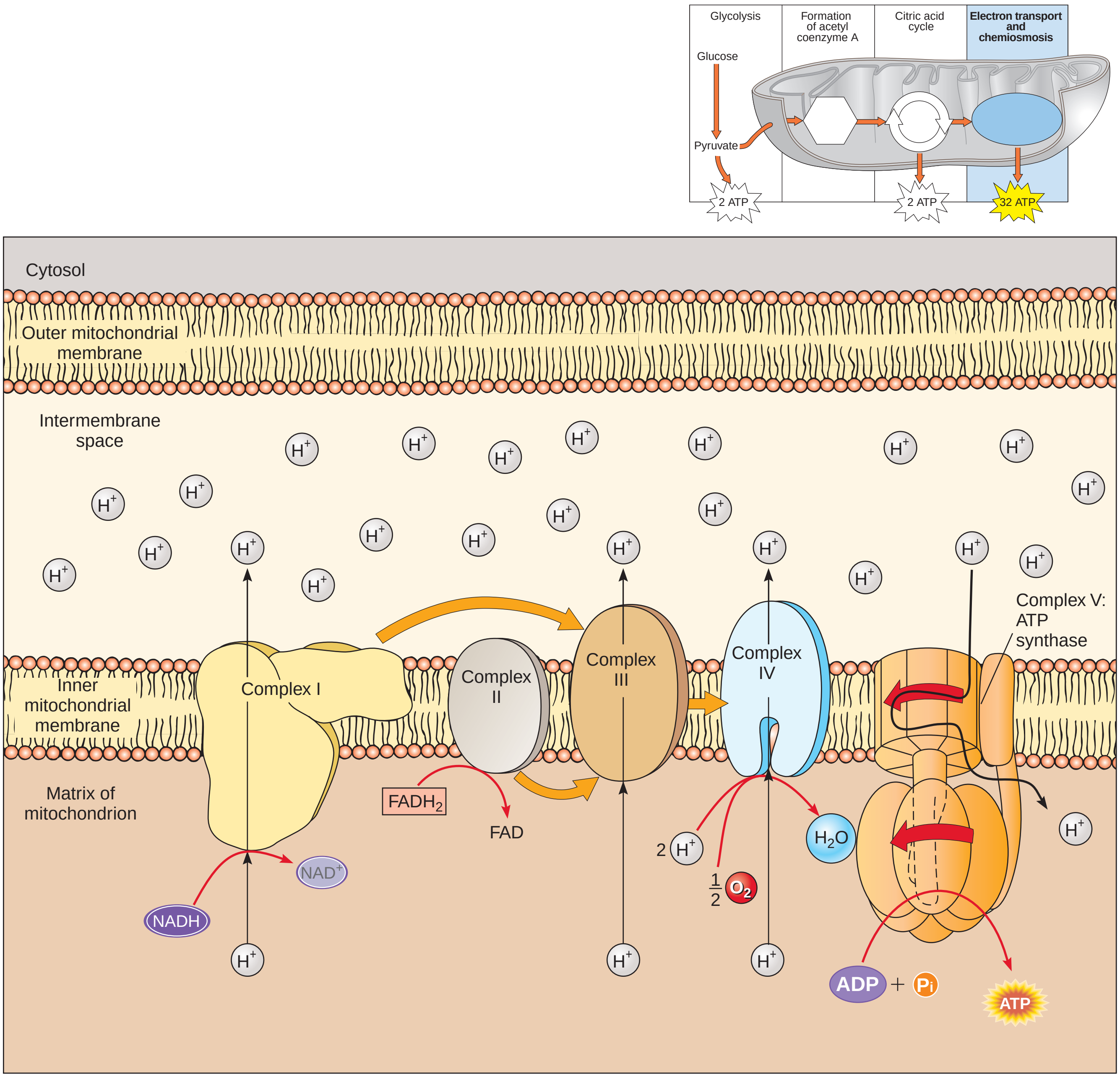
SPOTLIGHT ON ENRICHMENT

Free Radicals

Electrons are traded between molecules in the course of oxidation-reduction reactions, particularly in the Krebs cycle and the electron transport chain. In some instances, individual electrons may "leak" out of the process, leaving a molecule with an unpaired electron. These molecules (or fragments of molecules) with unpaired electrons are called free radicals or reactive oxygen species. The formation of a small amount of free radicals is normal wherever oxidative phosphorylation or aerobic metabolism takes place.

The concern about free radical formation is related to the damage that an excessive amount of these molecules can do, referred to as oxidative stress. These reactive oxygen species can damage cells in the body by inactivating enzymes; breaking DNA strands; binding NAD, thus preventing it from assisting in other oxidation-reduction reactions; and damaging the **fatty acids** in the cell membranes. Excessive oxidative stress has been associated with aging and the development of cancer, atherosclerosis, and other chronic diseases.

Fortunately, the body has defense mechanisms against free radicals, including enzymes for removal and chemicals that can react with the free radicals (antioxidants) to produce a more stable molecule. Free radicals and antioxidants will be discussed in more detail in Chapter 8.



The electron transport chain in the inner mitochondrial membrane includes three proton pumps that are located in three of the four electron transport complexes. (The orange arrows indicate the pathway of electrons; and the black arrows, the pathway of protons.) The energy released during electron transport is used to transport protons (H^+) from the mitochondrial matrix to the intermembrane space, where a high concentration of protons accumulates. The protons cannot diffuse back into the matrix except through special channels in ATP synthase in the inner membrane. The flow of the protons through ATP synthase provides the energy for generating ATP from ADP and inorganic phosphate (P_i). In the process, the inner part of ATP synthase rotates (thick red arrows) like a motor.

Figure 3.19 A Detailed View of the Electron Transport Chain

compounds that shuttle the electrons down the chain. Oxygen is the final electron acceptor, picking up electrons in the form of hydrogen to form water. The rate-limiting enzyme for the electron transport chain is **cytochrome oxidase (CO).** When the electrons are deposited into the electron transport chain, the resulting series of reactions release enough energy to power the ATP resynthesis reaction. When NAD is the electron

Guanosine triphosphate (GTP): A high-energy phosphate compound produced in the Krebs cycle used to replenish ATP.

Fatty acid: Chains of carbons and hydrogens ending with a carbon with a double bond to oxygen and a single bond to an oxygen/hydrogen (carboxyl group).

Cytochrome Oxidase (CO): The rate-limiting enzyme of the Krebs cycle.

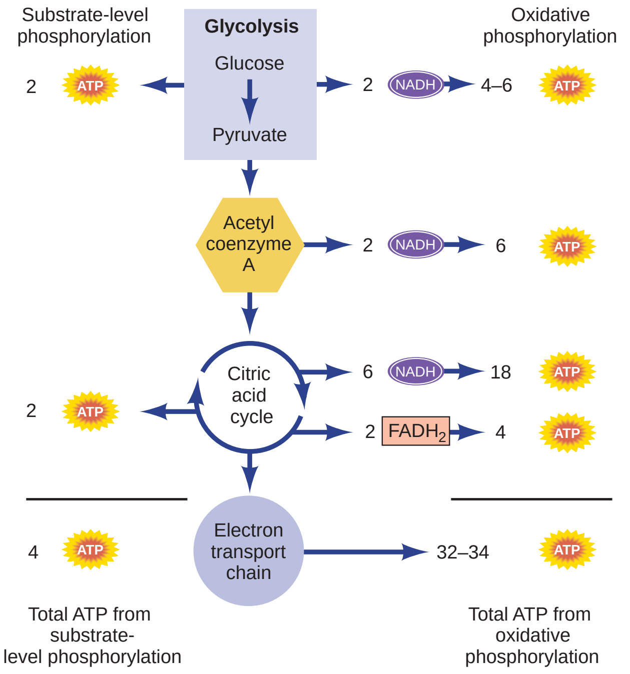


Figure 3.20 Tally of ATP production from the complete oxidation of glucose.

carrier, enough energy is released to reform three ATP, and when FAD is the electron carrier, the resulting ATP formation is two. Some scientists suggest that these figures may slightly overestimate the ATP produced and that the estimates may be closer to 2.5 and 1.5 ATP for NAD and FAD, respectively, although further studies are needed to confirm this view. In skeletal muscle, these electrons are transferred into the mitochondria via FAD; other tissues use NAD to shuttle these electrons into the mitochondria, which affects the final tally of ATP. The electrons picked up by NAD in the glycolysis phase can be shuttled into the mitochondria as FADH and entered into the reactions of the electron transport chain.

It is a relatively simple matter to account for the ATP produced from the aerobic metabolism of glucose (see Figure 3.20). In the glycolysis phase, two ATP are used and four are produced, giving a net production of two ATP. In addition, two NADH are formed in glycolysis. In the Krebs cycle, one ATP is produced via GTP and with two turns of the Krebs cycle for each glucose molecule, two ATP are the result. With the two turns of the Krebs cycle, eight NADH and two FADH are formed. In the electron transport chain, 24 ATP are formed from the eight NADH and four ATP are formed from the FADH. The two NADH from glycolysis are shuttled into skeletal muscle mitochondria as FADH, resulting in four additional ATP. Therefore, the net ATP for aerobic metabolism of glucose in skeletal muscle is 36 ATP. In other tissues the net ATP may be 38. If the starting point is glycogen rather than glucose, one ATP is saved, bringing the total ATP produced to 37 or 39, depending upon the type of tissue.

In comparison to the two other energy systems, oxidative phosphorylation has significant advantages in that it can produce many more ATP and has a virtually limitless duration. However, the series of reactions are very slow compared to creatine phosphate or anaerobic glycolysis, and are dependent upon the provision of oxygen. Due to these limitations, oxidative phosphorylation is the predominant energy system used at rest and to support low- to moderate-intensity exercise. Examples of activities where oxidative phosphorylation is the predominant energy system include “aerobic” activities, such as:

- Walking
- Jogging and distance running
- Cycling (longer distances, not sprint cycling)
- Swimming (longer distances, not sprints)
- Dance aerobics

Returning to the light controller analogy, the oxidative phosphorylation bulb burns brightly for many activities since they last longer than two minutes and the intensity of the exercise is lower when compared to anaerobic activities. However, the other systems are dimmed, not off. For example, when a distance runner sprints to the finish line the anaerobic energy systems are used.

To summarize the characteristics of the oxidative phosphorylation energy system:

- 124 Chemical steps/reactions
- 30 Compounds, 27 enzymes
- Rate-limiting enzymes: PFK, IDH, CO
- Slow
- 36 ATP via glucose, 37 ATP via glycogen (in skeletal muscle)
- Potentially limitless duration
- Aerobic
- Fatigue associated with fuel depletion (e.g., muscle glycogen)
- Predominant energy system in endurance exercise, e.g., long-distance running

The examination of the aerobic metabolism, or oxidation, of glucose is a good introduction to oxidative phosphorylation, and gives a consistent basis of comparison to anaerobic glycolysis, as they have the same starting point. What about the metabolism of other nutrients? In addition to carbohydrates, proteins and fats can be metabolized for energy. Figure 3.21 illustrates the overall scheme of the metabolism of carbohydrates, fats, and proteins (the example shows

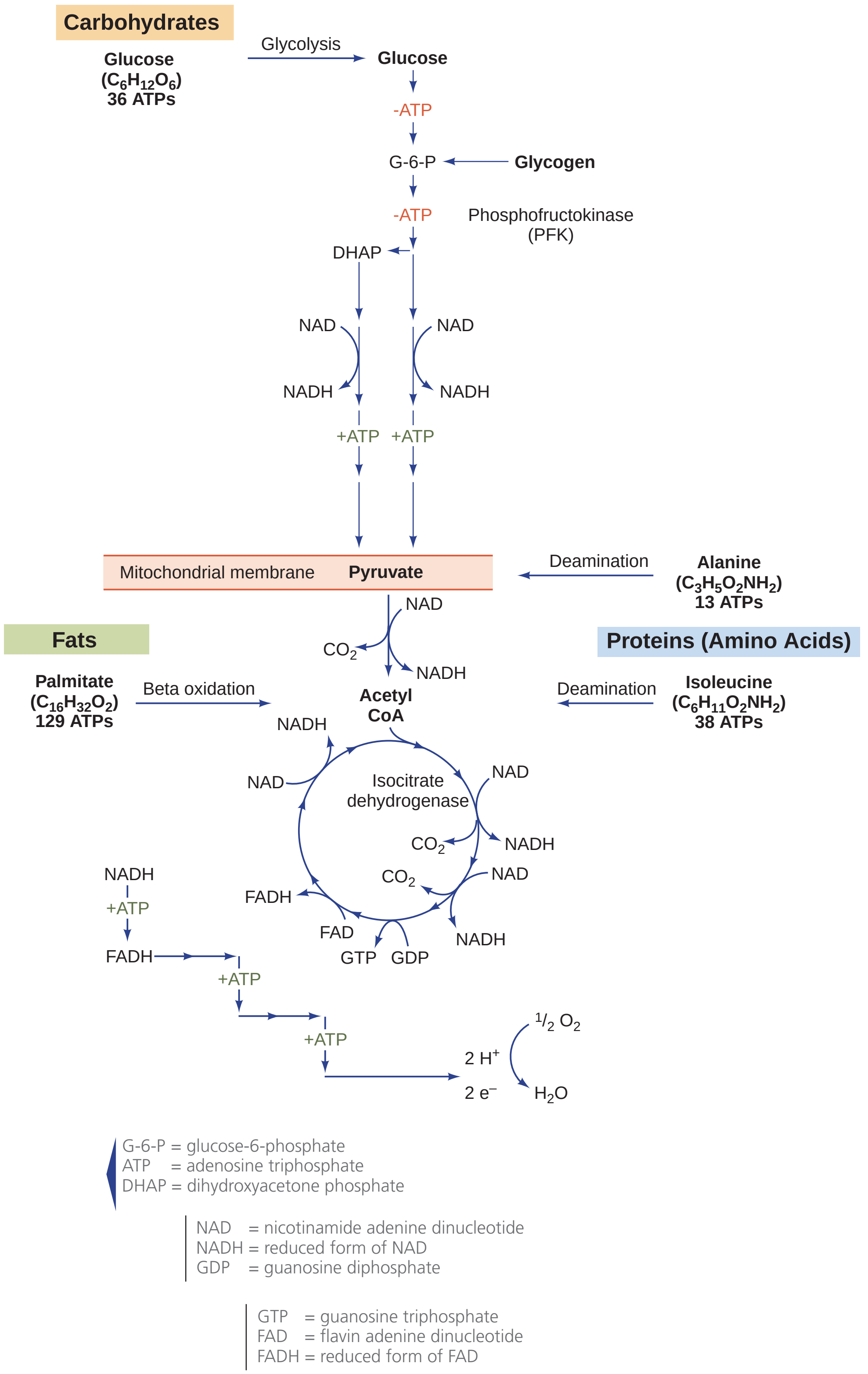


Figure 3.21 Oxidation of carbohydrates, proteins, and fats.

Carbohydrates are metabolized as glucose via glycolysis to pyruvate, and produce 36 ATP through oxidative phosphorylation in skeletal muscle. Fats are metabolized in a variety of ways; the fatty acid palmitate is shown. The process of beta oxidation converts two-carbon portions of palmitate to acetyl CoA where it enters oxidative phosphorylation, eventually producing 129 ATP. Metabolism of alanine and isoleucine are two examples of protein metabolism. After removing the nitrogen group, alanine can enter the metabolic pathway as pyruvate, producing 13 ATP while isoleucine enters as acetyl CoA, resulting in the production of 38 ATP.

two amino acids) through oxidative phosphorylation. Remember that the first step in the process is the preparation of the compounds for aerobic metabolism. Once acetyl CoA is formed, the steps of the Krebs cycle and the electron transport chain are the same regardless whether the original source was carbohydrates, proteins, or fats. Carbohydrates, proteins, and fats will be discussed in greater detail in Chapters 4, 5, and 6, respectively.

FAT OXIDATION

Metabolism of fat is complex and varied. The principal fats metabolized for energy in the body are fatty acids containing chains of either 16 or 18 carbons (e.g., **palmitate** and stearate, respectively). These fatty acid chains are stored as **triglycerides** in fat cells **(adipocytes)** and in other tissues such as muscle. A triglyceride is composed of a **glycerol** molecule with three fatty acid chains attached. The process of forming triglycerides is called **esterification.** When fat is needed for energy, triglycerides are broken down and the fatty acid chains are transported to mitochondria for aerobic metabolism. **Lipolysis** is the term used for the breakdown of triglycerides.

When fats are to be metabolized, they must first be "mobilized" from the adipocytes. Lipolysis occurs, breaking the triglycerides down into the glycerol and the three fatty acids. The fatty acids are then released from the adipocytes into the blood for transportation throughout the body. At this point, they are usually referred to as free fatty acids (FFA). This term is a bit of a misnomer, as fatty acids must be bound to a protein in order to be carried in the blood. Albumin is the most common plasma protein that binds FFA in the circulation.

As FFA are distributed throughout the body, they are taken up by various tissues such as muscle. After an activation step that requires the use of ATP, the fatty acids are transported into the mitochondria for aerobic metabolism. Before entering the Krebs cycle, however, the fatty acids must pass through another series of reactions called β (beta) oxidation.

Beta oxidation is a process comprising four chemical steps that occur in the mitochondrial matrix. The overall function of β oxidation is to remove two-carbon segments from the fatty-acid chains and convert them to acetyl CoA. Once the acetyl CoA molecules have been formed, they can enter the Krebs cycle and be oxidized. The process of β oxidation also results in FAD and NAD picking up electrons, which can be used in the electron transport chain. Eight two-carbon segments can be cleaved from a 16-carbon fatty acid such as palmitate, one of which is acetyl CoA, seven of which go through the series of chemical steps to form acetyl CoA. Compared to the 36 ATP produced from the aerobic metabolism of glucose, complete metabolism of the fatty acid palmitate results in the production of 129 ATP. Details of fat oxidation can be found in Chapter 6.

The clear advantage of fat metabolism is the large ATP yield. In addition, even a person with a relatively low percentage of body fat has a large number of kilocalories stored as fatty acids in adipocytes, which are accessible for metabolism. The disadvantages of fat metabolism include the increased number of steps required and the amount of oxygen needed for aerobic metabolism. This increased oxygen requirement will be discussed in an upcoming section.

PROTEIN OXIDATION

Protein is not "stored" as an energy source in the same sense as are carbohydrates (as glycogen) and fats (as adipose tissue). Proteins are typically incorporated into functional (e.g., enzymes) or structural (e.g., skeletal muscle) elements in the body. Many proteins can, however, be broken down into their amino acid building blocks under certain metabolic conditions. Amino acids can be metabolized aerobically once the amino- or nitrogen-containing group has been removed. Nitrogen groups are typically removed by either being transferred to another compound **(transamination)** or being removed completely **(deamination).** The nitrogen is eliminated from the body as urea in the urine.

Figure 3.21 illustrates the path of oxidation of two amino acids, **alanine** and **isoleucine.** Protein metabolism is complex because there are 20 amino acids and a variety of points of entry into the oxidative process. Alanine and isoleucine are amino acids that are readily oxidized, and are given as examples because each has a slightly different way of being metabolized. Alanine is a three-carbon amino acid, which when deaminated can be converted to a single pyruvate. The pyruvate can then be oxidized via the Krebs cycle as previously described. Isoleucine, one of the branched chain amino acids, contains six carbons. Two carbon fragments can be converted to acetyl CoA at a time, which can then be oxidized in the Krebs cycle. Three acetyl CoA can be formed from each isoleucine, giving three turns of the Krebs cycle, resulting in a higher ATP yield than for alanine. The branched chain amino acids, leucine, isoleucine, and valine, can be relatively easily metabolized by skeletal muscle.

Of the three energy-containing nutrients, protein is the least preferred as a fuel source. While amino acids can certainly be metabolized, they are not stored for ready access as are carbohydrates and fats. Along with the additional steps required to remove and dispose of the nitrogen groups, these limitations prevent protein from making up a large portion of the fuel sources for metabolism, particularly during exercise. Under metabolically stressful conditions, such as starvation or exercise in a glycogen-depleted state (e.g., latter stages

The Internet Café

Where do I find reliable information about energy systems?

It may come as a surprise that when the term *oxidative phosphorylation* is entered into one of the popular Internet search engines that nearly half a million matches are found. Many of the websites containing information about oxidative phosphorylation are university based (look for websites that end in .edu); professors have posted information, and in some cases, animations, to help students understand this complicated aspect of metabolism. The chemical reactions involved in oxidative phosphorylation are well defined, so the scientific information is the same, but it sometimes helps students in their understanding of complicated processes to read different explanations. Similarly, there are university-affiliated sites with information about anaerobic glycolysis, although in much smaller numbers.

In contrast, a search term such as *creatine phosphate energy system* yields many commercial sites (.com). The majority of these sites are selling creatine phosphate supplements, and finding .edu sites that are devoted to explaining the metabolic processes involved in the creatine phosphate energy system is harder.

of a marathon), protein may compose a larger percentage of the fuel utilization, but rarely exceeds approximately 10 percent of total energy production.

The preceding sections described how carbohydrates, fats, and proteins can be metabolized aerobically. All can be broken down chemically to form compounds that can be oxidized by the Krebs cycle, and the removed electrons are subsequently used in the electron transport chain to rephosphorylate ADP to form ATP. As part of this metabolic process, carbon dioxide is produced and oxygen is used as the final electron acceptor.

What's the point? Oxidative phosphorylation produces ATP relatively slowly but in large amounts by metabolizing carbohydrates, fats, and proteins in cell mitochondria. The process utilizes oxygen and involves preparing the compounds for oxidation via the Krebs cycle and the electron transport chain. Aerobic metabolism is the predominant energy system at rest and for low- to moderate-intensity activities.

OXYGEN CONSUMPTION

The body needs a constant supply of ATP, and at rest the vast majority of this energy is provided by oxidative phosphorylation, the aerobic energy system. Any increase in activity requires an increase in energy expenditure, which in turn results in an increase in the activity of oxidative phosphorylation. An increased utilization of the aerobic energy system results in an increase in the amount of oxygen consumed and the amount of carbon dioxide produced. As discussed in Chapter 2, indirect calorimetry can be used to measure energy expenditure by determining oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) with a metabolic measurement system.

It is common in exercise physiology to study the metabolic response to physical activity and exercise, particularly with incremental exercise tests. In this type of test, exercise intensity is increased every few minutes in stages or increments. A wide variety of physiological responses can be measured in response to the gradually increasing exercise stress. As exercise intensity increases, oxygen consumption increases in a linear fashion until maximum oxygen consumption is reached. That is, with each increment in exercise intensity, oxygen consumption increases by a similar amount (Figure 3.22).

Submaximal Exercise. If exercise intensity is increased to a level that is below the person's maximal ability (submaximal) and continued for some time, oxygen consumption rises to a level that provides sufficient energy to support that level of activity, and then plateaus (Figure 3.23). Think of an exercise session lasting 30 minutes, such as a person jogging. At the onset of exercise, oxygen consumption increases and if the exerciser maintains a steady pace, oxygen consumption will reach a "steady state." Once the person stops the exercise task, the need for increased energy is removed, and oxygen consumption will gradually return to pre-exercise levels.

Note in Figure 3.23 that if exercise begins after five minutes of resting, it takes a couple of minutes for oxygen consumption to reach the steady-state level. If one considers the large number of steps that are required

Palmitate: One of the most widely distributed fatty acids found in food and in stored body fat.

Triglyceride: Major storage form of fat in the body; consists of a glycerol molecule and three fatty-acid chains.

Adipocyte: A fat cell.

Glycerol: A structural component of triglycerides, the major storage form of fat in the body.

Esterification: Formation of triglycerides.

Lipolysis: Breakdown of fat.

Beta oxidation: Chemical process of breaking down fatty-acid chains for aerobic metabolism.

Transamination: Removal and transfer of a nitrogen group to another compound.

Deamination: Process of removing and eliminating a nitrogen group.

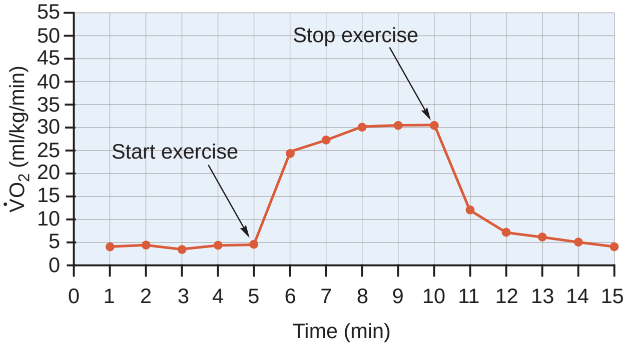
Alanine: An amino acid.

Isoleucine: A branched chain amino acid.

$\dot{V}O_2$ = oxygen consumption
ml/kg/min = milliliters oxygen per kilogram body weight per minute
Max = maximum

Figure 3.22 The Concept of Maximal Oxygen Consumption ($\dot{V}O_{2max}$)

Maximal oxygen consumption is measured with a maximal effort exercise test in which exercise intensity is increased at each stage. As exercise intensity increases, oxygen consumption increases in a linear fashion. Eventually, oxygen consumption does not increase further, although exercise intensity has continued to increase. This plateau in oxygen consumption is called $\dot{V}O_{2max}$.



$\dot{V}O_2$ = oxygen consumption
ml/kg/min = milliliters of oxygen per kilogram of body weight per minute
min = minute

Figure 3.23 Response of oxygen consumption to steady-state exercise.

After five minutes of resting, exercise begins and oxygen consumption increases and eventually plateaus at the level that is necessary to supply sufficient energy for the given intensity of exercise. Notice that it takes several minutes for oxygen consumption to rise to the required steady-state level; this is the oxygen deficit. Exercise ends at minute 10 and oxygen consumption declines, but it takes several minutes to return to the pre-exercise resting levels; this is the excess post-exercise oxygen consumption (EPOC).

in oxidative phosphorylation and the need to transport oxygen to the exercising muscle, it is understandable that some degree of "lag time" exists between the onset of exercise and the ability of the aerobic energy system to fully meet this elevated energy requirement. Where does the energy come from to support the exercise activity during this lag time? Fortunately, the anaerobic energy systems, creatine phosphate and anaerobic glycolysis, exist to provide ATP in these types of circumstances. This is yet another example of the interactions between the various energy systems. Because ATP energy has been "borrowed" from the anaerobic energy systems for what is primarily an aerobic exercise activity, the term **oxygen deficit** is typically used to describe this lag in oxygen consumption at the onset of exercise.

Also, note in Figure 3.23 that exercise is stopped at minute 10 and oxygen consumption begins to decline immediately, but does not reach its original pre-exercise level for several minutes. Even though exercise has ceased and the person is now resting, oxygen consumption remains slightly elevated for some period of time after exercise. This gradual decline in oxygen consumption after exercise has historically been referred to as the **oxygen debt,** but has been more recently and accurately termed the **excess post-exercise oxygen consumption (EPOC)** (Gaesser and Brooks, 1984). It is easy to understand what the majority of this extra oxygen consumption is for by recalling the aerobic recovery portions of the anaerobic energy systems.

When creatine phosphate is used to replenish ATP, creatine remains and must be eventually restored to creatine phosphate by the creatine shuttle. The creatine shuttle uses the energy from ATP that is produced aerobically in the mitochondria to rephosphorylate creatine into creatine phosphate. Therefore, any creatine phosphate used during the aerobic lag time in the exercise example would require some additional oxygen consumption after exercise to restore creatine to pre-exercise creatine phosphate levels. Similarly, lactate that may be produced by use of anaerobic glycolysis during the aerobic lag time also depends upon subsequent oxygen consumption. Lactate molecules are eventually taken up by highly aerobic tissues, converted to pyruvate, and metabolized aerobically in mitochondria. There are a number of additional factors that are responsible for the elevated oxygen consumption after exercise, but the majority of this excess oxygen consumption is devoted to "paying back" the energy borrowed from creatine phosphate and anaerobic glycolysis at the onset of the exercise task.

MAXIMAL OXYGEN CONSUMPTION ($\dot{V}O_{2max}$)

If an incremental exercise test continues to increase in intensity, oxygen consumption will continue to increase as well, up to a point. When this point is reached, if exercise intensity is increased again, oxygen consumption does not rise any further, rather, it plateaus (Figure 3.22). Each individual has an inherent maximal ability to consume oxygen, a characteristic known as **maximal oxygen consumption.** The exercise physiology term is $\dot{V}O_{2max}$.

A person's maximal ability to consume oxygen is a reflection of one's capacity to take up oxygen from the atmosphere, circulate it throughout the body, and use oxidative phosphorylation in muscles and other tissues to produce ATP. This ability is influenced by genetics, age, gender, and a host of other factors, the most influential of which is aerobic exercise training. Maximal oxygen consumption is not a static figure—it can be increased markedly if a person engages in regular aerobic exercise or can diminish over time if a person is sedentary.

As discussed in Chapter 2, there are two common ways to express oxygen consumption, in absolute or relative terms. Absolute oxygen consumption (in liters per minute or L/min) refers to the total amount of oxygen consumed every 60 seconds. In addition to aerobic training, maximal oxygen consumption is largely influenced by body size—larger people consume more oxygen. In order to draw accurate comparisons between people of different body sizes, $\dot{V}O_{2max}$ is often expressed in terms relative to body weight (milliliters per kilogram body weight per minute or ml/kg/min). Sports nutrition professionals should be familiar with approximate values

Oxygen deficit: The lag in oxygen consumption at the beginning of an exercise bout.

Oxygen debt: The elevated oxygen consumption that occurs for a short time during the recovery period after an exercise bout has ended; also known as EPOC.

Excess post-exercise oxygen consumption (EPOC): See oxygen debt.

Maximal oxygen consumption ($\dot{V}O_{2max}$): Highest amount of oxygen that can be utilized by the body; the maximal capacity of the aerobic energy system.

SPOTLIGHT ON ENRICHMENT

Alcohol Metabolism

Too often alcohol is left out of discussions of energy metabolism. Certainly carbohydrates and fats deserve the most attention because they are the primarily sources of energy at rest and during activity. However, when alcohol is consumed, one must account for its metabolism.

The chemical term for alcohol found in alcoholic beverages is *ethanol*. Ethanol is absorbed rapidly beginning in the stomach. If the stomach does not contain food, the absorption is especially rapid because the ethanol molecules will diffuse into the blood as soon as they touch the stomach cells. The presence of food in the stomach slows the absorption of alcohol because there is less surface area available for contact. Food also results in the contents of the stomach being emptied more slowly into the intestine. Once in the intestine alcohol is quickly absorbed. While food slows the relative rate of absorption, it is important to remember that when alcohol is consumed under any conditions, ethanol absorption is rapid.

Ethanol is transported to the liver where it is metabolized. There are two primary pathways. When ethanol is consumed at low to moderate levels (defined below) the primary pathway is the alcohol dehydrogenase (ADH) pathway. In this pathway, ethanol enters the liver cells and the enzyme ADH breaks down ethanol into acetaldehyde by removing hydrogen and transferring it to a niacin-containing molecule, NAD, to form NADH. Acetaldehyde is highly toxic to cells and must be converted to acetate, which is then converted to acetyl CoA. These reactions take place in the cytoplasm of the cell. For low to moderate alcohol consumption, this pathway can metabolize all the ethanol consumed.

When alcohol (i.e., ethanol) consumption is high, the ADH pathway is overwhelmed because the rate at which ADH breaks down ethanol does not increase as ethanol consumption increases. Thus, a second pathway is used to metabolize ethanol when alcohol consumption is high. This pathway is known as the microsomal ethanol-oxidizing system (MEOS) and takes place in the microsome. The microsome is a small structure found in the cellular fluid. Ethanol is converted to acetaldehyde, but the enzymes (e.g., cytochrome P450) and the by-products (e.g., NADP, reactive oxygen species) are different. Of significance, the reactive oxygen species, which are also known as free radicals, damage the liver cells (Lieber, 2003; Murray et al., 2003).

When alcohol is present, the breakdown of ethanol is the body's highest priority because an intermediary compound, acetaldehyde, is toxic. Alcohol contains energy (i.e., 7 kcal/g) because it is converted to acetyl CoA and oxidized via the Krebs cycle. Ethanol must be used immediately for energy; it cannot be stored as glycogen or in adipose tissue. Sometimes people say that alcohol "makes you fat" but an increase in stored fat due to alcohol intake is indirect. When alcohol intake is part of excess energy intake, the energy contained in the fat consumed via food is diverted to storage (i.e., adipocytes) rather than being used as energy immediately. Athletes often remove alcohol from their diets when they are trying to restrict caloric intake as part of an effort to lose weight.

As stated above, the pathway(s) used to metabolize ethanol depend on the amount consumed. Moderate alcohol intake is defined as the consumption of up to one drink per day for women and up to two drinks per day for men. A drink is defined as ½ ounce (oz) of ethanol. In practical terms, each of the following is considered a drink: 3 to 4 oz wine; 10 oz wine cooler; 12 oz beer; 1.5 oz hard liquor (e.g., rum, whiskey).

Table 3.2 Relative Values for $\dot{V}O_{2max}$ Expressed in Relative Terms as Milliliters of Oxygen per Kilogram Body Weight per Minute (ml/kg/min)

	Male	Female
Health/Fitness[a]	35	32.5
"Average"[b]	40–45	35–40
"Superior"[c]	54+	47+
"Well-trained"[d]	60+	50+
"Highest" Elite[e]	90+	80+

[a] minimum value associated with decreased risk of premature death from chronic disease
[b,c] 50th and 90th percentile rank from population norms (Appendix H, Whaley, M., ed. [2006]. *ACSM's Guidelines for Exercise Testing and Prescription,* 7th edition. Lippincott Williams & Wilkins, Baltimore, Maryland.)
[d,e] observed values of individual athletes.

for maximal oxygen consumption such as those shown in Table 3.2. Another approach to understanding $\dot{V}O_{2max}$ is to look at normative values and percentile ranks obtained by testing large numbers of people. One such set of normative values were developed from the Aerobic Center Longitudinal Study at the Cooper Institute and are used in the *ACSM's Guidelines for Exercise Testing and Prescription* (Appendix H). These "norms" are listed by percentile rank for males and females and by age ranges by decade. For example, the 50th percentile $\dot{V}O_{2max}$ for a male between 20 and 29 years old is 44.2 ml/kg/min and 37.8 ml/kg/min for a female in the same age range.

The descriptions and ranges for $\dot{V}O_2$ in Table 3.2 are general categories, some of which do not have precise definitions. For both males and females, the average resting oxygen consumption is estimated to be approximately 3.5 ml/kg/min (similar to resting heart rate is 72 beats per minute and resting blood pressure is 120/80 mm Hg), but there are large individual variations. The Health/Fitness category represents a *minimum* level of aerobic fitness that has been associated with improved health and a decrease in risk of premature death from chronic disease (Blair et al., 1989). The results of this and other studies imply that for good health, all people should have a $\dot{V}O_{2max}$ that at the very minimum meets this level (and preferably exceeds it). Average $\dot{V}O_{2max}$ for young adults (less than 40 years of age) is approximately 40–45 ml/kg/min for males and 35–40 ml/kg/min for females. These figures were derived from the 50th percentile rank from normative values in *ACSM's Guidelines for Exercise Testing and Prescription* (7th Edition, 2006), as were the values for the 90th percentile and above, designated as "Superior." Designations of "well-trained" and "elite" are often associated with endurance athletes or those with high levels of aerobic training and fitness. While no universally accepted definition exists, it is reasonable to suggest that males with a $\dot{V}O_{2max}$ in excess of 60 ml/kg/min and females exceeding 50 ml/kg/min can be considered well trained from an aerobic or endurance perspective. The highest measured values for $\dot{V}O_{2max}$ in humans, those athletes that combine the genetic predisposition with many years of intense training, can be slightly in excess of 90 ml/kg/min for males and just over 80 ml/kg/min for females.

FUEL UTILIZATION AND RESPIRATORY EXCHANGE RATIO (RER)

Carbohydrates, proteins, and fats can be used as fuel sources, both at rest and during exercise. Which fuel source is used and under what circumstances? How is the source of the fuel used for aerobic metabolism determined?

Although three fuel sources are available, protein is used only to a small degree under normal circumstances. The preferred fuel sources are carbohydrates and fats; which fuel source predominates is largely dependent upon activity level and exercise intensity, and can be modified by diet, activity duration, fitness level or exercise training status, and other factors.

At rest, the preferred fuel source is fat. As described earlier, even a person with a relatively low percentage of body fat has ample fat stores, and fat oxidation has a very high ATP yield. Because the rate of energy expenditure at rest is low and there is no need to replace ATP quickly, there is sufficient time for lipolysis, fat mobilization, and beta oxidation. Even though fat oxidation requires additional oxygen consumption, there is sufficient time at rest for the pulmonary and cardiovascular systems to supply all of the oxygen that is needed. The body does not rely a hundred percent on fat oxidation at rest, however. Some tissues, such as brain cells, rely on carbohydrates (glucose) as their primary source of fuel. In addition, excessive reliance on fat metabolism results in the production of keto acids. When produced in excess, keto acids can disturb the acid-base balance in the body. An example of this can be seen in those who have difficulty metabolizing carbohydrates. People with diabetes can be susceptible to diabetic ketoacidosis if their diabetes is not managed well and they rely too extensively on fat metabolism. Under normal circumstances, at rest fat is generally the predominant fuel source, making up approximately 85 percent of energy expenditure, while carbohydrates make up the balance (15 percent).

As activity increases, the body begins to rely more on carbohydrates and less on fat, as a percentage of total energy expenditure. As exercise intensity increases, the percentage of kilocalories derived from fat metabolism decreases and the percentage from carbohydrate oxidation increases. At fairly modest levels of physical activity or exercise, such as walking at a moderate pace, the mixture of fuels is about 50 percent from fats and 50 percent from carbohydrates. As intensity increases above these modest levels, carbohydrate becomes the predominant fuel source. At moderate to hard exercise intensities (e.g., a distance runner's race pace during a 10-kilometer/6.2-mile road race), nearly all of the energy expenditure is derived from carbohydrates. There are fewer chemical steps involved in carbohydrate oxidation and less oxygen consumption is required for the amount of ATP produced, making carbohydrates the preferred fuel source at higher intensities of exercise.

The distribution of fat and carbohydrate metabolism can be modified to a certain degree by other factors such as diet. The chronic consumption (i.e., over a period of days or weeks) of a high-carbohydrate diet influences the body to rely more heavily on carbohydrate metabolism to a certain degree, even at rest. Consuming a high-carbohydrate meal before exercise can also influence the body to rely slightly more on carbohydrates at the same exercise intensity compared to not eating or fasting before exercise. Similarly, chronic consumption of a high-fat diet influences the body to rely more on fat oxidation at rest and during low- and moderate-intensity exercise. Higher intensities of exercise, however, still rely predominantly on carbohydrates.

Fuel utilization may change somewhat over the course of a single exercise bout, even if the exercise is performed at the same intensity. At the onset of a moderate-intensity exercise session (e.g., jogging), carbohydrates may provide the majority of energy. Given the steps involved in fat oxidation (i.e., lipolysis, mobilization, beta oxidation) there may be a lag time between the onset of exercise and when fat metabolism reaches its peak. There is often a 10- to 20-minute period of time at the beginning of exercise when carbohydrate metabolism takes precedence until fat oxidation can catch up. Duration can also affect the fuel utilized in moderate to higher exercise intensity if the exercise continues for long periods of time. If the body is relying predominantly on carbohydrates, eventually the carbohydrate stores are reduced to the point that fat oxidation becomes the predominant fuel source.

An athlete's training status also affects the mixture of fuels utilized during exercise. Individuals that have engaged in extensive endurance training improve their ability to metabolize fat. At the same absolute exercise intensity (e.g., the same running pace), they will utilize a higher percentage of fat and a lesser percentage of carbohydrate than lesser-trained athletes. When exercise intensity is increased (e.g., faster running pace), even the well-trained athlete will still reduce the percentage of energy from fat and increase the percentage of energy from carbohydrates.

$$RER = \frac{\dot{V}CO_2}{\dot{V}O_2}$$

$\dot{V}CO_2$ = carbon dioxide production
$\dot{V}O_2$ = oxygen consumption

Figure 3.24 Respiratory Exchange Ratio (RER)

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

$$RER = \frac{\dot{V}CO_2}{\dot{V}O_2} = \frac{6\ CO_2}{6\ O_2} = 1.00$$

RER = respiratory exchange ratio
$\dot{V}CO_2$ = carbon dioxide production
$\dot{V}O_2$ = oxygen consumption

Figure 3.25 Respiratory exchange ratio of carbohydrate metabolism—glucose.

The metabolism of one molecule of glucose ($C_6H_{12}O_6$) requires six oxygen molecules and results in the production of six carbon dioxide molecules. The respiratory exchange ratio that results from metabolizing pure carbohydrates is 1.0.

Use of indirect calorimetry allows for the measurement of both oxygen consumption and carbon dioxide production. The proportion of energy coming from carbohydrates and fats can be estimated accurately by use of the **respiratory exchange ratio (RER),** a ratio of the amount of carbon dioxide produced to the amount of oxygen consumed (Figure 3.24). This ratio can be determined from $\dot{V}O_2$ and $\dot{V}CO_2$ measured from respiratory gases with a metabolic measurement system. This procedure is based upon a tissue-level exchange of gases during oxidative phosphorylation called the respiratory quotient (RQ).

Complete oxidation of glucose, a six-carbon sugar, requires six oxygen molecules (Figure 3.25). In the process of oxidizing glucose, six carbon dioxide molecules are produced. Therefore, if only carbohydrate (glucose) is being metabolized for energy, the RER = 1.0 (6 CO_2 produced divided by 6 O_2 consumed). Fatty-acid chains such as palmitate, however, contain many more carbons (16) than oxygen (2) (Figure 3.26). Complete oxidation of fat, therefore, requires significantly more oxygen to be consumed. In the example of palmitate, 23 oxygen molecules are needed for complete oxidation, resulting

Respiratory Exchange Ratio (RER): Ratio of carbon dioxide production to oxygen consumption; used to determine percentage of fats and carbohydrates used for metabolism.

$$C_{16}H_{32}O_2 + 23\ O_2 \rightarrow 16\ CO_2 + 16\ H_2O$$

$$RER = \frac{\dot{V}CO_2}{\dot{V}O_2} = \frac{16\ CO_2}{23\ O_2} = 0.70$$

RER = respiratory exchange ratio
$\dot{V}CO_2$ = carbon dioxide production
$\dot{V}O_2$ = oxygen consumption

Figure 3.26 Respiratory exchange ratio of fat metabolism—palmitate.

The metabolism of one molecule of fat (palmitate, $C_{16}H_{32}O_2$) requires 23 oxygen molecules and results in the production of 16 carbon dioxide molecules. The respiratory exchange ratio that results from metabolizing pure fat is 0.7.

in the production of 16 carbon dioxide molecules. The resulting RER = 0.70 (16 CO_2 produced divided by 23 O_2 consumed), indicating that fat is the only source of fuel. Because protein is not completely oxidized in the body due to the nitrogen group, and because protein metabolism generally comprises a very small percentage of the fuel utilized for energy, it is generally ignored as a part of this fuel utilization analysis. RER is therefore referred to as the nonprotein RER.

The source of fuel is rarely exclusively from carbohydrates or fats, but is usually a mixture of the two. The percentage that may come from each fuel source can depend on a variety of conditions such as previous diet, exercise intensity, and exercise duration. A metabolic measurement system can be used to determine oxygen consumption, carbon dioxide production, and RER. A table can then be used to determine the relative contribution of each fuel source to the energy expenditure (see Table 3.3). For example, if the RER = 0.75, approximately 85 percent of the total energy expenditure is coming from fat oxidation, while 15 percent is contributed by the metabolism of carbohydrates. This is the approximate RER and fuel distribution that is often found in humans at rest. At an RER of 0.95, the fuel utilization is nearly reversed, with approximately 83 percent of energy coming from carbohydrates and 17 percent coming from fats. An RER above 0.90 is common for physical activity or exercise that is in the moderate- to hard-intensity range, indicating that carbohydrate is the predominant fuel source for these activities.

What's the point? The body must decide which, or what, mixture of the three potential fuel sources (carbohydrate, fat, and protein) to use to meet its energy needs. Protein is the lowest priority. Fat is a very energy-dense fuel source and is preferred at rest and at low levels of activity. As exercise intensity increases, carbohydrates become the preferred fuel source.

Table 3.3 Nonprotein Respiratory Exchange Ratio and Percentages of Energy from Carbohydrates and Fats

RER	Percent CHO	Percent Fat
0.70	0	100
0.75	15	85
0.80	32	68
0.85	49	51
0.90	66	34
0.95	83	17
1.00	100	0

RER = respiratory exchange ratio; CHO = carbohydrate

The RER calculated from measured $\dot{V}O_2$ and $\dot{V}CO_2$ can be used to determine the percentage of energy that is being derived from carbohydrate and fat oxidation. The full table can be seen in Appendix I.

Carpenter, T.M. (1964). Tables, factors, and formulas for computing respiratory exchange and biological transformations of energy, 4th ed. Washington, DC: Carnegie Institution of Washington, p. 104.

INTEGRATION OF CARBOHYDRATE, FAT, AND PROTEIN METABOLISM

As seen throughout this chapter, the energy systems are integrated and each system is part of the body's overall ability to expend energy (i.e., "energy out"). These individual energy systems are not turned "off" or "on," rather, they are brighter or dimmer and in balance with each other. This chapter has explained how carbohydrate, fat, protein, and alcohol are metabolized individually to produce energy and the effect that exercise has on the usage of the energy-containing nutrients, especially carbohydrates and fats. However, the discussion of energy metabolism is incomplete without considering overall food intake or "energy in." Food provides both short-term and long-term energy for the body. For example, distance athletes consume small amounts of carbohydrates during competition (i.e., provides immediate energy) as part of a large amount of dietary carbohydrates daily (i.e., provides future energy by increasing muscle glycogen stores). The body has many ways it can adjust its metabolic pathways to meet its short- and long-term energy needs but it has certain pathways that it prefers to use. Some of these pathways cannot be used if the body is in a starvation state.

What happens when a person eats a candy bar, which is made up of carbohydrate, fat, and a small amount of protein? Does all the energy contained get oxidized immediately for fuel or does some get stored? If it gets stored, does it get stored as body fat? Those simple questions have surprisingly complicated answers. In part, the answers depend on whether the individual is in a fed, postabsorptive, or fasting/starvation state.

The fed (absorptive) state refers to the time period that surrounds a meal when food is eaten and the nutrients in it are absorbed. It is assumed that a meal is usually a mixture of carbohydrate, fat, and protein and that it will take approximately three to four hours for full absorption. The postabsorptive state is the period of time after the meal is fully absorbed but before the next meal is eaten, which can be minutes but is usually at least a couple of hours when the person is awake. If one goes to sleep at midnight and does not eat breakfast until 10:00 a.m., then the individual has been in a postabsorptive state for 10 hours. Fasting is an extended period of time when food is not consumed. For the purposes of discussing energy metabolism, fasting is defined as 18 to 48 hours without food. Starvation is defined as a total lack of food intake for more than 48 hours but may last for weeks or a few months. These different states influence the usage and storage of carbohydrate, fat, and protein, and the hormones that help regulate energy metabolism.

In the fed state the most important hormone is **insulin,** and the body's energy priority is delivering glucose from carbohydrate-containing foods. The red blood cells and the cells of the central nervous system cannot store glucose, so some of the glucose from food (in this example, the carbohydrates in the candy bar) gets utilized immediately by those cells. But much of the carbohydrates consumed does not get used immediately for energy; instead, it is stored in muscle and liver cells as glycogen. The body is looking out for both its short-term and long-term energy needs. When nonobese people are in energy balance (i.e., energy intake = energy expenditure), carbohydrate is primarily used for immediate energy or glycogen storage. Essentially none is converted to fatty acids and stored as fat.

The reason is the hormone insulin. In some respects insulin is a traffic cop directing the flow of metabolic traffic. Insulin affects cell membranes so glucose can be taken up by the cells and used immediately for energy. It also favors the storage of glycogen by activating the enzymes that help cells store glycogen and inhibiting the enzymes that break glycogen down. Insulin also has an enormous effect on fat storage and creates an environment in which fat from food can be readily stored as body fat. In this example, most of the fat in the candy bar is probably stored in adipose cells.

The fat-storage-friendly environment created in the fed (absorptive) state no longer exists in the postabsorptive state. This is because insulin concentration is low and insulin is no longer acting as a traffic cop. Instead, several other hormones are now directing traffic. Liver glycogen is broken down to provide a slow, steady stream of glucose to the blood. The body is now using the fat that was previously stored in adipose cells for energy. Some of the candy bar fat that was stored in fat cells is now coming out of those cells and being used by other cells for energy. For the nonobese person in energy balance, carbohydrate and fat stores will always be in flux, but that person's overall body composition is relatively stable.

What happens to the amino acids from the small amount of protein in the candy bar? In the fed state the amino acids will go to the liver and this organ will determine how they will be used. Most will be used for anabolic functions, such as building and repairing tissues, not catabolic functions such as using the amino acids for energy. When daily energy intake is balanced with energy expenditure, the carbohydrate and fat in food provide the energy that the body needs. Breaking down amino acids for energy is a low or last priority for the body.

Notice that the example above clearly states that the person is in energy balance and is not obese. If the body is in a fasting, semi-starvation, or starvation state, then it must adjust some of the energy pathways to respond to the reduction in food intake. In other words, the body must adapt to a reduced amount of

Insulin: Hormone produced by the beta cells of the pancreas that helps regulate carbohydrate metabolism among other actions.

THE EXPERTS IN. . .

Energy Systems and Exercise

Dr. George Brooks, Professor in the Department of Integrative Biology at the University of California, Berkeley, has been a major figure in the field of exercise metabolism for well over 20 years. He has published numerous articles from his research on humans and animals, which has contributed greatly to the understanding of the metabolism of glucose, glycogen, and lactate during exercise. He and his coworkers are largely responsible for developing the concept of the intercellular lactate shuttle and the term *excess post-exercise oxygen consumption (EPOC).*

carbohydrate, fat, and protein from food. It still must meet its short- and long-term energy needs but it emphasizes different metabolic pathways when food intake is low or absent.

Metabolic adjustments are also made when energy intake consistently exceeds energy output. In the case of carbohydrate, some is still used for immediate energy and muscle and liver glycogen stores are still a priority. However, glycogen storage is limited and sedentary individuals do not use much on a daily basis because they are physically inactive. When total caloric intake consistently exceeds expenditure and carbohydrate intake consistently exceeds the body's need for immediate energy and glycogen storage, carbohydrate undergoes a series of chemical reactions in which it is incorporated into fatty acids and stored in adipose cells (body fat).

Let's go back to the candy bar example and compare what happens in two different circumstances. When nonobese people are in energy balance, carbohydrates are primarily used for immediate energy or glycogen storage. This is what happens to the carbohydrates from the candy bar. Most of the fat from the candy bar get stored in adipose cells in the fed state, but fat gets released in the postabsorptive state and is used for energy. The daily energy intake from food equals daily energy expenditure so body composition remains the same.

Now consider what happens to the person who consistently takes in an excess amount of energy daily. The candy bar is part of the excess energy and carbohydrate intake, so after some carbohydrate is used for immediate energy and some is stored in liver and muscle glycogen, the remainder is converted to fatty acids and stored as body fat. Because the person consumes too much food over the course of the day, more fatty acids are stored in adipose cells than get released in the postabsorptive state. The amount of body fat slowly increases. This outcome is very different from the one in the individual who has an energy balance in which essentially none of the carbohydrates will be converted to fatty acids and fat is released in the postabsorptive state and used for energy by the body. Although this example does not specifically address physical activity, it should be noted that many people who are in energy balance are physically active, and those that are physically active or exercise can store more carbohydrates as glycogen than sedentary people.

The examples used in this section also assume that the individual is nonobese. Obesity complicates the situation because the cells of an obese individual are often insulin resistant and excessive body fat affects the hormonal balance in the body (see Chapter 12). An important point is that athletes should consider not only the individual energy-containing nutrients but overall energy intake (see Chapter 2).

KEEPING IT IN PERSPECTIVE

Understanding the Micro- and Macro-Aspects of Energy Metabolism

All students of nutrition and exercise physiology need to learn the details of energy metabolism. The study of energy involves understanding ATP and the potential energy that is stored in phosphate bonds. Memorization of chemical pathways, rate-limiting enzymes, cofactors, and all the steps involved in glycolysis, the Krebs cycle, and the electron transport chain helps individuals understand the details of a complicated process that humans cannot see but that sustains life. The micro-view of energy systems helps athletes understand the ultimate need for carbohydrates, fats, proteins, and vitamins.

In studying the minute details of the individual elements, there is always a risk that students lose sight of the broader perspective on energy. For the athlete, energy systems must be viewed in a larger context—the demands of exercise on the various energy systems and what may be done to manipulate the systems to the competitive athlete's advantage, which in many cases means delaying fatigue. Understanding the details of the creatine phosphate system is important for athletes performing high-intensity exercise but is of minor importance for endurance athletes. Similarly, long-distance athletes are concerned about having an adequate supply of muscle glycogen to provide the carbohydrates for oxidative phosphorylation. Understanding the function of the energy systems is also important to understand the alterations that may need to be made during different phases of an athlete's training (e.g., carbohydrate loading prior to an endurance competition). Training can alter the utilization of fats and carbohydrates to some degree. The athlete's perspective on energy systems will be influenced by the physiological demands of the sport.

Another perspective is providing energy substrates through food or supplements. In some cases, the athlete's goal is near-maximum stores of muscle glycogen or creatine phosphate. The broadest perspective is the total amount of energy needed to fuel activity and the consumption of appropriate amounts of carbohydrate, protein, fat, and alcohol. Keeping energy in perspective means focusing sometimes on the smallest details of metabolism and other times focusing on the larger aspects of food intake and exercise output.

Summary

The direct source of energy for most cellular processes is ATP. Creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation are the three major energy systems that are used to replenish ATP as it is being utilized. Each of these energy systems is active at all times, but one of the systems may be the predominant source of energy for ATP replenishment, depending upon a variety of factors related to energy need, such as duration and intensity of activity and force requirements. The advantage of the creatine phosphate system is its rapid production of ATP; however, the amount of ATP produced is very small. Anaerobic glycolysis can produce ATP relatively rapidly, but this system is limited by the accumulation of lactate and the associated cellular pH and muscle fatigue. These energy systems are also advantageous because they do not rely on the use of oxygen.

Oxidative phosphorylation can provide a virtually unlimited amount of ATP, albeit slowly, because many chemical steps and the presence of oxygen are required. Carbohydrates, proteins, and fats can be metabolized aerobically through the oxidative phosphorylation energy system. Protein metabolism generally accounts for a very small proportion of energy expenditure, except under relatively extreme conditions such as starvation. At rest, fat metabolism is the source of approximately 85 percent of energy expenditure. The proportion of carbohydrate and fat fuel utilization can change, depending upon a number of factors such as previous diet and intensity and duration of activity. As exercise intensity increases above moderate levels, carbohydrates become the predominant fuel source for energy expenditure.

Post-Test — Reassessing Knowledge of Energy Systems and Exercise

Now that you have more knowledge about energy systems and exercise, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. The direct source of energy for force production by muscle is ATP.
2. Creatine supplements result in immediate increases in strength, speed, and power.
3. Lactate is a metabolic waste product that causes fatigue.
4. The aerobic energy system is not active during high-intensity anaerobic exercise.
5. At rest and during low levels of physical activity, fat is the preferred source of fuel for the aerobic energy system.

Review Questions

1. How is ATP replenished by ADP?
2. What energy system supplies the predominant amount of energy during very-high-intensity, short-term exercise?
3. How is creatine rephosphorylated after its use in skeletal muscle?
4. What is the predominant energy system during high-intensity exercise lasting one to two minutes?
5. How is lactate that is produced as a result of anaerobic glycolysis disposed of or used in the body?
6. What is the predominant energy system during moderate-intensity, long-term exercise?
7. What is meant by the term $\dot{V}O_{2max}$?
8. When aerobic exercise begins, why does it take a few minutes for oxygen consumption to rise to a level that will supply sufficient energy to support the exercise? Where does the energy for exercise come from during this period of time?
9. Why does oxygen consumption remain elevated for a period of time after exercise?
10. Why are proteins not a preferred fuel source when compared to carbohydrates and fats?
11. Compare the advantages and disadvantages of carbohydrates and fats as fuel sources, particularly for exercise.
12. Briefly explain what happens to the carbohydrate, fat, and protein eaten by a nonobese person in energy balance in the fed and postabsorptive periods.

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4 Carbohydrates

Learning Objectives

1. Classify carbohydrates according to their chemical composition.
2. Describe the digestion and absorption of carbohydrates.
3. Explain the metabolism of glucose.
4. Describe how blood glucose and muscle glycogen are used to fuel exercise.
5. State carbohydrate recommendations for athletes, including specific guidelines for intake before, during, and after exercise.
6. Discuss the glycemic response of carbohydrate-containing foods and the use of the glycemic index by athletes.
7. Determine the daily carbohydrate needs of an athlete and select carbohydrate-containing foods to meet the recommended intake.
8. Compare and contrast carbohydrate loading protocols.
9. Assess an athlete's carbohydrate intake and determine if it meets guidelines for performance and health.

Pre-Test Assessing Current Knowledge of Carbohydrates

Read the following statements and decide if each is true or false.

1. The body uses carbohydrates primarily in the form of fruit sugar, fructose.
2. Sugars such as sucrose (table sugar) are unhealthy and should rarely be a part of an athlete's diet.
3. Low levels of muscle glycogen and blood glucose are often associated with fatigue, particularly during moderate- to high-intensity endurance exercise.
4. A diet that contains 70 percent of total kilocalories as carbohydrates will provide the necessary amount of carbohydrates for an athlete.
5. Most athletes consume enough carbohydrates daily.

Consumption of carbohydrates may be necessary before and during training or competition, and athletes can choose from a variety of liquid, solid, or semisolid products containing the proper amount and type of carbohydrates. Carbohydrate-containing foods also taste sweet, making them a palatable energy source.

Carbohydrates are compounds that contain carbon, hydrogen, and oxygen. The presence of these three atoms also gives the word **carbohydrate** its common abbreviation—CHO. Carbohydrates are found in food as **sugars, starches,** and **cellulose.** Carbohydrates are found in the body predominately in the form of **glucose** (mostly in the blood) and in the storage form of **glycogen** (in many tissues, predominately muscle and liver).

Carbohydrates are the primary energy source for moderate to intense exercise and provide approximately 4 kcal/g. The largest amount of carbohydrate in the body is stored in the form of muscle glycogen. Smaller amounts are stored as liver glycogen, which helps to maintain normal concentrations of glucose (a sugar) in the blood. Carbohydrates found in food replenish the carbohydrates used, although the body has a limited ability to make glucose from other substances.

The sugars and starches found in food provide energy because the body can digest and absorb these kinds of carbohydrates. The cellulose found in starchy foods does not provide energy because humans do not possess the enzymes necessary to digest it. However, cellulose and other **fibers** are important forms of carbohydrates since fiber is needed for good health. In addition to energy, starchy foods also contain vitamins, minerals, and other nutrients. Sugars only provide energy and do not contain vitamins, minerals, or fiber.

Athletes use carbohydrates as a source of energy and nutrients. Training and competition reduce carbohydrate stores, which must be replenished on a daily basis. The timing of carbohydrate intake can be important, especially immediately after exercise when muscle glycogen resynthesis begins.

Carbohydrates in Food

THE VARIOUS FORMS OF CARBOHYDRATES IN FOOD

To understand the differences in the various forms of carbohydrates in food, one must look more closely at their chemical composition. Carbohydrates are generally classified as **monosaccharides, disaccharides,** or **polysaccharides.** It helps to know that *saccharide* means sugar, and *mono* means one, *di* means two, and *poly* means many. Therefore, a monosaccharide consists of one sugar molecule, a disaccharide two sugar molecules, and a polysaccharide is made up of many sugar molecules. Sugar alcohols are derived from mono- and disaccharides and are discussed separately (see Spotlight on Enrichment: Sugar Alcohols).

The three monosaccharides found in foods are glucose, **fructose,** and **galactose.** Their structures are shown in Figure 4.1 and their characteristics are outlined in Table 4.1.

In which foods are these monosaccharides found? Although glucose can be found by itself in foods, most of the time it is a component of food disaccharides and polysaccharides. Fructose is naturally found in fruits and vegetables but the largest amount of fructose in American diets is added to foods when they are processed. If one looks at the food label of a sweet tasting processed food there is a good chance that one of the ingredients is high-fructose corn syrup. Galactose is a monosaccharide but it is found naturally in food only as part of the disaccharide, **lactose.**

There are three disaccharides found in food—**sucrose,** lactose and **maltose.** Their chemical structures and characteristics are shown in Figure 4.2 and Table 4.2. Sucrose is made of one molecule of glucose and one molecule of fructose. Lactose is a combination

Table 4.1 Characteristics of Monosaccharides

Chemical Name	Sweetness (100 = sweetness of table sugar)	Glycemic Index (based on 100)	Miscellaneous
Glucose	75	100	In the body, found circulating in the blood and stored as glycogen. In food, generally found as part of disaccharides and polysaccharides (starches). When added to food, glucose is referred to as dextrose.
Fructose	170	19	In the body, found temporarily in the liver before being converted to glucose. In food, found naturally in fruits and vegetables and added to processed foods typically as high fructose corn syrup.
Galactose	30	Unknown	Found in food only as part of lactose.

of one molecule each of glucose and galactose. Maltose is made up of two glucose molecules.

Sucrose is found naturally in fruits, vegetables, honey, and maple syrup. It is also found in sugar beets and sugar cane, which are processed into white and brown sugar. Sucrose is added to many processed foods. Lactose is naturally found in milk. It is often referred to as milk sugar and is sometimes added to processed foods. Maltose is produced during the **fermentation** process that is used to make maltose syrup (commonly used in Asian cooking), beer and other alcoholic beverages.

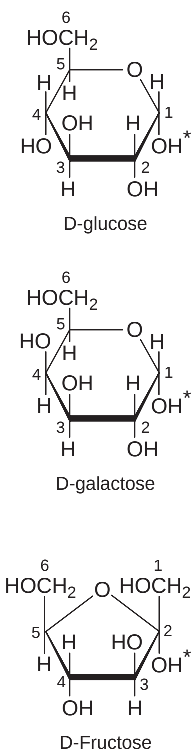

Figure 4.1 Chemical Structure of the Monosaccharides—Glucose, Fructose, and Galactose

The chemical structures are shown using the Haworth model. The carbons are numbered and the * refers to the anomeric carbon, which forms the ring structure, is the reducing end of the molecule, and can react with the OH group.

Carbohydrates: Sugars, starches, and cellulose. Chemical compound made from carbon, hydrogen, and oxygen.

Sugar: Simple carbohydrates (mono- or disaccharides); In everyday language, used interchangeably with sucrose.

Starch: A polysaccharide.

Cellulose: The main constituent of the cell walls of plants.

Glucose: Sugar found naturally in food, usually as a component of food disaccharides and polysaccharides. Glucose is a monosaccharide.

Glycogen: A highly branched glucose chain. The storage form of carbohydrates in humans and animals.

Fiber: An indigestible carbohydrate. Fiber is a polysaccharide.

Monosaccharide: A one-sugar unit. Mono = one, saccharide = sugar. Glucose, fructose, and galactose are monosaccharides.

Disaccharide: A two-sugar unit. Di = two, saccharide = sugar. Sucrose, lactose, and maltose are disaccharides.

Polysaccharide: Chains of glucose molecules such as starch. Poly = many, saccharide = sugar.

Fructose: Sugar found naturally in fruits and vegetables. May also be processed from corn syrup and added to foods. Fructose is a monosaccharide.

Galactose: Sugar found naturally in food only as part of the disaccharide, lactose. Galactose is a monosaccharide.

Lactose: Sugar found naturally in milk. May also be added to processed foods. Lactose is a disaccharide made up of glucose and galactose.

Sucrose: A disaccharide made of glucose and fructose.

Maltose: Sugar produced during the fermentation process that is used to make beer and other alcoholic beverages. Maltose is a disaccharide made up of two glucose molecules.

Fermentation: The breaking down of a substance into a simpler one by a microorganism, such as the production of alcohol from sugar by yeast.

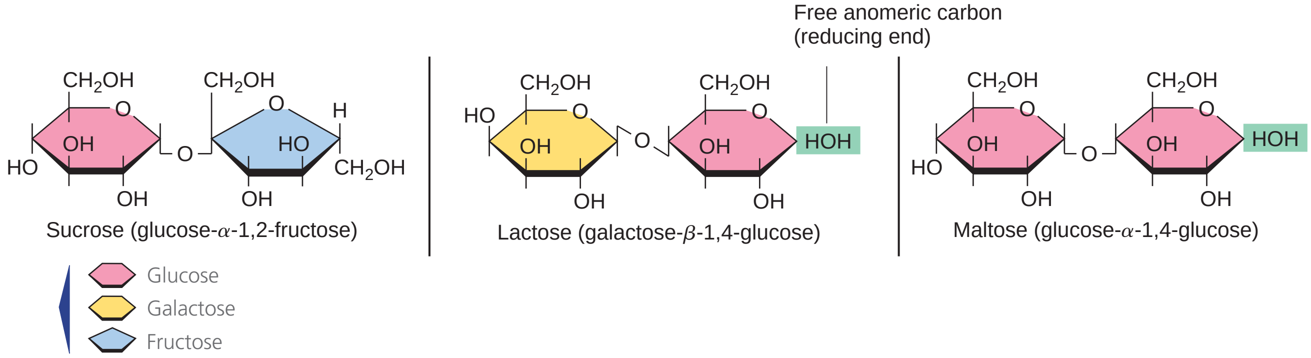

Figure 4.2 Chemical Structure of the Disaccharides—Sucrose, Lactose, and Maltose

Table 4.2 Characteristics of Disaccharides

Chemical Name	Monosaccharide Composition	Sweetness (100 = Sweetness of table sugar)	Glycemic Index (based on 100)	Miscellaneous
Sucrose	Glucose + fructose	100	68	Found in fruits, vegetables, honey, and maple syrup; sugar beets and sugar cane are processed into white and brown sugar.
Lactose	Glucose + galactose	15	46	Most adults lose their ability to digest lactose (e.g., milk sugar).
Maltose	Glucose + glucose	40	105	Minor disaccharide in most diets.

Christina Micek

Carbohydrates can be found in a wide variety of foods including breads, cereals, pastas, beans, fruits, vegetables, milk, and nuts.

Polysaccharides are chains of glucose. These glucose chains are known as starch, fiber, and glycogen. Starches in food may be straight chains (amylose) or branched chains (amylopectin). Enzymes in the digestive tract help to break down these chains into their basic component, glucose. Fiber is a tightly packed polysaccharide that is the structural component of plants. Humans lack the enzymes needed to break down fiber. Glycogen is a highly branched glucose chain and is the form in which humans and animals store carbohydrates in their bodies (see Figure 4.3). Although glycogen is found in muscle and liver tissue of live animals, it is not considered a food source of carbohydrates for humans, because it degrades rapidly.

Starch is found in many foods, including grains, **legumes** (beans), and tubers. Grains are grasses that bear seeds and include wheat, corn, rice, rye, oats, barley, and millet and foods that are made from them such as breads, cereals, and pasta. Legumes are plants that have a double-seamed pod containing a single row of beans. Examples of legumes are lentils, split peas, black-eyed peas, and many kinds of beans such as soy, kidney, lima, and northern beans. Beans are also known by their color—white, pink, red, or black. Tubers, such as white or sweet potatoes and yams, have underground stems and are often referred to as starchy vegetables.

Dietary fiber is found naturally in grains. Whole grains, which contain the **endosperm,** the **germ,** and the **bran,** have more fiber than grains that are highly refined. When whole grains are processed, the germ and the bran are removed. Since these two parts contain most of the fiber, the processing results in a substantial loss of fiber. Other sources of dietary fiber include legumes, seeds, fruits, and vegetables, including the starchy vegetables.

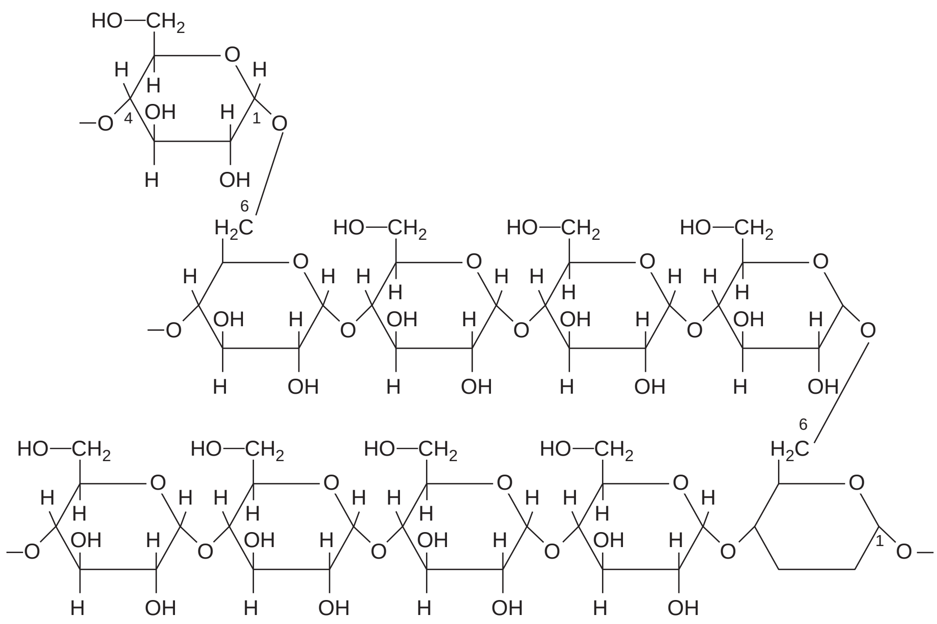

Figure 4.3 The Chemical Structure of Glycogen

Glycogen is a series of glucose molecules linked together in a long, branching chain.

In addition to dietary fiber, some processed foods may contain added fibers that have been extracted from plants. Ingredients such as cellulose, **guar gum,** or pectin are often added to foods in small amounts. These are known as functional fibers and are generally added to affect the food's texture by making it more solid. Fiber supplements may also contain these fibers or another functional fiber, **psyllium.**

CLASSIFYING FOOD CARBOHYDRATES

There is no single, perfect way to classify the various carbohydrates found in foods, so a number of terms have been used to distinguish them. Often carbohydrates are divided into two categories, sugars and starches. Sugars are also known as simple sugars or simple carbohydrates and starches are referred to as complex carbohydrates. The widespread processing of carbohydrate-containing foods has given rise to new terms. The term *highly processed* refers to foods that are primarily sugar (e.g., sugared beverages) or products made from grains that have been highly refined and sweetened (e.g., sugared cereals). In contrast, whole grains and foods made from them are referred to as minimally processed, fiber-containing, or quality carbohydrates. All of these terms are an attempt to distinguish carbohydrate foods based on their nutrient content.

Unfortunately, carbohydrates have also been referred to as *good* and *bad*. *Bad* has been used to describe highly processed, fiber-deficient, and/or highly sweetened carbohydrate foods and beverages. While the original intention was to distinguish more nutritious foods from less nutritious ones, this terminology is unfortunate since the words *good* and *bad* carry powerful language and cultural connotations. Rather than simply labeling carbohydrate foods as good or bad, one should consider the context and frequency of their consumption. There are circumstances that make it appropriate to consume carbohydrates typically referred to as bad. For example, the consumption of large amounts of simple sugars is generally discouraged because they are considered "empty calories." Empty refers to a lack of nutrients, not a lack of calories, and excess consumption of such foods and beverages may contribute to obesity and malnutrition. But, there are circumstances when sugars (e.g., sucrose or table sugar) may be a "good" choice. For example, the most appropriate, rapid source of energy for athletes, particularly during or immediately after endurance exercise, may be sucrose.

In such cases the immediate focus is an energy source that is rapidly digested, absorbed, and metabolized, not its nutrient content. At times, the consumption of high-sugar, low-fiber foods and beverages may

Legumes: Plants that have a double-seamed pod containing a single row of beans. Lentils and beans are legumes.

Endosperm: Tissue that surrounds and nourishes the embryo inside a plant seed.

Germ: When referring to grains, the embryo of the plant seed.

Bran: The husk of the cereal grain.

Guar gum: A polysaccharide added to processed foods as a thickener.

Psyllium: The seed of a fleawort that swells when moist and is a functional fiber.

Acme Food Arts/Jupiter Images

Vegetables are tasty and nutritious, particularly orange and leafy green ones.

be necessary (e.g., during a long race or training session) and the immediate energy needs of exercise will outweigh the longer-term "healthy diet" perspective. From the perspective of health, the majority of carbohydrates consumed in the diet should be minimally processed fiber-containing carbohydrates, such as whole grains, beans, legumes, fruits, and vegetables. Highly processed carbohydrate foods lose fiber and nutrients in the processing and they often have sugar, fat, and/or salt added. They are not the nutritional equivalents of minimally processed carbohydrate-containing foods, and this distinction in nutrient content is important. However, describing carbohydrate-containing foods as good or bad is confusing and does not help athletes determine the quality or quantity of carbohydrates that they need in their diets for training, performance, and health.

SPOTLIGHT ON ENRICHMENT

Sugar Alcohols

Sugar alcohols can be formed from monosaccharides and dissacharides. They are less sweet and typically have fewer kilocalories than sucrose (table sugar). Common sugar alcohols are glycerol, sorbitol, mannitol, and xylitol.

Glycerol is part of the structure of triglycerides, the most common type of fat found in food and in the body. A triglyceride is a glycerol molecule with three fatty acids attached. Because it is an integral part of the structure of a triglyceride, glycerol may be thought of as a fat, but this is erroneous—glycerol is a sugar alcohol. When triglycerides are metabolized, the fatty acids are broken down and oxidized for energy. The majority of glycerol produced from the breakdown of triglycerides will be used to resynthesize other triglycerides, but a small amount may be converted to glucose (see Gluconeogenesis).

Glycerol may be added to food, in which case the terms *glycerin* or *glycerine* are used. Glycerin provides sweetness and moisture and has become popular in foods sold to consumers who are following a low-carbohydrate diet. Glycerol contains approximately 4.3 kcal/g, so its caloric content is approximately the same as sucrose (~ 4 kcal/g). However, only a small amount of glycerin is typically used in a product and its absorption from the gastrointestinal tract is slow, so glucose and **insulin** concentrations are not rapidly elevated. Such products are often advertised as containing "low-impact carbs," a marketing term that is used to describe a slow rise in **blood glucose** and insulin concentrations after a carbohydrate-containing food is consumed.

Sorbitol and mannitol are found in some foods naturally, and are used in sugar-free foods because they contain fewer kilocalories per gram (2.6 and 1.6, respectively) than sucrose or fructose. They are also incompletely absorbed. When absorbed, the rise in blood glucose is much slower when compared to sucrose-containing foods. When these sugar alcohols have been added to foods, the label must carry a warning stating that excess consumption may have a laxative effect, because the unabsorbed portion remains in the digestive tract and may cause diarrhea. Excess consumption is defined as 20 g/day of mannitol or 50 g/day of sorbitol, although some people have symptoms at lower doses.

The sugar alcohol xylitol (2.4 kcal/g) is frequently used in chewing gum because it can help prevent dental caries. Although the sugar alcohols are found in foods, they receive less attention than the sugars and starches because sugar alcohol intake is typically a small part of total carbohydrate intake (Nabors, 2002).

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Examples of foods that contain sugar alcohols such as glycerol, sorbitol, mannitol, or xylitol.

Digestion and Absorption of Carbohydrates from Food

Digestion is the breakdown of foods into smaller parts so the body can absorb them. Absorption involves taking these smaller parts into the cells of the intestine where they will then be transported to other parts of the body. The digestive tract starts at the mouth and includes the stomach, small intestine (i.e., duodenum, jejunum, ileum), large intestine (i.e., colon [ascending, transverse, and descending], cecum, appendix, rectum), and anus (Figure 4.4). The majority of digestion and absorption takes place in the small intestine, although the mouth, stomach, and large intestine do account for some digestion and for absorption of some nutrients.

As mentioned previously, starches are polysaccharides, which are chains of glucose. When a starch-containing food is consumed, the chains must be broken down to yield glucose. This process begins in the mouth and continues in the stomach, but digestion of starch occurs predominantly in the small intestine. Ultimately, the starch will be broken down to its basic unit—glucose.

The three disaccharides found in food—sucrose, lactose, and maltose—are digested in the small intestine (not the mouth or stomach). The enzyme sucrase breaks down sucrose to yield glucose and fructose. Sucrase can also break down maltose to two molecules of glucose, but dietary maltose intake is usually small. The enzyme lactase breaks down lactose into glucose and galactose. People who lack a sufficient amount of lactase are unable to break down the lactose or milk sugar, resulting in a condition known as lactose intolerance. Lactose intolerance is discussed later in this chapter.

After the breakdown of starches and disaccharides, only the monosaccharides—glucose, fructose, and galactose—remain. Glucose is typically present in the largest amount since it is the only monosaccharide found in starch and maltose and it is half of each molecule of sucrose and lactose. Galactose is absorbed by the same mechanism as glucose, while fructose absorption occurs by a different process.

GLUCOSE ABSORPTION

Glucose absorption is carrier dependent and requires active transport. A specific carrier loaded with a molecule of sodium must be present in the cell wall of the intestinal villi before the glucose can attach (Figure 4.5). Once attached, the glucose is moved from one side of the intestinal cell to the other. The glucose is then detached from the transporter and enters the portal vein where it will travel in the blood to the liver. Similar to a revolving door, the carrier returns to the other side of the cell to transport additional glucose molecules. The attachment and transport of the glucose carrier across the small intestine requires a small amount of energy. This process is known as active transport. Galactose uses the same carrier and process for absorption. However, once transported to the liver, the galactose is immediately trapped by the liver cells and converted to glucose.

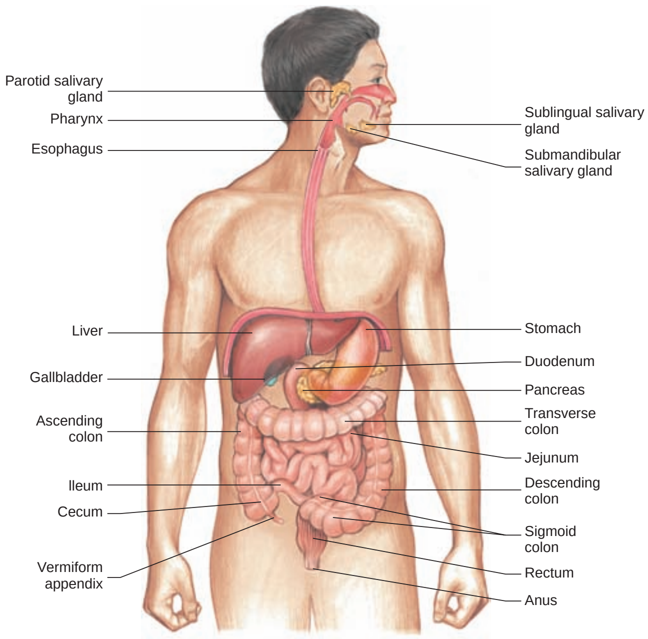


Figure 4.4 The Human Digestive System

FRUCTOSE ABSORPTION

Fructose must also attach to a specific carrier to cross the wall of the small intestine. However, the fructose carrier is different from the glucose carrier. The number of fructose carriers is limited; therefore, if the amount of fructose in the small intestine is greater than the number of carriers present, then some of the fructose will not be absorbed. Absorption of fructose also depends on a concentration gradient, but when fructose is present in the small intestine, it is greater than the concentration in the blood since there is no fructose circulating in the blood. Sport beverage manufacturers are careful not to include too much fructose in their drinks, since fructose that is not absorbed from the small intestine passes through to the colon, ferments, and causes gastrointestinal distress such as bloating and gas.

Once absorbed, fructose is carried directly to the liver via the portal vein. The liver is extremely efficient in capturing fructose, which will eventually be converted to glucose by the liver cells. The liver's ability to capture all

Insulin: A hormone produced by the pancreas that helps to regulate blood glucose.

Blood glucose: The type of sugar found in the blood.

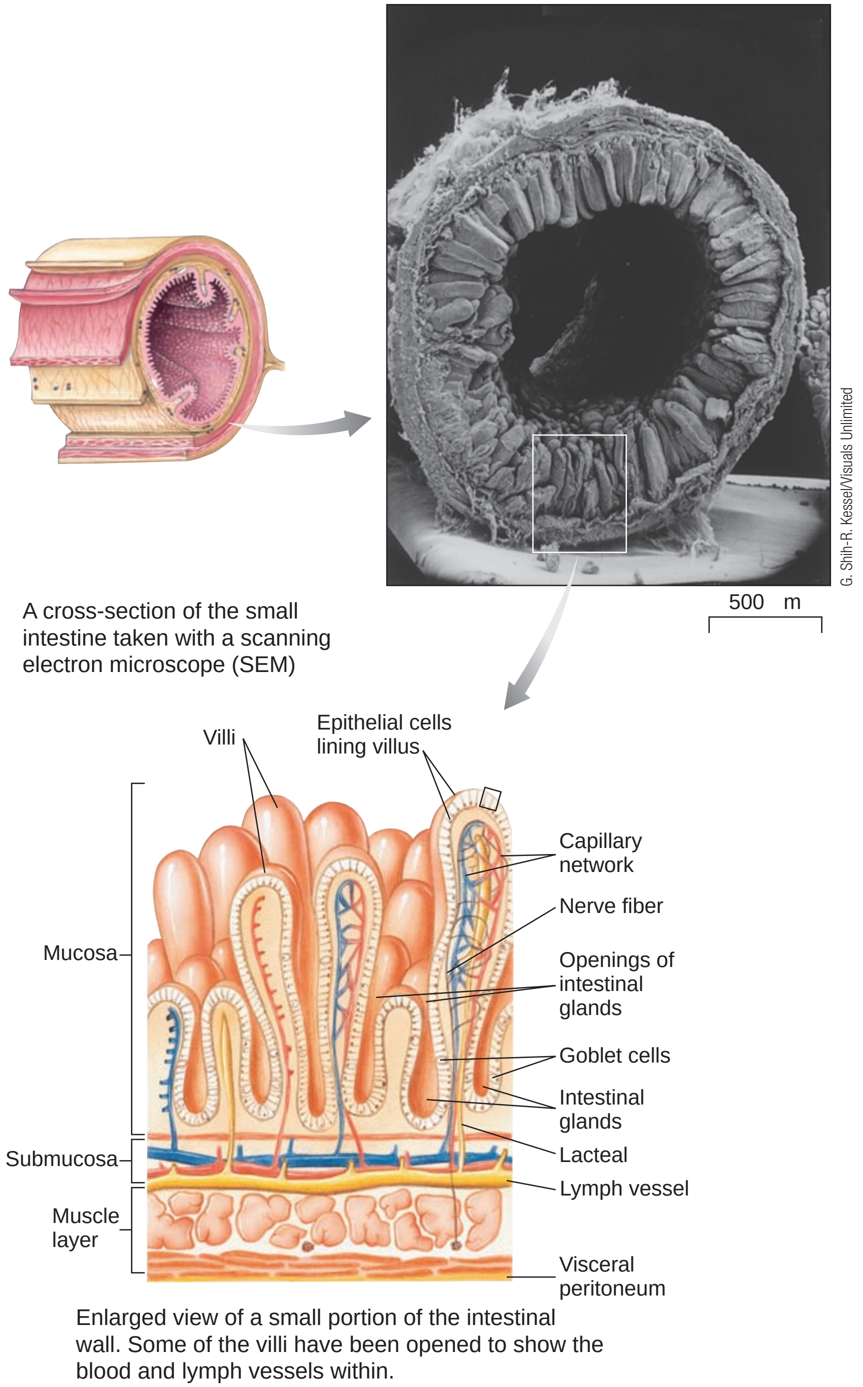


Figure 4.5 The Structure of the Small Intestine

The villi, microvilli, and capillary network provide surface area for the digestion and absorption of food.

of the fructose and galactose that is absorbed prevents either of these monosaccharides from leaving the liver and circulating in the blood. Ultimately, all of the sugars and starches found in food are broken down to monosaccharides and absorbed. Glucose is the end point, the eventual form of sugar that the body uses, regardless of whether the original compound was a polysaccharide, a disaccharide, or a monosaccharide.

Metabolism of Glucose in the Body

Metabolism refers to all of the physical and chemical changes that take place within the cells of the body. Glucose is needed for cellular energy, and the metabolism of glucose is regulated by a number of hormones. The most predominant of the glucose regulating (glucoregulatory)

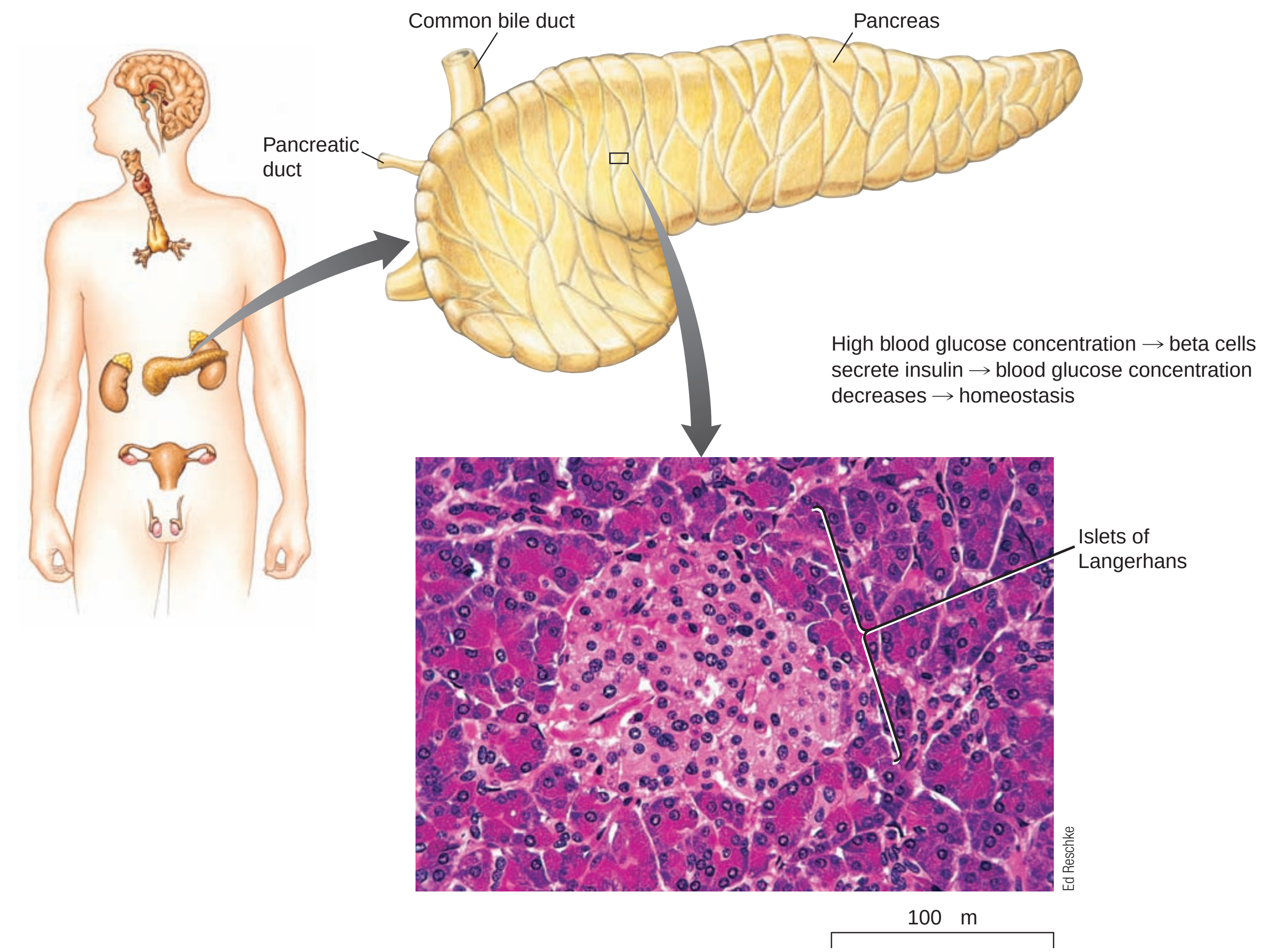


Figure 4.6 The Pancreas—Alpha (α) and Beta (β) Cells in Islets of Langerhans

Beta cells in the Islets of Langerhans in the pancreas synthesize and secrete insulin. Glucagon is secreted by the alpha cells.

hormones are insulin and **glucagon.** Glucose metabolism is intricate and involves many metabolic pathways. These pathways include: 1) the regulation of blood glucose concentration, 2) the immediate use of glucose for energy, 3) the storage of glucose as glycogen, 4) the use of excess glucose for fatty-acid synthesis, and 5) the production of glucose from lactate, amino acids, or glycerol.

REGULATION OF BLOOD GLUCOSE

The normal range of concentration of blood glucose is approximately 70 to 110 mg/dl (3.89–6.06 mmol/L), and sensitive hormonal mechanisms are used to maintain equilibrium **(homeostasis)** within this fairly narrow range. For example, when blood glucose concentration is elevated after a carbohydrate-containing meal, the hormone insulin is secreted from the beta (β) cells of the **pancreas** to stimulate the transport of glucose from the blood into the cells of various tissues. When blood glucose concentration is too low, the hormone glucagon is secreted from the alpha (α) cells of the pancreas to stimulate the release of glucose stored as liver glycogen into the blood (see Figure 4.6). Blood glucose concentration is always in flux, but hormonal mechanisms are in place to bring blood glucose concentration back within the normal range (equilibrium).

Metabolism: All of the physical and chemical changes that take place within the cells of the body.

Glucagon: A hormone produced by the pancreas that raises blood glucose concentration by stimulating the conversion of glycogen to glucose in the liver. It also stimulates gluconeogenesis, the manufacture of glucose by the liver from other compounds. Glucagon is counter-regulatory to insulin.

Homeostasis: A state of equilibrium.

Pancreas: An organ that produces and secretes the hormones insulin and glucagon into the blood. It also secretes digestive juices into the small intestine.

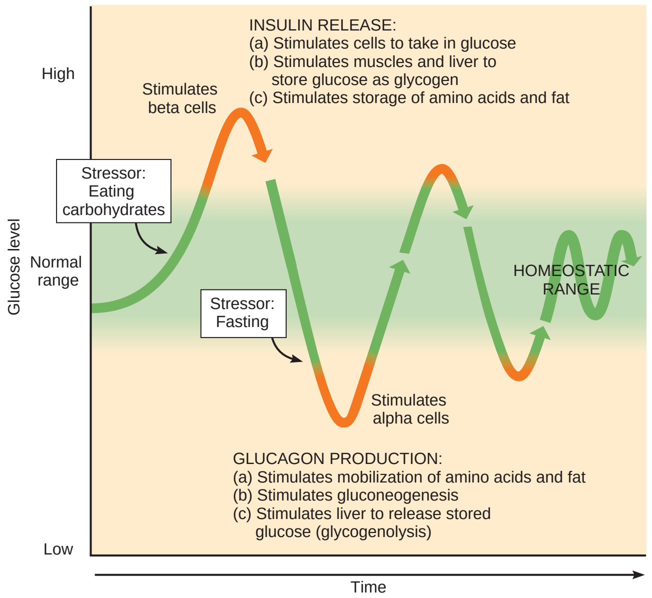


Figure 4.7 Regulation of Blood Glucose

Blood glucose rises in response to eating carbohydrate, which stimulates the beta cells to release insulin. Fasting for more than a few hours results in blood glucose declining, which stimulates the alpha cells to release glucagon.

A very simple example of how blood glucose is regulated hormonally is illustrated in Figure 4.7. When carbohydrates such as sucrose are consumed, glucose is quickly digested, absorbed, and transported into the blood. Blood glucose concentration rises and a temporary state of **hyperglycemia** (high blood glucose) exists. The rise of blood glucose stimulates β cells of the pancreas to increase the secretion of insulin. Insulin mediates the transfer of glucose out of the blood and into most cells, such as red blood cells, resting muscle cells, and fat cells. As the glucose enters the cells, the concentration of glucose in the blood begins to drop. Not all cells in the body need insulin to take up glucose, however. Exceptions are brain and liver cells, which are not dependent on insulin for the transport of glucose. Exercising muscle cells can also take up glucose from the blood without insulin.

Blood glucose concentration can drop too low, such as when a person goes without eating for several hours. This condition is known as **hypoglycemia,** which is usually defined as a blood glucose concentration below 50 mg/dl (2.76 mmol/L). In response to a decreasing blood glucose concentration and hypoglycemia, the hormone glucagon is released from the α cells of the pancreas. Glucagon stimulates the breakdown of stored glycogen in the liver and its release into the blood as glucose. Insulin and glucagon counter each other's actions (**counter-regulatory**); they act in opposition to either remove or add glucose to the blood to help keep the concentration of blood glucose within the normal range over time (homeostasis).

Glycemic Effect of Various Carbohydrates and the Glycemic Index. Since the 1980s scientists, have been studying the effect that different carbohydrate foods have on blood glucose (known as **glycemic response**) and insulin secretion. Hundreds of carbohydrate-containing foods have been tested and their glycemic responses have been quantified (Foster-Powell, Holt, and Brand-Miller, 2002). This has led to the classification of carbohydrate foods based on their **glycemic index (GI).**

Under normal circumstances, the result of carbohydrate consumption, digestion, and absorption is a relatively rapid increase in blood glucose, which reaches a peak and is then followed by a decline due to the secretion of insulin and the subsequent increase in glucose uptake by tissues. The time course and magnitude of this glycemic response are highly variable with different foods and do not fall neatly into categories based on chemical structure (i.e., mono-, di-, or polysaccharides) or other descriptions, such as simple or complex carbohydrates. For example, the consumption of the same amount of two monosaccharides (simple sugars), glucose and fructose, results in very different blood glucose responses. Glucose ingestion results in a rapid and large increase in blood glucose, which in turn, rapidly returns to baseline levels. Fructose consumption, on the other hand, results in a much slower and lower glycemic response—it rises more slowly, does not reach as high a level, and returns more slowly to baseline. The glycemic response of a low GI food, applesauce, and a moderate GI food, orange juice, is illustrated in Figure 4.8.

The concept of the glycemic index was created, tested on a variety of foods, and initially published by Jenkins et al. in 1981. The GI is a ranking based on the blood glucose response of a particular food compared to a reference food. Glucose or white bread containing 50 g of carbohydrate is typically used as the reference food. Test foods contain an identical amount of carbohydrate, and the blood glucose response is

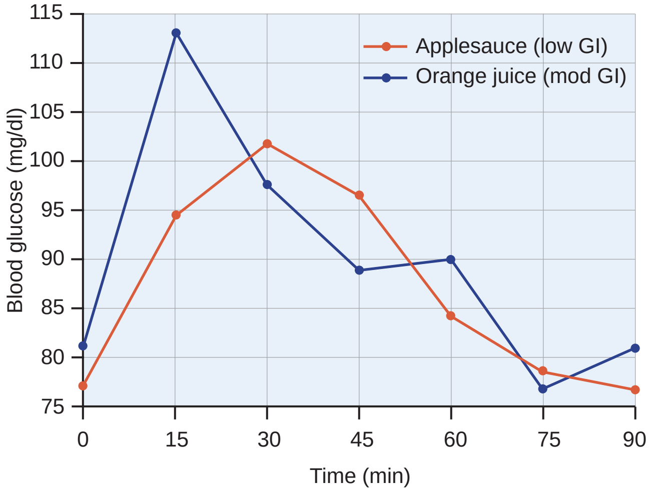
Hyperglycemia: Elevated blood glucose. Hyper = excessive, glyc = sugar, emia = blood.

Hypoglycemia: Low blood glucose. Usually defined as a blood glucose concentration below 50 mg/dl (2.76 mmol/L). Hypo = under, glyc = sugar, emia = blood.

Counter-regulatory: Counter refers to opposing; regulatory is a mechanism that controls a process. Counter-regulatory refers to two or more compounds that oppose each other's actions.

Glycemic response: The effect that carbohydrate foods have on blood glucose concentration and insulin secretion.

Glycemic Index (GI): A method of categorizing carbohydrate-containing foods based on the body's glucose response after their ingestion, digestion, and absorption. The index is based on scores up to 100.



mg/dl = milligrams per deciliter
mod = moderate
min = minutes

Figure 4.8 Glycemic Response to a Low and Moderate Glycemic Index Food

Blood glucose and insulin response to 50 g of carbohydrate in unsweetened applesauce (a low glycemic index [GI] food) and unsweetened orange juice (a moderate glycemic index food). Note that when a food with a higher GI is consumed, blood glucose rises more quickly, reaches a higher level, and declines more quickly than a food with a lower GI. The insulin response is also higher and remains higher for the food with the higher glycemic index, even though the same amount of carbohydrate is consumed.

determined for two to three hours after consumption of the test food. Extensive testing of foods has resulted in the publication of tables of glycemic indices for a wide variety of foods in scientific journals (Foster-Powell, Holt, and Brand-Miller, 2002) and online (www.mendosa.com).

The variability in glucose and insulin response with different foods has important implications, and the GI may be a useful tool, particularly for those who must carefully control their blood glucose concentration, such as people with **diabetes** (Doyle and Papadopoulos, 2000). Nondiabetic athletes may also benefit from considering the GI of the carbohydrates they consume. There may be specific situations in which an athlete would want to consume foods with a high glycemic index and provoke a large blood glucose and insulin response, such as when attempting to synthesize muscle glycogen quickly after glycogen-depleting exercise.

In general, highly refined starchy foods and starchy vegetables (e.g., white bread, corn flakes, and baked potatoes) have a high glycemic index, which means that blood glucose levels rise quickly after their consumption. This rapid rise in blood glucose is followed by a rapid rise in insulin. Legumes, beans, fruits, and nonstarchy vegetables have a low glycemic index. Blood glucose rises slowly because the digestion and subsequent absorption of glucose is slower when compared to highly refined starchy foods. A slow rise in blood glucose also results in a slow rise in insulin (Ludwig, 2002). More information about glycemic index and its relationship to health can be found in Spotlight on Enrichment: Glycemic Index and Glycemic Load.

Diabetes: A medical disorder of carbohydrate metabolism. May be due to inadequate insulin production (type 1) or decreased insulin sensitivity (type 2).

David M. Dennis/Photolibrary

David M. Dennis/Photolibrary

Highly processed starches such as white bread, pasta, or rice have a high glycemic index while beans and legumes have a low glycemic index.

IMMEDIATE USE OF GLUCOSE FOR ENERGY

As glucose is taken up into a cell, it can be either metabolized or stored for later use, depending upon the current energy state of the cell. If the energy need of the cell is low and the cell has the enzymatic capability, glucose will be stored as glycogen as described below. The metabolism of glucose follows the process of glycolysis as explained in Chapter 3. The energy content of carbohydrate is approximately 4 kcal/g.

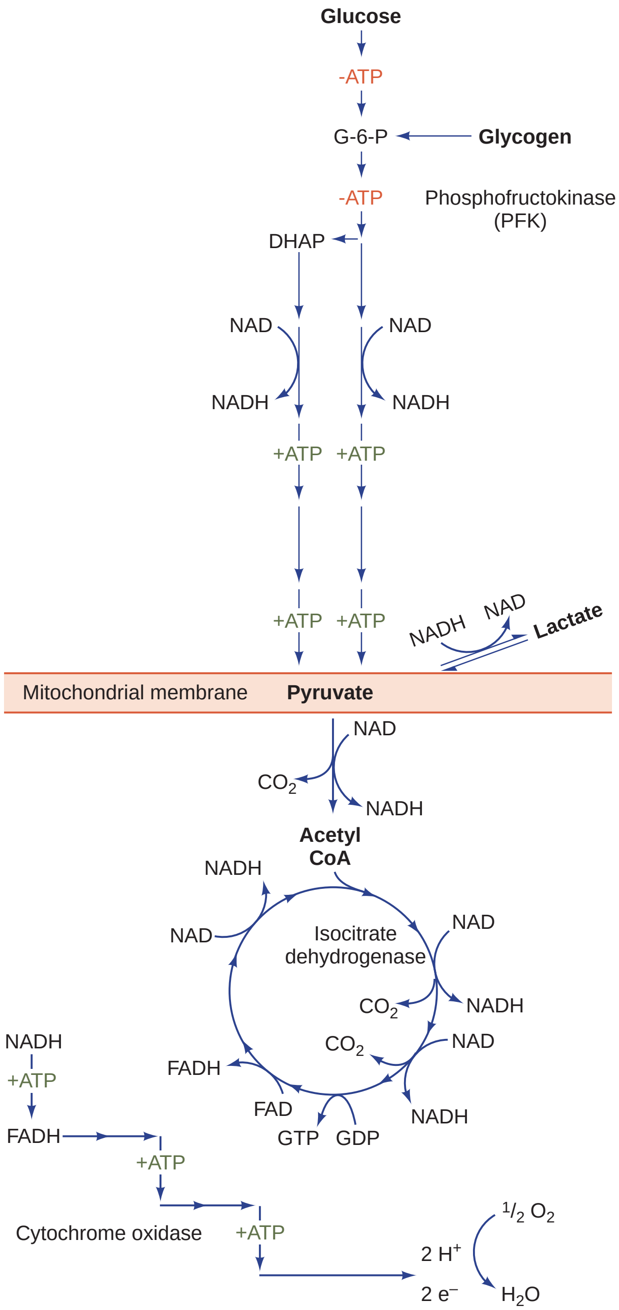
In glycolysis, glucose is broken down in a series of chemical steps to form pyruvate, often referred to as a glycolytic intermediate. From pyruvate, the completion of the metabolism of glucose follows one of two pathways: conversion to lactate (anaerobic glycolysis) or oxidation of pyruvate in the mitochondria (oxidative phosphorylation) (Figure 4.9 and Appendix J). How glucose is metabolized is dependent upon a variety of factors: the type of cell, the enzymatic capability of the cell, energy state, hormonal status, training history, and intensity of exercise.

Certain types of cells are more likely to use glucose anaerobically and as a result produce lactate. Some cells lack the organelles or enzymatic capability to oxidize glucose. For example, erythrocytes (red blood cells) have no mitochondria and are therefore incapable of metabolizing glucose aerobically; they derive their energy from anaerobic glycolysis. Fast-twitch muscle fibers do contain mitochondria and the inherent oxidative enzymes, yet they are biased to use glucose anaerobically. They contain a highly active form of lactate dehydrogenase (LDH), the enzyme that catalyzes the conversion of pyruvate to lactate, and are thus likely to use anaerobic glycolysis even when oxygen delivery to the cell is sufficient. Fast-twitch muscle fibers are also typically not recruited for use until exercise intensity is relatively high, indicating that the energy need of the muscle cells is high, further favoring the use of a more rapid energy-producing system such as anaerobic glycolysis.

Cells in the body that are considered to be highly aerobic (e.g., heart muscle cells, slow-twitch muscle fibers) will predominately metabolize glucose aerobically via oxidative phosphorylation. Glucose taken up into these cells will proceed through the steps of glycolysis to pyruvate. Pyruvate is then transported into mitochondria where it is oxidized in the steps of the Krebs cycle, and energy (i.e., ATP) is ultimately produced via the electron transport chain.

THE STORAGE OF GLUCOSE AS GLYCOGEN

If the immediate energy needs of a cell are low, glucose is often stored in the form of glycogen for future use. As shown in Figure 4.3, glycogen is a series of glucose molecules that have been linked chemically. Glycogen can be stored in many types of cells, but two of the major storage



G-6-P = glucose-6-phosphate
ATP = adenosine triphosphate
DHAP = dihydroxyacetone phosphate

NAD = nicotinamide adenine dinucleotide
NADH = reduced form of NAD
GDP = guanosine diphosphate

GTP = guanosine triphosphate
FAD = flavin adenine dinucleotide
FADH = reduced form of FAD

Figure 4.9 Metabolism of Carbohydrate

Glucose or glycogen is broken down to pyruvate and is either converted to lactate (anaerobic metabolism) or is oxidized (aerobic metabolism).

sites for carbohydrate in the body are skeletal muscle and liver. By far, the largest amount of glycogen is stored in skeletal muscle, approximately 400 g in the average-sized person, with approximately 90 g of glycogen stored in the liver of a person in a rested, well-fed state.

The pathway to glycogen formation is favored when conditions exist to activate the primary enzyme that controls this process, **glycogen synthase.** Glycogen storage is favored when the energy need of the cell is low and insulin is elevated, as occurs when a person is resting after a meal, particularly a meal that contains carbohydrate. Glycogen synthesis is further enhanced in muscle when glycogen stores have been reduced through exercise. Thus, athletes who exercise regularly and consume sufficient carbohydrate typically have higher muscle glycogen levels at rest than sedentary people.

THE CONVERSION OF EXCESS GLUCOSE TO FAT

For the athlete or physically active person, the majority of carbohydrate that is consumed is either stored as glycogen or metabolized. However, carbohydrate that is consumed in amounts in excess of what can be stored as glycogen can be converted to other stored forms of energy, namely fat. The term for the synthesis of fatty acids is **lipogenesis.**

As discussed in Chapters 3 and 6, fats that are used by the body for energy are composed of long chains of carbon molecules. The fatty-acid chains most commonly used by humans for metabolism contain either 16 or 18 carbons. They are synthesized by attaching carbons two at a time in the form of acetyl CoA until a chain of 16 or 18 carbons is formed. Lipogenesis takes place in the liver or in adipocytes (fat cells).

Excess glucose can be taken up by the liver or adipocytes, and through glycolysis, can be a source of acetyl CoA for fatty-acid synthesis. The chemical pathway is somewhat indirect, but acetyl CoA formed from glucose can be used to synthesize fatty-acid chains. Fatty-acid chains can be attached in groups of three to a glycerol molecule to form a triglyceride, which is the major storage form of fat in the body. Excess glucose can also be used as a source to form glycerol that can be used in triglyceride synthesis.

Athletes who consume a high-carbohydrate diet based upon their training demands (within their total caloric needs for the day) typically do not need to worry about the formation of fat from carbohydrate because they are not consuming *excess* carbohydrate. Exercise and training result in decreases in muscle glycogen, which then stimulates the storage of dietary carbohydrate as glycogen. Consumption of a high-carbohydrate diet also stimulates the body to favor the metabolism of a higher percentage of carbohydrate than fat at rest, so a larger proportion of the dietary carbohydrate consumed is metabolized. Athletes need to be aware, however, of excess carbohydrate intake during periods when training intensity, frequency, and/or duration is decreased, such as during the off-season or when injured. The primary population that needs to be concerned about lipogenesis from excess carbohydrate intake is the sedentary population that is consuming too many kilocalories and excess carbohydrate.

GLUCONEOGENESIS: PRODUCING GLUCOSE FROM LACTATE, AMINO ACIDS, AND GLYCEROL

While most of the body's glucose needs are supplied by dietary carbohydrate, the body does have a limited ability to produce glucose from other sources. The process of producing glucose from other sources is called **gluconeogenesis.** The major sources for the production of glucose are lactate, amino acids, and glycerol. The production of glucose from lactate was outlined in Chapter 3.

During periods of fasting or starvation, proteins in the body can be broken down into amino acids, which can then be metabolized (see Chapter 3). Amino acids that can be converted to certain intermediates in glycolysis or the Krebs cycle can also be used in gluconeogenesis to form glucose in the liver. Alanine is an example of an amino acid that can be used to form glucose. In fact, 18 of the 20 amino acids are biochemically capable of being converted to glucose.

When stored triglycerides are broken down, the fatty-acid chains and glycerol can be metabolized for energy. Glycerol can be converted to an intermediate in glycolysis, and can be used to form glucose via gluconeogenesis. This occurs in the liver. However, the liver has a limited capacity to form glucose from glycerol in this way. Therefore, the major sources for glucose formation by gluconeogenesis are lactate and amino acids.

What's the point? Glucose can be metabolized immediately for energy or stored as glycogen for future use as energy. The body can synthesize fatty acids from excess glucose, a problem for inactive people who consume too many kilocalories and excess carbohydrate. The body also has a limited ability to produce glucose from lactate, amino acids, and glycerol.

Glycogen synthase: The primary enzyme that controls the process of glycogen formation.

Lipogenesis: The production of fat.

Gluconeogenesis: The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

Carbohydrates as a Source of Energy for Exercise

As discussed in Chapter 3, muscle can use a variety of fuel sources to provide the energy necessary for exercise (e.g., creatine phosphate, carbohydrates, fats, and/or proteins). The fuel source utilized depends on a variety of factors, with exercise intensity playing a major role. Very-high-intensity, very-short-duration anaerobic exercise typically uses creatine phosphate as the energy source to replenish ATP. Carbohydrate is used as the predominant source of energy via anaerobic glycolysis during high-intensity, short-duration anaerobic exercise or through oxidative phosphorylation during moderate- to high-intensity aerobic exercise.

Carbohydrate used by exercising muscle can come from stored muscle glycogen or from glucose that is brought into the muscle from the blood. Glucose is made available in the blood from the liver as a result of at least three processes: the breakdown of liver glycogen, the production of glucose from other sources (gluconeogenesis), or the ingestion of carbohydrates as food or fluids, which are absorbed and passed through the liver.

USE OF MUSCLE GLYCOGEN

Exercising muscle preferentially uses carbohydrate from stored glycogen. A study conducted by Bergström and Hultman (1967) has become the classic description of muscle glycogen utilization during exercise. Subjects rode on a cycle ergometer at a moderately hard aerobic intensity and their muscle glycogen utilization was determined every 15 minutes by muscle biopsy. Results of this study clearly show the decline in muscle glycogen as exercise time progressed (see Figure 4.10). After 60 minutes of exercise, muscle glycogen fell to very low levels that corresponded with fatigue, an inability of the subjects to complete the next 15 minute exercise period. Although not shown in Figure 4.10, the study also demonstrated that the rate of muscle glycogen usage was related to exercise intensity; muscle glycogen was used at a higher rate at higher exercise intensities.

The results of the Bergström and Hultman study, as well as many subsequent studies, demonstrate that muscle glycogen is a primary source of energy during moderate to intense aerobic exercise and during higher intensity, repeated intervals. Muscle glycogen depletion is associated with fatigue during prolonged endurance exercise and can often occur in intermittent high-intensity exercise, such as the repeated sprints that occur during soccer matches.

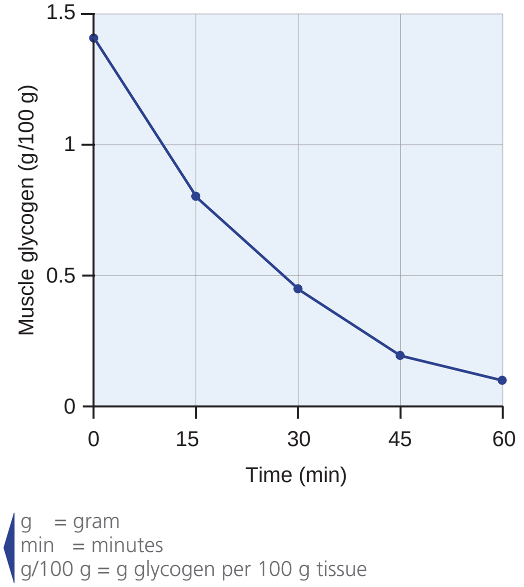
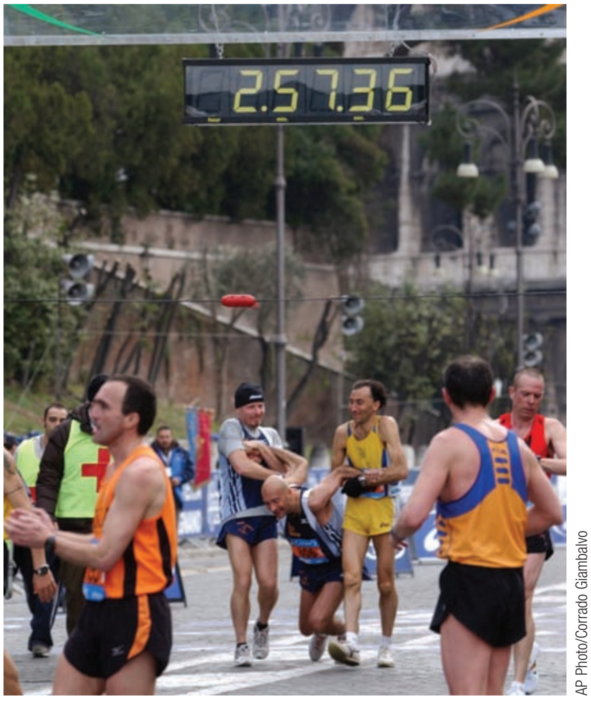


Figure 4.10 Muscle Glycogen Utilization during Exercise

Subjects rode at a hard aerobic intensity on a cycle ergometer and had their muscle glycogen measured at 15-minute intervals. Subjects repeated the 15-minute intervals until they were too fatigued to continue at the required intensity, which corresponded to a very low muscle glycogen concentration. Redrawn from: Bergström, J. and Hultman, E. (1967). A study of the glycogen metabolism during exercise in man. *Scandinavian Journal of Clinical Laboratory Investigation,* 19, 218–228.



AP Photo/Corrado Giambalvo

Low muscle glycogen stores can lead to fatigue in prolonged endurance events such as a marathon.

USE OF BLOOD GLUCOSE

Exercise stimulates the uptake of glucose from the blood because it has a very strong insulin-like effect. As glucose is being taken out of the blood by exercising muscle, a fall in blood glucose is prevented by two metabolic adjustments, both stimulated by the release of the hormone glucagon by the pancreas. Liver glycogen is broken down and released into the blood as glucose, a process called **glycogenolysis.** Glucagon also stimulates the process of gluconeogenesis by the liver to make glucose available to maintain blood glucose. Initially, this response acts to maintain or even slightly elevate blood glucose, but if exercise continues for a prolonged duration, reductions in blood glucose may occur as liver glycogen is reduced and gluconeogenesis fails to produce glucose at the rate that it is being utilized.

Although the exercising muscles begin to take up and use glucose, they rely most heavily on muscle glycogen if sufficient stores are available. An excellent example of this preference for glycogen over glucose is illustrated by the study of Coyle et al. (1986) in which muscle glycogen and blood glucose concentrations were determined when well-trained cyclists rode a prolonged endurance trial at a relatively hard aerobic intensity (see Figure 4.11). During the trial when subjects consumed only a placebo beverage, blood glucose eventually began to fall and fatigue was associated with the point at which muscle glycogen fell to a very low concentration. In a subsequent cycling trial, the subjects consumed a carbohydrate drink that resulted in maintenance of blood glucose throughout the exercise trial. Muscle glycogen utilization was no different from that during the placebo trial, however, indicating a preference to use muscle glycogen even when blood glucose remained high.

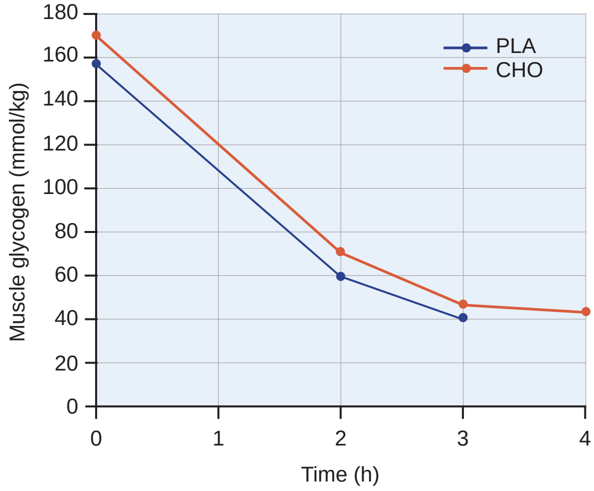


Figure 4.11 Muscle glycogen usage when carbohydrate is consumed during exercise.

Well-trained, competitive cyclists rode at a hard aerobic intensity while consuming either a carbohydrate drink or a placebo beverage. Muscle glycogen utilization was the same regardless of the carbohydrate intake during the ride. When consuming the placebo, the cyclists fatigued at the three-hour time point, but when they consumed carbohydrate, they were able to maintain this exercise intensity for an additional hour. Redrawn from: Coyle, E.F., Coggan, A.R., Hemmert, M.K., and Ivy, J.L. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology,* 61, 165–172.

EFFECTS OF TRAINING ON CARBOHYRATE USAGE

Regular exercise training, specifically aerobic training, stimulates an increase in the oxidative (aerobic) capacity of muscle, primarily through an increase in the number and size of mitochondria and an increase in oxidative enzyme activity. This increase in oxidative capacity increases the muscle's maximal capacity to utilize carbohydrates and to oxidize lactate. When a person increases exercise intensity to the same relative level (e.g., to the same percentage of maximum aerobic capacity), the utilization of carbohydrate as a percentage of the total energy expenditure is approximately the same.

The increase in ability to metabolize carbohydrate is due mostly to the increased oxidative or aerobic capacity of the muscle. The activity of the enzymes catalyzing the anaerobic pathway, glycolysis, do not change much, probably because they are already at a high level of intrinsic activity in the muscle before training. Another adaptation that increases the muscle's total capacity to utilize carbohydrate is the increase in stored muscle glycogen as a result of regular exercise training. As demonstrated elegantly in a one-legged cycling study by Bergström and Hultman (1966), muscles that exercised and reduced muscle glycogen synthesized and stored significantly more glycogen afterwards than the leg muscles that were not exercised. Resting muscle glycogen levels in average, sedentary adults are approximately 20–30 percent lower than those of trained athletes.

The increase in oxidative capacity due to aerobic exercise training also increases the ability of the muscle to metabolize fat for energy. Therefore, after weeks to months of aerobic exercise training, it is common for a person exercising at the same absolute intensity (e.g., the same running pace) to metabolize less carbohydrate

Glycogenolysis: The breakdown of liver glycogen to glucose and the release of that glucose into the blood. -lysis = the process of disintegration.

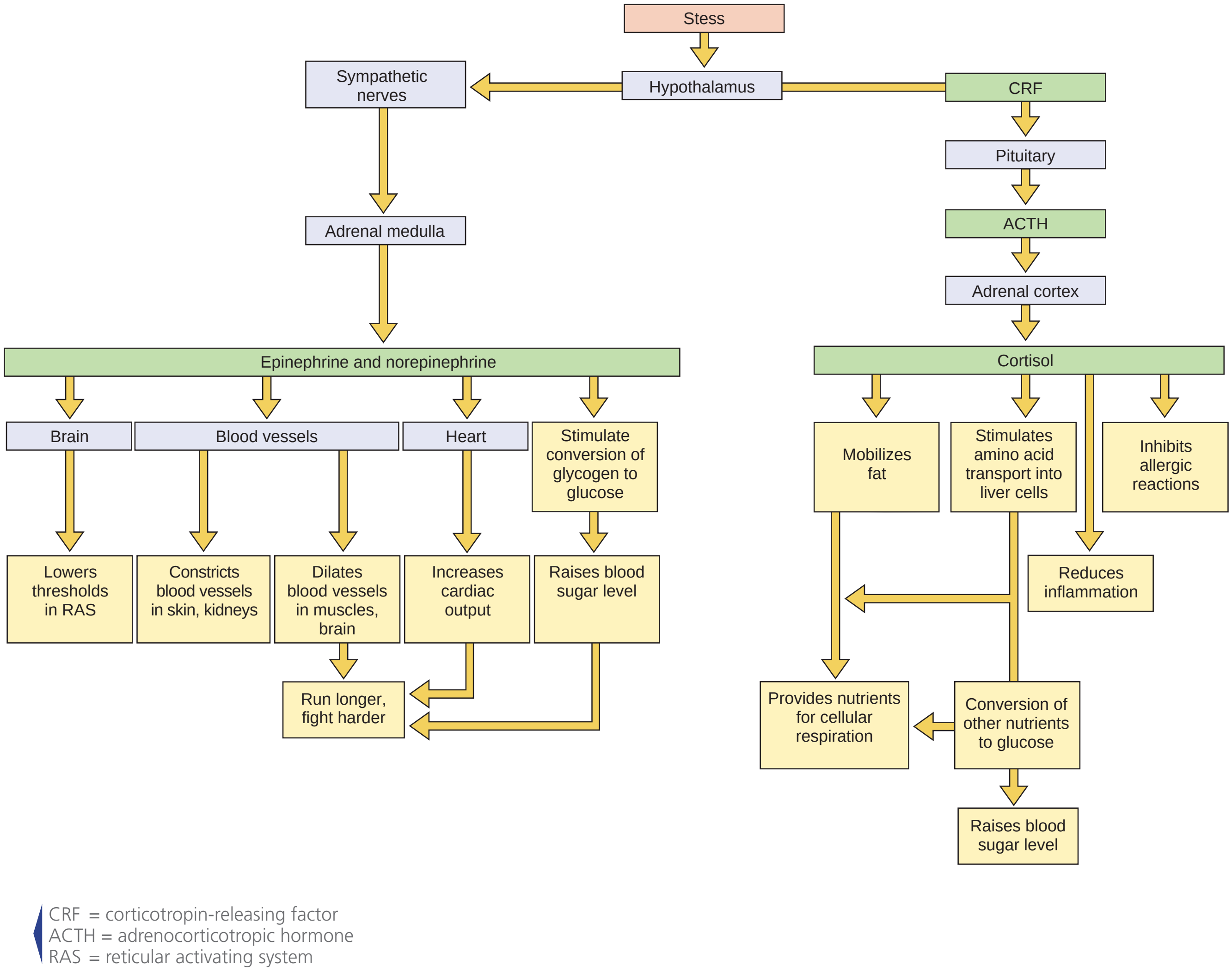


Figure 4.12 Physiological Response to Stress

and more fat (fat metabolism will be explained in greater detail in Chapter 6).

HORMONAL RGULATION OF GLUCOSE METABOLISM DURING EXERCISE

Glucose metabolism during exercise is regulated by several overlapping or redundant hormonal mechanisms. Glucagon is a hormone secreted by the alpha (α) cells of the pancreas that is a counter-regulatory hormone to insulin. It stimulates essentially the opposite effect of insulin (i.e., glycogen breakdown instead of glycogen synthesis). Glucagon is secreted during periods of fasting or starvation, and exercise is metabolically similar to these conditions. During exercise, insulin secretion is suppressed and glucagon secretion is stimulated.

Glucagon stimulates glycogen breakdown in the liver and the release of glucose into the blood, thus acting to maintain or increase blood glucose. It also stimulates the process of gluconeogenesis by the liver, in which the liver can take precursors such as lactate or amino acids and make new glucose that can subsequently be released into the blood. This process begins early in exercise and can be thought of as a preemptive response to prevent a fall in blood glucose, rather than as a reactive response to blood glucose declining (one of the rare feed-forward mechanisms in the body, which usually operate in a feedback fashion).

The stress of higher exercise intensity results in a substantial stimulation of the sympathetic nervous system; this leads to a release of two important stress hormones, the catecholamines epinephrine and norepinephrine. Epinephrine (also known as adrenaline) is secreted from the adrenal glands, while the majority of the norepinephrine originates from the nerve endings of sympathetic nervous system cells. The catecholamines also stimulate glycogen breakdown and gluconeogenesis and thus provide an additional mechanism to regulate blood glucose. Another stress hormone, cortisol, aids blood glucose regulation indirectly by stimulating the breakdown of proteins into amino acids that may be used in gluconeogenesis (Figure 4.12).

INFLUENCE OF EXERCISE INTENSITY AND DURATION

Exercise intensity and duration have a substantial effect on metabolism, both on the metabolic rate and on the source of fuel utilized. Carbohydrates, fats, and proteins can be utilized as sources of energy for metabolism and are used in different proportions under different conditions. As exercise intensity increases, the proportion of energy that is derived from fat decreases and the proportion from carbohydrate increases. Therefore, carbohydrate is the main source of energy for moderate- to high-intensity exercise. The interplay between carbohydrate and fat metabolism is complex and is discussed in greater detail in Chapters 3 and 6. Proteins normally make up a small percentage of energy metabolism and is discussed in more detail in Chapter 5.

What's the point? Exercise creates a similar hormonal response to starvation and stress. Exercise results in a suppression of insulin and elevated concentrations of glucagon, cortisol, epinephrine, and norepinephrine, which, when combined, act to make the body's stored nutrients available for metabolism.

Carbohydrate Recommendations for Athletes

It has been established that carbohydrate exists in a variety of different forms in food and is an extremely important source of energy for exercise, sports training, and performance. How much carbohydrate should an athlete eat? What types of carbohydrate should be consumed? Given the specific recommendations for carbohydrate consumption, what are the practical applications for athletes with different training and competitive requirements? This section focuses on the answers to these questions.

RECOMMENDED TOTAL DAILY CARBOHYDRATE INTAKE FOR ATHLETES IN TRAINING

The current recommendation for total carbohydrate intake for athletes in training is 5 to 10 g/kg body weight daily (American Dietetic Association, 2000; Burke et al., 2001). This recommendation assumes that energy (caloric) intake is adequate. This broad recommendation should be fine-tuned to meet the individual needs of the athlete based on the intensity and duration of training as shown in Table 4.3. Further adjustments to the general recommendation may be made based on body size, gender, and the amount of dietary proteins and fats needed.

Athletes must consume enough carbohydrates daily to replenish muscle glycogen used during training. Prolonged moderate-intensity exercise, such as distance running and distance cycling, depletes muscle glycogen, and studies have shown that at least 5 g/kg/d is needed to replenish it to a level that allows for training on consecutive days (Sherman et al., 1993). However, an intake of 5 to 7 g/kg/d does not restore muscle glycogen levels of endurance athletes to pre-exercise or near maximum capacity. Endurance athletes need to consume 8 to 10 g/kg/d to maintain high levels of muscle glycogen over weeks and months of training (Sherman et al., 1993).

The majority of studies conducted on muscle glycogen depletion and replenishment have used endurance athletes as subjects (Jacobs and Sherman, 1999). The body of scientific literature clearly shows that prolonged endurance exercise depletes muscle glycogen and daily carbohydrate intake is needed to restore it. What about athletes in other sports? Limited studies have shown that the recommendations made for endurance athletes also apply to athletes in intermittent, high-intensity sports such as soccer and ice hockey (Bangsbo, Norregaard, and Thorsoe, 1992; Akermark et al., 1996; Balsom et al., 1999). The depletion of muscle glycogen when performing intermittent, high-intensity exercise during practice and games is similar to the depletion seen after prolonged moderate-intensity exercise.

Sprinters, weight lifters, and hurdlers are examples of athletes who perform very-high-intensity exercise for a very short period of time. Muscle glycogen is reduced during training and competition, but it can typically be restored with a moderate carbohydrate intake (i.e., 5 to 7 g/kg/d). There is no evidence that athletes who depend on strength and power but not endurance would benefit from high-carbohydrate diets (i.e., >8 g/kg) on a daily basis (Lamb et al., 1990; Vandenberghe et al., 1995).

The needs of **ultraendurance** athletes may, at times, exceed the general range for daily carbohydrate intake for other athletes. Examples of ultraendurance sports include Ironman® triathlons and multiple-day cycling events (stage races) such as the Tour de France. These are grueling events that require huge amounts of energy, much of which comes from muscle glycogen. Ultraendurance athletes may need between 10 and 19 g/kg daily because of the higher carbohydrate needs associated with heavy training and ultraendurance competitions (Burke, Kiens, and Ivy, 2004; Seebohar, 2006). It should be noted that these carbohydrate recommendations are very high and can be difficult for ultraendurance athletes to meet. They must eat frequently while awake and may need to consume carbohydrate during the night (e.g., after waking to go to the bathroom or setting the alarm during

Ultraendurance: Very prolonged endurance activities such as the Ironman-length triathlons. Ultra = excessive.

Table 4.3 General Carbohydrate Recommendations Based on Exercise Intensity and Duration

Exercise Intensity and Duration	Examples of Sports	Daily Carbohydrate Recommendation (Energy intake must be adequate)
Very high intensity, very short duration (less than 1 minute)	Field events such as shot put, discus, or high jump Track sprints (50–200 m) Swimming sprints (50 m) Sprint cycling (200 m) Weightlifting Power lifting Bobsled (running start)	5–7 g/kg
High intensity, short duration (1 to 30 minutes continuous)	Track (200 to 1,500 m) Swimming (100 to 1,500 m) Cycling (short distance) Rowing (crew) Canoeing/Kayaking (racing) Skiing (downhill racing) Figure skating Mountain biking	5–7 g/kg
High intensity, short duration (1 to 30 minutes with some rest periods)	Gymnastics Wrestling Boxing Fencing Judo Tae kwon do	5–8 g/kg
Moderate intensity, moderate duration (30 to 60 minutes)	10 km running (elite runners finish in < 30 minutes)	6–8 g/kg
Intermittent high intensity, moderate to long duration (more than 1 hour)	Soccer (football) Basketball Ice hockey Field hockey Lacrosse Tennis Water polo	6–8 g/kg; 8 to 10 g/kg during heavy training and competition
Moderate intensity, long duration (1 to 4 hours)	Distance running (marathon) Distance swimming Distance cycling Nordic (cross country) skiing	8–10 g/kg during periods of heavy training and competition
Moderate intensity, ultralong duration (more than 4 hours)	Ultradistance running Ultradistance swimming Ultradistance cycling Triathlon Adventure sports	8–19 g/kg depending on the stage of training
Low intensity, long duration (more than 1 hour)	Golf Baseball Softball	5–7 g/kg
Other	Bodybuilding American football	5–10 g/kg depending on the stage of training 5–8 g/kg; Varies according to position

Legend: m = meter; g/kg = gram per kilogram body weight; km = kilometer

Dunford, M. Ed., (2006). *Sports Nutrition: A Practical Manual for Professionals.* Chicago: American Dietetic Association.

the night to wake and eat). In addition to carbohydrate-containing meals, ultraendurance athletes may include sports bars, beverages, and gels before, during, and after training to try and reach their daily carbohydrate goals.

Expressing Carbohydrate Recommendations. All of the carbohydrate recommendations for athletes mentioned so far in this text have been expressed on a gram per kilogram body weight basis (g/kg). In other words, recommendations are stated as an absolute amount of carbohydrate. Recommendations may also be stated as a relative amount—a percent of total energy intake (e.g., 70 percent of total kilocalories as carbohydrate).

Recommendations given as a percentage, relative to the amount of energy consumed, can be misinterpreted. For example, a female endurance athlete states that she consumes a high-carbohydrate diet consisting of 70 percent of her total calories as carbohydrate. Is this an adequate amount? It depends on whether she consumes enough energy, as shown in Table 4.4. This example shows how an athlete could meet the *percentage* of carbohydrate recommended, but fall short of the minimum *amount* of carbohydrate recommended. Also notice in this example both athletes state that they consume a "high" carbohydrate diet. High and low are relative terms and unless such terms are defined, using these words to describe dietary carbohydrate intake can be misleading. To avoid misinterpretations, it is best to express recommendations on an absolute basis: grams of carbohydrate per kilogram body weight (g/kg). However, it is not uncommon to see carbohydrate recommendations made to athletes as a percentage of total kilocalories. The usual recommendation for most athletes is 50–65 percent of total caloric intake, increasing to 70 percent for those athletes with higher carbohydrate needs (e.g., athletes in endurance sports). These percentages assume that total daily energy intake is adequate.

Table 4.4 Two 70 percent Carbohydrate Diets Compared

	Jennifer	Liza
Total carbohydrate intake	350 g	245 g
Total energy intake	2,000 kcal	1,400 kcal
% energy intake as carbohydrate	70 ("high")	70 ("high")
Carbohydrate (g) per kg of body weight	6.4 g/kg	4.5 g/kg

Is a 70 percent carbohydrate diet adequate? In this example, two female athletes, Jennifer and Liza, both weigh 121 pounds (55 kg). Each correctly states that she is consuming a diet consisting of 70 percent carbohydrate. Each also states that she is consuming a "high" carbohydrate diet. When their actual intakes are compared, the differences between these two diets are dramatic. In Jennifer's case, the answer to the question, "Is a 70 percent carbohydrate diet adequate?" is yes. In Liza's case, the answer is no. Liza's carbohydrate intake is high in relation to her caloric intake, but because her caloric intake is so low, her carbohydrate intake is below the minimum recommended for athletes.

RECOMMENDED AMOUNT AND TIMING OF CARBOHYDRATE INTAKE BEFORE, DURING, AND AFTER TRAINING OR COMPETITION

Once the daily carbohydrate need is established, the focus turns to dividing the total carbohydrate intake appropriately over the course of the day. The athlete's training and conditioning program and the unique demands of the competitive environment before, during, and after exercise will dictate the amount and timing of carbohydrate intake.

Intake Prior to Training and Competition. The dietary goals of the athlete prior to exercise include avoiding hunger, delaying fatigue, minimizing gastrointestinal distress, and preventing **hypohydration** (below a normal state of hydration). With the exception of preventing hypohydration, all of these goals involve carbohydrate. Athletes should determine both the amount and timing of carbohydrate consumption (as well as proteins, fats, and fluids) needed to support exercise. For most athletes, dietary intake training becomes the basis for fine-tuning the amount and timing of carbohydrate and other nutrients consumed prior to competition. Precompetition intake can be tricky because start times for some events may not be known, familiar foods may not be available, environmental conditions may be different from usual training conditions, and the stress of competition may result in increased gastrointestinal distress.

As is the case with total daily carbohydrate recommendations, the majority of research on pre-exercise carbohydrate intake has been conducted on endurance athletes while training. Studies show that carbohydrate intake up to three or four hours prior to endurance exercise is beneficial (Hargreaves, Hawley, and Jeukendrup, 2004). Muscle glycogen stores have been replenished with carbohydrates consumed over the past 24-hours, so the benefit comes primarily from enhanced liver glycogen and the glucose that eventually appears in the blood after the breakdown of the carbohydrates in the pre-exercise meal. The effect is similar to "topping off" a car's gas tank before starting on a long trip. Pre-exercise carbohydrates are also recommended for athletes in intermittent high-intensity sports such as soccer. Food intake prior to very-high-intensity short duration sports such as sprinting has not been studied extensively because no performance benefit would be expected. However, most athletes do eat between one and four hours prior to exercise to avoid hunger and to ensure that they consume sufficient carbohydrates over the course of the day.

The amount of carbohydrate in the pre-exercise meal depends upon how close the meal is consumed to the start of exercise. Gastrointestinal distress can be caused by exercise, especially at the intensities at which athletes train and compete, because blood flow to the gastrointestinal tract is reduced. It is

Hypohydration: An insufficient amount of water; below the normal state of hydration.

recommended that approximately 1 g of carbohydrate per kilogram body weight (1 g/kg) be consumed one hour prior to exercise. As the time before exercise increases, the amount of carbohydrate can be increased; for example, two hours prior to exercise, 2 g of carbohydrate per kilogram body weight can typically be tolerated (Coleman, 2006). Larger amounts of carbohydrate (e.g., 3–4.5 g/kg eaten 3–4 hours prior to exercise) may be appropriate for athletes under certain circumstances and will depend on the athlete's tolerance. The adjustment of carbohydrate amount based on time prior to exercise helps athletes prevent gastrointestinal distress and avoid hunger.

An active area of research regarding endurance athletes is whether low glycemic index foods are preferred for a precompetition meal. Most of the studies have been conducted on trained distance cyclists who consumed 1 g/kg low GI carbohydrate approximately one hour before exercise. Some studies showed low GI carbohydrates to be beneficial because blood glucose concentrations were maintained during one to two hours of exercise due to the slow absorption of glucose from the low GI carbohydrate. Other studies did not find a benefit, but no studies found that low GI foods were detrimental (Siu and Wong, 2004). Although the research is not conclusive, some endurance athletes include low GI carbohydrate-containing foods as part of their pre-exercise meal.

In the past, athletes were advised against the consumption of high glycemic carbohydrates (e.g., sugar, white bread, sugary cereals, and many sports drinks) in the one-hour period prior to exercise (Foster, Costill, and Fink, 1979). It was speculated that the ingestion of a high glycemic food resulted in high blood glucose and insulin concentrations that in turn caused low blood glucose with the onset of exercise. But subsequent research demonstrated that high GI carbohydrates are not a problem for the majority of athletes (Sherman, Peden, and Wright, 1991). Exercise has a very strong insulin-like effect, that is, it stimulates glucose uptake. If exercise is initiated at the time insulin is high and blood glucose is being lowered, the additional glucose uptake by exercising muscles could result in blood glucose being temporarily lowered too much. For most endurance athletes, the effect of high GI foods on blood glucose would be transient and the body would reestablish a normal blood glucose concentration as it usually does during exercise. Thus, performance would not likely be impaired.

However, a small number of athletes may be prone to reactive (rebound) hypoglycemia, a low blood glucose concentration that follows food intake. When these athletes consume a food with a high glycemic index one hour or less before prolonged exercise, blood glucose and insulin concentrations rise rapidly, which then shortly results in low blood glucose (hypoglycemia). The reestablishment of a blood glucose concentration within the normal range takes longer and performance may be affected. Athletes who respond in this way will need to experiment with the amount and timing of high glycemic index foods prior to exercise (Hargreaves, Hawley, and Jeukendrup, 2004).

The timing of the carbohydrate meal before exercise is a major issue when considering recommendations about the glycemic nature of the meal and its potential impact on performance. Virtually every study that has shown a detrimental impact of high GI meals on endurance performance has been timed so that the meal was consumed 45 to 60 minutes before exercise. From a practical perspective, few athletes would consume a meal this close to a competitive event or hard training session. Two or more hours is a more likely time period for food consumption prior to exercise for most athletes because of concerns of gastrointestinal upset during exercise. Whether a high or low glycemic meal is consumed several hours before exercise, insulin and blood glucose have usually returned to normal during this time frame. The bottom line: for most athletes the glycemic index of the pre-exercise meal should rarely be of concern.

Athletes need fluid prior to exercise, thus liquid pre-exercise meals that contain carbohydrates are popular. Liquid meals may also be better tolerated since they move out of the stomach and into the gastrointestinal tract faster than most solid meals. Tolerability is always important but is especially so prior to competition when the gastrointestinal tract is prone to additional upset due to psychological stress and nervousness.

The pre-exercise meal is important but it cannot completely offset the lack of muscle and liver glycogen that results from repeated days of insufficient carbohydrate intake. For athletes who restrict carbohydrates and energy to compete in a specific weight category (e.g., wrestlers, lightweight rowers, kick boxers), the precompetition meal does provide an opportunity to replenish some glycogen stores and to increase blood glucose concentrations. However, the time between weight certification and the start of the competition is probably too short to adequately replenish depleted glycogen stores. Nonetheless, these athletes try to consume as much carbohydrate prior to competition as they can tolerate.

Intake during Training and Competition. Athletes who perform endurance exercise or intermittent high-intensity exercise for more than one hour are at risk for glycogen depletion, hypoglycemia, and fatigue during training and competition (Coyle, 2004). Ultra-distance racers, triathletes, marathon runners, distance cyclists, and other long-duration athletes must consume both carbohydrates and fluids during heavy training and competition or they may fail to finish. Although the need is not


JOEL SAGET/AFP/Getty Images

While racing, Lance Armstrong (wearing the yellow jersey) eats a banana, which provides carbohydrates.

as great, intermittent high-intensity athletes such as soccer and basketball players also benefit from carbohydrate (and fluid) intake during practices and games. Carbohydrate intake during training and competition helps these athletes to spare muscle glycogen, maintain blood glucose concentrations, and delay fatigue.

It is recommended that 30 to 60 g of carbohydrate be consumed each hour during prolonged exercise either as fluid or food (Coleman, 2006). This recommendation is based on the cumulative results of research studies (reviewed by Coyle, 2004) and the maximum rate of glucose absorption from the gastrointestinal tract, which is estimated to be 1 g/min or 60 g/hour (Guezennec, 1995). Too great a carbohydrate concentration will slow gastric emptying (i.e., how quickly the contents of the stomach pass into the intestine). During exercise many athletes consume beverages (sports drinks) that contain 6 to 8 percent carbohydrate. At those concentrations, 1,000 ml (a little more than four 8-ounce cups) would contain 60 to 80 g of carbohydrate. There has been speculation that moderate- to high-glycemic index foods are beneficial during prolonged exercise because such foods are rapidly digested and absorbed (Burke, Collier, and Hargreaves, 1998). However, there is a lack of scientific studies to confirm or dispute the benefits of moderate or high GI foods during exercise greater than one hour.

Intake after Training and Competition. Long, intense training sessions or competitive events may leave athletes with substantially reduced or depleted liver and muscle glycogen stores. Athletes need to consider a variety of factors to optimally replenish those stores. As discussed earlier, one of the conditions that stimulate the synthesis of glycogen is its depletion. Some muscle glycogen may be resynthesized after hard exercise even if the athlete does not eat, although the amount is minimal. The glucose used for glycogen synthesis in this case comes from the liver through gluconeogenesis, particularly from lactate. To optimize glycogen replacement, however, two things are needed: carbohydrate and insulin.

Glucose molecules are needed to re-form the glycogen chains and are typically obtained by consuming carbohydrate-rich foods. Insulin plays an important role by facilitating uptake of glucose into muscle cells and by activating the enzyme principally responsible for glycogen resynthesis, glycogen synthase. Consumption of foods or beverages containing carbohydrate provides the source of glucose and will also stimulate the release of insulin from the pancreas. A substantial amount of research supports the following guidelines for optimal muscle glycogen resynthesis:

Timing—To maximize the rate at which muscle glycogen is replaced, carbohydrate should be consumed as soon after the exercise bout as possible. Studies show that waiting as little as two hours after exercise to begin consuming carbohydrate will significantly slow the rate of muscle glycogen resynthesis (Ivy, Katz et al., 1988). Athletes should therefore begin consuming carbohydrate as soon as is practical after the exercise session or competition is over.

Meal size—Consumption of carbohydrate in smaller, more frequent meals appears to further aid the rate at which muscle glycogen is replaced in the hours after exercise (Doyle, Sherman, and Strauss, 1993). With large single meals, blood glucose and insulin rise rapidly and then return to baseline relatively quickly. Elevations in blood glucose and insulin can be sustained for a longer period of time with smaller, more frequent feedings, which maintains the appropriate environment for muscle glycogen synthesis. It is also likely to be more palatable for the athlete to consume smaller amounts of food and/or beverages over several hours than trying to consume a large meal soon after fatiguing exercise.

Type of carbohydrate—Carbohydrate beverages that are consumed after exercise to replace glycogen should contain mostly glucose and/or sucrose as the carbohydrate source. Studies clearly show that beverages containing mostly fructose do not result in glycogen synthesis rates that are as high as those beverages with glucose and sucrose (Blom et al., 1987). Athletes may consume fructose because it is found naturally in fruit juices and because it is often added to beverages to enhance flavor and sweetness. However, fructose-containing beverages should not be the primary recovery beverage because of the reduced effect on muscle glycogen resynthesis and the potential for gastrointestinal upset.

While carbohydrate beverages may be adequate for glycogen recovery, athletes may be hungry after a hard workout or competition and may prefer to consume solid food. It has been shown that solid foods that

Sports Drinks, Bars, and Gels

Manipulation of carbohydrate intake during exercise to improve performance has been studied extensively, particularly for endurance or intermittent high-intensity sports or activities. Numerous research studies have sought to determine the optimal amount, type, form, concentration, and timing of carbohydrate intake during exercise. The results of these studies have led to the development and marketing of a variety of commercially available carbohydrate products intended for use during exercise.

The first "sports drink" (Gatorade®) was developed with a dual purpose—fluid and electrolyte replacement for sweating athletes along with energy replacement. Gastric emptying, and therefore water absorption, may be hampered by too much carbohydrate in the beverage, so many sports drinks are formulated to provide carbohydrate in a concentration that will not interfere with fluid balance and thermoregulation. This aspect of beverages is discussed in more detail in Chapter 7, but Table 4.5 lists some of the carbohydrate-related characteristics of popular sports beverages. Athletes need to be aware of the carbohydrate content of sports beverages so they can consume the recommended amount and type of carbohydrate during exercise.

Sports drinks containing the majority of their carbohydrate in the form of glucose or glucose polymers (maltodextrins) have been shown to have a more beneficial effect on performance than other types of carbohydrates such as fructose. However, a small amount of fructose is usually added to sports drinks to improve their flavor, which may encourage athletes to consume more fluid. Although consuming carbohydrate after fatigue has occurred can be helpful, it is more beneficial to endurance performance to delay fatigue by consuming carbohydrate at the onset of exercise and continuing throughout exercise to maintain blood glucose and carbohydrate availability.

Sandra Mu/Getty Images

Carbohydrate can be consumed during exercise in forms other than a beverage (see Table 4.6). For example, carbohydrate is available in a semiliquid, concentrated gel form. These gels are usually packaged in small pouches or carried in small

Table 4.5 Carbohydrate and Energy Content of Sports Beverages

Beverage	Serving Size (oz)	Energy (kcal)	CHO (source)	CHO (g)	CHO (%)
Hydrade®*	8	55	HFCS	10	4
Gatorade Original Thirst Quencher®	8	50	Sucrose syrup; glucose-fructose syrup	14	6
Gatorade Endurance Formula®	8	50	Sucrose syrup; glucose-fructose syrup	14	6
Accelerade®	8	80	Sucrose, maltodextrin, fructose	14	6
AllSport Body Quencher®	8	60	HFCS	16	7
POWERade®	8	64	HFCS, glucose polymers	17	7

Legend: oz = fluid ounces; kcal = kilocalories; CHO = carbohydrate; g = grams; HFCS = high-fructose corn syrup

Nutrient information was obtained from company websites and product labels.

* Also contains 5.1% glycerol, a sugar alcohol.

Table 4.6 Carbohydrate and Energy Content of Sports Gels and Bars

Food	Serving Size	Energy (kcal)	CHO (source)	CHO (g)	Fiber (g)
Gu Energy Gel®	1 package (32 g)	100	Maltodextrin (glucose polymers)	25	0
Clif Shots®	1 package (32 g)	100	Organic brown rice syrup	25	0
Balance Bar (various flavors)	1 bar	200	High fructose corn syrup, honey, high maltose corn syrup, sugar	22–24	<1–2
Clif Bar® (various flavors)	1 bar	230–250	Brown rice syrup, rolled oats, cane juice, fig paste, and/or dried fruits	44–48	4–5
EAS AdvantEdge Carb Control Bar	1 bar	240	Glycerine, maltitol, maltitol syrup, oligofructose, xylitol*	21	3
EAS AdvantEdge Energy Bar	1 bar	210	High fructose corn syrup, high maltose corn syrup, sugar	27	2
Power Bar	1 bar	230	High fructose corn syrup, fruit juice concentrate	20	3

Legend: kcal = kilocalories; CHO = carbohydrate; g = grams

*Glycerine, maltitol, and xylitol are sugar alcohols.

containers, making the carbohydrate convenient to carry, open, and consume during exercise. A typical packet provides 100 kcal and 25 g of carbohydrate. Two to three packages of gel consumed each hour during prolonged exercise provides the recommended 30–60 g of carbohydrate per hour. Gels are consumed with water, which provides the fluid that will also be needed during exercise.

The carbohydrate used in a product is often chosen because of its glycemic response. Glucose polymers provide a slow, sustained delivery of glucose into the blood. Other products contain sugars such as sucrose that are rapidly absorbed. Some contain sugar alcohols, which are slowly absorbed and have little impact on glucose and insulin concentrations. Reading the ingredient list will help athletes choose the most appropriate product for a given situation.

Carbohydrate can be consumed easily and comfortably in liquid and gel form during exercise but some endurance athletes can also tolerate solid carbohydrate foods. For example, distance running is not very compatible with chewing and swallowing solid food, but a marathon runner may be able to tolerate a ripe banana. Other endurance and ultraendurance athletes (e.g., distance cyclists) may desire some solid food in their stomach because it lessens the feeling of hunger.

Because athletes generally need more carbohydrate than sedentary individuals and some athletes need substantial amounts of carbohydrate daily to replenish muscle glycogen, products containing carbohydrate in a convenient form have been developed. Known as sports or energy bars, these bars often contain substantial amounts of carbohydrates, along with varying amounts of fiber, proteins, and fats. While an energy bar marketed to athletes may have about the same amount of carbohydrates as two packets of a gel, its fiber and fat content is typically too high to be tolerated during higher intensity exercise such as distance running. However, adventure athletes, who may engage in many hours of mountain biking, trail running, and orienteering, often snack on sports bars during or between events and the higher carbohydrate and caloric content are beneficial. The important point is that athletes need to determine the appropriate amount, type, and form of carbohydrate and then identify products that best meet these needs.

Carbohydrate in liquid, semisolid, and bar form are convenient ways to obtain the carbohydrates needed and many athletes consume some of these products at times other than during exercise. Athletes should be aware that convenient and good-tasting carbohydrate foods and beverages are easy to overconsume and can result in an excess caloric intake. This is especially true for recreational athletes, whose carbohydrate needs are typically not much greater than that recommended for the general population, athletes in low-energy-expenditure sports (e.g., baseball, softball), and athletes in the off-season when intensity and duration of training are low.

contain carbohydrates can be as effective as beverages in replenishing muscle glycogen (Keizer et al., 1987). This is one situation in which athletes may want to pay particular attention to the glycemic index of foods, as the consumption of high GI foods in the postexercise (recovery) period can enhance the resynthesis of muscle glycogen (Burke, Collier, and Hargreaves, 1993). By definition, consumption of high glycemic index foods results in higher blood glucose and insulin responses, conditions that favor the rapid synthesis of muscle glycogen.

Amount of carbohydrate—The highest rates of muscle glycogen synthesis have been observed in the hours after fatiguing exercise when approximately 1.5 g/kg of carbohydrate were consumed in the first hour immediately after exercise (Doyle, Sherman, and Strauss, 1993; Ivy, Lee et al., 1988). In these studies, subjects consumed approximately 120 g of carbohydrate in the first hour postexercise. This might be considered the "priming" dose of carbohydrate to initiate the glycogen synthesis process, with more carbohydrate being consumed over the next few hours depending upon the need for rapid resynthesis. For athletes needing maximal rates of muscle glycogen synthesis, 0.75 to 1.5 g/kg of carbohydrate should be consumed each subsequent hour until approximately four hours after exercise. It is important to recognize that the higher end of this range is a large amount of carbohydrate and may cause gastrointestinal upset.

Addition of protein/amino acids—A number of studies suggest that adding proteins to the meal after exercise may increase the rate at which muscle glycogen is replaced (van Loon et al., 2000; Zawadzki, Yaspelkis III, and Ivy, 1992). Some amino acids and proteins may have an additional effect on insulin secretion, acting to increase and prolong the insulin response that stimulates muscle glycogen synthesis.

Whey protein was initially studied as an addition to carbohydrate for postexercise consumption, and resulted in the recommendation of a 4:1 ratio of carbohydrates to proteins for recovery drinks (e.g., Endurox and Acclerade). However, more recent studies have called this recommendation into question (Jentjens et al., 2001). Studies that have shown higher rates of muscle glycogen synthesis when combining proteins with carbohydrates may be confounded by the addition of extra kilocalories with the proteins in comparison to the carbohydrates alone. When the amount of kilocalories consumed after exercise was equalized by increasing the amount of carbohydrate, the protein-and-carbohydrate beverage was no different from the carbohydrate-only beverage. The addition of protein to the recovery beverage or food certainly does not impede glycogen recovery over carbohydrate alone, and may result in an increase in postexercise protein synthesis (see Chapter 5). Because athletes need to consume both carbohydrate and protein after exercise, they may choose foods that contain both (e.g., chocolate milk, fruit-in-the-bottom yogurt, turkey sandwich), but the ratio of carbohydrates to proteins needed has not been established definitively.

Foodcollection/Getty Images

Bodybuilders need to focus on carbohydrates, too. These men are contestants in a drug-free bodybuilding championship.

CARBOHYDRATE LOADING

Carbohydrate loading (also known as carbohydrate supercompensation) is a technique that some athletes use to attain maximum glycogen stores prior to an important competition. This technique is appropriate for endurance and ultraendurance athletes who perform 90 minutes or more of continuous exercise and it may be used by some bodybuilders as part of their precontest preparations. In the case of endurance and ultraendurance athletes, without maximum levels of glycogen when the race begins these athletes could run out of stored carbohydrate as a fuel source and be forced to reduce the intensity of their exercise or drop out of the race. In the case of bodybuilders, maximum glycogen storage is a strategy used to promote muscle definition, one feature on which contestants are judged. In these circumstances, performance could be enhanced by carbohydrate loading.

A carbohydrate-loading protocol was first reported in 1967 (Bergström, Hermansen, and Saltin, 1967) and this method is still used today by some bodybuilders and some endurance athletes. As shown in Figure 4.13, seven days prior to the competition, exhaustive exercise is performed for 3½ days in combination with an extremely low carbohydrate diet. During this phase, known as the depletion stage, carbohydrate stores are severely depleted by exercise and remain low due to the lack of dietary carbohydrate. Side effects include irritability, hypoglycemia, fatigue, inability to accomplish the required exercise, and risk for injury. The depletion stage is followed by 3½ days of very light or no exercise and a high-carbohydrate diet (~8 g/kg/d). This phase, known as the repletion stage, supplies large amounts of carbohydrate to glycogen-starved muscles. In response

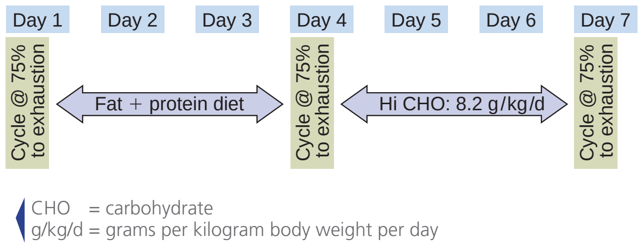


Figure 4.13 "Classical" Carbohydrate-Loading Protocol

Drawn from the methods of: Bergström, J., Hermansen, L., and Saltin, B. (1967). Diet, muscle glycogen, and physical performance. *Acta Physiologica Scandinavica,* 71, 140–150.

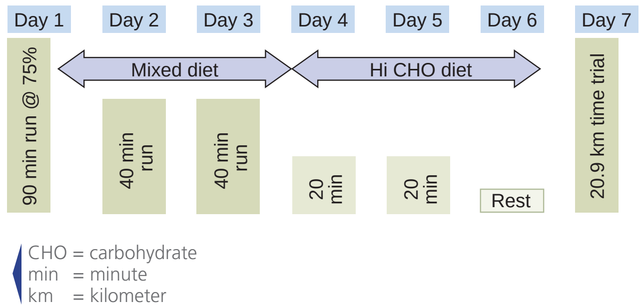


Figure 4.14 "Modified" Carbohydrate-Loading Protocol

Drawn from the methods of: Sherman, W.M., Costill, D.L., Fink, W.J., and Miller, J.M. (1981). The effect of exercise and diet manipulation on muscle glycogen and its subsequent use during performance. *International Journal of Sports Medicine,* 2, 114–118.

the body "supercompensates" and near maximum glycogen storage is achieved. Typical resting muscle glycogen concentration is approximately 100–125 mmol/kg and with this "classic" protocol, subjects stored muscle glycogen at levels approaching 220 mmol/kg. The repletion stage may also have some adverse effects including gastrointestinal distress due to the reintroduction of sugars, starches, and fiber and an increase in muscle water storage. While the increase in water storage is a normal part of the glycogen resynthesis process, it can leave athletes feeling heavy, waterlogged, and uncomfortable.

The original carbohydrate-loading protocol was tested and used by endurance athletes but better protocols have been developed. Several aspects of the original depletion stage were problematic. First, carbohydrate intake was so low during the depletion stage that normal training and conditioning could not be maintained. Additionally, the risk for injury was too great. These limitations resulted in the testing and development of other protocols.

In 1981, Sherman et al. published a modified protocol that eliminates the severe depletion stage but still results in high levels of stored muscle glycogen (see Figure 4.14). This six-day plan includes a three-day depletion stage that consists of a dietary carbohydrate intake of 5 g/kg/d. Recall that this level of carbohydrate intake is the minimum amount recommended to athletes in training. It is sufficient to allow athletes to complete the required training during this stage—90 min of hard training (70 percent of $\dot{V}O_{2max}$) on the first day followed by two days of hard training for 40 min. Glycogen depletion is achieved but the serious side effects associated with the original depletion stage are avoided. The repletion stage calls for a carbohydrate intake of 10 g/kg/d for three days and two days of 20 min of exercise followed by a rest day. This repletion phase is similar to the original protocol. This modified approach utilizes a strategy that is more similar to what an endurance athlete would likely do in the week prior to a big event, such as gradually tapering exercise. The only manipulation that differs from a usual training regime is to slightly reduce the amount of carbohydrate early in the week when the exercise duration is longer, and increase dietary carbohydrate later in the week when there is more rest time. Muscle glycogen levels of 205 mmol/kg can be obtained without the adverse effects often experienced by athletes following the classical regimen.

Researchers continue to look at ways to modify the carbohydrate-loading protocol, such as by manipulating the time period required. Since 2002, some studies have shown that high levels of muscle glycogen can be attained within one day if large amounts of carbohydrate are consumed. These levels can be attained in one to three days if the athlete refrains from exercise (Bussau et al., 2002) or if the athlete performs three minutes of high-intensity exercise, then rests, and consumes a large amount of carbohydrate (Fairchild et al., 2002). It is important to note that these studies do not show higher muscle glycogen supercompensation than Sherman's modified method, and may involve strategies incompatible with the athlete's pre-competition preparation (e.g., complete cessation from exercise or performing very-high-intensity exercise the day before). Carbohydrate-loading techniques remain an area of active research.

EFFECTS OF INADEQUATE TOTAL CARBOHYDRATE INTAKE ON TRAINING AND PERFORMANCE

The amount and timing of carbohydrates before, during, and after exercise must be considered in the context of total dietary intake over days, weeks, and months of training. Daily dietary intake considers not only the 24-hour consumption of carbohydrates but also total caloric intake and the relative contribution of carbohydrates, proteins, fats, and alcohol. Daily intake will vary,

Carbohydrate loading: A diet and exercise protocol used to attain maximum glycogen stores prior to an important competition.

but over time both energy and carbohydrate intake must be adequate. If not, training and performance will be negatively affected.

First and foremost, the body must meet its energy needs. Insufficient total energy intake means that some of the carbohydrates consumed will be used for immediate energy and will be unavailable for storage as muscle or liver glycogen (Burke, Kiens, and Ivy, 2004). Surveys of female athletes suggest that energy intake is often low (Burke, 2001). The need to balance energy intake with energy expenditure is covered in Chapter 2.

Surveys also suggest that many athletes do not meet the recommendations for total daily carbohydrate intake. Burke, Kiens, and Ivy (2004) report the following daily mean (average) intake of carbohydrates:

Male nonendurance athletes: 5.8 g/kg

Male endurance athletes: 7.6 g/kg

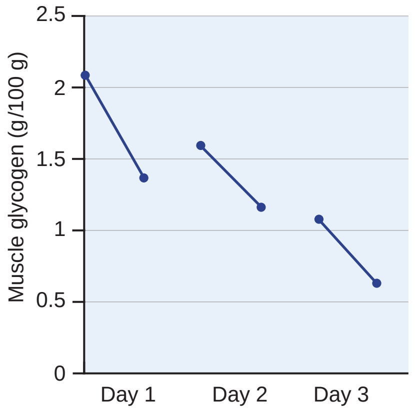
Female nonendurance athletes: 4.6 g/kg

Female endurance athletes: 5.7 g/kg

Female nonendurance athletes report the lowest daily carbohydrate intake and fail to exceed the minimum amount of carbohydrate recommended (5 g/kg/d). On average, both male and female endurance athletes fall short of the recommended 8–10 g/kg daily. Because female endurance athletes fail to attain even the mid-range recommendation for training (6 g/kg/d), it is suspected that many of these athletes do not restore muscle glycogen to pre-exercise levels with repeated days of training. Low energy intake, which is more frequently reported in females than in males, compounds the low carbohydrate problem.

Insufficient carbohydrate intake can lead to hypoglycemia and both acute and chronic fatigue. As mentioned previously, the symptoms of hypoglycemia are loss of concentration, apathy, light-headedness, shakiness, and hunger. When blood glucose concentration is low during exercise, the uptake of glucose by the brain is reduced and the ability to concentrate is decreased. Other hypoglycemic symptoms, such as light-headedness, may also affect the athlete's perception of exercise difficulty. Fatigue that results from low carbohydrate intake over a period of days, weeks, or months can have a substantial negative effect on training and performance.

The muscle glycogen levels an athlete has at the beginning of exercise may affect both the intensity and duration of that exercise session. Therefore, athletes should pay attention to the effect that each exercise session has on carbohydrate stores and the dietary steps necessary to maintain adequate glycogen levels on a daily basis. Low muscle glycogen levels may compromise the athlete's ability to complete a training session or work out at the required intensity. Insufficient carbohydrate stores may not be the result of a single, depleting exercise session, but a result of fatiguing exercise on a daily, weekly, or monthly basis.



g = gram
g/100 g = g glycogen per 100 g of tissue

Figure 4.15 Decline of Muscle Glycogen with Successive Days of Training

Well-trained endurance runners had muscle glycogen measured before and after they completed 10-mile runs on a treadmill in the laboratory each day for three consecutive days. The runners ate their normal moderate-carbohydrate diet. Note the sequential decline in muscle glycogen.

Costill, D.L., Bowers, R., Branam, G., and Sparks, K. (1971). Muscle glycogen utilization during prolonged exercise on successive days. *Journal of Applied Physiology,* 31, 834–838.

A classic study published by Costill et al. (1971) demonstrates the daily pattern of declining muscle glycogen when athletes train hard and do not consume enough carbohydrate (see Figure 4.15). Distance runners trained 10 miles each day and ate a normal, mixed diet. Muscle biopsies clearly show the decline in resting muscle glycogen levels each day. In fact, the runners began their 10-mile run on the third day with lower muscle glycogen levels than they had when they finished the first 10-mile run. Although they were able to complete their training runs, it can easily be seen how the glycogen losses over a few days of training may adversely affect training or competitive efforts later in the week.

In another study, when runners and cyclists trained hard every day for a week and ate a diet containing a moderate amount of carbohydrate, preexercise muscle glycogen levels gradually declined stepwise, similar to the Costill study (Sherman et al., 1993). Once again, these athletes were able to complete their training sessions, but the potential adverse effects may come when the athletes are chronically short of carbohydrate. Rowers that consumed insufficient carbohydrate over the course of a month not only had lower muscle glycogen levels, but were also unable to produce as much power during high-intensity-rowing training (Simonsen et al., 1991).

Months of low-carbohydrate intake, in conjunction with a long-term negative energy balance, are factors that contribute to overtraining syndrome. There is no single cause for this condition, but chronic low-carbohydrate intake is one likely factor. An increase in energy and carbohydrate intakes and rest are all part of the treatment plan (Shephard, 2001).

What's the point? The need for adequate carbohydrate on a daily basis is a critical factor in maintaining the ability to train and perform. Athletes should consume sufficient carbohydrate daily or they run the risk of exercise-limiting carbohydrate deficits.

RECOMMENDED TOTAL DAILY CARBOHYDRATE AND FIBER INTAKES FOR GENERAL HEALTH

For general health, it is recommended that carbohydrate intake for adults should be 45 to 65 percent of total energy intake, assuming that energy intake is adequate (Institute of Medicine, 2002). This recommendation is based on scientific studies conducted in the general population. These studies found associations between dietary intake and the prevention of nutrient inadequacies as well as a reduced risk for chronic diseases, such as cardiovascular disease. Recommendations for the general population are made as a percentage of total energy intake, so some calculations are necessary before comparisons can be made to athletes.

An adult woman who engages in daily activity equivalent to walking 2 miles needs an estimated 2,000 kcal per day. Based on this caloric intake and the recommendation that carbohydrate be 45 to 65 percent of total energy, 225 to 325 g of carbohydrate are recommended daily. Assuming this woman is 55 kg (121 lb), her recommended carbohydrate intake is ~4 to 6 g/kg/d. General recommendations take into consideration the low physical activity that is characteristic of the majority of U.S. adults. If the woman in this example was more active and needed 2,700 kcal daily, her recommended daily carbohydrate intake would be ~300 to 440 g or ~5.5 to 8 g/kg.

Most athletes consume between 5 and 8 g/kg daily. Those who engage in prolonged endurance exercise need more carbohydrate (and kilocalories). They also have a high level of fitness. There is no evidence that a high-carbohydrate intake that accompanies a high level of physical activity is unhealthy. The recommended carbohydrate intake for athletes—5 to 10 g/kg/d—is consistent with the recommendations made for good health. This amount of carbohydrate is also speculated to reduce the risk for exercise-induced immune system suppression, something that is common in endurance athletes who consume low levels of carbohydrate for several days (Gleeson, Nieman, and Pedersen, 2004).

Another carbohydrate-related recommendation for general health is sufficient fiber intake. It is recommended that women consume 25 g of fiber daily while men should consume 38 g per day (Institute of Medicine, 2002). The average daily fiber intake of U.S. adults is 15 to 19 g. Limited surveys of collegiate (Hinton et al., 2004) and elite (Ziegler et al., 2002) athletes suggest that the fiber intake of athletes does not differ from that of the general population. Female athletes report a fiber intake of ~15 to 19 g/d while male athletes consume

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There are a wide variety of whole grain breads to choose from, which provide more fiber and nutrients than highly processed white bread.

about 18 to 19 g daily. Fiber intake is associated with the consumption of carbohydrate-containing foods such as fruits, vegetables, whole grains, legumes, beans, and nuts. Sugar is devoid of fiber, and grains that are highly refined (e.g., whole wheat that is processed to make white bread) lose most of the fiber originally present before processing. Depending on the kinds of foods and beverages consumed, it is possible for athletes to meet carbohydrate recommendations but fall short of meeting fiber recommendations.

Athletes use the glycemic index as a tool to enhance carbohydrate availability during and after exercise. The GI, and a newer measure, **glycemic load (GL),** may also be related to health, particularly the prevention or delay of

SPOTLIGHT ON ENRICHMENT

Glycemic Index (GI) and Glycemic Load (GL)

The glycemic index is a method of categorizing foods based on the body's glucose response after their ingestion, digestion, and absorption. The index assigns glucose a score of 100. Foods with a GI < 60 are considered low GI foods, but these categories are arbitrary. Figure 4.16 gives examples of such foods.

In general, high GI foods are highly refined grains (e.g., white rice), processed grain products with added sugar and low fiber content (e.g., sweetened cereals), and starchy vegetables (e.g., some kinds of potatoes). Beans, legumes, dairy products, and some fruits have a low GI because the carbohydrate contained is more slowly absorbed. Medium glycemic index foods are less rapidly absorbed than high GI foods. Some medium GI foods contain sugar (as sucrose) but also have added fats, which slows the absorption.

Think of the glycemic index as a measure of carbohydrate quality. Quality is an important aspect but so is quantity. Glycemic load was developed so that both quality and quantity could be considered. GL is calculated by multiplying the amount of carbohydrate in a typical portion (quantity) by the glycemic index (quality) of that food (and then dividing by 100). Table 4.7 gives the glycemic load of various foods, but these values should be used cautiously because they are preliminary data.

The glycemic load gives a truer picture of how blood glucose is elevated and the insulin response that follows. From the perspective of health, foods with a high glycemic load cause a high glycemic response (hyperglycemia) in the two hours after consumption. This hyperglycemia results in an elevated and prolonged insulin response (hyperinsulinemia). In the absence of exercise, blood glucose and insulin concentrations remain high for many hours. In many individuals (who are routinely sedentary), high blood glucose and insulin concentrations result in reactive hypoglycemia, excessive food intake, dysfunction of the insulin-producing cells in the pancreas, and elevated free fatty acids in the blood. These responses are risk factors for a number of chronic diseases.

At present, there is no recommended numeric guideline for glycemic load. Epidemiological studies have shown an association between diets habitually high in GL and obesity, type 2 diabetes, and cardiovascular disease (Bell and Sears, 2003). In these population studies, people who reported the highest intake of highly processed carbohydrates had a greater risk for developing these chronic diseases. While GL recommendations have not been quantified, there is a practical way for all people,

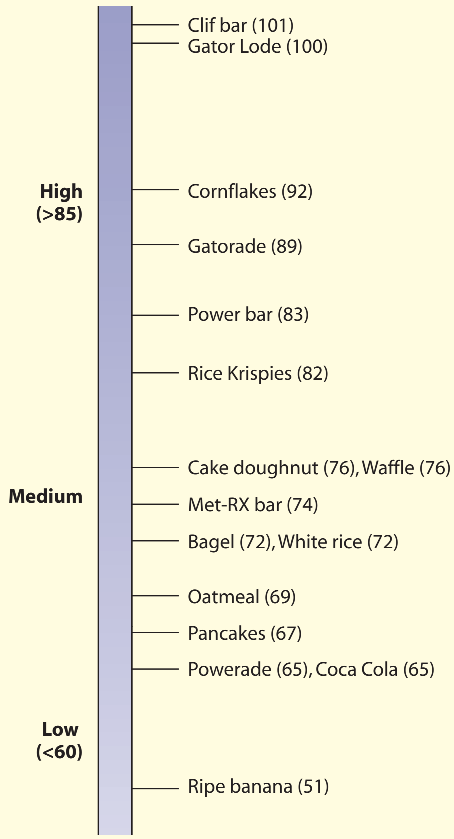

Figure 4.16 Glycemic Index of Selected Foods

The glycemic index (GI) is determined based on 50 g of total carbohydrate in each food. A score of 100 is assigned to glucose.

Foster-Powell, K., Holt, S.H., and Brand-Miller, J.C. (2002). International table of glycemic index and glycemic load values. *American Journal of Clinical Nutrition,* 76(1), 5–56 and Gretebeck, R.J., Gretebeck, K.,A., and Titelback, T.J. (2002). *Glycemic index of popular sport drinks and energy foods.* Journal of the American Dietetic Association, 102(3), 415–417.

including athletes, to consume a diet with lower glycemic load carbohydrates: frequent consumption of fruits, vegetables, beans, legumes, whole grains, and high fiber and less refined grain products without added sugars.

The use of glycemic index and glycemic load has been controversial in the United States. Opponents of their use argue chronic diseases (Ludwig, 2002). The consumption of high GI and GL foods is appropriate as part of the athlete's diet plan to match the demand for carbohydrate during prolonged exercise and in the recovery period when glycogen is being rapidly resynthesized. However, for the general population, the majority of whom are not physically active, the habitual intake of high glycemic index and glycemic load foods increases the risk for obesity, type 2 diabetes, and heart disease (Brand-Miller, 2003). The health effects

Glycemic load (GL): A method of categorizing carbohydrate-containing foods based on both quality (using glycemic index) and quantity (amount consumed).

Table 4.7 Glycemic Load of Selected Foods

Food	Serving Size (g)	Available CHO (g/serving)	Glycemic Load (GL) (per serving)
Pancakes (from shake mix)	80	58	39
White rice, parboiled	150	36	26
Bagel	70	35	25
Power Bar	65	42	24
Cornflakes	30	26	24
Oatmeal	50	35	24
Doughnut, cake type	47	23	17
Coca-Cola	250 ml (8 oz)	26	16
Brown rice, steamed	150	33	16
Bananas, ripe	120	25	13
Apple juice, unsweetened	250 ml (8 oz)	29	12
Waffles	35	13	10
Apple, raw	120	16	6

Legend: g = gram; ml = milliliter; oz = ounce

Glycemic load is a measure of both carbohydrate quality and quantity. The higher the glycemic load (GL), the greater the expected rise in blood glucose and insulin. These data should be used cautiously because they are preliminary data.

Table adapted from: Foster-Powell, K., Holt, S.H., and Brand-Miller, J.C. (2002). International table of glycemic index and glycemic load values. *American Journal of Clinical Nutrition,* 76, 5–56.

In Australia, the glycemic index is included on the label.

that the concepts are too complicated for consumers and not enough research has been conducted, especially on mixed foods and meals. For example, the glycemic load of white rice is considered high, but the glycemic response of stir-fried vegetables and tofu eaten over white rice is not known. The tofu contains both proteins and fats and may affect the absorption of the carbohydrates found in the rice. In contrast, the World Health Organization has endorsed the use of the glycemic index and countries such as Australia put GI values on food labels. For good health, athletes should routinely consume many low GI and GL foods, however, the use of high and medium GI and GL foods to improve training and performance is also warranted in certain situations, such as in the postexercise recovery period.

of high glycemic index and glycemic load foods are discussed in detail in the Spotlight on Enrichment: Glycemic Index and Glycemic Load.

Translating Daily Carbohydrate Recommendations to Food Choices

Carbohydrate recommendations for athletes are scientifically based and reflect the need to maintain glucose homeostasis, maintain adequate muscle glycogen stores, and to fuel exercise. It is not difficult to understand the physiological need for carbohydrates. The challenge is to translate those recommendations into food choices that will support training, performance, the immune system, and long-term good health.

PLANNING A CARBOHYDRATE-RICH DIET

Many athletes fail to consume an adequate amount of carbohydrate. In some cases this may be due to a lack of knowledge about the amount of carbohydrate needed. Table 4.8 lists the estimated daily total carbohydrate intake needed by athletes based on their weight. For example, the 165 lb (75 kg) cyclist who needs 8–10 g/kg will need 600 to 750 g of carbohydrate daily. Each gram of carbohydrate contains approximately 4 kcal. Therefore, this athlete will need to consume 2,400 to 3,000 kcal from carbohydrates alone. This is not an easy task!

In addition to the total amount of carbohydrate needed, athletes must also know the amount of carbohydrates found in various foods or food groups. Table 4.9 lists representative foods in each group and the amount of

Table 4.8 Estimated Total Daily Carbohydrate Intake Based on Body Weight

Weight lb (kg*)	5 g/kg	6 g/kg	7 g/kg	8 g/kg	9 g/kg	10 g/kg
85 to 95 (39 to 43)	195–215	234–258	273–301	312–344	351–387	390–430
96 to 105 (44 to 48)	220–240	264–288	308–336	352–384	396–432	440–480
106 to 115 (48 to 52)	240–260	288–312	336–364	384–416	432–468	480–520
116 to 125 (53 to 57)	265–285	318–342	371–399	424–456	477–513	530–570
126 to 135 (57 to 61)	285–305	342–366	399–427	456–488	513–549	570–610
136 to 145 (62 to 66)	310–330	372–396	434–462	496–528	558–594	620–660
146 to 155 (66 to 70)	330–350	396–420	462–490	528–560	594–630	660–700
156 to 165 (71 to 75)	355–375	426–450	497–525	568–600	639–675	710–750
166 to 175 (75 to 79)	375–395	450–474	525–553	600–632	675–711	750–790
176 to 185 (80 to 84)	400–420	480–504	560–588	640–672	720–756	800–840
186 to 195 (84 to 89)	420–445	504–534	588–623	672–712	756–801	840–890
196 to 205 (89 to 93)	445–465	534–558	623–651	712–744	801–837	890–930
206 to 215 (94 to 98)	470–490	564–588	658–686	752–784	846–882	940–980
216 to 225 (98 to 102)	490–510	588–612	686–714	784–816	882–918	980–1,020
226 to 235 (103 to 107)	515–535	618–642	721–749	824–856	927–963	1,030–1,070
236 to 245 (107 to 111)	535–555	642–666	749–777	856–888	963–999	1,070–1,110
246 to 255 (112 to 116)	560–580	672–696	784–812	896–928	1,008–1,044	1,120–1,160
256 to 265 (116 to 120)	580–600	696–720	812–840	928–960	1,044–1,080	1,160–1,200
266 to 275 (121 to 125)	605–625	726–750	847–875	968–1,000	1,089–1,125	1,210–1,250
276 to 285 (125 to 129)	625–645	750–774	875–903	1,000–1,161	1,125–1,161	1,250–1,290

Legend: lb = pound; kg = kilogram; g/kg = gram per kilogram body weight

* Weight in kg is rounded to the nearest whole number.

Table 4.9 Carbohydrate-Containing Foods by Food Group

Food Group	Food	One Serving	CHO (g)	Fiber (g)	Whole Grain
Starches	Bagel, plain	4-in diameter (71 g)	38	1.6	No
	Bagel, whole grain	4-in diameter (85 g)	35	6	Yes
	Bread, white	1 slice	14	0.5	No
	Bread, whole grain	1 slice	14	5	Yes
	Cereal, sweet (e.g., Froot Loops, Honey Nut Cheerios)	1 cup (30 g)	24–28	1–2	Not usually
	Cereal, low sugar (e.g., Cornflakes, Cheerios)	1 cup (28 g)	22–24	1–3	Varies
	Cereal, high fiber (e.g., Raisin Bran)	½ cup (30) g	22	4	Usually
	Corn chips	1 oz	16	1	Usually
	Corn bread	1 piece (55 g)	18	1	Not usually
	Crackers (e.g., Ritz, Saltines)	5 crackers	10	0.5	Varies
	Energy bars (e.g., CLIF Bars®)	1 bar	35–43	1–5	Varies
	English muffin	Both halves	25	1.5	Not usually
	Grits	1 cup cooked	31	<1	Not Usually
	Granola bar	1 bar (43 g)	29	1	Varies
	Hamburger bun	Both halves	21	1	No
	Oatmeal	1 cup cooked	25	4	Yes
	Pancakes, buttermilk	3 pancakes each 4-in diameter	33	1	Not usually
	Pasta (e.g., spaghetti or macaroni noodles)	½ cup cooked	19	<1	Not usually
	Pita bread	1 (60 g)	33	1	Varies
	Popcorn	1 cup popped	6	1	Yes
	Potato chips	1 oz	15	1	No
	Pretzel sticks	10 (30 g)	20	1	No
	Pretzel, soft	1	43	1	No
	Rice, brown	½ cup cooked	22	2	Yes
	Rice, white	½ cup cooked	22	<0.5	No
	Tortillas (corn)	1 6-in diameter	12	1.5	Yes
	Tortillas (flour)	1 8-in diameter	28	1	Not usually
	Waffle	1 7-in diameter	25	1.5	Not usually
	Wheat germ	2 tablespoons	6	1.5	Yes

continued

Table 4.9 Carbohydrate-Containing Foods by Food Group (continued)

Food Group	Food	One Serving	CHO (g)	Fiber (g)
Starchy vegetables	Corn	½ cup cooked	15	1.6
	Peas (green)	½ cup cooked	11	3.5
	Potatoes (mashed)	⅔ cup cooked	25	2
	Squash (winter)	½ cup cooked	5	0.9
	Sweet potatoes	¼ cup cooked	26	2.5
	Yams	¾ cup cooked	28	4
Beans/legumes	Dried beans or lentils	½ cup cooked	20	6–8
	Hummus	¼ cup	8	3.4
	Miso (soybean) soup	1 cup	8	2
	Split pea soup	1 cup	19	1.5
Fruits	Apple	~2.5-in diameter	19	3.3
	Applesauce	½ cup	25	1.5
	Banana	~9 in long	27	3
	Blueberries or raspberries	1 cup	15–21	3.5–8
	Cantaloupe	¾ cup or ~¼ of a 5-in diameter melon	10	1
	Peach	~2.5-in diameter	9	1.5
	Plum	~3-in diameter	9	1
	Orange	~2.5-in diameter	15	3
	Orange juice	½ cup	13	0.5
	Strawberries	1 cup	11	3
	Tangerine	2	19	4
Vegetables	Broccoli	½ cup cooked	6	2.5
	Cabbage	½ cup cooked	3	1.5
	Carrot	½ cup cooked or 1 raw carrot ~8 in long	6	2
	Lettuce (dark green, leafy)	1½ cups (84 g)	2	1
	Pepper	½ cup raw	3.5	1.3
	Spinach	½ cup cooked	3.5	2
	Tomato	~2.5-in diameter	5	1.5
Milk	Chocolate milk	1 cup	26	1
	Milk	1 cup	12	0
	Soy milk	1 cup	18	3
	Yogurt (plain)	1 cup	17	0
	Yogurt (sweetened)	1 cup	26	0

Table 4.9 Carbohydrate-Containing Foods by Food Group (continued)

Food Group	Food	One Serving	CHO (g)	Fiber (g)
Sugared beverages	6% carbohydrate sports beverage	1 cup	14	0
	High carbohydrate sports beverage	12 oz	88	0
	Soft drink	12 oz (1 can)	40	0
Mixed foods	Cheese pizza, thick crust	2 slices (142 g)	55	2.5
	Cheese pizza, thin crust	2 slices (166 g)	46	2
	Cheese lasagna	1 cup	45	3
	Chili with beans	1 cup	22	6
	Chili without beans	1 cup	12	3
Nuts	Almonds	¼ cup	7	4
	Peanut butter	2 tablespoons	6	2
	Pecans	¼ cup	4	2.5
	Walnuts	¼ cup	4	2
	Hazelnuts (filberts)	¼ cup	6	3

Legend: CHO = carbohydrates; g = gram; in = inch; oz = ounce

Table 4.10 Guidelines for Number of Servings from Carbohydrate-Containing Food Groups Based on Energy Intake

Food Group	Servings/ 2,000 kcal	Servings/ 2,200 kcal	Servings/ 2,400 kcal	Servings/ 2,600 kcal	Servings/ 2,800 kcal	Servings/ 3,000 kcal	Servings/ 3,200 kcal	Servings/ 3,400 kcal
Fruits	4	4	4	4	5	5	6	6
Vegetables*	5	6	6	7	7	8	8	8
Grains**	6	7	8	9	10	10	10	11
Beans	1	1	1	1	1	1	1	1
Milk	2–3	3	3	3	3	3–4	3–4	4
Sugar***	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Legend: kcal = kilocalorie

Based on the DASH Eating Plan, 2005, with slight modifications for use with athletes.

*Vegetables include the starchy vegetables.

**Grains include starches.

***The amount of sugar included in the diet should be moderate. Many athletes consume sports beverages, which contain sugar.

carbohydrate contained in one serving. Because there are so many carbohydrate-containing foods to choose from, it is helpful to have a framework for planning meals. Table 4.10 provides such a framework by listing the number of servings from each food group recommended for various caloric levels. Since the athlete's diet should support good health in addition to supporting training and performance, much of the carbohydrate-containing food eaten should be whole grain, rich in fiber, and nutrient dense. Many foods have all of these characteristics.

Even when athletes have information about the carbohydrate content of food, it is not always easy to consume the proper amount. Athletes may lack the time and skill to prepare carbohydrate-rich meals or might be too tired after training and prefer to sleep.

SPOTLIGHT ON A REAL ATHLETE

Lucas, a Cross Country Runner

In this section the efforts of a male collegiate, cross country runner to meet his recommended carbohydrate intake will be followed. Lucas, who is 20 years old and currently weighs about 138 pounds (~63 kg), wants to consume 8 g/kg of carbohydrate daily. This level of carbohydrate is necessary because he is running 75 to 80 miles per week. How should he plan his diet?

To begin, Lucas needs to determine his total carbohydrate intake for the day. He could calculate this by multiplying his weight in kg by 8 or by looking at the amounts listed for his weight in Table 4.8. Both these methods suggest that his daily carbohydrate intake should be approximately 500 g.

Once Lucas establishes a daily goal he would then need to know the kinds of foods that contain carbohydrates: starches, starchy vegetables, beans and legumes, fruits, vegetables, milk, and sugared beverages (see Table 4.9). Each person will have preferences for certain foods in each group. For example, Lucas prefers making a smoothie with yogurt rather than drinking milk at breakfast, favors spaghetti noodles over other types of pasta because he knows how to cook them, and is familiar with black beans but not navy beans because he grew up in the Southwest.

Even with the knowledge of the amount of carbohydrates found in various foods, the task of creating a diet plan for the entire day can be daunting. Since Lucas needs approximately 3,400 kcal daily to maintain his present body composition, he can use the framework suggested in Table 4.10 to plan his diet. Using this framework also helps Lucas obtain nutrients other than carbohydrate.

The athlete's schedule and access to food are important considerations. In Lucas' case, he grabs a quick breakfast before going to morning classes. His biggest meal of the day is an early lunch since the team has access to the training table set up for athletes in the dorm dining room. He trains for at least three hours in the afternoon. After he gets home from training he takes a nap and later he has an easy-to-fix dinner. Most evenings he studies and socializes with friends and he usually has a late night snack. Considering all of the issues mentioned above, Lucas can create a skeleton of his daily diet by choosing carbohydrate foods from each group and fitting them into his training and school schedule. The one-day diet plan that Lucas created is shown in Table 4.11.

Figure 4.17 shows a dietary analysis of Lucas' one-day diet plan for energy, carbohydrate, and fiber. Lucas' goals included a total energy intake of approximately 3,400 kcal (~54 kcal/kg) and a carbohydrate intake of 500 g (8 g/kg). Lucas' intake was estimated at 3,333 kcal and 532 g of carbohydrate. His intake of dietary fiber, 37 g, nearly met the recommended intake of 38 g for adult men. On this day

Table 4.11 Example of a 24-hour dietary intake of a male collegiate cross country runner.

Time/place	Food
7:30 a.m. quick breakfast, at home	Yogurt smoothie: 1 cup low-fat plain yogurt ½ cup frozen, sweetened strawberries 2 T honey ½ cup skim milk
11:15 a.m. at training table for athletes	2 large vegetarian burritos: 2 12-in low-fat flour tortillas ½ cup low-fat black beans ½ cup cheddar cheese 1½ cup seasoned rice ½ cup grilled peppers 4 T guacamole (avocado) 2 T sour cream ½ cup tomato salsa 16 oz soda 8 oz water
2:00–5:00 p.m. during practice	16 oz 6% carbohydrate drink Orange
After practice	Energy bar
7:00 p.m. dinner, usually at home but sometimes out	Turkey sandwich: 2 slices sourdough bread 3 oz smoked turkey 2 slices of tomatoes 1 T mayonnaise 2 tsp mustard Apple 2 Fig Newtons 1 cup non-fat milk
Late night snack	2 slices pepperoni pizza 16 oz noncaffeinated soda

Legend: T = tablespoon; in = inch; oz = ounce; tsp = teaspoon

Lucas essentially met his established goals. It is not considered a problem that Lucas slightly exceeded or fell short of the recommended amounts. The amounts of energy and fiber were nearly the amounts recommended (remember the amounts listed in nutrient databases are only estimates). The additional carbohydrates are appropriate as long as proteins, fats, and total energy intakes are adequate.

While the goal for total amount of carbohydrates was exceeded, a closer look at the sources of carbohydrates are necessary. Based on the food groups used by MyPyramid, Lucas exceeded the intake of grains, but fell short of recommended fruit and vegetable consumption (see Figure 4.17). Vegetable intake was particularly low, a common problem in the United States. An analysis of carbohydrate source

Nutrient	DRI	Intake	0%	50%	100%
Energy					
Kilocalories	3365 kcal	3332.8 kcal			99%
Carbohydrate	379–547 g	532.15 g			
Fat, total	75–131 g	93.86 g			
Protein	84–294 g	124.09 g			
Carbs					
Dietary fiber, total	38 g	37.4 g			98%
Sugar, total	no rec	310.37 g			

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	Goal*	Actual	% Goal
Grains	10 oz. eq.	11.8 oz. eq.	118%
Vegetables	4 cup eq.	1.2 cup eq.	30%
Fruits	2.5 cup eq.	1.7 cup eq.	68%
Milk	3 cup eq.	5.4 cup eq.	180%
Meat & Beans	7 oz. eq.	8.8 oz. eq.	126%
Discretionary	648	1152	178%

*Your results are based on a 3200 calorie pattern, the maximum caloric intake used by MyPyramid.

Figure 4.17 Dietary analysis of 24-hour diet of a male collegiate cross country runner.

(not shown in Figure 4.17) reveals that nearly 25 percent of Lucas' carbohydrate intake was in the form of sugared drinks (e.g., soda, sports beverages). Thus, the quantity of carbohydrate was appropriate, but the quality (e.g., nutrient content) could be improved.

Now contrast Lucas' intake over 24-hours with two people that Lucas sometimes trains with—Sophie, who is a female cross country runner, and Jackson, who is an elite distance runner. In doing so, some of the practical problems that athletes face are highlighted.

Sophie is typical of many female collegiate cross country runners. She trains hard, running 50 to 60 miles per week, but does not consume a lot of food. She says she is not hungry but she also is concerned about gaining body fat, so even when she is hungry she keeps an eye on how much she eats. She lives in the dorm and does not like some of the food offered or how the food is prepared. She finds herself thinking about appearance, weight, and energy (kcal) restriction more frequently than performance, the energy needed to train, and the amount of muscle mass she has. Her typical daily intake is 275 g of carbohydrate and 1,800 kcal. At her current weight of 50 kg, this amount of carbohydrate is 5.5 g/kg, far less than is recommended to adequately replenish glycogen stores in an endurance athlete engaged in hard training.

Jackson is an ultraendurance athlete whose need for carbohydrate represents the extreme end of the carbohydrate spectrum. He runs about 120 miles a week in preparation for the Badwater Ultramarathon, a 135-mile (217-km) race beginning in Death Valley (282 ft [85 m] below sea-level) and ending at an altitude of 8,360 ft (2,533 m). His goal is to consume at least 10 g/kg of carbohydrate daily. He has a good appetite but he finds it difficult to eat frequently throughout the day due to work. He eats large carbohydrate-containing meals but he cannot consume sufficient carbohydrate from meals alone. His carbohydrate needs are so high that consuming concentrated carbohydrate supplements is a must. He also struggles with the amount of fiber in his diet, sometimes consuming 60 g a day, which results in frequent bowel movements. To reduce the fiber but obtain the carbohydrate, he finds himself drinking sugared drinks often.

Recall that surveys show that most athletes do not consume the recommended amount of carbohydrate. As Lucas' diet illustrates, it is possible to do so. However, many athletes find themselves in situations similar to Sophie's and must make a concerted effort to eat more carbohydrate-containing foods and fiber, along with more energy. The challenge for those who need greater than 10 g/kg is to be able to consume an adequate volume of carbohydrates day after day and to avoid excessively high fiber intakes. Knowing the carbohydrate recommendation is the easy part; eating a sufficient amount of carbohydrate is harder than it appears at first glance. More information about diet planning can be found in Chapter 10.


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Vegetables can be quickly stir fried in a wok.


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Fruit and yogurt both contain carbohydrates and other nutrients.

Lack of time, money, and knowledge can be barriers to proper carbohydrate intake. More information on diet planning can be found in Chapter 10.

PRACTICAL ISSUES TO CONSIDER WHEN PLANNING A CARBOHDRATE-RICH DIET

Laboratory research has helped identify the important roles that carbohydrates play in supporting training and enhancing performance. However, scientific knowledge must be translated into recommendations and these recommendations must be practical for athletes to achieve. In addition to practical issues such as food availability, food choices may be influenced by individual preferences, such as the desire to be a vegetarian, or medical conditions, such as lactose intolerance or diabetes.

Having Carbohydrate-Rich Foods Available. Many athletes know the kinds of foods that they should eat but find it difficult to "just do it." They often return home from a hard practice tired and hungry. Planning is key and a well-stocked pantry of easy-to-fix carbohydrate-containing foods increases the likelihood of making good food choices. Table 4.12 gives examples of such foods.

Vegan: One who does not eat food of animal origin.

Choosing Carbohydrate-Rich Meals in Fast-Food and Other Restaurants. Like most Americans, athletes find restaurant food appealing. Athletes frequently travel to compete and often the team bus stops at a fast-food restaurant. Eating out may be a favorite way to socialize. For these and other reasons athletes often eat away from home.

The challenge when eating in restaurants is to order foods that fit within the athlete's diet plan. Many entrees, especially in fast-food restaurants, are high in fats, sugar, and salt and low in fiber-containing carbohydrates. A double cheeseburger, large order of fries, and a milkshake provide lots of calories and fat but few high-quality carbohydrates. Although a typical fast-food meal may be consumed occasionally, a steady diet of such fare will typically leave the athlete short of recommended carbohydrate and nutrient intakes. Figure 4.18 lists some good choices for athletes when eating in restaurants.

Vegetarian Diets. Vegetarians do not eat meat, fish, or poultry, but some consume animal products such as milk or yogurt. **Vegans** avoid any foods of animal origin. Obtaining an adequate amount of carbohydrates is not difficult for vegetarian athletes since so many carbohydrate-containing foods are of plant origin. Those who avoid milk products would still have ample food groups from which to choose—starches, starchy vegetables, beans and legumes, nuts, fruits, vegetables, and sugar. Vegans could also choose foods from these groups but

Table 4.12 Carbohydrate-Containing Foods That Are Easy to Store and Prepare

Carbohydrate-Containing Food	Storage and Preparation Tips
Bread or bagels	Keep in freezer. Put in toaster twice.
Waffles	Buy frozen waffles and heat in toaster. Top with syrup or jam.
Pancakes	Buy pourable pancake mix. Add water and cook. Top with syrup or jam.
Cereal	Add shelf-stable (UHT) milk, which does not need refrigeration until it is opened. Cereal can also be used as a topping for yogurt.
Oatmeal or grits	Buy instant oatmeal or grits packages and add hot water.
Pasta	Cook dry or frozen pasta noodles. Heat a jar of tomato-based spaghetti sauce. Combine.
Tortillas (fresh or frozen) and beans (canned)	Spoon canned beans on tortilla (add cheese if desired). Microwave 1 minute. Add salsa and fold.
Fruits	Apples and bananas tend to last longer than fresh berries or stone fruits (e.g., peaches or nectarines). If fruits get overripe add to smoothies.
Vegetables	Fresh carrots tend to last a long time when stored in a cool place. Frozen or canned vegetables are easy to store and prepare.
Canned beans	Most kinds of beans can be purchased in cans and only need to be reheated.
Milk	Milk that has been processed using ultra high temperature (UHT) pasteurization can remain on the shelf until opened.
Frozen entrees	Several brands specialize in "healthy" frozen entrees that contain high-carbohydrate, moderate-protein, low-fat, and low-sodium meals.
Nuts	Unopened jar or cans can remain on the shelf; after opening nuts can be stored in the freezer.

Breakfast Menu Items:

Pancakes or waffles with syrup*
Hot cereal, such as oatmeal
Cold cereal with milk
Toast or muffin with jelly
Bagel
Fruit
Juice, such as orange juice*
Milk*
Cocoa*

Lunch or Dinner Menu Items:

Hearty soup, such as minestrone or bean, with crackers or roll
Salad* or other vegetables
Deli sandwiches with lower fat meats and plenty of vegetables
Baked potato*
Chili*
Thick crust pizza with vegetable toppings
Pasta with marinara sauce
Vegetarian burritos (beans, vegetables, and tortillas)
Asian vegetable dishes with noodles or rice, such as vegetable chow mein
Fruit smoothies
Soft-serve low-fat yogurt

Figure 4.18 Carbohydrate-Rich Choices when Eating in Restaurants.

*Typically available at fast-food restaurants would want to avoid any prepared products that contain an animal-derived ingredient. The American Dietetic Association and Dietitians of Canada support the position that well-planned vegetarian diets are healthy, nutritionally adequate, and able to meet sports nutrition recommendations (American Dietetic Association, 2003).

Sugar Intake and the Use of Artificial Sweeteners. In 2003, per capita sugar consumption in the United States was 156 lb per year, 36 lb per year greater than in 1970 (Johlin, Panther, and Kraft, 2004; Howard and Wylie-Rosett, 2002). Sugar is commonly consumed as sweetened breakfast cereals, sweetened grains such as cookies, cakes, and other bakery products, soft drinks and other sweetened beverages, candy, jam, and table sugar. Sugars found in fruits and milk are generally not included in sugar consumption figures.

The effect that a high sugar intake may have on chronic disease has been controversial, but evidence is mounting that a high consumption of sugar-sweetened beverages, such as soft drinks and fruit punch, by both children and adults results in weight gain and increased risk for type 2 diabetes (Schulze et al., 2004; James et al., 2004; Raben et al., 2002). Consumption of regular soft drinks is reported to be the largest contributor of sugar in the diets of males and females ages six to 54 (Guthrie and Morton, 2000). The source of sugar in regular soft drinks is usually high-fructose corn syrup (HFCS).

Bray, Nielson, and Poplin (2004) note that the consumption of high-fructose corn syrup (both in sweetened drinks and foods) increased more than 1,000 percent between 1970 and 1990 and mirrors the rise in obesity. There is concern that beverages with HFCS provide a liquid source of calories but little satiety. Fructose does not stimulate insulin or leptin, hormones that are known to help regulate food intake and body weight. Thus, it is plausible that high-fructose corn syrup consumption is associated with an increased caloric intake and weight gain. Many health professionals are specifically recommending that people reduce their intake of sugared beverages. Of course, weight gain is influenced by more than just food intake, and lack of daily activity by adults and children is a major public health concern.

Sugar intake and weight gain have always been of interest to American consumers. Surveys suggest that approximately 85 percent of all U.S. adults use low-calorie, reduced sugar, or sugar-free foods and beverages at least once every two weeks. The most popular sugar-free products are artificially sweetened soft drinks and other beverages. Consumers also add sugar substitutes to coffee and tea and to home-cooked products. The demand for artificially sweetened and sugar-free products continues to rise (Caloric Control Council, 2004).

Americans report that they use **artificial sweeteners** to reduce calorie intake and to eat a healthier diet. Athletes need carbohydrates, of which sugar is one, but many athletes worry that they consume too much sugar and too many excess calories from sugar. They consider artificially sweetened foods as alternatives to highly sweetened foods and ask the logical questions, "What are artificial sweeteners?" and "Are they safe?"

Artificial sweeteners (technically known as nonnutritive sweeteners) are not found naturally in foods; rather they are laboratory-manufactured compounds that provide a sweet taste but few or no calories. Saccharin (Sweet 'n Low®), aspartame (Nutrasweet®, Equal®), acesulfame potassium (Acesulfame K or Sunett®), sucralose (Splenda®), and neotame are examples of nonnutritive sweeteners. Table 4.13 explains the various artificial sweeteners and their similarities and differences.

Questions about safety have been raised ever since the Food and Drug Administration approved the first artificial sweeteners. The position of the American Dietetic Association (2004) is that "nonnutritive sweeteners are safe for use within the approved regulations." However, concerns about artificial sweeteners are frequently raised, most often via the media, and individuals who use artificial sweeteners should evaluate any safety concerns raised.

Perhaps the biggest questions are about the effectiveness of artificial sweeteners to reduce total caloric intake, promote weight loss, and prevent or slow weight gain. When artificial sweeteners first came into the market there was great hope that they would play an important role in weight reduction for overweight and obese people. Theoretically, if a person substituted artificial sweeteners for sugar, then the caloric deficit over time from the substitution would result in weight loss. But the prevalence of obesity and the use of artificial sweeteners have both increased substantially over the past 30 years. It may be that instead of substituting artificially sweetened foods for sugar-sweetened products people are using artificial sweeteners in addition to foods sweetened with sugar. The causes of obesity are multifactorial, but clearly artificial sweeteners are not the weight-related panacea that both industry and consumers hoped they would be.

Theoretically, the use of artificial sweeteners could improve diet quality (American Dietetic Association, 2004). For example, suppose a person normally consumed 12 oz (~360 ml) of a sugared soft drink, which has about 150 kcal. If an artificially sweetened soft drink was consumed and food with the same amount of kilocalories but more nutrients was eaten, an argument could be made that the quality of the diet was improved. To date there have been no studies that have examined if people usually make such substitutions, but athletes may choose to do so as part of their overall diet plan.

Table 4.13 Artificial (Nonnutritive) Sweeteners

Artificial Sweetener	Description
Acesulfame potassium (Acesulfame K or Sunett®)	• Often mixed with other artificial sweeteners such as aspartame • ADI* is 15 mg/kg/d in the U.S.; 9 mg/kg/d in Europe (~ 490 to 818 mg/kg/d for a 120-lb person) • Average intake in the U.S. is below 9 mg/kg/d
Aspartame (Nutrasweet®, Equal®)	• Made of two amino acids, L-aspartic acid and L-phenylalanine • Warning label is required because those with phenylketonuria cannot metabolize the phenylalanine • FDA approved. Opponents question its safety on the basis that it causes seizure, headache, memory loss, and mood change. • ADI* is 50 mg/kg/d in the U.S.; 40 mg/kg/d internationally (~ 2,180 to 2,725 mg/d for a 120-lb person) • Diet soft drinks (12 oz) sweetened only with aspartame contain about 200 mg • Average intake in the U.S. is between 3.0 and 5.2 mg/kg/d
Neotame	• Intensely sweet (7,000 to 13,000 times sweeter than sugar) • ADI* is 18 mg/d in the U.S.; 2 mg/kg/d internationally (~ 109 to 981 mg/day for a 120 lb person) • Average intake in the U.S. is between 0.04 and 0.10 mg/kg/d
Saccharin (Sweet 'n Low®)	• Oldest artificial sweetener (discovered in 1879) • Once thought to be a cause of bladder cancer but studies in humans do not support this association • Often found in restaurants as single-serving packets • ADI* is 5 mg/kg/d (~ 273 mg/d for a 120-lb person) • Average intake in the U.S. is 50 mg/d
Sucralose (Splenda®)	• Derived from sugar but is not digestible due to the substitution of three chlorine atoms for three OH groups • Also contains maltodextrin, a starch, which gives it bulk so that it will measure like sugar in recipes • ADI* is 5 mg/kg/d (~ 272 mg/day for a 120-lb person) • Average intake in the U.S. probably does not exceed 2 mg/d

Legend: mg/kg/d = milligrams per kilogram body weight per day; mg/d = milligrams per day; lb = pound; oz = ounce; mg = milligrams

*The Acceptable Daily Intake (ADI) is an estimate of the amount a person could consume daily over a lifetime without appreciable risk. The ADI is based on animal studies and has a large margin of safety. The ADI is expressed as mg/kg/d.

American Dietetic Association (2004). Position paper: Use of nutritive and nonnutritive sweeteners. *Journal of the American Dietetic Association,* 104(2), 255–275.

INDIVIDUAL ISSUES THAT INFLUENCE CARBOHYDRATE INTAKE

Lactose intolerance. The digestion of lactose (milk sugar) requires the enzyme lactase, known scientifically as β-galactosidase. In humans and other mammals, lactase activity is high during infancy. In most humans, lactase activity begins to decline at about age two but in some Caucasians the decline does not begin until adolescence. While the decline is extensive, most adults do have a low level of lactase activity. Lactose maldigestion occurs when there is insufficient lactase relative to the amount of lactose consumed in the diet. In people of Northern European descent, lactase activity remains at infant levels throughout adulthood and their tolerance of lactose remains high (Vesa, Marteau, and Korpela, 2000; de Vrese et al., 2001).

In the United States, nearly 100 percent of Asian-Americans and Native Americans maldigest lactose because their amount of lactase activity is very low. Approximately 75 percent of African-Americans and half (53 percent) of the Hispanic population also have low lactase activity. Maldigestion by U.S. Caucasians is estimated to be 6 percent to 22 percent (Jackson and Savaiano, 2001). Altogether, about 80 million people in the United States malabsorb lactose due to low lactase activity.

Lactose malabsorption results in gas, bloating, diarrhea, nausea, and abdominal pain, a condition

Artificial sweetener: Laboratory-manufactured compound that provides a sweet taste but few or no calories. Technically known as a nonnutritive sweetener.

known as lactose intolerance. Because lactase activity is low but not absent, people who are lactose intolerant can usually digest about 9 to 12 g of lactose. An 8-oz (240 ml) glass of milk has about 12 g of lactose. Chocolate milk appears to be better tolerated than milk not flavored with chocolate (de Vrese et al., 2001).

Those with lactose intolerance typically can digest fermented milk products, such as yogurt or *Acidophilus* milk better than other milks or unfermented milk products, even though the same amount of lactose is consumed. One reason is that fermented products contain bacteria that produce β-galactosidase (lactase). A second reason is that solids, such as yogurt, tend to move more slowly through the gastrointestinal tract than fluids, which allows for more time to digest the lactose (de Vrese et al., 2001). This same effect is found when milk is consumed with a meal (Jackson and Savaiano, 2001).

Those who maldigest lactose typically use trial and error to determine the lactose-containing foods to include in their diets. They experiment with the amount consumed, the form (i.e., solid, semisolid, liquid), and the presence of fermentation bacteria. Other tactics include adding lactase tablets to food or drinking milk that has lactase added. These strategies allow people to consume dairy products, a concentrated source of calcium in the diet. In several studies of Caucasians with lactose intolerance, subjects limited their dairy intake, and therefore, their calcium intake. Lactose maldigestion is thought to be one factor that contributes to low calcium intake and low bone mineral density, both of which are associated with osteoporosis (Jackson and Savaiano, 2001).

Gas, bloating, and diarrhea are not unique to lactose intolerance. These same symptoms are associated with irritable bowel syndrome, which affects about 20 percent of the adult population. Athletes who experience such symptoms should seek medical care to determine their probable cause and the most appropriate treatment.

Fructose Intolerance. Lactose intolerance has been frequently studied, but the study of fructose intolerance is in its infancy. Some researchers feel that fructose intolerance is under-recognized and therefore not treated (Choi et al., 2003). The symptoms are often the same as lactose intolerance or irritable bowel syndrome—bloating, gas, and diarrhea. Bloating results because unabsorbed fructose draws water into the gastrointestinal tract. Gas is produced when bacteria in the colon ferment the unabsorbed fructose. In the process of fermentation, short-chain fatty acids are produced and this results in increased gastrointestinal motility. Theoretically, all of these symptoms should be resolved if fructose-containing foods in the diet are reduced or eliminated (Choi et al., 2003; Skoog and Bharucha, 2004).

In 1970, high-fructose corn syrup (HFCS) represented only 5 percent of the sugar in the U.S. diet; by 2001 it represented 55 percent (Johlin, Panther, and Kraft, 2004). Fructose is better absorbed when glucose is present in equal amounts. Fructose is not well absorbed when it is accompanied by sorbitol, a sugar alcohol that is found naturally in some foods and added to many sugar-free foods (see Spotlight on

KEEPING IT IN PERSPECTIVE

Carbohydrates Are for Fuel and Fun

Many athletes follow rigorous training programs and must replenish glycogen stores by eating carbohydrate-rich diets daily. Endurance and ultraendurance athletes carefully plan their carbohydrate intake before, during, and after exercise or they risk nearly depleting muscle glycogen during competition or hard training. Many marathon runners and triathletes have stories about "bonking" or "hitting the wall," popular terms that describe glycogen depletion. This need for constant carbohydrate-containing foods sometimes means that athletes get rigid about their food intake. The key to meeting carbohydrate recommendations is to maintain a flexible eating plan.

Because they know the importance of sufficient carbohydrate intake daily, many dedicated athletes find themselves eating the same foods everyday. Structure and consistency are important, but food intake can become mechanical and the joy of eating can be diminished. To maintain flexibility, athletes should experiment with new carbohydrate-containing foods during the active recovery period ("off-season") or when not preparing for an important competition. Learning to cook different kinds of foods or finding new restaurants can be fun and can lead to the inclusion of a greater variety of carbohydrate foods. Eating traditional foods from different ethnic groups helps with variety, since most ethnic diets include a carbohydrate food as a staple and use different spices. For example, Italian food is pasta based, Asian food is rice and soybean based, Mexican food is rice and bean based, and South American food is tuber, bean, and nut based. The key to maintaining a flexible eating plan is the inclusion of a variety of foods daily. Food is for fuel and fun and athletes must find the right balance.

Enrichment: Sugar Alcohols). For those with fructose intolerance, large amounts of soft drinks, fruit juice such as orange juice, honey, or dates may contain too much fructose relative to the amount of glucose. Cherries, apples, pears, and foods with sorbitol added may also be problematic. A fructose-reduced diet is likely to reduce the bloating, gas, and diarrhea. However, such a diet requires a high degree of motivation and careful label reading.

Altered Glucose or Insulin Responses. The hormonal response to carbohydrate intake described earlier in the chapter helps the body to keep blood glucose in homeostasis. About 90 percent of adult Americans have a normal response, but at least 18 million Americans have diabetes. In those with type 1 diabetes, insulin secretion is absent. These individuals will need to match their food intake with the proper amount of insulin, which is injected or released from an insulin pump. In those with type 2 diabetes (about 16 to 17 million of the 18 million adults with diabetes), insulin secretion is diminished or the cells are resistant to the influence of insulin. These individuals may take medications to stimulate the release of more insulin. They should reduce the intake of high glycemic foods that rapidly increase blood glucose concentrations. If insulin resistance is present, reducing excess body fat and engaging in at least 30 minutes of moderately intense exercise five days a week will help reduce the body's resistance to the action of insulin. More information about diabetes can be found in Chapter 12.

Being diagnosed with diabetes does not preclude one from excelling in athletics. For example, swimmer Gary Hall Jr., who has type 1 diabetes, has won 10 Olympic medals, five of them gold. During training and competitions he tested his blood glucose 10 to 12 times a day with the possibility that he had to inject insulin each time. The challenge for athletes with type 1 diabetes is to properly match insulin injections, food intake, and exercise. Sports dietitians work with such athletes who adjust carbohydrate and insulin intakes to maintain normal blood glucose concentrations before, during, and after exercise (Hayes, 2006).

Exercise is encouraged for individuals with type 2 diabetes because it improves blood glucose control. Total carbohydrate and energy intakes are also important because many people with type 2 diabetes need to lose body fat. These individuals will also benefit from working with a dietitian to devise a diet plan with adequate but not excessive carbohydrates or calories. Some world-class athletes have type 2 diabetes, including Sir Steve Redgrave, a British rower who was knighted after he won his fifth consecutive Olympic gold medal, an unparalleled Olympic achievement.

The Internet Café

Where Do I Find Information about Carbohydrate and Athletes?

One of the leading sites for information about sports nutrition, including extensive information on carbohydrate and fluid intake before, during, and after exercise, is the Gatorade Sports Science Institute (GSSI). Well-researched articles written by experts are available free of charge. This is a commercial website and Gatorade products are advertised. **www.gssiweb.com/**

Glycemic index and glycemic load values for more than 750 foods are available at **www.mendosa.com.** This site is maintained by David Mendosa, a freelance medical writer specializing in diabetes. This is a commercial website that offers a subscription newsletter and allows banner advertising.

Many sports-governing bodies (e.g., U.S. Track and Field, USA Swimming) and commercial sports-related websites, especially those targeting self-coached athletes, have information about carbohydrate intake and training. Many of these articles are written by sports dietitians or exercise physiologists and are unbiased and scientifically correct.

THE EXPERTS IN. . .

Carbohydrate and Exercise

Many exercise physiologists have conducted carbohydrate research to determine the amount and type of carbohydrate needed to support training and improve performance. David Costill, Ph.D., is a pioneer in sports nutrition and performance research in the United States. Using a muscle biopsy technique developed in Scandinavia, he conducted numerous studies of muscle glycogen utilization and replenishment. Mike Sherman, Ph.D., focused on carbohydrate manipulations to improve human performance and the pathophysiology of carbohydrate metabolism (e.g., diabetic models in rats). Studies now considered classics in the area of timing of carbohydrate intake were conducted by Edward Coyle, Ph.D. (carbohydrate consumption during exercise) and John Ivy, Ph.D. (muscle glycogen replacement after exercise). These researchers are among the hundreds of exercise physiologists who continue to advance the knowledge of carbohydrate in training and performance.

A small percentage of the nondiabetic population may have either reactive hypoglycemia or fasting hypoglycemia. Reactive hypoglycemia refers to a low blood glucose concentration that follows food intake. For example, if a person with reactive hypoglycemia were to consume a high glycemic food, blood glucose would rise rapidly. However, glucagon secretion may be slow or limited and would be insufficient to completely offset the action of insulin. In that case, the blood glucose level would continue to fall and result in hypoglycemia. The symptoms of hypoglycemia are hunger, shakiness, light-headedness, and loss of concentration. Treatment for reactive hypoglycemia involves the avoidance of foods that cause blood glucose to rise rapidly and the consumption of small meals or snacks every three hours to help keep blood glucose stable. Fasting hypoglycemia is rare and needs immediate medical attention because it is usually a symptom of an underlying disease such as a tumor.

Some nondiabetic endurance athletes may experience exercise-induced hypoglycemia, which impairs performance. Although the exact number of athletes affected is not known, it is estimated that it is less than 25 percent. Consuming carbohydrate before and, most importantly, during prolonged exercise prevents hypoglycemia. Training helps endurance athletes make adaptations that also reduce the risk. These adaptations include the use of fats as a fuel source, an increase in the production of glucose in the liver, and changes in hormone sensitivity. However, athletes who overtrain actually reverse some of the training adaptations and may experience hypoglycemia that results in fatigue (Brun et al., 2001).

Abnormal glucose or insulin responses require dietary management but do not preclude people from training, competing, or excelling in athletics. These individuals must manage externally what is typically controlled internally in those with normal blood glucose regulation. It may be an inconvenience to have to closely monitor carbohydrate intake but it is not an insurmountable barrier. Sports dietitians can help such athletes devise an appropriate dietary plan.

Summary

Carbohydrates are found in food as **sugars, starches,** and **fiber.** Sugars and starches are digested and absorbed from the gastrointestinal tract; fiber is indigestible. After absorption, carbohydrates are found as **glucose** (blood sugar), muscle **glycogen,** and liver glycogen. The metabolism of glucose is intricate and involves many metabolic pathways, including the immediate use of glucose for energy and the storage of glucose as glycogen for future use as energy. Carbohydrates are the primary energy source for moderate to intense exercise. Exercising muscle prefers to use carbohydrate from stored glycogen rather than from blood glucose so athletes need sufficient glycogen stores.

Exercise reduces glycogen stores, which must be replenished on a daily basis. The general recommendation for carbohydrate intake for athletes in training is 5 to 10 g/kg body weight daily. This recommendation assumes that energy (caloric) intake is adequate. The general recommendation must be individualized based on the intensity and duration of exercise during training and competition. General recommendations are also made for carbohydrate consumption before, during, and after exercise and competition. Athletes fine-tune these recommendations to help meet their training and competition goals. **Carbohydrate loading** is one technique that endurance athletes and some bodybuilders use before an important competition.

Insufficient carbohydrate intake can lead to hypoglycemia and both acute and chronic fatigue. Many athletes fail to consume enough carbohydrates daily and some consistently fall short of recommended intakes over a period of weeks or months. Sufficient carbohydrate intake is an important element in athletic training and competition.

Even when athletes know and understand the carbohydrate recommendations, meeting those recommendations is not easy. Athletes must purchase or prepare carbohydrate-rich meals daily. Some athletes have **lactose** intolerance, reactive hypoglycemia, or **diabetes,** and these conditions influence the choice of carbohydrate-containing foods. Proper carbohydrate intake positively affects training, performance and health.

Post-Test Reassessing Knowledge of Carbohydrates

Now that you have more knowledge about carbohydrates, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. The body uses carbohydrates primarily in the form of fruit sugar, fructose.
2. Sugars such as sucrose (table sugar) are unhealthy and should rarely be a part of an athlete's diet.
3. Low levels of muscle glycogen and blood glucose are often associated with fatigue, particularly during moderate- to high-intensity endurance exercise.
4. A diet that contains 70 percent of total kilocalories as carbohydrates will provide the necessary amount of carbohydrates for an athlete.
5. Most athletes consume enough carbohydrates daily.

Review Questions

1. Where are carbohydrates found in foods? In the body?
2. How do monosaccharides, disaccharides, and polysaccharides differ?
3. Compare and contrast the absorption of glucose and fructose.
4. How is blood glucose regulated?
5. What is the fate of glucose when it is taken into a cell?
6. Who is more likely to convert glucose to fat—active or sedentary individuals? Why?
7. Does exercising muscle prefer to use stored glycogen or blood glucose?
8. When exercising muscle uses blood glucose, what keeps blood glucose from dropping too low?
9. What is the current recommendation for total carbohydrate intake for athletes in training?
10. What are the current recommendations for carbohydrate intake before, during, and after training or competition?
11. What are some practical issues that prevent athletes from meeting the daily recommended intake of carbohydrates?
12. Under which circumstances would the use of the glycemic index be helpful to athletes?
13. What are the advantages of consuming starches rather than sugars? Disadvantages?
14. Compare and contrast the various artificial sweeteners.
15. What is lactose intolerance and who is most likely to maldigest lactose?

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5 Proteins

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Learning Objectives

1. Describe amino acids and how the structure of a protein affects its function.
2. Distinguish between indispensable, conditionally indispensable, and dispensable amino acids.
3. Describe the digestion, absorption, transport, and metabolism of amino acids.
4. Describe when and how the body uses protein to fuel exercise.
5. State protein recommendations for athletes and the effects of high and low protein and/or energy intakes on training, performance, and health.
6. Identify sources of dietary protein.
7. Assess an athlete's dietary protein intake.
8. Evaluate dietary supplements containing amino acids and proteins, such as whey and casein, for safety and effectiveness.

Pre-Test Assessing Current Knowledge of Proteins

Read the following statements and decide if each is true or false.

1. Skeletal muscle is the primary site for protein metabolism and is the tissue that regulates protein breakdown and synthesis throughout the body.
2. In prolonged endurance exercise, approximately 3 to 5 percent of the total energy used is provided by amino acids.
3. To increase skeletal muscle mass, the body must be in positive nitrogen balance, which requires an adequate amount of protein and energy (calories).
4. The daily recommended protein intake for strength athletes is 2.0 to 3.0 grams per kilogram body weight, twice that recommended for endurance athletes.
5. Strength athletes usually need protein supplements because it is difficult to obtain a sufficient amount of protein from food alone.

Since the days of the ancient Olympiads, **protein** has held a special place in the athlete's diet. Protein is critical to growth and development, including growth of muscle tissue, so its place as an important nutrient has been earned. But its role can be overstated if it is elevated above other nutrients. No one nutrient, by itself, ensures proper nutrition. Protein functions optimally only when **energy** intake from carbohydrate and fat is sufficient.

A primary function of protein is to build and maintain tissues. To increase muscle mass, an athlete must engage in resistance exercise, consume a sufficient amount of energy (kcal), and be in positive nitrogen (protein) balance. Because so much emphasis is put on protein and muscle growth, it can easily be forgotten that protein is also the basis of **enzymes** and many **hormones,** and of structural, transport, and immune system proteins. Although it is not the primary function of protein, the **amino acids** that make up protein can be used to provide energy. In prolonged endurance exercise, amino acids are an important energy source even though carbohydrates and fats supply the majority of the energy.

The basic component of all proteins is the amino acid, a nitrogen-containing compound. Proteins found in food are broken down into amino acids through the processes of digestion and absorption. Once absorbed, the amino acids are transported to the liver, which plays a major role in amino acid metabolism. Body proteins are constantly being manufactured and broken down. Dietary protein and degraded body proteins provide a steady stream of amino acids for protein synthesis. In a prolonged starvation state the body's ability to maintain nitrogen balance is compromised and muscle tissue will be sacrificed to ensure survival.

Proteins are found in both plant and animal foods. Although they differ in quality (i.e., amount and type of amino acids), in industrialized countries it is easy to consume an adequate amount of protein with sufficient quality. The amount of protein recommended for athletes is usually higher than for nonathletes, although protein consumption typically exceeds recommendations in both athletes and nonathletes when energy (kcal) intake is adequate. Timing of protein intake is important, especially during the postexercise (recovery) period.

Athletes have numerous protein-containing foods to choose from as well as a range of protein supplements. Protein supplements are generally manufactured using food proteins such as milk or soy, and protein supplements have not been proven more or less effective than protein-containing foods. Protein supplements are safe for healthy adults. Supplements of individual amino acids (e.g., glutamine, **branched chain amino acids**) under certain conditions (e.g., endurance running) have shown some promise, but more research is needed to confirm effectiveness.

Proteins are found in both plant and animal foods.

Proteins

Proteins are made up of amino acids, which contain carbon, hydrogen, oxygen, and nitrogen. It is the nitrogen that distinguishes them from the composition of carbohydrates, fats, and alcohol, which are made up of only carbon, hydrogen, and oxygen. To understand their functions one must understand the structures of proteins. The basic structural component is an amino acid.

AMINO ACIDS

An amino acid is a chemical compound that contains an NH_2 (i.e., amino) group and a COOH (i.e., carboxyl) group of atoms. The basic structure of an amino acid is shown in Figure 5.1. The nitrogen content of an amino acid is approximately 16 percent. There are a total of 20 different amino acids that will be used by the body to make various proteins. Amino acids may have side chains (e.g., glycine, leucine), acid groups (e.g., glutamine), basic groups (e.g., lysine), or rings (e.g., tryptophan). Some contain sulfur (e.g., cysteine, methionine). These differences in amino acid structure play critical roles in the functions of the proteins created. Important features of the 20 amino acids are shown in Table 5.1.

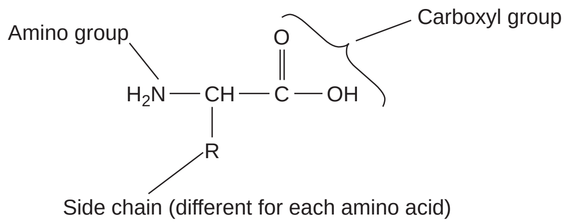


Figure 5.1 The Basic Structure of an Amino Acid

INDISPENSABLE AND DISPENSABLE AMINO ACIDS

Of the 20 amino acids needed by healthy adults, nine are considered **indispensable** because the body cannot manufacture them. The remaining 11 amino acids are termed **dispensable** because they can be manufactured in the liver. Six of these 11 amino acids are referred to as **conditionally indispensable**, because during periods of stress the body cannot manufacture a sufficient amount. Illness, injury, and prolonged endurance exercise are examples of physiologically stressful conditions. In the past, the terms ***essential*** and ***nonessential*** were used to describe indispensable and dispensable amino acids, respectively. *Nonessential* is a misleading term because it implies that such amino acids are not needed. In fact, they are needed but the body has the ability to manufacture them if they are not consumed directly from food. Indispensable and dispensable are now the preferred terminology when describing amino acids.

In the United States and other countries where a variety of food, including protein-containing food, is widely available, few healthy adults are at risk for amino acid deficiencies. They consume an adequate amount of protein daily and receive ample amounts of all the indispensable amino acids. Those at risk for low protein intake include those with **eating disorders** and **disordered eating,** the frail elderly, and people with liver or kidney disease.

PROTEIN QUALITY

Protein quality is determined based on the amounts and types of amino acids and the extent to which the amino acids are absorbed. Protein quality is a critical issue in human growth and development. In countries where protein foods are abundant, sufficient protein quality is a near certainty, an assumption that should not be made in countries where protein foods are limited.

Humans must obtain through diet all of the indispensable amino acids, which are found in lower concentrations in plant proteins than in animal proteins. Animal proteins are termed **complete proteins** because they contain all the indispensable amino acids in the

Protein: Amino acids linked by peptide bonds.

Energy: The capacity to perform work.

Enzyme: A protein-containing compound that catalyzes biochemical reactions.

Hormone: A compound that has a regulatory effect.

Amino acid: The basic component of all proteins.

Branched chain amino acid (BCAA): One of three amino acids (leucine, isoleucine, and valine) that has a side chain that is branched.

Indispensable amino acid: Amino acid that must be provided by the diet because the body cannot manufacture it.

Dispensable amino acid: Amino acid that the body can manufacture.

Conditionally indispensable amino acid: Under normal conditions, an amino acid that can be manufactured by the body in sufficient amounts, but under physiologically stressful conditions an insufficient amount may be produced.

Essential amino acid (EAA): See indispensable amino acid.

Nonessential amino acid: See dispensable amino acid.

Eating disorder: Substantial deviation from normal eating, which meets established diagnostic criteria.

Disordered eating: A deviation from normal eating.

Protein quality: The amounts and types of amino acids contained in a protein and their ability to support growth and development.

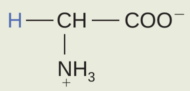
Complete protein: Protein that contains all the indispensable amino acids in the proper concentrations and proportions to each other to prevent amino acid deficiencies and to support growth.

Table 5.1 Summary of the 20 Indispensable and Dispensable Amino Acids

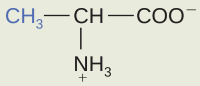
Amino Acid	Figure Number	Classification	Glucogenic	Ketogenic	Miscellaneous
Alanine (Ala)	2	Dispensable	Yes	No	Can be produced in the muscle from pyruvate but must be transported to the liver for conversion to pyruvate to produce glucose. An important glucose-generating pathway during starvation
Arginine (Arg)	14	Conditionally indispensable	Yes	No	
Asparagine (Asn)	12	Dispensable	Yes	No	
Aspartic acid (Asp)	10	Dispensable	Yes	No	One of the two amino acids that make up the structure of the artificial sweetener aspartame
Cysteine (Cys)	8	Conditionally indispensable	Yes	No	
Glutamic acid (Glu)	11	Dispensable	Yes	No	
Glutamine (Gln)	13	Conditionally indispensable	Yes	No	Represents about half of all the amino acids in the amino acid pool; possible role as a countermeasure for the immunological stress of endurance exercise
Glycine (Gly)	1	Conditionally indispensable	Yes	No	
Histidine (His)	16	Indispensable	Yes	No	
Isoleucine (Ile)	5	Indispensable	Yes	Yes	Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low
Leucine (Leu)	4	Indispensable	No	Yes	Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low
Lysine (Lys)	15	Indispensable	No	Yes	
Methionine (Met)	9	Indispensable	Yes	No	
Phenylalanine (Phe)	17	Indispensable	Yes	Yes	One of the two amino acids that make up the structure of the artificial sweetener aspartame
Proline (Pro)	20	Conditionally indispensable	Yes	No	
Serine (Ser)	6	Dispensable	Yes	No	
Threonine (Thr)	7	Indispensable	Yes	Yes	
Tryptophan (Trp)	19	Indispensable	Yes	Yes	
Tyrosine (Typ)	18	Conditionally indispensable	Yes	Yes	
Valine (Val)	3	Indispensable	Yes	No	Branched chain amino acid; muscle can use as an energy source during prolonged endurance exercise when muscle glycogen stores are low

Table 5.1 Summary of the 20 Indispensable and Dispensable Amino Acids (continued)

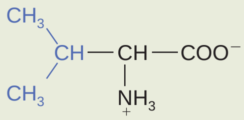
1. Glycine (Gly)



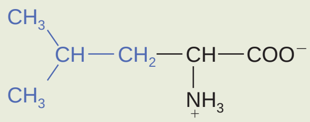
2. Alanine (Ala)



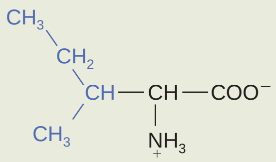
3. Valine (Val)



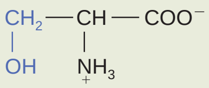
4. Leucine (Leu)



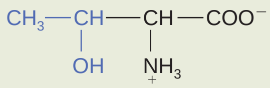
5. Isoleucine (Ile)



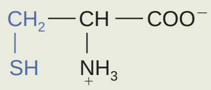
6. Serine (Ser)



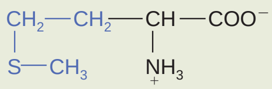
7. Threonine (Thr)



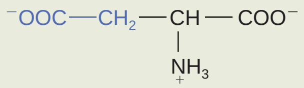
8. Cysteine (Cys)



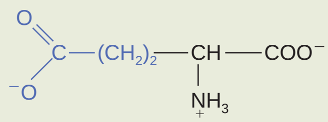
9. Methionine (Met)



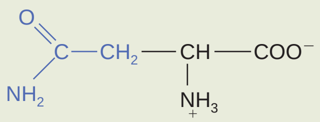
10. Aspartic acid (Asp)



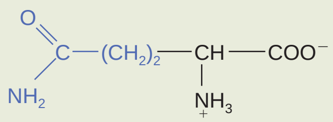
11. Glutamic acid (Glu)



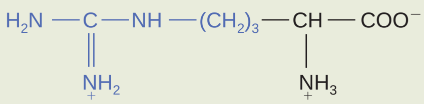
12. Asparagine (Asn)



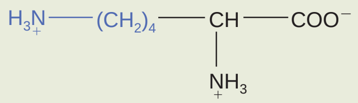
13. Glutamine (Gln)



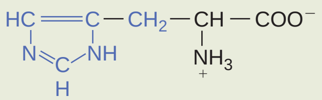
14. Arginine (Arg)



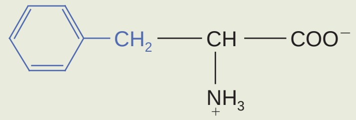
15. Lysine (Lys)



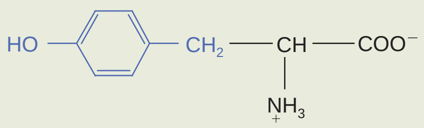
16. Histidine (His)



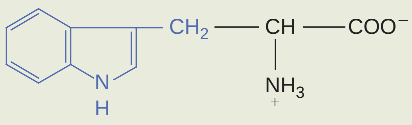
17. Phenylalanine (Phe)



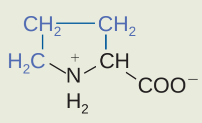
18. Tyrosine (Tyr)



19. Tryptophan (Trp)



20. Proline (Pro)



proper amounts and proportions to each other to prevent amino acid deficiencies and to support growth. In contrast, plant proteins may lack one or more of the indispensable amino acids or the proper concentrations and are termed **incomplete proteins.** The indispensable amino acids that are of greatest concern are lysine, threonine, and the sulfur-containing amino acids, cysteine and methionine. If the intake of these specific amino acids is limited, then protein deficiencies could occur.

It is possible to pair different plant proteins with each other and bring the total concentration of all the indispensable amino acids to an adequate level. This is the concept of **complementary proteins** or combining two incomplete proteins. When consumed together (i.e., during the same day), the complementary proteins can be nutritionally equal to a complete (animal) protein. This concept is more fully illustrated when vegetarian diets are discussed later in the chapter.

BASIC STRUCTURE OF POLYPEPTIDES

Peptide refers to two or more amino acids that are combined. Specifically, **dipeptide** refers to two amino acids, **tripeptide** to three amino acids, and **polypeptide** to four or more amino acids. Most proteins are polypeptides and are made up of many amino acids, often numbering in the hundreds or thousands. *Protein* and *polypeptide* are terms that are used interchangeably. *Dipeptide* and *tripeptide* are terms that are typically used when discussing digestion and absorption.

Polypeptides are synthesized on ribosomes, organelles found in large numbers in the cytoplasm of cells. The primary structure of the protein is determined at its creation based on information contained in DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). The RNA acts like a blueprint for the type, number, and sequence of amino acids to be included in a particular polypeptide. The differences in amino acids influence the bonding abilities of the polypeptide, which affect the shape of the protein. For example, proteins can be straight, coiled, or folded based on the type, number, and sequence of amino acids in the polypeptide. The primary structure of the polypeptide determines how a protein functions.

The secondary structure of the polypeptide is a result of weak bonding of amino acids that are located close to each other. These weak bonds give more rigidity and stability to the protein, an important characteristic for structural proteins such as collagen. The tertiary (third) level of structure is a result of interactions of amino acids that are located far away from each other. These interactions, if present, cause the polypeptide to form a loop. The loop results in a clustering of certain amino acids, which then function in a particular way. For example, a cluster of amino acids may have a positive or negative charge and accept or repel other compounds, such as water. Quaternary (fourth) level structure involves more than one polypeptide, typically two or four. Because of their quaternary structure, these proteins can interact with other molecules. Insulin, which interacts with glucose, is an example of a compound made up of two polypeptides.

FUNCTIONS OF POLYPEPTIDES

As explained above, the structure of the protein determines its function. Body proteins are often classified in five major categories: enzymes, hormones, structural proteins, transport proteins, and immune system proteins.

Enzymes are polypeptides that are necessary to catalyze reactions. It is the structure of the enzyme, particularly the quaternary structure, which allows the protein-based enzyme to interact with other compounds. The unique structure of each enzyme interacts with its substrate much like a key fits into and opens a specific lock. The purpose of enzymes is to regulate the speed of chemical reactions (refer to the more detailed description of enzymes in Chapter 2).

Hormones are compounds that act as chemical messengers to regulate metabolic reactions. Many hormones are protein based, although some hormones are made from cholesterol (e.g., steroid hormones). Insulin, glucagon, and human growth hormone are just three examples of the hundreds of hormones made from amino acids. Insulin is a relatively small polypeptide, made up of only 51 amino acids, yet it is one of the body's most essential hormones. Part of the polypeptide chain folds back on itself (due to its secondary structure) and the two protein chains that make up its quaternary structure are linked by disulfide bonds. Because insulin is small, it can move through the blood quickly and the folded chain and the disulfide bonds give it great stability.

Structural proteins include the proteins of muscle and connective tissue (e.g., actin, myosin, and collagen), as well as proteins found in skin, hair, and nails. Structural proteins can be constructed into long polypeptide strands, similar to a long chain. These strands can be twisted and folded into a wide variety of three-dimensional shapes (secondary structure). Elements of the constituent amino acids in the polypeptide chains, such as sulfide groups, may be brought close together by the twisting and folding and may form interconnected bonds (tertiary structure). The secondary and tertiary structures of the polypeptide are responsible for the differences in rigidity and the durability of these polypeptides.

Examples of transport proteins include lipoproteins (lipid carriers) and hemoglobin, which carries oxygen and carbon dioxide in the blood. Without its particular quaternary structure, hemoglobin would not be as efficient. Four polypeptide chains are bonded in such a way that they can work in concert and can change shape slightly when necessary. This structure allows hemoglobin to be flexible and capable of changing its ability to bind and release oxygen. For example, hemoglobin needs a high affinity to bind oxygen in the lungs and carry it throughout the body, but it must reduce its affinity for oxygen so oxygen can be released for use by the tissues.

The immune system is a protein-based system that protects the body from the invasion of foreign particles, including viruses and bacteria. One immune system response is the activation of lymphocytes, cells that produce antibodies. All antibodies are compounds that are made of polypeptide chains (usually four) in the shape of a Y. The antibody fits the virus or bacteria like a key in a lock, aiding in their destruction. The shape of the "key" is due to disulfide bonds and the sequence of the amino acids.

All of the compounds described above are proteins, but none of these compounds are provided directly from proteins found in foods. Enzymes, hormones, and the other protein-based compounds are manufactured in the body from indispensable and dispensable amino acids. To understand how food proteins become body proteins one must know how amino acids found in food are digested, absorbed, transported, and metabolized.

Digestion, Absorption, and Transportation of Protein

Digestion begins as soon as proteins found in food arrive in the stomach. Absorption takes place primarily in the **jejunum** and **ileum** (i.e., middle and lower small intestine) by several mechanisms. Once absorbed, the amino acids will be transported to the liver, which acts as a clearinghouse. After a meal the majority of the amino acids absorbed will remain in the liver for metabolism, while the remainder will circulate in the blood and be transported to other parts of the body.

DIGESTION OF PROTEINS

Protein digestion begins when a food protein comes in contact with the gastric juice of the stomach. The hydrochloric acid (HCl) in the gastric juice begins to **denature** (change the structure of) the protein. At the same time, the HCl activates pepsin, an enzyme that will break down the polypeptides into smaller units. Pepsin prefers to break the bonds of certain amino acids, such as leucine and tryptophan. This initial stage of digestion generally breaks down very large polypeptides into smaller units, but these smaller units are still very large amino acid chains.

As the denatured and partially digested polypeptides move from the stomach to the small intestine, a number of digestive enzymes are activated. Some of these are found in pancreatic juice, which is secreted from the pancreas into the small intestine. Other digestive enzymes are released from the cells of the brush border that line the gastrointestinal tract. Similar to pepsin, these enzymes prefer to break the bonds of specific amino acids. For example, some enzymes break down amino acids with rings while other enzymes break down amino acids with side chains.

Due to the action of the various enzymes, the large polypeptides that entered from the stomach are broken down into small polypeptides (usually no more than six amino acids), tripeptides, dipeptides, and free amino acids. The cells of the gastrointestinal tract can normally absorb nothing larger than a tripeptide, so the small polypeptides are broken down further by brush border enzymes.

ABSORPTION OF PROTEINS

Absorption takes place primarily in the jejunum and the ileum. Two-thirds of the amino acids absorbed are in the form of dipeptides or tripeptides, while one-third are individual amino acids. Absorption takes place in a variety of ways but one of the most common is the use of a carrier that moves these compounds across the cell membrane. There are a number of different carriers and each has an affinity for certain amino acids. Some of the carriers require sodium to load the amino acids. Not surprisingly, indispensable amino acids are absorbed more rapidly than dispensable amino acids.

Since proteins must be broken down into dipeptides, tripeptides, and free amino acids to be absorbed, protein supplements may be sold as "predigested." The predigestion is a result of exposing the food proteins in the supplement to enzymatic action during the manufacturing process. Due to a lack of scientific studies, it

Incomplete protein: Protein that lacks one or more of the indispensable amino acids in the proper amounts and proportions to each other to prevent amino acid deficiencies and to support growth.

Complementary proteins: The pairing of two incomplete proteins to provide sufficient quantity and quality of amino acids.

Peptide: Two or more amino acids linked by peptide bonds.

Dipeptide: Two amino acids linked by peptide bonds.

Tripeptide: Three amino acids linked by peptide bonds.

Polypeptide: Four or more amino acids linked by peptide bonds; often contain hundreds of amino acids.

Jejunum: The middle portion of the small intestine.

Ileum: The lowest portion of the small intestine.

Denature: To change the chemical structure of a protein by chemical or mechanical means.

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A wide array of protein supplements is available. Some are sold as "predigested."

is not known if supplements containing predigested dipeptides and tripeptides are absorbed faster or differently than food proteins broken down into dipeptides and tripeptides by digestive enzymes. It is known that free amino acids do compete with each other for absorption because of carrier competition. If some free amino acids are found in higher concentrations than others, it is possible that they would be preferentially absorbed over the amino acids found in lower concentrations (Gropper, Smith, and Groff, 2005). Well-designed research studies are needed in this area.

Protein from food provides about two-thirds of the amino acids absorbed from the small intestine. These amino acids are described as being **exogenous** (from outside the body). The other one-third of the amino acids is **endogenous** (from inside the body). Endogenous proteins include mucosal cells shed into the gastrointestinal tract and gastrointestinal secretions that contain enzymes and other protein-based compounds. These endogenous proteins are broken down and absorbed in a manner similar to proteins originally derived from food, although they are often absorbed lower in the gastrointestinal tract, including the colon. This is the body's way of recycling amino acids, but not all of them can be reclaimed. Those that are not absorbed are excreted in fecal material, which represents one way that nitrogen is lost from the body and is one reason why dietary protein must be consumed daily. Once amino acids are absorbed, the body does not distinguish between the amino acids originally obtained from food and those from endogenous sources.

Once inside the mucosal cells, any dipeptides and tripeptides are broken down into free amino acids by cellular enzymes. Some of the amino acids will not leave the intestinal cells because they will be used to make cellular proteins. Those that are not incorporated into cellular proteins will be released into the blood via the **portal** (liver) **vein.**

TRANSPORTATION OF PROTEINS

The liver serves as a clearinghouse for the amino acids by monitoring the supply of amino acids and dictating which amino acids will be transported to which tissues. Exceptions to this are the branched chain amino acids (BCAA)—leucine, isoleucine, and valine. The liver has very low levels of the enzyme BCAA transferase, which is needed to transfer these amino acids to tissues. Therefore, the branched chain amino acids leave the liver, circulate in the **plasma,** and are taken up by skeletal muscle cells, which have high levels of the enzyme that the liver lacks. BCAA transferase is also found in the heart, kidneys, and adipose tissue.

After a protein-containing meal, 50 to 65 percent of the amino acids absorbed will be found in the liver. The remainder of the amino acids absorbed will be immediately released as free amino acids into the blood and lymph and become part of the **amino acid pool,** which is shown in Figure 5.2. The concentration of amino acids in the blood is increased for several hours after a protein-containing meal is consumed.

The amino acid pool refers to free amino acids that are circulating in the blood or in the fluid found within or between cells. Half of the amino acid pool is found in or near skeletal muscle tissue while the remainder is distributed throughout the body. Some of the amino acids in the amino acid pool have recently been absorbed from the gastrointestinal tract, but most come from a different source—the breakdown of body tissues, including muscle tissue. The amino acid pool undergoes constant change but on average contains about 150 g of amino acids, of which ~80 g is glutamine. There are more dispensable amino acids in the pool than indispensable amino acids. The amino acid pool is always in flux as a result of food intake, exercise, and the breaking down or building of tissues, especially muscle. This constant flux is referred to as **protein turnover.** It is thought that a relatively large amount of energy (~20 percent of resting metabolism) is expended each day on synthesizing and degrading proteins.

Metabolism of Proteins (Amino Acids)

The liver is a major site for amino acid metabolism. The liver monitors the body's amino acid needs and responds accordingly with anabolic or catabolic processes. **Anabolic** is defined as building complex molecules from simple molecules. An example is the synthesis of a protein. **Catabolic** is the breakdown of complex molecules into simple ones. The use of protein for energy is a catabolic process, as the protein must be broken down into its amino acid components, some of which are then metabolized for energy. The liver plays the primary role in amino acid metabolism but it functions

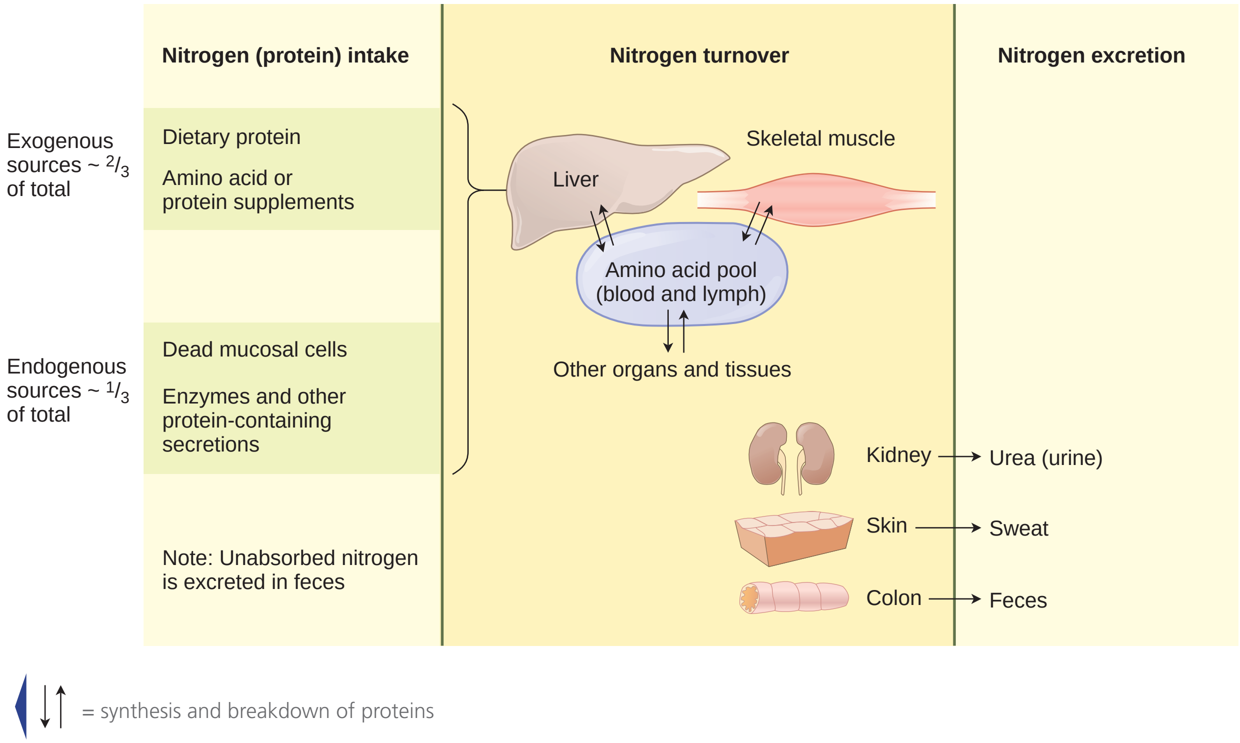
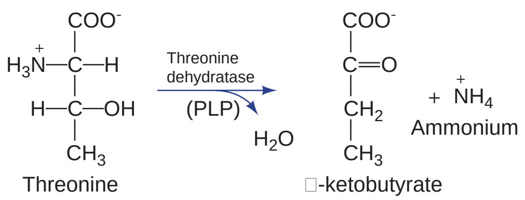


Figure 5.2 Nitrogen Intake, Turnover, and Excretion

The amino acid pool is a reservoir of amino acids. It is always in flux as dietary protein is consumed, body proteins are broken down and synthesized, and nitrogen is excreted in urine, sweat, and feces.



PLP = pyroxidoxal phosphate (Vitamin B_6 containing enzyme)

Figure 5.3 An Example of Deamination

The amino acid threonine is deaminated to form α-ketobutyrate (an α-keto acid).

in concert with other tissues, such as skeletal muscle and kidneys.

What is the fate of the amino acids absorbed from the gastrointestinal tract and transported to the liver? The liver uses approximately 20 percent of these amino acids to make proteins and other nitrogen-containing compounds. The liver catabolizes (breaks down) the majority of the amino acids delivered from the gastrointestinal tract. Two important metabolic processes are **deamination** and **transamination.** Deamination refers to the removal of the amino group from the amino acid (see Figure 5.3). When the amino group is removed, the remaining compound is an **alpha-keto acid (α-keto acid),** frequently referred to as the **carbon skeleton.** Transamination involves the transfer of an amino group to another carbon skeleton, whereby an amino acid is formed. Transamination allows the liver to manufacture dispensible amino acids from indispensable amino acids. Deamination and transamination are regulated

Exogenous: Originating from outside of the body.

Endogenous: Originating from within the body.

Portal vein: A vein that carries blood to the liver; usually refers to the vein from the intestines to the liver.

Plasma: Fluid component of blood; does not include cells.

Amino acid pool: The amino acids circulating in the plasma or in the fluid found within or between cells.

Protein turnover: The constant change in body proteins as a result of protein synthesis and breakdown.

Anabolism: Metabolic processes involving the synthesis of simple molecules into complex molecules.

Catabolism: Metabolic processes involving the breakdown of complex molecules into simpler molecules.

Deamination: The removal of an amino group.

Transamination: The transfer of an amino group.

Alpha-keto acid (α-keto acid): The chemical compound that is a result of the deamination (i.e., nitrogen removal) of amino acids.

Carbon skeleton: The carbon-containing structure that remains after an amino acid has been deaminated (i.e., nitrogen removed).

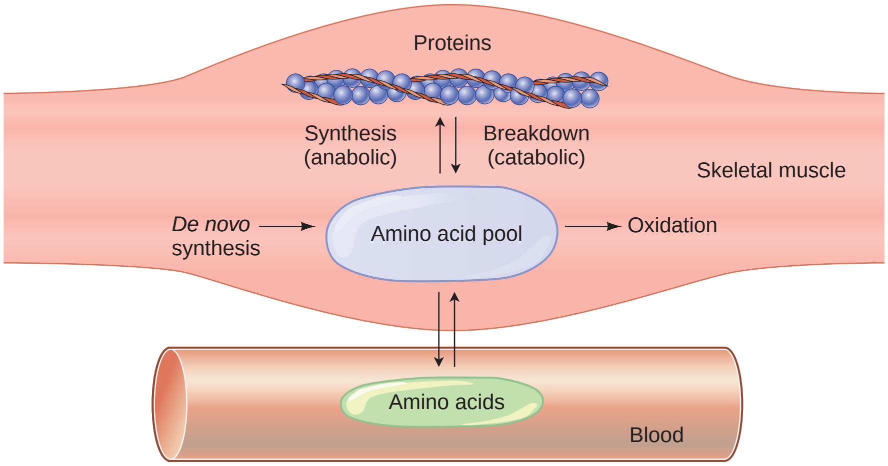


Figure 5.4 Skeletal Muscle Protein Turnover

A general depiction of muscle protein turnover (synthesis and breakdown). The amino acid pool in muscle tissue is derived from amino acids taken up from the blood, those synthesized in the muscle (de novo synthesis), or those from the breakdown of muscle protein. Amino acids from this pool can be used to synthesize muscle proteins, metabolized for energy via oxidative phosphorylation, or released into the blood for distribution to other tissues in the body.

by enzymes and are part of an intricate system that the liver uses to monitor and respond to the body's amino acid and protein needs.

Amino acids absorbed from food that do not remain in the liver become part of the amino acid pool. The amino acids in the pool are also involved in both anabolic and catabolic processes. For example, the synthesis of skeletal muscle protein is an anabolic process that uses amino acids from the pool to synthesize new proteins. When skeletal muscle proteins are degraded, a catabolic process, the amino acids are returned to the amino acid pool.

PROTEIN ANABOLISM

One of the major functions of the liver is protein anabolism. Some amino acids will be incorporated into liver enzymes. Others will be used to make **plasma proteins.** For example, the liver manufactures albumin, a protein that circulates in the blood and helps to transport nutrients to tissues. Many of the proteins made in the liver are synthesized and released in response to infection or injury. As mentioned earlier, the liver continually monitors the body's amino acid and protein needs and responds to changing conditions.

In addition to protein synthesis, the liver uses amino acids to manufacture compounds such as creatine. Recall from Chapter 3 that creatine can be obtained directly from the diet (e.g., beef, fish) and/or synthesized from the amino acids arginine, glycine, and methionine. The creatine synthesis process begins in the kidney but is completed in the liver.

Of particular interest to athletes is the synthesis and breakdown of skeletal muscle proteins. Figure 5.4 illustrates protein turnover. An anabolic state occurs when the synthesis of proteins is greater than their breakdown. In the anabolic state, amino acids from the amino acid pool are incorporated into the synthesis of proteins. How does this anabolic process occur? The process of protein synthesis occurs by the stimulation of a specific gene within a cell, which then sets into motion a series of complex steps resulting in the assembly of a specific protein.

A gene is a section of DNA in a chromosome of a cell that contains specific information to control hereditary characteristics. When stimulated, genes "express" these characteristics, usually through the synthesis of specific proteins. For example, the mechanical stress of force production by muscle that occurs as a result of strength training stimulates the genes that regulate the synthesis of actin and myosin. The target genes are signaled in a variety of ways beginning with the first step of the process, transcription. In transcription, the code for making each specific protein is copied to RNA. The next step is translation, during which RNA passes on the directions for manufacturing the protein to the ribosomes, cell organelles that assemble the amino acids from the amino acid pool into the correct sequence for that specific protein.

A simple analogy for this series of steps is the process of designing and building a house. The architect creates and keeps an original, detailed set of drawings and plans for the house. The architect does not build the house, however; this task is usually the responsibility of a building contractor. The contractor takes a copy of the architectural plans to the construction site and gives specific instructions to the construction workers to build the house as it appears in the plans. The original architectural plan is the gene (the specific DNA sequence in the cell), the "working copy" of the house construction plan is the RNA, and the construction site of cell protein synthesis is the ribosomes.

There are many factors that influence muscle protein synthesis and degradation, including genetics, exercise, nutrition, hormones, injury, and disease. The synthesis of muscle protein is strongly influenced by exercise, specifically strength training. The mechanical force that is developed by muscle during strength training stimulates both protein synthesis and protein breakdown. Protein synthesis is stimulated to a greater degree because one of the adaptations of skeletal muscle in response to strength training over time is **hypertrophy,** an increase in the amount of muscle tissue. The greatest increase is in **myofibrillar proteins,** the proteins that make up the force-producing elements of the muscle.

Feeding also promotes an anabolic state in the muscle, particularly if the meal contains adequate amino acids. Insulin has an important role in this anabolic process by stimulating protein synthesis and acting to inhibit protein degradation. Athletes have long known that strength training stimulates muscle growth and have recently begun to explore the manipulation of protein intake in conjunction with their strength training to optimize protein synthesis (see Timing of Protein Intake). Unfortunately, it is difficult to study optimal protein synthesis in athletes.

PROTEIN CATABOLISM

Amino acids that are not used for building proteins are catabolized. In other words, excess amino acids are not "stored" for future use in the same way that carbohydrates and fats are stored. Carbohydrate can be stored in liver or muscle as glycogen and fat can be stored in adipocytes (fat cells) and at a later time removed easily from storage and used as energy. In contrast, the so-called "storage" site for protein is skeletal muscle. Under relatively extreme circumstances, protein can be removed from the skeletal muscle, but the removal of a large amount of amino acids has a very negative effect on the muscle's ability to function.

Amino acids can provide energy. In fact, the source of approximately half of the ATP used by the liver comes from amino acids. When the amino group is transferred or removed, the carbon skeleton (alpha-keto acid) can be oxidized to produce energy (i.e., ATP). Although it is commonly written that amino acids are oxidized for energy, this is technically incorrect because the nitrogen is not oxidized. The term "oxidation of amino acids" is understood to mean that after the nitrogen is removed, the carbon skeleton of the amino acid is oxidized for energy and the nitrogen goes through the urea cycle in the liver.

Similar to carbohydrate, protein yields approximately 4 kcal/g. Energy is best supplied for exercise by carbohydrate and fat rather than protein. Sufficient caloric intake in the form of carbohydrate and fat is referred to as having a **protein-sparing effect.** In other words, the carbohydrate and fat provide the energy that the body needs and the protein is "spared" from this function. The protein is available for other important functions that can only be provided by protein. When people consume sufficient energy, all the important protein-related functions can be met and, in fact, some of the protein consumed *will* be metabolized for energy. Problems can result if caloric intake is too low and some protein *must* be used to meet energy needs.

The metabolic pathways for producing energy from protein are not reviewed in detail here; however, the catabolism of amino acids to provide ATP is summarized. Under aerobic conditions the carbon skeleton of an amino acid can be used in the Krebs cycle. As shown in Figure 5.5, amino acids have different entry points into the Krebs cycle, which is based on the structure of each amino acid. Some amino acids, such as alanine and glycine, can be converted to pyruvate. Others, such as leucine, are converted to acetyl Co-A. Additional pathways include the conversion of various amino acids to intermediate compounds of the Krebs cycle.

Six amino acids are most commonly broken down in muscle cells to yield energy—the branched chain amino acids (leucine, isoleucine, and valine), aspartate, asparagine, and glutamate. The breakdown of muscle, or **proteolysis,** is stimulated by the stress hormone **cortisol,** which is secreted by the adrenal glands. When the body is stressed, one response is the oxidation of amino acids. Endurance exercise represents an **acute** (short-term) stress so the use of amino acids for energy is not unexpected.

Endurance exercise results in an increased oxidation of leucine. At the beginning of an endurance exercise task there is usually sufficient carbohydrate stored as muscle glycogen, so little of the energy needed comes from amino acids initially. But as muscle glycogen stores decline substantially, the muscle uses some amino acids, particularly leucine, for energy. This metabolic response is influenced by the carbohydrate content of the athlete's diet. When the athlete has been consuming a low-carbohydrate diet

Plasma protein: Any polypeptide that circulates in the fluid portion of the blood or lymph, (e.g., albumin).

Hypertrophy: An increase in size due to enlargement, not an increase in number; in relation to muscle refers to an increase in the size of a muscle due to an increase in the size of individual muscle cells rather than an increase in the total number of muscle cells.

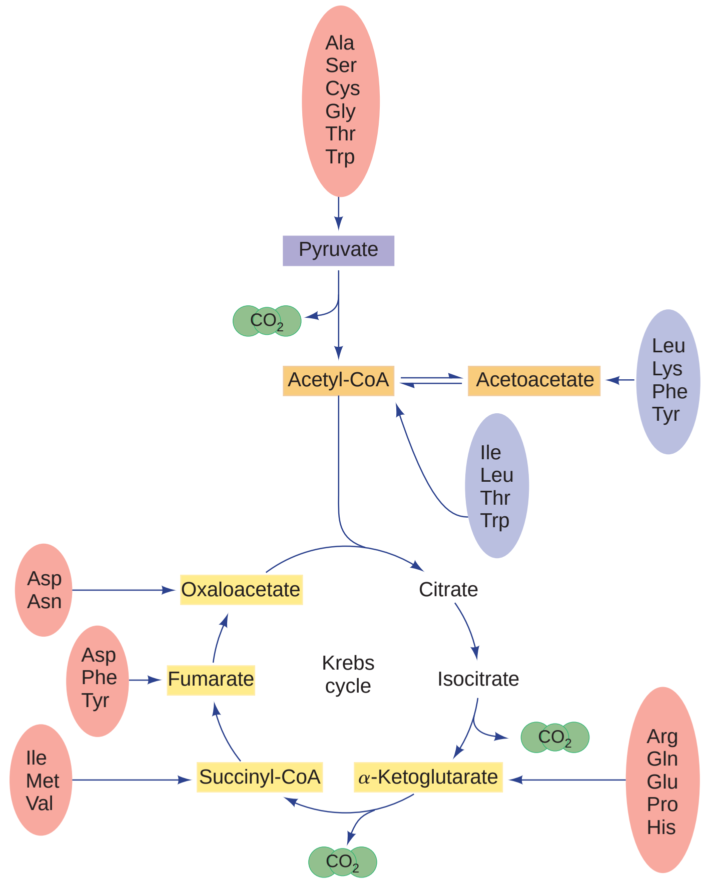
Myofibrillar proteins: The strandlike proteins that make up the force-producing elements of skeletal muscle, specifically the contractile proteins actin and myosin.

Protein-sparing effect: The consumption of sufficient kilocalories in the form of carbohydrate and fat, which protects protein from being used as energy before other protein-related functions are met.

Proteolysis: The breakdown of proteins into amino acids.

Cortisol: A glucocorticoid hormone that is secreted by the adrenal cortex that stimulates protein and fat breakdown and counters the effects of insulin.

Acute: Short-term.



Ala = alanine	Glu = glutamic acid	Leu = leucine	Ser = serine
Arg = arginine	Gln = glutamine	Lys = lysine	Thr = threonine
Asn = asparagine	Gly = glycine	Met = methionine	Trp = tryptophan
Asp = aspartic acid	His = histidine	Phe = phenylalanine	Tyr = tyrosine
Cys = cysteine	Ile = isoleucine	Pro = proline	Val = valine

Figure 5.5 Amino Acids Used for ATP Production

The structure of the amino acid determines the entry point into the Krebs cycle.

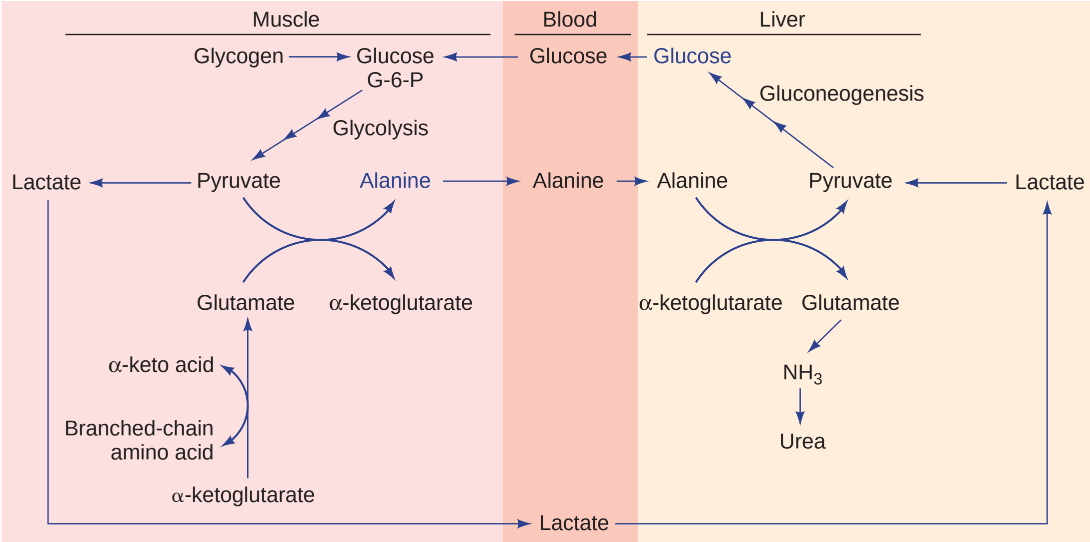
Sandra Mu/Getty Images

Prolonged endurance exercise results in increased protein metabolism, particularly in the later stages of a triathlon.

and is carbohydrate depleted, the oxidation of leucine is increased, while a high-carbohydrate diet and near-maximal muscle glycogen stores decrease the need for leucine oxidation (McKenzie et al., 2000).

As a percentage of the total energy used, that which comes from amino acids is small, about 3 to 5 percent. However, under the stress of endurance exercise, amino acids can represent an important energy source. For this reason, endurance athletes have explored the use of BCAA supplements, which will be discussed later in this chapter.

A discussion of protein catabolism would not be complete without mention of the ammonia (NH_3) or ammonium ions (NH^+_4) that are produced as a result of the catabolism of amino acids. Ammonia, which is toxic to the body, must be converted to urea, a related compound that can be safely transported in the blood to the kidneys where it is excreted in urine. The conversion of ammonia to urea takes place in the liver, so



G-6-P = glucose-6-phosphate
NH_3 = ammonia

Figure 5.6 Glucose-Alanine Cycle

Muscle produces pyruvate as a result of using the glycolysis or glycogenolysis energy pathway. This pyruvate can be converted to alanine, which is then released into the blood and taken up by the liver. The liver can then convert the alanine to pyruvate for use in gluconeogenesis to produce glucose. The newly formed glucose can be released into the blood for distribution throughout the body and use by a variety of tissues.

ammonia that is a result of amino acid catabolism in the liver can readily enter the urea cycle. Ammonia is also produced in the muscle as a result of the breakdown of adenosine monophosphate (AMP), which produces a compound that can be oxidized in the Krebs cycle for energy. This ammonia must be transported in the blood to the liver for conversion to urea. Urea contains nitrogen, so a small amount of nitrogen is lost every day via the urine. This loss of nitrogen is one reason that dietary protein must be consumed daily.

In addition to the oxidation of amino acids to produce ATP, a second major metabolic use of protein during exercise is for **gluconeogenesis** (i.e., the production of glucose from a noncarbohydrate source). The glucose-alanine cycle illustrates how amino acids can be used to generate glucose (see Figure 5.6). Exercising muscle may use carbohydrate (glucose and/or glycogen) for metabolism and in this process some of the pyruvate produced by **glycolysis** is converted (via transamination) to the amino acid alanine. Alanine is not used by the muscle, but is released into the blood where it travels to the liver. In the liver, alanine (as well as other amino acids) can be converted to pyruvate to produce glucose, a process known as gluconeogenesis. The newly formed glucose can then be released into the blood where it circulates and is taken up and used by a variety of tissues (e.g., brain, kidney, muscle). Eighteen of the 20 amino acids can be converted into glucose (only leucine and lysine cannot) and this primarily takes place in the liver. Although various amino acids can provide the carbon skeleton for gluconeogenesis, during exercise lactate is most likely the major source.

Effects of Training on Protein Usage. The effect of exercise training on the use of protein as a fuel source is not well established. Based on adaptations of other metabolic energy systems to the **chronic** stress of exercise, it is logical to assume that protein metabolism would be enhanced after exercise training, particularly endurance exercise training. The level of transaminase enzymes in muscle can increase two-fold, and studies with animal models show an increased ability to oxidize BCAA during exercise. However, evidence in humans (McKenzie et al., 2000) suggests that the amount of amino acid oxidation, specifically leucine, is actually reduced at both the same absolute and relative exercise intensity after endurance exercise training. The endurance exercise training apparently enhances fat oxidation to such a degree that the body does not need to rely as much on protein metabolism, giving further evidence that protein is not the body's preferred fuel source.

Gluconeogenesis: The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

Glycolysis: A series of linked chemical reactions that break down glucose for energy to replace ATP.

Chronic: Always present or recurring; long-term.

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Athletes must be in positive nitrogen balance to increase skeletal muscle mass. Negative nitrogen balance, as a result of starvation, leads to substantially reduced skeletal muscle mass.

PROTEIN BALANCE AND TURNOVER

The body is in a constant state of protein turnover. In other words, every day the body simultaneously degrades and synthesizes proteins. It is estimated that 1 to 2 percent of the total protein in the body is degraded each day (i.e., proteins are broken down to the amino acids that formed them). The source of most of the degraded protein is skeletal muscle, and these amino acids become part of the amino acid pool. About 80 percent of the amino acids that result from protein degradation are resynthesized into new proteins. However, at least 20 percent of the amino acids are not made into new proteins and are broken down to yield nitrogen, which must be excreted in the urine or feces, and carbon skeletons, which are used for energy. Approximately 5 to 7 g of nitrogen, which is equivalent to 30 to 40 g of protein, is excreted via the urine each day. This fact alone makes it obvious that humans need to consume protein in their diets each day.

The term protein turnover is used to compare protein synthesis with protein degradation. In a growth state, protein synthesis outpaces protein degradation. In a starvation state, protein degradation outpaces protein synthesis. Each protein in the body has its own turnover rate. Some turn over very quickly, in a matter of minutes, while others take several months to turn over.

Protein metabolism is never static; rather, it is always changing. One way to measure and describe the changes is to determine **nitrogen balance.** Nitrogen balance is the difference between total nitrogen (protein) intake and total nitrogen loss (via the urine and feces), usually determined over several weeks. When intake is equal to loss, a state of nitrogen balance exists. When intake is greater than loss, a person is in positive nitrogen balance. Conversely, when loss is greater than intake, a state of negative nitrogen balance is present.

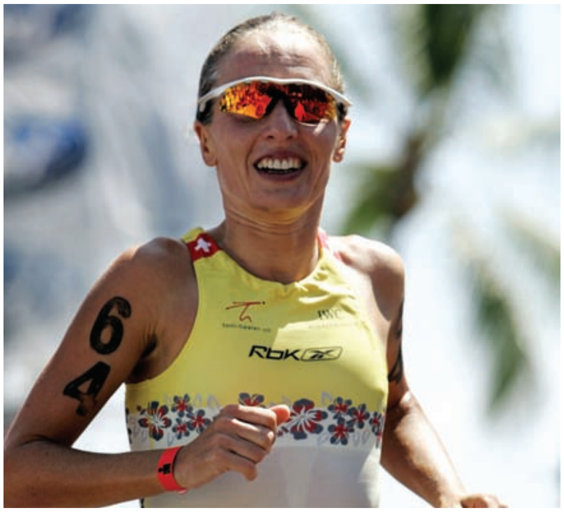
Under normal conditions most adults are in nitrogen balance. Their intake of nitrogen is in equilibrium with their nitrogen losses. There is also equilibrium in their protein turnover. In other words, the amount of protein being synthesized is equal to the amount of protein being degraded. On average, the adult body turns over about 320 g of protein a day. Those adults who want to be in a growth state must achieve positive nitrogen balance. Adult growth states include pregnancy and substantial increases in skeletal muscle mass, which is a goal for many athletes, particularly strength athletes. To achieve positive nitrogen balance both energy and protein intake must be sufficient. More details about increasing skeletal muscle mass can be found in Chapter 11.

Negative nitrogen balance is not desirable. Examples of conditions in which negative nitrogen balance occurs include starvation and semistarvation states (e.g., eating disorders such as anorexia athletica) and disease states such as fast-growing cancers.

Protein turnover and nitrogen balance are not the same, but they are related. In a growth state, the body is in positive nitrogen balance. Protein synthesis is also outpacing protein degradation. Although the exact mechanisms for regulating balance and turnover are not entirely known, the amino acid pool does play a role (Gropper, Smith, and Groff, 2005). Unfortunately, protein turnover and nitrogen balance are difficult to study in humans.

In addition to the amino acid pool, the body has a **labile protein reserve.** This reserve of amino acids is found in liver and other organs **(visceral tissues).** Labile refers to something that readily or frequently undergoes change. The labile protein reserve allows the body to respond to very short-term changes in protein intake. For example, if on a given day a person consumed little food and little protein (e.g., fasting), then the body can immediately tap the labile protein reserve and provide

AP Photo/Eduardo Verdugo



AP Photo/Elaine Thompson

Both strength/power and endurance athletes need adequate protein daily.

amino acids to the amino acid pool. Having the ability to quickly use liver and other visceral tissue proteins as a source of amino acids allows the body to protect the skeletal muscle from being used as an amino acid source for short-term emergencies (Institute of Medicine, 2002).

When faced with semistarvation or starvation the body adapts by decreasing the rate of protein synthesis and increasing protein degradation. The rate of protein synthesis is decreased overall by at least 30 percent and to a greater degree in skeletal muscle than in other tissues. This is another example of the negative impact that insufficient energy intake has on protein metabolism. Under starvation conditions the hormonal balance also changes. Food is not being consumed, so little insulin is being produced and the muscle and fat cells become resistant to the insulin that is present. Without the influence of insulin, protein synthesis is further reduced because insulin promotes the uptake of amino acids by the muscle cells. The **hormonal milieu** in this case favors the breakdown of muscle protein to provide amino acids such as alanine, which can be used to make glucose. Earlier it was mentioned that visceral tissues (i.e., liver and other organs) protect the skeletal muscle from being used as an amino acid source for short-term emergencies. During prolonged starvation the situation is reversed and the amino acids in skeletal muscle are used to protect the visceral tissues. The reason for this change is that visceral tissue proteins turn over very quickly and these visceral proteins are critical for the body's survival. Skeletal muscle is sacrificed in long-term and extreme starvation states.

INTEGRATION OF METABOLIC PATHWAYS

Carbohydrate, protein, and fat metabolism are complicated, so each is usually explained individually. However, all metabolic pathways are integrated and the liver plays a major role in metabolizing carbohydrate, protein, and fat and regulating their metabolism. Substrate utilization will depend, in part, on whether the body is in a fed (absorptive) state or a postabsorptive state, the two states humans experience under normal conditions. Other conditions, such as fasting or long-term starvation, force the body to reprioritize its metabolic processes. Table 5.2 shows the metabolic pathways favored under various conditions.

The fed state refers to the three to four hours after a meal is eaten, and for this discussion assumes that a mixture of carbohydrate, protein, and fat is consumed and that the individual is nonobese. Insulin is the hormone that primarily affects substrate metabolism at this time. In general, as a result of insulin, the liver and muscle cells take up glucose, synthesize glycogen, and produce energy (i.e., glycolysis). Additionally, fatty acids are synthesized in the liver and stored in adipose tissue and protein synthesis is increased.

Other metabolic pathways are favored in the postabsorptive state, which begins about three to four hours after eating and may last as long as 12 to 18 hours. The liver provides glucose to the blood by breaking down liver glycogen. Some glucose is also produced from noncarbohydrate sources (i.e., gluconeogenesis). Fatty acids are released from adipose cells and are used by both the liver and muscle to produce ATP. Glucagon, a counter-regulatory hormone to insulin, stimulates

Nitrogen balance: When total nitrogen (protein) intake is in equilibrium with total nitrogen loss.

Labile protein reserve: Proteins in the liver and other organs that can be broken down quickly to provide amino acids.

Visceral tissue: Tissue of the major organs, such as the liver.

Hormonal milieu: The hormonal environment.

Table 5.2 Metabolic Pathways Favored Under Normal and Starvation Conditions

	Liver	Muscle	Adipose Tissue	Central Nervous System (CNS)
Fed (absorptive) state	Glucose used as energy, stored as glycogen, and converted to fatty acids if energy intake is greater than expenditure; Amino acids metabolized; Fatty acids transported to adipose tissue for storage as triglycerides	Glucose used for energy or stored as glycogen	Fatty acids are stored as triglycerides (3 fatty acids + glycerol)	Glucose from food used to provide energy
Postabsorptive state	Glycogen broken down to provide glucose; Manufacture of glucose from lactate and alanine (provided by muscle) and glycerol (provided by the breakdown of fat from adipose tissue) begins	Glucose used for energy, some glycogen storage continues; Lactate and alanine released to liver to make glucose; Fatty acid uptake (provided by the breakdown of fat from adipose tissue) for use as energy	Triglycerides are broken down to provide fatty acids to muscle and liver; Glycerol to liver to be used for glucose	Glucose comes predominantly from liver glycogen
Fasting (18 to 48 hours without food)	Liver glycogen is depleted; glucose made from lactate and amino acids provided by muscle; Red blood cells also provide some lactate	Muscle protein degraded to provide amino acids to liver; Lactate to liver for glucose synthesis	Same as above	Glucose provided by the liver (from lactate and amino acids)
Starvation (>48 hours without food)	Liver continues to manufacture glucose, predominantly from glycerol (from adipose tissue) to prevent muscle from providing amino acids and lactate; Fatty acids broken down to produce ketones (for use by CNS and muscle)	Muscle depends predominantly on fatty acids and ketones for energy	Triglycerides are broken down to provide fatty acids to muscle and liver; Glycerol to liver to be used for glucose	CNS depends primarily on ketones produced by the liver for energy

protein degradation in skeletal muscle, although it also stimulates the synthesis of liver proteins.

Fasting, a lack of food intake for 18 to 48 hours, forces the body to adapt its energy systems to an uncommon and threatening circumstance. Glycogen is nearly depleted in the liver, and gluconeogenesis must be increased. This forces the liver to use more amino acids as a source to produce glucose. Recall that 18 of the 20 amino acids are glucogenic, meaning that they are biochemically capable of being used to manufacture glucose. Some of these amino acids are in muscle cells and the fasting state increases the rate at which skeletal muscle is broken down. Degrading muscle proteins results in a mixture of amino acids being released; however, one of the most prominent is alanine. Alanine and lactate, also present in muscle cells, and glycerol, obtained from the breakdown of fatty acids stored in adipose tissue, will be transported to the liver for the manufacture of glucose.

Long-term starvation (lack of food intake for >48 hours) poses a clear threat to the body and more metabolic adjustments are made. Amino acids must be protected from being used for glucose so that they can be available for the synthesis of vital compounds such as the plasma proteins and enzymes. To meet its glucose needs the body depends on glycerol (released from adipose tissue) to manufacture glucose. The brain uses some of the glucose produced but because the amount is small, it will use ketones predominantly for energy under starvation conditions (it cannot use fatty acids for fuel). Fatty acids become the primary fuel source for skeletal muscle and liver. All these adaptations are made to prevent or delay the breakdown of body proteins.

Although this explanation is very brief, it does point out how the body shifts its metabolic pathways in response to various conditions and the role that the liver plays. Consuming a sufficient amount of energy from dietary carbohydrate and fat sources is an important influence on protein metabolism. Fasting and starvation are obviously not desirable conditions for the athlete.

What's the point? The body is in a constant state of protein turnover—anabolism (synthesis) and catabolism (breakdown), processes that are highly influenced by the liver and total caloric (energy) intake. Skeletal muscle proteins are synthesized using amino acids from the amino acid pool. Conversely, skeletal muscle can be broken down to provide amino acids back to the pool.

Protein Recommendations for Athletes

Many years of research has led to well-established protein recommendations for nonathletes. There is a general consensus on the amount of protein needed by strength, endurance, and ultraendurance athletes, although controversies still exist and more research on highly trained athletes is needed. There are many obstacles to studying protein balance, turnover, need, and timing in athletes.

RECOMMENDED TOTAL DAILY PROTEIN INTAKE FOR ATHLETES AND NONATHLETES

The Dietary Reference Intake (DRI) for adults is 0.8 g of protein/kg body weight daily (Institute of Medicine, 2002). Recommendations for protein intake for athletes usually fall between 1.0 and 2.0 grams of protein/kg body weight/day (g/kg/d). These recommendations make two assumptions: 1) energy intake is adequate and 2) the quality of the protein is good. In the United States and other developed countries, protein quality is usually not a concern. However, it cannot be assumed that energy intake is adequate for all athletes.

Although 1.0 to 2.0 g/kg/d is the general protein guideline, more specific recommendations are made depending on the predominant type of training (i.e., endurance, ultraendurance, or strength). It is typically recommended that endurance athletes consume 1.2 to 1.4 g/kg of protein daily while the recommendation for strength athletes is 1.6 to 1.7 g/kg of protein daily (American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine, 2000). Recreational athletes may need the same or just slightly more protein than nonathletes (0.8 to 1.0 g/kg/d) and ultraendurance athletes may need much more depending on the training mesocycle (up to 2.0 g/kg/d) (Seebohar, 2006). General protein recommendations are shown in Table 5.3.

While these ranges are good guidelines, they may need to be adjusted slightly depending upon the individual athlete's specific circumstances. Similar to carbohydrate and fat recommendations, protein intake may need to change as the training cycles change. For example, a strength athlete may consume 1.5 g/kg/d during training periods when the goal is muscle mass maintenance but increase protein intake slightly when the goal is to increase muscle mass. Many athletes engage in both endurance and strength training to various degrees over the course of a year's training, and increasing or decreasing the amount of protein in their diets to match their training goals is appropriate.

Table 5.3 General Protein Recommendations Based on Activity

Level of Activity	Recommended Daily Protein Intake
Sedentary adults	0.8 g/kg
Active adults (e.g., recreational athletes not in training)	0.8 to 1.0 g/kg
Endurance athletes	1.2 to 1.4 g/kg
Ultraendurance athletes	1.2 to 2.0 g/kg
Strength athletes	1.6 to 1.7 g/kg

Legend: g/kg = grams per kilogram body weight

The need for protein is influenced by energy intake. As a rule of thumb, when energy intake is deficient, protein intake should be increased. The extent of the increase will depend on whether the deficits are long- or short-term, but a general recommendation is to increase protein intake by ~15 percent. For an athlete whose usual protein intake is 1.2 g/kg as part of a diet that provides sufficient energy, it is prudent to increase protein intake to 1.4 g/kg when energy intake is deficient (e.g., "dieting"). Low protein intake when coupled with low energy intake over time will eventually affect the body's "stores" of protein (i.e., muscle mass), training, performance and, ultimately, the ability to engage in physical activity.

Expressing Protein Recommendations as a Relative Amount. All of the protein recommendations for athletes mentioned so far have been expressed on a gram per kilogram body weight basis (g/kg). In other words, protein recommendations are stated as an absolute amount. Sometimes recommendations are stated as a percent of total energy intake (e.g., 15 percent of total calories as protein), which is a relative amount. This relative method is problematic for athletes for two reasons: 1) athletes may not be consuming an adequate amount of energy and 2) protein requirements increase when energy intake is deficient. The Spotlight on Enrichment: Protein Intake feature discusses how percentages based on total energy intake are distorted when caloric intake is low.

Nutrient recommendations are often expressed as a percentage of calories because it is easier for consumers to understand. The typical American does not know his or her weight in kilograms, so a recommendation to consume 0.8 g of protein per kilogram body weight is not seen as being very practical. The Acceptable Macronutrient Distribution Range (AMDR) for protein for adults is 10 to 35 percent of energy. This recommendation was developed for the general population and assumes that energy intake is adequate and that physical activity is low. The lower end of this recommended range (10 percent) corresponds to the 0.8 g of protein per kilogram body weight recommended for adults (Institute of Medicine, 2002).

Percentage guidelines for protein intake for athletes usually range from 10 to 30 percent of total caloric intake. For endurance athletes, an intake of 10 to 15 percent of total calories from protein is typical because carbohydrate intake is relatively high (60 to 70 percent). The remaining kilocalories, 15 to 30 percent of total caloric intake, will likely be provided by fat. In some cases, alcohol may be a source of a small percentage of total caloric intake.

Guidelines for percentage of protein intake for strength athletes often range from 15 to 20 percent of total calories. These percentages take into account that carbohydrate intake must be sufficient (~50 to 60 percent of total caloric intake). Given these guidelines, fat intake would range from 20 to 35 percent of total calories, although a small percentage may be provided by alcohol. Other configurations have been suggested, such as the 40–30–30 diet (40 percent carbohydrate and 30 percent each protein and fat), which is discussed in Chapter 12. Although percentage of total calorie guidelines can be useful for athletes consuming sufficient calories, it is recommended that athletes use recommendations based on g/kg because such figures will not be distorted by low caloric intake.

Recommended Protein Intake for Vegetarian Athletes. Vegetarians do not consume the flesh of animals (e.g., meat, fish or poultry), but may consume animal products (e.g., eggs, milk, cheese). **Vegans** do not consume any product derived from animals. There have been no studies examining the amount of protein required by vegetarian athletes. A common recommendation for physically active vegetarians is to consume 10 percent more than the nonvegetarian athlete. Thus, general protein guidelines for vegetarian athletes are in the range of 1.1 to 2.2 g/kg/d. This 10 percent figure is an adjustment for the lower digestibility of plant proteins when compared to animal proteins. Consuming this amount of protein is not difficult if energy intake is sufficient. Vegans tend to have lower protein intakes than nonvegans. It is recommended that vegan athletes emphasize more protein-rich vegetarian foods (e.g., beans, legumes, soy milk, tofu) than vegetarian foods that are relatively low in protein (e.g., fruits, vegetables) (Larson-Meyer, 2006). More information about vegetarianism can be found in the section entitled, Vegetarian Diets.

TIMING OF PROTEIN INTAKE

Obtaining an adequate amount of protein each day is fundamentally important, but athletes should not overlook the importance of the timing of protein intake throughout the day, especially after exercise. Consuming protein prior to resistance exercise has not been as well studied (see Spotlight on Enrichment: Other Protein Timing Issues for Athletes).

Protein Consumption after Exercise. The acute effect of exercise is to put the body into a catabolic state, breaking down certain tissues to provide the energy to sustain the exercise. For example, muscle glycogen is broken

SPOTLIGHT ON ENRICHMENT

Protein Intake Expressed as a Percentage of Total Calories Can Be Deceiving

Dietary analysis programs often calculate protein intake as a percentage of total energy intake. When caloric intake is adequate, protein intake is considered adequate if at least 10 percent of total caloric intake is provided by protein. However, if total caloric intake is too low, then protein intake may be too low. For example, a 50-kg (110-lb) woman needs at least 40 grams of protein daily (0.8 g/kg/d × 50 kg). If she were sedentary, she would need approximately 1,500 kcal per day (30 kcal/kg × 50 kg). Forty grams of protein is 160 kcal (40 g × 4 kcal/g) and would be approximately 10 to 11 percent of her total caloric intake (160 kcal ÷ 1,500 kcal). Because her calorie intake was adequate, the percentage of calories provided by protein represents an amount of protein that is adequate.

This is not the case if her caloric intake is too low. If her caloric intake were 1,200 kcal and protein provided 11 percent of her intake, the amount of protein she consumed would only be 33 g (1,200 kcal × 0.11 = 132 kcal from protein; 132 kcal ÷ 4 kcal/g = 33 g). When calculated on a g/kg basis, her protein intake would be only 0.66 g/kg (33 g ÷ 50 kg), less than the 0.8 g/kg recommended. Percentages get distorted when caloric intake is very low, so expressing protein on a gram per kilogram basis is recommended.

down to provide glucose, stored fats are broken down to mobilize fatty acids, and muscle proteins are broken down to provide amino acids that can be used as energy (e.g., leucine). An important recovery strategy for athletes is to reverse the catabolic state, and put the body in an energy and hormonal state that favors recovery and long-term tissue growth. Athletes interested in stimulating muscle growth have attempted to do this by consuming amino acids, protein, and/or carbohydrate and protein foods or beverages relatively soon after exercise.

The first one to two hours after exercise is sometimes referred to as the "anabolic window." This is the time period when it is important to reverse the catabolic state and promote a hormonal and nutritional state that favors replacement of energy stores and the synthesis of protein rather than its breakdown. As discussed in Chapter 4, the hours immediately after exercise are the most important for initiating optimal glycogen replacement. A similar "window" exists for restoration of protein.

Taking advantage of the favorable postexercise anabolic environment requires proper nutritional intake, although the details are still under investigation. Levenhagen and colleagues (2002) demonstrated that a supplement containing 10 g of protein from casein along with 8 g of carbohydrate and 3 g of lipid (fat) consumed immediately after exercise increased whole-body protein synthesis as well as protein synthesis in the leg, the muscles that were tested. This study also found that the carbohydrate/lipid mixture without protein and the placebo resulted in a net loss of whole-body and leg protein. Other studies have shown that amino acids ingested as whey or as indispensable and dispensable amino acids, both singly and in combination, promote protein synthesis after exercise. The amount of amino acids used in these studies was relatively small and larger amounts do not seem to be necessary or more effective because such levels would exceed the saturation point of the amino acid pool (Borsheim, Aarsland, and Wolfe, 2004; Miller et al., 2003; Borsheim et al., 2002; Tipton et al., 2002).

These research studies used beverages or amino acid infusions, but there is no reason to assume that protein foods that contain the same indispensable amino acids (e.g., milk, chicken, fish) would be less effective. Stated on a g/kg basis, ~0.1 g/kg of indispensable amino acids are recommended after exercise. A more practical recommendation is to include a beverage with some protein or food that contains animal protein immediately following exercise. For example, 8 ounces of low-fat chocolate milk contains 8 g of protein (Gibala and Howarth, 2006).

As described in Chapter 4, carbohydrate, especially high glycemic carbohydrate, consumed immediately after exercise is beneficial because it helps restore muscle glycogen. The carbohydrate also stimulates the release of insulin. Although its primary role is cellular glucose uptake, insulin also increases amino acid uptake into muscle and inhibits the process of muscle degradation. Athletes often consume a protein-carbohydrate drink (e.g., a specially formulated sports beverage or milk) after exercise. Food containing carbohydrate and protein (e.g., fruit-in-the-bottom yogurt) after exercise would likely be beneficial, too. The important point is to provide the body with the nutrients it needs immediately after exercise to begin resynthesis of tissue that has been catabolized during exercise. In this respect, consumption of both carbohydrate and protein (both of

Vegan: One who does not eat food of animal origin.

SPOTLIGHT ON ENRICHMENT

Other Protein Timing Issues for Athletes

There is general scientific agreement that protein (and carbohydrate) intake immediately after training is beneficial. An area receiving more attention is the intake of protein, alone or with carbohydrate, prior to resistance exercise. Trained athletes, particularly strength athletes, are looking for ways to maximize muscle protein synthesis and reduce breakdown. Consuming protein does temporarily elevate blood amino acid concentrations, and it is theorized that this condition may stimulate the synthesis of muscle protein. At least one study has shown this to be the case (Hulmi et al., 2005). Carbohydrate stimulates insulin release, which is known to influence amino acid uptake into muscle so the presence of carbohydrate may also have a beneficial effect. More research is needed to draw definitive conclusions.

Athletes trying to maximize muscle mass often ask about the amount of protein that should be consumed at one time. Some athletes have been told that no more than 30 g of protein can be absorbed from the gastrointestinal tract at once and that they should consume small amounts of protein throughout the day for maximum protein absorption. There is no scientific evidence to support or refute this figure. The maximum amount of protein that can be absorbed or should be taken to enhance absorption in trained athletes is not known at this time.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Both bodybuilders and football players spend many hours lifting weights during training, but their performance demands are very different.

which also provide energy) shortly after exercise ends is advantageous.

INTAKE OF PROTEIN ABOVE RECOMMENDED LEVELS AND THE EFFECTS ON TRAINING, PERFORMANCE, AND HEALTH

Bodybuilders are known for their high intake of dietary protein via both food and supplements. Surveys suggest that many bodybuilders consume more than 2.0 g/kg/d (Poortmans and Dellalieux, 2000). At 220 pounds (100 kg) a 2.0 g/kg daily intake would be 200 g of protein. Because weight in pounds is the familiar unit of measure in the United States, strength athletes are sometimes told that their protein intake should be 1 gram per pound, which is the equivalent of 2.2 g/kg. "Hardcore" male bodybuilders who openly discuss anabolic steroid use on Internet discussion groups typically suggest that protein intake should be approximately 3.0 to 3.5 g/kg/d when anabolic steroids are used. Based on this range, an athlete weighing 220 pounds (100 kg) might consume between 300 and 350 g of protein daily. There is no scientific evidence to support or refute this recommendation because it is not ethical to conduct such studies.

It is important to understand that the goals of a bodybuilder are different from those of other strength athletes and these goals influence their protein intake. Bodybuilders are judged on muscle size, definition, and proportion (the development of all muscle groups). They are also judged on stage presence, which includes posing and charisma, as well as overall appearance. They are not judged on muscle strength or power, attributes that are important to most strength athletes because they enhance performance. One of the bodybuilder's goals is to achieve the maximum *amount* of muscle mass that is genetically possible, while strength and power athletes have a goal of maximum muscle effectiveness, regardless of size. Both a bodybuilder and a linebacker on a football team will spend many hours training in the gym, but the performance demands of their sports are very different (Lambert, Frank, and Evans, 2004).

The recommended protein intake for strength-trained athletes is based on maintaining a positive nitrogen balance. Resistance exercise results in a decrease in nitrogen excretion, which is one reason protein recommendations for strength athletes are 1.6 to 1.7 g/kg/d and only slightly higher than that for endurance athletes. But bodybuilders are looking to not only be in positive nitrogen balance but to take in the amount of protein that correlates with *maximum* muscle protein synthesis. Such an amount has not yet been determined through scientific studies, so many bodybuilders (and some other strength athletes such as football players) may take large amounts of protein in hopes of achieving maximum levels of muscle mass. The looming question for those consuming large amounts of protein daily is: Are such high levels of protein intake safe?

Short-Term Effects. In the past, caution was raised regarding high-protein diets (typically defined as greater than 2.0 g/kg/d), especially for those athletes who took protein supplements. It was thought that excessive protein would stress healthy kidneys and liver in the short-term. This does not seem to be the case for those with normal kidney function. A seven-day study of bodybuilders and other well-trained athletes detected no short-term harmful effects on renal function with protein intakes up to 2.8 g/kg/d (Poortmanns and Dellalieux, 2000). All of the athletes in this study were healthy and had normal kidney and liver function. Athletes should be aware that they could experience problems with high-protein diets if they have latent (hidden) or known kidney or liver conditions. Any athlete consuming large amounts of protein should monitor their health and contact a physician if problems appear.

Athletes should also be aware of the potential training and performance problems that can be caused by excessive amounts of protein (≥2.5 grams of protein/kg body weight/d). The primary concerns are dehydration, low carbohydrate intake, and excessive caloric intake. Protein supplements make it easy to consume a lot of protein, but all of these concerns could also be associated with an excess of dietary protein.

Large amounts of protein can result in dehydration because additional water is needed to metabolize protein. Athletes who consume large amounts of protein should be aware of the need for adequate fluid intake. Urea, one of the by-products of protein metabolism, must be eliminated from the body by the kidneys via the urine. Urea is an osmotically active compound that draws more water into the collecting tubules of the kidneys, increasing the volume of the urine and resulting in the loss of water from the body. Water and fluid balance will be discussed further in Chapter 7.

Consuming large amounts of protein may come at the expense of the inclusion of enough carbohydrate foods. If protein *replaces* adequate carbohydrate intake, then the athlete will be consuming a high-protein, low-carbohydrate diet. This could result in lower muscle glycogen stores after several days of demanding training. If protein intake consistently *exceeds* usual intake, then caloric intake may be too high and body fat may increase over time. Maintaining macronutrient and energy balance is important.

Long-Term Effects. High-protein diets consumed by healthy individuals have manageable short-term effects, but what about the long-term effects? Concern has been expressed about the increased urinary excretion of calcium that accompanies high-protein diets. When protein is metabolized, acid is produced. To neutralize the acid, the body draws calcium carbonate from bones. The carbonate neutralizes the acid and the calcium is excreted in the urine. Studies of athletes and nonathletes have shown that excessive amounts of protein can result in increased urinary calcium excretion (Kerstetter, O'Brien, and Insogna, 2003; Heaney, 1993).

Concerns have also been raised about an association between long-term intake of high-protein diets (defined as >1.5 g/kg/d in many medical studies) and two medical conditions, osteoporosis and renal (kidney) disease. Long-term high protein intake, especially protein from animal sources, which contain amino acids with a high sulfur content, does increase the amount of calcium excreted in the urine. Most (~80 percent) of the increase in excreted calcium is a result of an increase in calcium absorption from the intestine. The remaining 20 percent increase is currently unexplained but bone could be the source. Therefore, the long-term effects (if any) of high-protein diets on bone metabolism and the potential for osteoporosis are not clear (Kerstetter, O'Brien, and Insogna, 2003). There is some medical evidence that lifelong high-protein consumption may affect the life span of the kidney and accelerate the progression of renal disease (Lentine and Wrone, 2004). More research is needed to clarify the long-term health effects of a high-protein intake.

The Internet Café

Where do I find reliable information about protein, exercise, and health?

Athletes who search for information about protein on the Internet will often be directed to commercial sites that are selling protein supplements or high-protein weight loss diets. Unbiased information about protein needs for athletes is lacking. Some university or medical-related sites give general information about protein, such as that found at Harvard School of Public Health **(www.hsph.harvard.edu/nutritionsource/protein.html).**

More information about vegetarianism can be found at The Vegetarian Resource Group, **www.vrg.org,** a nonprofit organization dedicated to educating the public about vegetarianism.

ENERGY RESTRICTION AND PROTEIN INTAKE IN ATHLETES

The amount of protein required is related to energy intake. Under normal conditions, an adequate energy intake from either carbohydrate or fat spares amino acids from being used for energy and helps maintain nitrogen balance. Athletes need to be in nitrogen balance to maintain muscle mass and need to be in positive nitrogen balance to increase muscle mass.

Adjustments to protein intake will need to be made when energy intake is deficient. There is much evidence that high-protein, low-energy diets can achieve positive nitrogen balance in rats. However, amino acid metabolism in rats is different from that of humans. Unfortunately, the body of literature in humans is small and not well defined (Millward, 2004 and 2001). Nevertheless, it is also recommended that when humans are energy deficient they should increase protein intake in an effort to maintain nitrogen balance.

The amount of protein needed depends on the magnitude of the energy deficit and whether it is acute or chronic. The most serious situations are those athletes who self-impose starvation and are not receiving treatment for their eating disorders. In these cases the energy deficits are substantial and sustained over several months or years. Some athletes maintain small chronic energy deficits and their pattern of eating is one of restricting calories. In other cases, such as those who need to obtain a particular weight to qualify (e.g., wrestlers, lightweight

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Some athletes have eating patterns that result in small daily energy (kcal) deficits that occur over long periods of time.

rowers, kick boxers), the energy deficits may be substantial and rapid. Each situation is discussed below.

Long-Term, Substantial Energy Deficits. When a chronic energy deficit is present, more protein is needed than when energy intake is sufficient. Nitrogen balance cannot be maintained if energy and protein intakes are too low. Studies of athletes with anorexia nervosa report low intakes of both energy and protein. In one study, the mean daily protein intake of athletes with anorexia nervosa was 0.7 g/kg body weight (range 0.5 to 1.0 g/kg/d) (Sundgot-Borgen, 1993). Athletes with eating disorders are struggling with psychological issues that interfere with the consumption of food and will need intense counseling from well-trained practitioners. Among the nutritional goals will be appropriate energy and protein intakes.

A study of female athletes with subclinical eating disorders (i.e., the presence of some but not all the features of an eating disorder) reported that the mean daily energy intake was 1,989 kcal, or approximately 500 kcal/d less than estimated energy expenditure. Some athletes were consuming fewer than 1,700 kcal daily. Mean daily protein intake was 1.2 g/kg (Beals and Manore, 2000 and 1998). These athletes could benefit from nutritional counseling that addresses disordered eating behaviors, determines appropriate energy intake, and evaluates protein intake in light of chronic energy restriction (See Chapter 13).

Long-Term, Small Energy Deficits. Distance runners and female gymnasts and figure skaters are examples of athletes who commonly have small, but long-term energy deficits. They differ from those in their sports who have eating disorders because caloric intake is restricted to a lesser degree, body image is accurate, and they do not have an excessive fear of weight gain. They do, however, want a body that is well matched for their sport. In the case of runners, they desire a lightweight body with a sufficient amount of muscle mass, and in the case of gymnasts and figure skaters, a strong but aesthetically pleasing body. These athletes try to achieve this by maintaining a low percentage of body fat without losing muscle mass.

One survey of female endurance and aesthetic sport athletes who did not have eating disorders reported an average daily consumption of approximately 2,400 kcal or about 100 kcal per day less than their estimated energy expenditure. Their average protein intake was approximately 1.5 g/kg (Beals and Manore, 1998). In other words, these athletes tended to slightly undereat and consume slightly more protein than that recommended for endurance athletes (i.e., 1.2 to 1.4 g/kg/d). Such a diet could be nutritionally sound as long as carbohydrate intake is sufficient and a variety of nutrient-dense foods are consumed.

Intermediate-Term, Small-to-Medium Energy Deficits. Many athletes periodically want to lose body fat and will reduce caloric intake for a short time (a few weeks to a few months) to achieve fat loss. Some studies have shown that high-protein diets produce greater weight loss than low-fat diets. The current evidence suggests that weight loss diets for the general (sedentary) population should be reduced in calories and total energy intake should be distributed as 35 to 50 percent carbohydrate, 25 to 30 percent protein, and 25 to 35 percent fat (Schoeller and Buchholz, 2005). However, subjects of these studies were not athletes and substantially reducing carbohydrate intake will likely be detrimental to an athlete's training.

To achieve weight loss, athletes reduce caloric intake and usually alter the macronutrient balance of their current diets by increasing protein intake, reducing carbohydrate intake slightly (but still consuming enough for adequate glycogen resynthesis), substantially reducing fat intake, and eliminating alcohol. The increase in protein is thought to blunt the reduction in resting energy expenditure (REE), which usually accompanies energy restriction (i.e., "dieting"). Protein also increases the thermic effect of food (TEF), although the influence on overall energy balance is likely to be small. Recall from Chapter 2 that both REE and TEF are on the "energy out" side of the energy balance equation, and these effects may result in a slightly greater weight loss when compared to weight loss diets with less protein (Luscombe et al., 2002). A high-protein, low-calorie diet is often recommended to athletes who desire to lose weight as body fat. Although this recommendation may be prudent, scientific studies of effectiveness in athletes are lacking.

Short-Term, Substantial-Energy Deficits. When energy deficits are large and short-term, such as when an athlete is "making weight," the goals are to lose body weight through fat and water loss but maintain as much muscle protein as possible. This is difficult to accomplish. Under starvation conditions, the loss of weight comes from several components, including water, glycogen, protein, and fat. In the first 10 days of fasting/starvation, only about one-third of the body weight lost is lost as body fat (Brownell, Steen, and Wilmore, 1987). Six to 16 percent is lost from protein stores. This type of severe energy restriction raises serious concerns about hydration status, the potential for heat illness, maintenance of muscle mass, ability to exercise due to depleted glycogen stores, hypoglycemia, and declines in resting metabolic rate.

EFFECTS OF AN INADEQUATE PROTEIN AND ENERGY INTAKE ON TRAINING, PERFORMANCE, AND HEALTH

Studies have shown that athletes who consume an inadequate amount of protein also usually consume an inadequate amount of energy (kcal), so the problems they face are numerous. The lack of protein is an especially important problem because of its critical role in building and maintaining muscle mass and supporting the immune system.

Protein synthesis and degradation is a constant process and there must be a balance between protein intake and protein loss. The primary problem with consuming a chronically low protein, low-energy diet (i.e., a semi-starvation state) is that protein balance cannot be maintained. The body has few intermediate-term options if dietary protein is not available over a period of weeks and months. It must reduce the synthesis of some body proteins and degrade muscle protein, thus returning the body to balance but at a lower functional level. Protein balance will be achieved but at the expense of training, performance, and health. Severe starvation leads to the loss of homeostasis, general weakness, and, ultimately, death.

The immune system is highly dependent on protein because of the rapid turnover of immune system cells and the number of immune-related proteins (e.g., immunoglobulins, which act like antibodies). Low protein intake usually accompanies low energy intake and low nutrient intake, all of which can negatively affect the immune system. While low protein intake and immune system function have not been studied directly in athletes, studies of people who restrict energy severely (i.e., "dieters") have shown that some immune mechanisms are impaired. These studies are interpreted to mean that a low protein intake is detrimental to the functionality of the immune system (Gleeson, Nieman, and Pedersen, 2004).

What's the point? Protein recommendations for athletes generally range from 1.0 to 2.0 g/kg/d, depending on the athlete's training and body composition goals. Many athletes consume a sufficient amount of protein daily. Athletes who consume low-protein, low-energy diets could experience negative effects on performance, body composition, and health. When caloric intake is restricted, protein needs are higher. The effects of long-term, excessively high protein diets have not been well studied.

Translating Daily Protein Recommendations to Food Choices

FOOD PROTEINS

Proteins are found in both animal and plant foods. Meat, fish, and poultry are familiar protein-containing foods. Eggs, milk, and milk products also contain protein. Beans, legumes, nuts, and seeds are popular plant protein sources. Grains and vegetables contain smaller amounts than other protein-containing foods, but because these

THE EXPERTS IN. . .

Protein and Exercise

Some of the experts in the field of protein and exercise conduct their research at Canadian universities. The work of Peter W.R. Lemon, Ph.D., and colleagues helped to determine daily protein requirements in trained athletes. Mark Tarnopolsky, Ph.D., has published numerous articles on the metabolism of amino acids and protein turnover. Martin J. Gibala, Ph.D., conducts research focusing on the regulation of energy provision in skeletal muscle and the cellular adaptations that are made in amino acid metabolism during exercise. He also conducts applied research to determine the role of exercise and dietary interventions on athletic performance. While researchers from across the globe contribute to the body of scientific knowledge of protein and exercise, scientists from Canada have a long history of doing so.

Table 5.4 Protein Content of Selected Foods

Food	Amount	Protein (g)
Meat (lean ground beef)	3 oz	21
Chicken (roasted breast)	3 oz	26
Fish (halibut)	3 oz	23
Egg	1 large	6
Milk	8 oz	9
Cheese	1 oz	7
Beans (dried)	½ cup cooked	8
Lentils	½ cup cooked	9
Peanuts	¼ cup	10
Almonds	¼ cup	8
Sunflower seeds	1 oz	6
Rice (white)	½ cup cooked	2
Rice (brown)	½ cup cooked	2.5
Spaghetti noodles	½ cup cooked	3.5
Potato (baked)	1 large (~7 oz)	5
Sweet potato	½ cup cooked	1
Bread (white)	1 slice	2
Bread (whole wheat)	1 slice	2.5–3

Legend: g = gram; oz = ounce

foods may be eaten in large quantities, they often contribute a reasonable amount to total daily protein intake. The protein content of various foods is listed in Table 5.4.

Each **macronutrient** (e.g., carbohydrate, protein, fat) must be considered individually, but in reality most foods contain a mixture of macronutrients, and thus protein foods may not be chosen solely for the amount of protein contained. Table 5.5 groups protein-containing foods based on their fat and carbohydrate contents. For example, athletes who are looking for protein without much fat or carbohydrate could choose egg whites or very lean cuts of meat, fish, or poultry. Those athletes who want both proteins and carbohydrates but wish to limit fat intake could choose beans, legumes, and nonfat dairy products. Nuts provide heart-healthy fats as well as proteins and carbohydrates. As Table 5.5 illustrates, there are many choices.

Macronutrient: Nutrient needed in relatively large amounts. The term includes energy, carbohydrates, proteins, fats, cholesterol, and fiber but frequently refers to carbohydrates, proteins, and fats.

The majority of athletes consume sufficient protein.

Beans and corn tortillas provide complementary proteins in this vegetarian meal.

PROTEIN INTAKE BY ATHLETES

Table 5.6 on page 160 summarizes the average daily protein and energy intakes of various athletes. The majority of athletes consume sufficient protein. Low protein intake is most common in females who restrict energy and in males who compete in weight-restricted sports. Bodybuilders, weight lifters, and other strength athletes are most likely to consume large amounts of protein. Many athletes consume an appropriate level of protein (Nogueira and Da Costa, 2004; Onywera et al., 2004; Jonnalagadda, Ziegler, and Nelson, 2004; Paschoal and Amancio, 2004; Leydon and Wall, 2002; Mullins et al., 2001; Poortmans and Dellalieux, 2000).

VEGETARIAN DIETS

Vegetarians do not eat meat, fish, or poultry but many do consume some animal proteins. For example, milk, cheese, and eggs may make up a substantial part of a

Table 5.5 Protein, Fat, and Carbohydrate Content of Selected Foods

Food	Amount	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)
Egg whites	¼ cup	6	0	1	30
Chicken (white meat, roasted)	3 oz	26	3	0	140
Turkey (white meat, roasted)	3 oz	25.5	0.5	0	115
Fish (cod, halibut or roughy)	3 oz	19	0.5	0	89
Tuna (fresh or water packed)	3 oz	23	0.5	0	106
Meat (flank steak)	3 oz	30	8	0	199
T-bone steak	3 oz	21	16.5	0	238
Chicken (dark meat, roasted)	3 oz	23	8	0	174
Turkey (dark meat, roasted)	3 oz	24	6	0	159
Pork (tenderloin, roasted)	3 oz	24	4	0	139
Veal (lean)	3 oz	27	6	0	167
Fish (oily such as salmon)	3 oz	20	4	0	118
Tuna (oil packed, drained)	3 oz	25	7	0	168
Milk (whole, 3.3%)	8 oz	8	8	11	146
Milk (reduced fat, 2%)	8 oz	8	5	11	122
Milk (low-fat, 1%)	8 oz	8	2	12	102
Milk (nonfat)	8 oz	8	Trace	12	83
Yogurt (low-fat, fruit in the bottom)	8 oz	6	1.5	31	160
Yogurt (nonfat, artificially sweetened)	8 oz	11	Trace	19	122
Cheese (cheddar)	1 oz	7	9	0	114
Cheese (fat-free)	1 slice	4	0	3	30
Beans	½ cup cooked	8	0.5	24	129
Lentils	½ cup cooked	9	Trace	20	115
Peanuts (oil roasted)	¼ cup	10	19	7	221
Almonds (dry roasted)	¼ cup	8	18	7	206
Sunflower seeds (dry roasted)	¼ cup	6	16	8	186
Sunflower seeds (oil roasted)	¼cup	6	17	4	178
Rice (white)	½ cup cooked	2	Trace	22	103
Rice (brown)	½ cup cooked	2.5	~1	22	108
Spaghetti noodles	½ cup cooked	3.5	0.5	19.5	95
Potato (baked)	1 large (~7 oz)	5	Trace	43	188
Sweet potato	½ cup cooked	1	Trace	12	51
Bread (white)	1 slice (25 g)	2	0.8	13	67
Bread (whole wheat)	1 slice (44 g)	2.5–3	~2.5	21.5	~119

Legend: g = gram; oz = ounce; kcal = kilocalorie vegetarian's diet. When animal foods are included, the likelihood is high that the diet will provide protein of sufficient quality. When no animal proteins are consumed, vegetarians should assess protein quality and be aware of the concept of complementary proteins.

Plant proteins (i.e., incomplete proteins) may either lack one or more of the indispensable amino acids or the proper concentrations of these amino acids. Of greatest concern are lysine, threonine, and the sulfur-containing amino acids cysteine and methionine. Legumes such as lentils and beans are low in methionine and cysteine. However, grains, nuts, and seeds are high in these sulfur-containing amino acids. Grains lack lysine but legumes have high levels. Vegetables lack threonine but grains have adequate amounts.

Consuming two plant proteins, each with a relatively high amount of the amino acid that the other lacks, can result in an adequate intake of all of the indispensable amino acids. This is the concept of complementary proteins. Beans and rice, lentils and rice, corn

SPOTLIGHT ON A REAL ATHLETE

Lucas, a Cross Country Runner

As in the previous chapter, a 24-hour dietary intake is analyzed for Lucas, a collegiate cross country runner (see Figure 5.7). Recall that due to the demands of his training, Lucas needs approximately 3,400 kcal (~54 kcal/kg) daily. His need for carbohydrate during the preseason mesocycle that emphasizes longer distance runs (75 to 80 miles a week) is estimated to be 8 g/kg/d. The guideline for protein for endurance athletes is approximately 1.2 to 1.4 g/kg/d and may be as high as 2.0 g/kg/d for ultraendurance athletes during some phases of their training. In Lucas' case he would like to consume approximately 1.5 g/kg/d.

According to the dietary analysis, Lucas consumed 3,333 kcal and 532 g of carbohydrate (8.5 g/kg/d). These amounts are very close to his goals. Lucas' protein intake was 124 g or ~2 g/kg/d (15 percent of total caloric intake). He exceeded his goal for protein but he does not consume an excessive amount. In fact, his intake reflects that of many Americans and is in line with guidelines for ultraendurance athletes. His total energy intake was adequate and he met his goal for total carbohydrate intake. He consumed high-quality protein both as animal protein (e.g., cheese and milk) and complementary proteins (e.g., black beans and rice). His macronutrient and energy intakes are balanced. From a performance perspective, the quantity and quality of Lucas' protein intake was appropriate.

Marcus, a Running Back (American Football)

Now consider the diet of a strength athlete such as a college football player. Marcus is a 6-ft (183-cm), 200-lb (91-kg) running back. Marcus' goals for the three months prior to fall

Nutrient	DRI	Intake	0% 50% 100%
Energy			
Kilocalories	3365 kcal	3332.8 kcal	99%
Carbohydrate	379–547 g	532.15 g	
Fat, total	75–131 g	93.86 g	
Protein	84–294 g	124.09 g	

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	Goal*	Actual	% Goal
Grains	10 oz. eq.	11.8 oz. eq.	118%
Vegetables	4 cup eq.	1.2 cup eq.	30%
Fruits	2.5 cup eq.	1.7 cup eq.	68%
Milk	3 cup eq.	5.4 cup eq.	180%
Meat & Beans	7 oz. eq.	8.8 oz. eq.	126%
Discretionary	648	1152	178%

*Your results are based on a 3200 calorie pattern, the maximum caloric intake used by MyPyramid.

Figure 5.7 Dietary Analysis of 24-Hour Diet of a Male Collegiate Cross Country Runner and beans, and peanut butter and bread consumed at the same meal or within the same day are examples of complementary proteins. Many cultures have a long history of combining plant proteins in traditional dishes or meals that result in the consumption of complementary proteins. New Orleans is famous for its red beans and rice, Mexican cuisine features corn tortillas and pinto beans, and Asian dishes often include stir-fried tofu (made from soy beans) and rice. An important issue for vegans is that they consume a variety of plant proteins to ensure that they consume all the indispensable amino acids in the proper quantities. Many vegans include soy protein isolate in their diets because it is usually considered comparable in quality to animal protein. Adequate energy intake is also important.

PROTEIN SUPPLEMENTS

Protein supplements are popular among athletes with higher than average protein needs, particularly

practice include increasing body weight (as muscle mass) by 10 lb (4.5 kg), increasing muscle strength, and maintaining aerobic fitness. To achieve this he has developed a training plan that predominately consists of strength training along with some speed and agility drills. For the hypertrophy or muscle-building phase, Marcus emphasizes an increased volume of strength training. To accomplish this, he works out four to six days a week in the weight room with multiple sets of each exercise. As he gets closer to fall practice, he will reduce the number of repetitions but increase the resistance of each exercise to transition into a strength and power development phase. To support training, it is estimated that he needs approximately 4,000 kcal (44 kcal/kg), 600 g carbohydrate (6.6 g/kg), 155 g protein (1.7 g/kg), and 110 g of fat (1.2 g/kg) daily.

Marcus can easily meet his energy and nutrient needs as shown in Figure 5.8. The composition of the diet shown is very close to the recommended guidelines, although these guidelines are just estimates and athletes' diets are not expected to match them exactly. His protein intake (2.0 g/kg/d) is slightly higher than recommended (1.7 g/kg/d) because his carbohydrate intake is slightly lower (6.5 g/kg/d versus 6.6 g/kg/d). Marcus' diet as shown will provide the nutrients he needs to support his training and includes foods that are easy to prepare and readily available at the grocery store.

Breakfast: 2 cups oatmeal with ½ cup nonfat milk, ¼ cup raisins, one honey-wheat English muffin with 1 tablespoon each margarine and jelly, 8 ounces orange juice.

Lunch: 2 sandwiches, each including 2 slices of whole wheat bread, 3 ounces lean turkey, 1 slice Swiss cheese, sliced tomato, lettuce, mustard, and 1 tablespoon light mayonnaise; 1 apple, 8 ounces nonfat milk.

Dinner: 6 ounces grilled halibut, 1 large baked potato with ¼ cup fat-free sour cream, 1½ cups broccoli, 5 Fig Newtons, 1 cup frozen yogurt.

Snacks: 8 ounces reduced-fat chocolate milk (postexercise), 2 bananas, 1 peanut butter Powerbar.

Energy: 4,009 kcal (44 kcal/kg)

Carbohydrate: 589 g (6.5 g/kg or ~59% of total caloric intake)

Protein: 185 g (2.0 g/kg or ~18% of total caloric intake)

Fat: 112 g (1.2 g/kg or ~25% of total caloric intake)

Figure 5.8 Sample Diet for a Strength Athlete

Legend: kcal = kilocalorie; g=gram; g/kg=grams per kilogram body weight

Table 5.6 Average Daily Protein and Energy Intakes of Athletes

Study	Subjects	Average Daily Protein Intake	Average Daily Energy Intake
Nogueira & Da Costa, 2004	29 male, 9 female Brazilian triathletes	Males: Mean = 2.0 g/kg, 142 g Females: Mean = 1.6 g/kg, 88 g	Males: Mean = 3,660 kcal Females: Mean = 2,300 kcal
Onywera, Kiplamai, Tuitoek et al., 2004	10 male elite Kenyan runners; 8 ran cross country, 2 ran 1,500 m	Mean = 1.3 g/kg, 72 g	Mean = 2,987 kcal
Jonnalagadda, Ziegler, & Nelson, 2004	23 male, 26 female elite figure skaters	Males: Mean = 1.2 g/kg, 82 g Females: Mean = 1.16 g/kg, 54 g	Males: Mean = 2,112 kcal Females: Mean = 1,490 kcal
Paschoal & Amancio, 2004	8 male elite Brazilian swimmers	Mean = 2.27 g/kg Range = 1.30 to 2.85 g/kg	Mean = 53.4 kcal/kg
Leydon & Wall, 2002	20 male and female New Zealander jockeys	Males: Mean = 1.1 g/kg, 58 g Range = 44 to 74 g Females: Mean = 0.95 g/kg, 47 g Range = 18 to 75 g	Males: Mean = 6,359 kJ (1,514 kcal) Lowest mean = 3,371 kJ (803 kcal) Females: Mean = 6,213 kj (1,479 kcal); Lowest mean = 3,454 kJ (822 kcal)
Poortmans & Dellalieux, 2000	20 Belgian male bodybuilders (BB) and 17 male athletes (OA) in the sports of cycling, judo, and rowing	BB: Mean = 1.94 g/kg, 169 g OA: Mean = 1.35 g/kg, 99 g	BB: Mean = 3,908 kcal OA: Mean = 2,607 kcal
Mullins et al., 2001	19 female American heptathletes	1.4 g/kg, 95 g Range = 0.7 to 3.1 g/kg, 53 to 186 g	36 g/kg, 2,357 kcal Range = 21 to 87 g/kg, 1,553 to 5,276 kcal

Legend: g/kg = grams per kilograms body weight; g = gram; kcal = kilocalorie; kcal/kg = kilocalories per kilogram body weight

Protein supplements are heavily advertised to strength/power athletes.

bodybuilders and strength athletes. These supplements are marketed as powders, premixed drinks, and bars. They are heavily advertised to athletes who are building and maintaining large amounts of muscle mass.

As illustrated in the Spotlight, Marcus, a running back, and Lucas, a distance runner, both consumed more than enough protein from food alone. Obtaining protein from food is relatively easy and reasonably affordable. Obtaining protein from supplements is usually more expensive but may be more convenient because of portability and preparation (e.g., adding protein powder to water can be done quickly anywhere). For example, Marcus typically goes home after lifting weights and has a quick snack of chocolate milk and a banana. But he also keeps a protein powder handy for a number of reasons—he likes the variety, it is easy to bring to the gym if he is not going back home, it does not need to be refrigerated, and he sometimes comes home to find that his roommate has eaten his bananas and finished the carton of milk. The protein powder he buys has about the same number of calories as his usual postexercise snack but has more protein and less carbohydrate, so he must consider the differences in their nutrient content. Marcus may choose a protein supplement for a number of good reasons, but because he can get enough protein from food, protein supplements are not a required part of his diet. For those who choose to supplement, such supplements seem to be safe for healthy adults.

Table 5.7 Nutrient Content of Selected Protein Supplements

Protein Supplement	Amount	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
100% Whey Protein Fuel (powder)*	1 scoop (33 g) in 6 oz of water	130	25	2	1
Myoplex Original**	1 packet	270	42	3	23
Heavyweight Gainer 900***	4 scoops	630	35	9.5	101
Protein Plus bars****	1 bar (85 g)	320	34	8	29

Legend: kcal = kilocalories; g = gram; oz = ounce

*TwinLab, Hauppauge, NY

**EAS, Golden, CO

***Champion Nutrition, Concord, CA

****Met-Rx, Bohemia, NY

Protein supplements often contain whey, casein, and soy proteins, some of the same proteins that are contained in milk, meat, fish, poultry, eggs, and soy. In the presence of resistance training and adequate calories, proteins from either food or supplement sources can contribute to increasing muscle size and strength. Protein supplements are neither more nor less effective than food proteins for muscle growth.

Table 5.7 lists some popular products advertised as protein supplements. Protein powders may contain only protein but many also contain some carbohydrate to make them more palatable. Sometimes athletes will mix protein powders with sugary or artificially sweetened drinks, such as Kool-Aid or Crystal Lite. Protein bars vary in their protein, carbohydrate, and fat content. Reading the label carefully helps consumers determine the nutrient content of a product and how such a product may fit into their overall diet plan.

Whey versus Casein. Advertisements for protein supplements often make a special point of the type of protein contained—whey or casein. Whey and casein are both milk proteins but they have different amino acid profiles. Whey protein has long been popular among strength athletes because of its protein quality.

Both whey and casein are processed from milk. When milk is coagulated (thickened) whey is found in the liquid portion while casein is found in the semisolid portion known as curds. The whey can be processed further into whey protein isolate, whey protein concentrate, or whey powder. Whey protein concentrate and whey powder contain lactose. Whey protein isolate, which is typically added to protein supplements and infant formulas, is a concentrated source of protein because both the carbohydrate (e.g., lactose) and the fat are removed. The end product is high in indispensable amino acids, particularly the branched chain amino acids (i.e., leucine, isoleucine, and valine) (Geiser, 2003). Casein has a different amino acid composition and is particularly high in glutamine, an amino acid that is considered conditionally indispensable under physiological stress such as endurance exercise.

When whey is compared to casein, the amino acids in whey are absorbed faster. This difference in absorption rate is not surprising since whey has a high percentage of indispensable amino acids, which are absorbed more rapidly than the dispensable amino acids. Whey is often referred to as a "fast-acting" protein while casein is described as a "slow-acting" protein. The purported benefit of taking whey is that a faster rate of absorption would lead to high levels of indispensable amino acids in the amino acid pool and, ultimately, to an increase in muscle size. This theory has not been proven.

Whey protein supplements have been marketed to athletes for a long time. There are some studies (reviewed below) that have found that whey protein supplements are associated with an increase in muscle size and strength in some subjects However, there is little evidence that the gains in muscle size or strength associated with whey proteins are greater than those of other protein sources (Lemon, 2000).

Preliminary research reported that resistance-trained athletes who used whey supplements had a greater increase in lean tissue than those who received a placebo. However, the increase was small, approximately 2 kg (~4½ lb), and the whey-supplemented group did not always perform better (e.g., squat strength, knee flexion peak torque) than the placebo group (Burke et al., 2001). A 2006 study found that a combination of whey and casein resulted in greater increases in fat-free mass and performance (bench and leg presses) in resistance-trained male athletes than a carbohydrate placebo or a combination of whey, BCAA, and glutamine (Kerksick et al., 2006). Cribb et al. (2007) reported gains in muscle size and strength in some of the recreational bodybuilders who consumed whey protein supplements. Study comparisons are difficult because of small sample sizes, differences in subjects (resistance-trained versus untrained), and protein sources (whey-only versus whey + casein versus whey + individual amino acids). This is an area of active research and supplementation with whey protein shows some promise, but more studies are needed to clarify the effectiveness of whey protein supplements.

Those athletes who choose to supplement with whey proteins often consume them when they want an immediate rise in amino acid concentrations, such as immediately after exercise. Those who supplement with casein do so for its more sustained effect on the amino acid pool. Either whey or casein taken after exercise seems to increase muscle protein synthesis (Tipton et al., 2004). Many protein supplements contain both whey and casein to take advantage of their different absorption rates. In recent years whey's popularity has increased because of preliminary studies that suggest whey may also have antioxidant properties. The likely mechanism is whey's influence on the intracellular conversion of the amino acid cysteine to glutathione, a powerful antioxidant.

AMINO ACID SUPPLEMENTS

Proteins are made up of amino acids. Amino acids, especially the indispensable amino acids, stimulate muscle protein synthesis in the presence of resistance training. This fact has made supplementation of specific amino acids popular. Essential amino acids (EAA) and β-hydroxy-β-methylbutyrate (HMB) are popular supplements marketed to strength athletes. Endurance athletes may consider use of supplemental branched chain amino acids or glutamine because of the impact that the stress of endurance exercise has on these amino acids. In each case the purported benefit of these amino acids in supplement form is that the amounts are more concentrated than the amounts found in food.

Essential Amino Acids (EAA). Many supplements marketed to strength athletes advertise the number or amount of indispensable (essential) amino acids contained in the product. While it is true that the body cannot manufacture these amino acids, there is no evidence that indispensable amino acids cannot be provided in ample amounts by consuming protein-containing foods. While there are theories as to the optimal amounts or combinations of indispensable amino acids in improving athletic performance, there is a lack of studies to show a performance benefit for EAA supplements (Wagenmakers, 1999). However, this is an active area of research since indispensable amino acid supplementation has been shown to stimulate protein anabolism in elderly subjects (Volpi et al., 2003).

β-hydroxy-β-methylbutyrate (HMB). HMB is a metabolite of leucine, one of the indispensable amino acids. Three grams of supplemental HMB is hypothesized to increase muscle size and strength. The proposed mechanism is the effect HMB has on minimizing cellular protein breakdown after exposure to resistance exercise (Slater and Jenkins, 2000).

In 2003, Nissen and Sharp conducted a meta-analysis of studies of dietary supplements used in conjunction with resistance training to increase muscle size and strength. HMB was one of two supplements (the other was creatine) that was found to be beneficial. In the nine HMB studies that the authors reviewed, six included untrained subjects. There have also been reports of gains in muscle size and strength in elderly men and women who are experiencing muscle protein wasting.

However, studies in trained male athletes (e.g., rugby and American football players) have generally shown no effect on muscle size, strength, body composition, and aerobic or anaerobic capacity (Hoffman et al., 2004; O'Connor and Crowe, 2003; Ransone et al., 2003; Slater et al., 2001). HMB supplements of 3 g per day seem to be safe (Crowe, O'Connor and Lukins, 2003) but not effective in trained athletes.

Glutamine. Under normal conditions glutamine is considered a dispensable amino acid, but its status changes under physiologic stress, such as prolonged endurance exercise and illness. Glutamine is a fuel source for immune system cells. If glutamine is not available, some immune cells are impaired, which increases the risk for infections. Endurance athletes are at increased risk for upper respiratory infections (Krieger, Crowe, and Blank, 2004). Low blood glutamine levels have been detected in endurance athletes, so the question of whether supplemental glutamine is necessary or beneficial has been raised.

Glutamine supplements of 5 to 10 g seem to be safe. Unfortunately, it is hard to draw conclusions about effectiveness because the number of studies is small and the results inconsistent. Castell (2002) reported a decrease in the incidence of infections in endurance athletes who supplemented with glutamine. However, Gleeson, Nieman and Pederson (2004) and Nieman (2001) reviewed a number of studies and concluded that glutamine supplementation is not an effective countermeasure for immunological stress. Because glutamine supplementation is controversial, a prudent approach for the endurance athlete may be to increase protein-containing foods in the diet. Glutamine is found in protein foods and it is known that some endurance athletes consume diets low or marginal in protein.

Branched Chain Amino Acids. Leucine, isoleucine, and valine are the branched chain amino acids, so named because of their chemical structure. During prolonged endurance exercise when glycogen stores are low, skeletal muscle can metabolize these amino acids for energy. In addition to being used as an energy source, BCAA compete with tryptophan, an amino acid associated with mental fatigue. BCAA are also involved in the immune system (Newsholme and Blomstrand, 2006; Gleeson, 2005; Wagenmakers, 1999).

Endurance athletes may seriously consider supplemental BCAA based on functionality. In theory, greater availability of BCAA late in prolonged exercise could provide a much-needed fuel source. Higher blood levels of BCAA in the presence of tryptophan could help to delay fatigue. Immune response, particularly the ability to resist upper respiratory infections, might be improved. Strength athletes are interested in the possibility that BCAA supplements could reduce delayed-onset muscle soreness.

Supplemental BCAA of 10 to 30 g/d seem to be safe. However, supplemental BCAA have not been shown to improve endurance performance in trained endurance athletes. Nor have they been shown to protect the breakdown of muscle during exercise or help repair muscle faster after exercise (Gleeson, 2005), although results of preliminary studies do warrant more research (Shimomura et al., 2006). Mental fatigue is a complex neurophysiologic condition. A few studies have shown that BCAA supplementation has little to no effect on fatigue while other studies have shown that fatigue is reduced (Newsholme and Blomstrand, 2006). Although the trials are small, some positive effects have been reported in studies that examined immune response (Bassit et al., 2000, 2002). BCAA supplementation remains an active area of research, but at the present time the evidence for positive effects from supplementation is lacking or not convincing. Adequate daily protein intake, which provides BCAA, is important.

The decision to take a dietary supplement should be based on legality, ethics, safety, and effectiveness. The supplements listed above do not appear on the National Collegiate Athletic Association (NCAA) banned substance list. However, the institution cannot provide such supplements to student athletes because they are considered muscle-building supplements. NCAA Bylaw 16.5.2 (g) states that only nonmuscle-building nutritional supplements may be given to student athletes for the purpose of providing additional calories and electrolytes (as long as the nonmuscle building supplements do not contain any NCAA banned substances).

Glucosamine. Glucosamine, sold separately or in combination with chondroitin, is a dietary supplement marketed to relieve joint pain both in athletes and in those with osteoarthritis. Glucosamine is manufactured by the body from glucose and the amino acid glutamine and is not related to dietary intake. It is part of glycosaminoglycan (an unbranched polysaccharide), which is found in the extracellular matrix of the joints. Because of its ability to attract water, it is referred to as a "joint lubricant." Chondroitin is also synthesized by the body; supplements are typically obtained from shark cartilage or seashells (Delafuente, 2000).

The exact mechanism of glucosamine/chondroitin supplements is not known, but it is theorized to prevent the breakdown of cartilage and/or stimulate the synthesis of cartilage. Evidence suggests that glucosamine/

KEEPING IT IN PERSPECTIVE

The Role of Protein for Athletes

Protein is an important nutrient and it receives much attention because of its role in the growth and development of skeletal muscle. It deserves attention, but no nutrient should be the sole or predominant focus of the athlete's diet. Overemphasizing protein can mean losing sight of the broader dietary picture, which includes adequate energy, carbohydrate, and fat intakes.

Protein is no different from other nutrients in that both the "big" picture and the details are important. The "big" picture issues include an adequate amount of protein (based on energy intake) and macronutrient balance (the amount of protein relative to the amount of carbohydrate and fat needed). There is no point to the strength athlete taking in large amounts of protein only to find that carbohydrate intake is too low to support a well-planned resistance training program. Determining the appropriate energy intake and the amount of protein required are important first steps. Athletes need to assess their current dietary intake to determine if, and how much, more protein is needed. Protein is one of several nutrients that should be consumed in the postexercise recovery period, although the amount needed is small compared to the amounts of carbohydrate and fluid needed.

The athlete's fundamental protein needs should be met before the fine-tuning takes place. Protein quality (e.g., animal or plant), absorption (e.g., whey or casein), and source of protein (e.g., foods or supplements) are issues that each individual athlete should consider. Some of the questions that athletes have do not yet have scientific answers. For example, what is the maximum amount of protein that the gastrointestinal tract can absorb at one time? How much protein is needed daily for maximum muscle protein synthesis? The answers are not yet known. Part of keeping protein intake in perspective is to understand what is known, what is theorized, and what is pure conjecture. This is known: Protein is one important aspect of the athlete's diet.

chondroitin supplements can be effective in delaying the progression of osteoarthritis (Wang et al., 2004). However, athletes and those with osteoarthritis often use these supplements as an alternative medication to nonsteroidal anti-inflammatory drugs (NSAID) even though the supplements do not provide the immediate pain relief associated with NSAID use. Part of the popularity is that glucosamine/chondroitin supplements are purported to be less toxic and have fewer side effects than NSAIDs. The expected outcome of supplementation is joint pain relief and improved range of motion over time (McAlindon et al., 2000).

Although no **dose-response studies** have been conducted, typical daily doses are 1,500 mg of glucosamine and 1,200 mg of chondroitin sulfate for the first 60 days and a daily maintenance dose of 750 mg of glucosamine and 600 mg of chondroitin sulfate. These doses seem to be safe. Because these compounds are sold as dietary supplements in the United States, quality control (e.g., purity, potency) could be a problem. In Europe, glucosamine sulfate is sold as a prescription medication. Those allergic to shellfish should be aware that chondroitin supplements may be derived from seashells and some residual fish could be left after the cleaning process.

The effectiveness of glucosamine/chondroitin supplements and, especially their potential benefit over NSAIDs, have been controversial because of concerns over the experimental design of the various studies conducted. Some studies have shown that glucosamine/chondroitin supplements provide relief from knee pain that may be a result of cartilage damage (Braham, Dawson, and Goodman, 2003). There is a critical need for well-designed studies using trained athletes as subjects.

Clegg et al. (2006) conducted a randomized, double-blind, placebo-controlled intervention study that examined the effect of glucosamine and chondroitin, both singly and combined, and an NSAID (celecoxib) as a 24-week treatment of knee pain from osteoarthritis. The average age of the participants was 59 years and knee pain ranged from mild to moderate to severe. The supplements, whether administered separately or together, were not more effective than placebo for reducing knee pain by 20 percent. The response rate was lowest with placebo and highest with celecoxib, although some subjects did not receive pain relief from any compound. Further study is needed because the data suggested that those with moderate or severe knee pain who took glucosamine/chondrotin supplements had a significantly higher rate of response when compared to placebo. This remains an active area of research.

Dose-response studies: A research experiment for the purpose of finding out the degree of result that occurs for a given amount of stimulus.

Summary

Proteins are made up of **amino acids,** which contain carbon, hydrogen, oxygen, and nitrogen. Protein is a critical nutrient, in part, because of the roles that it plays in the growth and development of tissues and the immune system. It has many other important roles including the synthesis of enzymes and hormones. Amino acids can also be **catabolized** to provide **energy.** Protein functions optimally when energy intake from carbohydrate and fat is sufficient. When energy intake is insufficient, such as with fasting or starvation, more amino acids are broken down to provide the carbon skeletons needed by the liver to manufacture glucose.

The recommended daily protein intake for endurance athletes is 1.2 to 1.4 g/kg while the recommendation for strength athletes is 1.6 to 1.7 g/kg. Ultraendurance athletes may need as much as 2.0 g/kg/d during some phases of their training. Recently, the timing of protein intake has received more attention as the importance of the consumption of a small amount of protein within one to two hours after exercise has been found to be beneficial to muscle protein synthesis and repair. Most athletes consume an adequate amount of protein but some consume too little protein, usually in conjunction with too little energy. Low protein and energy intakes have the potential to impair performance and health.

Proteins are found in both animal and plant foods. When animal foods are consumed the likelihood is high that the diet will provide **protein** of sufficient **quality.** Vegetarians who do not consume any animal-derived proteins can also obtain sufficient protein quality by correctly combining different plant proteins. Athletes can consume enough food to meet their higher-than-average protein needs. Protein supplements are popular, particularly among bodybuilders and strength athletes, and seem to be safe but no more or less effective than proteins found in food. Individual amino acid supplements do not seem to be effective for increasing muscle size or strength in trained athletes. Supplemental glutamine and **branched chain amino acids** have been studied in endurance athletes and seem to be safe, but their effectiveness is still unknown due to small study size and inconsistent results.

Post-Test Reassessing Knowledge of Proteins

Now that you have more knowledge about protein, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. Skeletal muscle is the primary site for protein metabolism and is the tissue that regulates protein breakdown and synthesis throughout the body.
2. In prolonged endurance exercise, approximately 3 to 5 percent of the total energy used is provided by amino acids.
3. To increase skeletal muscle mass, the body must be in positive nitrogen balance, which requires an adequate amount of protein and energy (calories).
4. The daily recommended protein intake for strength athletes is 2.0 to 3.0 g/kg body weight, twice that recommended for endurance athletes.
5. Strength athletes usually need protein supplements because it is difficult to obtain a sufficient amount of protein from food alone.

Review Questions

1. Amino acids contain which chemical elements?
2. How do the structures of amino acids differ? How do these structural differences influence function?
3. What is meant by protein quality? How do plant and animal proteins differ in quality?
4. Briefly describe the digestion, absorption, and transport of protein found in food.
5. What is the amino acid pool? Why is such a pool important?
6. Describe anabolic and catabolic processes that involve amino acids.
7. What is nitrogen balance? Under what conditions is nitrogen balance positive or negative?
8. Describe the role the amino acid leucine plays in fueling endurance exercise.
9. Explain how protein metabolism is affected when the body is faced with short- and long-term starvation.
10. What is the recommended daily intake of protein for adult nonathletes? Endurance athletes? Strength athletes? Ultraendurance athletes?
11. Why is the timing of protein intake important?
12. What effect might exceptionally high protein intake have on training, performance, or health?
13. What effect might a low protein intake have on training, performance, or health?
14. Compare and contrast animal and plant proteins.
15. Describe how vegans can met their protein needs.
16. Are protein and individual amino acid supplements safe and effective? What information is needed to draw conclusions about safety and effectiveness?

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6 Fats

Learning Objectives

1. Classify fats according to their chemical composition.
2. Distinguish between saturated and unsaturated, monounsaturated and polyunsaturated, *cis* and *trans*, and omega-3 and omega-6 fatty acids.
3. Describe the digestion, absorption, transportation, and storage of fat.
4. Explain the metabolism of fat, including mobilization, transportation, uptake, activation, translocation, and oxidation.
5. Explain ketosis and the effect it may have on training.
6. Describe how the body uses fat to fuel exercise.
7. State fat recommendations for athletes and calculate the amount of fat needed daily.
8. Identify sources of dietary fat.
9. Assess an athlete's dietary fat intake.
10. Evaluate fat-related dietary supplements.

Pre-Test Assessing Current Knowledge of Fats

Read the following statements about fats and decide if each is true or false.

1. A low-calorie, low-carbohydrate diet that results in ketosis is dangerous for athletes because it leads to the medical condition known as ketoacidosis.
2. At rest, the highest percentage of total energy expenditure is from fat, not carbohydrate.
3. To lose body fat, it is best to perform low-intensity exercise, which keeps one in the fat burning zone.
4. To improve performance, endurance athletes should ingest caffeine because more free fatty acids are oxidized for energy and muscle glycogen is spared.
5. Athletes typically need to follow a very-low-fat diet.

The word fat is used in many different ways. In physiology, a **fat** is a long chain of carbon molecules. The fatty acid chains that are most commonly used by humans for metabolism contain either 16 or 18 carbons, such as **palmitic acid** (palmitate) and **oleic acid.** In medicine, fats are known as **lipids,** large fat-containing components in the blood. **Triglycerides, sterols** (e.g., **cholesterol**), and **phospholipids** are examples, and some play a substantial role in the development of **cardiovascular disease.** In nutrition, fats are energy-containing nutrients found in food. In all of these disciplines, fat is also used to describe the body's long-term storage site for fats, although the precise term is **adipose tissue.** To further complicate the issue, in everyday language fat is often used as an adjective, describing a body weight that is greater than desirable.

Confusion can result unless the most appropriate terms are used within the proper context. In many cases that means talking about specific chemical compounds, such as triglycerides, **saturated fats,** or cholesterol. All of these compounds are described as lipids when found in blood and as fats when found in food. What do people mean when they say "too much fat?" Too much adipose tissue? Too much fat in the diet? Too much fat in the blood? When talking about various fats in the fields of nutrition, health, and medicine, precise terms need to be used.

Fats are an important nutrient for athletes because they are a primary energy source at rest and during low-intensity activity. Along with carbohydrates, fats are an important energy source for moderate-intensity exercise. The largest amount of fat in the body is stored in adipose tissue in the form of triglycerides, while smaller amounts are stored as muscle triglycerides. Aerobic training can increase the body's ability to utilize fats.

Most of the fats found in food provide energy because the body can digest, absorb, and metabolize them. An exception is cholesterol, which cannot be broken down for energy because of its chemical structure. However, cholesterol is important for good health because it is needed for a variety of physiological functions such as a building block for essential hormones. However, in some individuals excessive amounts of cholesterol can be absorbed and ultimately deposited in the walls of arteries, potentially leading to a blockage, so limiting dietary cholesterol may be helpful. All humans need some fat in their diets to provide the essential fatty acids that the body cannot manufacture, so dietary fat should not be viewed automatically as bad. Some fat is also necessary for the absorption of the fat-soluble vitamins, and fat-containing foods taste good and satisfy hunger, making them a palatable energy source.

There are four sources of energy provided by diet—carbohydrates, fats, proteins, and alcohol. Fats are the most concentrated form of energy, with each gram containing approximately 9 kcal. Alcohol contains approximately 7 kcal/g, and proteins and carbohydrates contain approximately 4 kcal/g each, so fats have the highest caloric density. Athletes who expend a lot of energy during daily training

It is important to know the amounts and types of dietary fats found in foods.

need to include enough fat in their diets or they risk consuming too little energy (kcal). However, many athletes do not want to be in energy balance. Reducing dietary fat is a strategy frequently used by athletes who wish to reduce energy intake and, over time, body fat. Lowering dietary fat intake can be appropriate, but too low of a fat intake can also be detrimental to performance and health.

The best way to understand the different kinds of fats is to understand their chemistry. The length of the chain, which is measured by the number of carbons contained, and the degree of saturation, which is determined by the number of hydrogen atoms attached to each carbon atom, are two characteristics used to categorize fats. The processing of food can change the chemical configuration, so processed fats may differ from naturally occurring ones. The chemical structure of the fat influences how it is digested, absorbed, and transported, so an understanding of physiology is needed. Fat is an important nutrient to support training and performance, but because fats influence **chronic** diseases, notably cardiovascular diseases, their influence on health and disease must be considered as well.

Fatty Acids, Sterols, and Phospholipids

Fats vary in their chemical composition. The predominant fats in food and in the body are triglycerides, which are made up of three fatty acids attached to a **glycerol** molecule. Sterols, such as cholesterol, and phospholipids, phosphate-containing fats, are also found in food and in the body. These three classes of fat compose the category known as lipids.

FATTY ACIDS

To understand the differences in the various fats, one must look closely at their chemical composition. This discussion begins with fatty acids, which are chains of carbon and hydrogen ending with a **carboxyl** group (a carbon with a **double bond** to oxygen and a single bond to an oxygen/hydrogen, written as COOH). The length of the fatty acid chain can range from four to 24 carbons. The number of carbons will be an even number because fatty acid chains are manufactured by adding two carbons at a time. An example of a fatty acid is shown in Figure 6.1. The fatty acid in this example, oleic acid, has 18 carbons. The fatty acids used most commonly in metabolism in humans have 16 or 18 carbons.

A saturated fatty acid contains no double bonds between carbons. The term saturated refers to the fact that no additional hydrogen atoms can be incorporated.

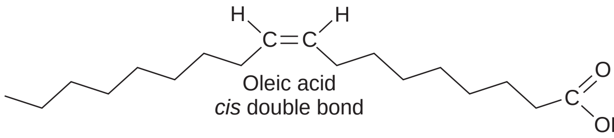

Figure 6.1 Oleic Acid

Oleic acid is an 18-carbon fat that is found in plant and animal fats.

An example of one saturated fatty acid, palmitic acid, is shown at the top of Figure 6.2.

Unsaturated fatty acids contain one or more double bonds between carbons, reducing the number of hydrogen atoms that can be bound to the structure. When only one double bond between carbons is present, it is referred to as a **monounsaturated** fatty acid (mono means "one"). When two or more double bonds are present, these fatty acids are referred to as **polyunsaturated** fatty acids (poly means "many"). Unsaturated fatty acids have 16 to 22 carbons and from one to six double bonds. Examples are shown in Figure 6.2.

Fat: A general term used to describe an energy-containing component of food and the storage of energy in adipose tissue. May also refer to excess body weight as adipose tissue.

Palmitic acid (palmitate): A fatty acid that contains 16 carbons.

Oleic acid: A fatty acid that contains 18 carbons.

Lipid: General medical term for fats found in the blood.

Triglyceride: A fat composed of three fatty acids attached to a glycerol molecule, known technically as a triacylglycerol.

Sterol: A fat whose core structure contains four rings.

Cholesterol: A fat-like substance that is manufactured in the body and is found in animal foods.

Phospholipid: A fat that is similar to a triglyceride but contains phosphate.

Cardiovascular disease: Any of a number of diseases that are related to the heart or blood vessels.

Adipose tissue: Fat tissue. Made up of adipocytes (fat cells).

Saturated fat: A fat that contains no double bonds between carbons.

Chronic: Lasts for a long period of time. Opposite of acute.

Glycerol: A carbon-, hydrogen-, and oxygen-containing molecule that is the backbone of all triglycerides. Glycerol is a sugar alcohol, not a fat.

Carboxyl group: Carbon with a double bond to oxygen and a single bond to oxygen/hydrogen.

Double bond: A chemical bond between two atoms that share two pairs of electrons.

Unsaturated fat: Fatty acids containing one or more double bonds between carbons.

Monounsaturated fat: A fat containing only one double bond between carbons.

Polyunsaturated fat: A fatty acid with two or more double bonds.

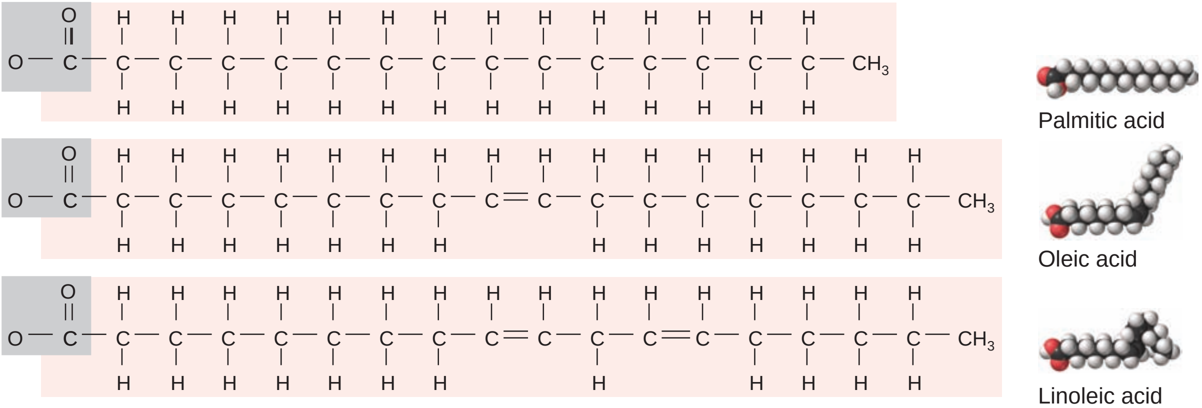

Figure 6.2 Saturated, Monounsaturated, and Polyunsaturated Fatty Acids

Palmitic acid (palmitate) is a 16-carbon saturated fat found in plant and animal fats. Oleic acid is an 18-carbon monounsaturated fat found in plant and animal fats. Linoleic acid is an 18-carbon polyunsaturated fat found in the seed and oil of plants such as corn, safflower, sunflower, soybean, and peanuts.

When double bonds between carbons are present, as in the case of mono- and polyunsaturated fatty acids, the fatty acid can be in the ***cis*** or ***trans*** formation. *Cis* refers to groups that are on the same side of the double bond between carbons. *Trans*, which means "across" or "on the other side," refers to groups that are on opposite sides of the double bond between carbons. Nearly all unsaturated fatty acids occur naturally in the *cis* form. The *cis* form allows fatty acids to "bend," which is an important feature when these fatty acids are incorporated into cell membranes. *Trans* fatty acids are not usually found in nature but are produced synthetically through the addition of hydrogen atoms to an unsaturated fatty acid. This results in the fatty acid chain being "straight." This **hydrogenation** process is used in commercial food processing to make liquid oils more solid (e.g., soybean oil made into margarine) and to increase the shelf life of the product. Figure 6.3 illustrates unsaturated fatty acids in their *cis* and *trans* forms. When the term *partially hydrogenated* appears on a food label, it indicates this type of manufactured fatty acid has been added to the food product, and the food may therefore contain *trans* fatty acids. Most food manufacturers are looking for alternative processes in an effort to reduce the amount of *trans* fat in their products.

Polyunsaturated fatty acids can be further distinguished by their fatty acid series. This refers to the presence of a double bond between carbons that is counted from the last carbon in the chain (farthest from the carboxyl group carbon). This terminal carbon is referred to as **omega** or n-. The three fatty acid series are termed omega-3 (n-3), omega-6 (n-6), or omega-9 (n-9) families. Figure 6.4 shows an example of each. Foods containing omega-3 fatty acids are often discussed in relation to their beneficial effect on blood lipid levels and their potential for reducing cardiovascular disease risk. Linoleic acid, one of two essential fatty acids, is an omega-6 fatty acid. Oleic acid, the predominant fatty acid in olive oil, is an omega-9 fatty acid.

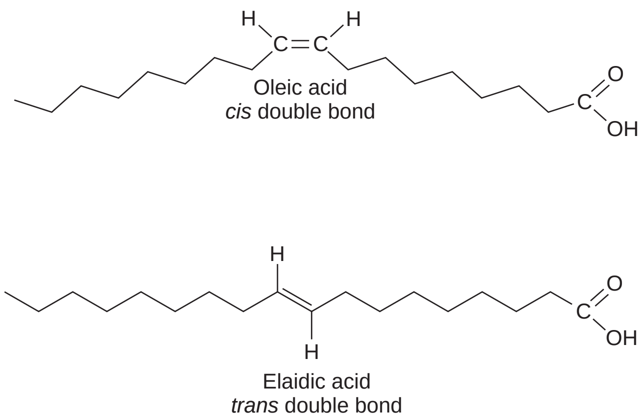

Figure 6.3 *cis* and *trans* Formations

Oleic acid, which naturally occurs in the *cis* formation, is an 18-carbon monounsaturated fat that is widely found in plant and animal fats. Elaidic acid is the *trans* isomer of oleic acid and is found in hydrogenated vegetable oils such as margarine.

TRIGLYCERIDES IN FOODS

Fatty acids are the building blocks of fat found in food. Nearly 95 percent of all the fat consumed in the diet is in the form of triglycerides. A triglyceride is composed of four parts—three fatty acids attached to a glycerol—as shown in Figure 6.5. The three fatty acids can all be the same, but a triglyceride usually contains a combination of different fatty acids. The nature of the individual fatty acids that make up a triglyceride influence the temperature at which the fat will melt. Those triglycerides with unsaturated fatty acids tend to be liquid at room temperature and are known as oils. Those triglycerides that contain primarily saturated fatty acids do not melt until the temperature is higher and

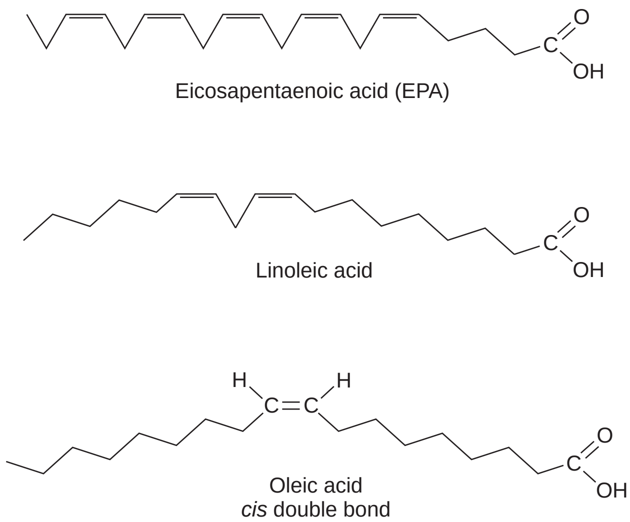

Figure 6.4 Omega-3, -6, and -9 Fatty Acids

Eicosapentaenoic acid (EPA) is an omega-3 fatty acid found in fish oils. Linoleic acid, an omega-6 fatty acid, is found in a variety of vegetable oils. Oleic acid, an omega-9 fatty acid, is widely found in plant and animal fats.

Emilio Ereza/Superstock

Vegetable oils are excellent sources of monounsaturated and polyunsaturated fatty acids.

are solid at room temperature. Although the term triglyceride is commonly used, it should be noted that the technically correct term is **triacylglycerol** and this latter term is frequently used in the scientific literature.

The triglycerides found in food contain a combination of saturated, monounsaturated, and polyunsaturated fatty acids. Foods can be grouped according to the predominant fatty acid. For example, coconut oil contains 92 percent saturated fatty acids, 6 percent monounsaturated fatty acids, and 2 percent polyunsaturated fatty acids. Coconut oil is classified as a saturated fat because saturated fatty acids predominate. Other foods that contain predominantly saturated fatty acids include palm kernel oil, beef, and milk and milk products that contain fat (e.g., whole milk, butter, ice cream).

Oils are predominantly, but not exclusively, polyunsaturated fatty acids. Most vegetable oils contain about 10 to 15 percent saturated fatty acids. Oils are usually

***Cis*:** Describes a chemical formation where groups are on the same side of the double bond between carbons.

***Trans*:** Describes a chemical formation in which groups are on opposite sides of the double bond between carbons.

Hydrogenated/hydrogenation: A chemical process that adds hydrogen. In food processing, used to make oils more solid.

Omega fatty acid: A fatty acid that contains a double bond that is counted from the omega or terminal end. These fatty acids are characterized as omega-3, omega-6, or omega-9.

Triacylglycerol (triglyceride): A fat composed of three fatty acids attached to a glycerol molecule.

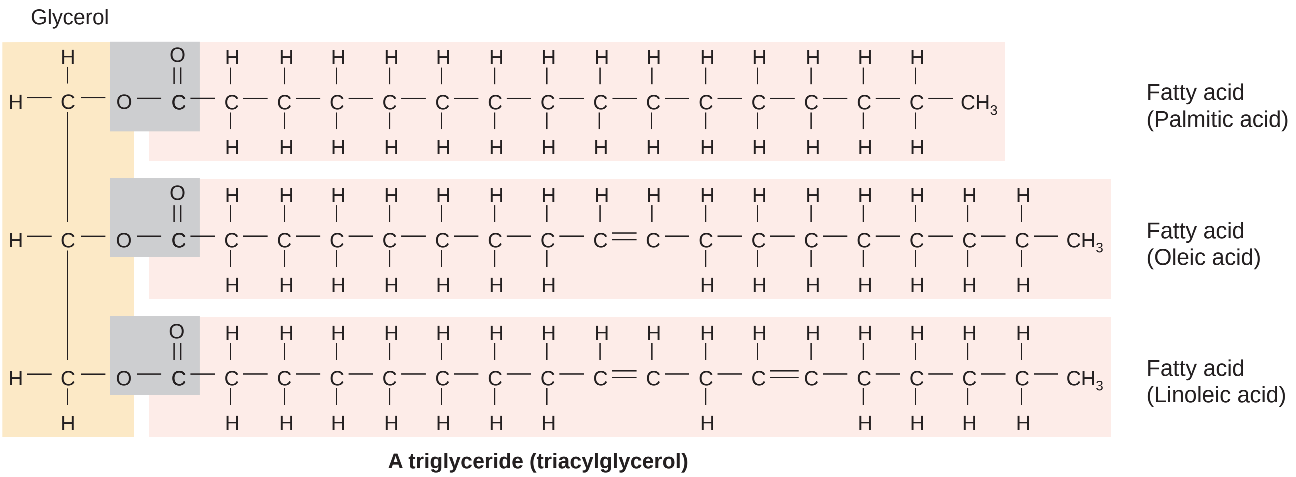

Figure 6.5 Structure of Triglycerides

A triglyceride is composed of three fatty acids attached to a glycerol.

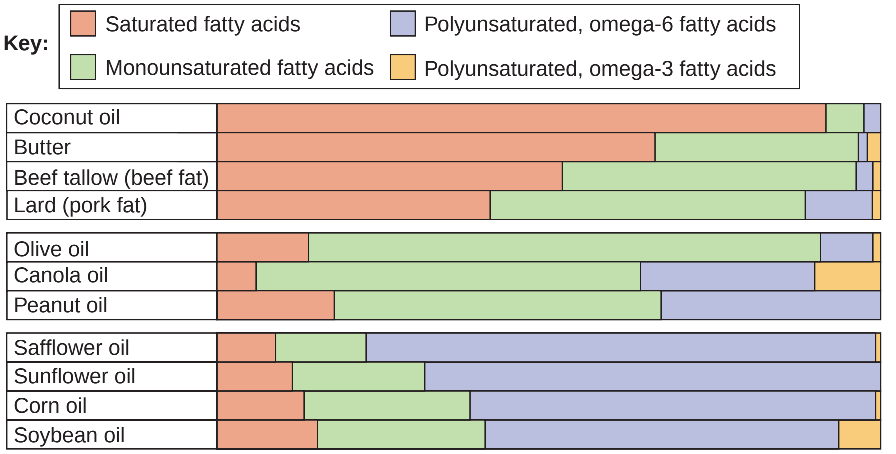

Figure 6.6 Fatty Acid Distribution in Selected Foods

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Cholesterol is only found in animal foods such as milk and milk products in which the fat has not been removed.

distinguished by their predominant unsaturated fatty acid, which is either a mono- or polyunsaturated fat. Olive oil and canola oil contain primarily monounsaturated fatty acids. In other oils, such as safflower or corn oil, the polyunsaturated fatty acids predominate. Figure 6.6 illustrates the fatty acid distribution of some fat-containing foods.

Two 18-carbon fatty acids are essential fatty acids—**linoleic** and **alpha-linolenic.** The body cannot manufacture these essential fatty acids, so they must be consumed in the diet. Fortunately, these two essential fatty acids are widely found in food. Linoleic, an omega-6 fatty acid, is in many vegetable oils such as corn, soy, safflower, and sunflower oils. Alpha-linolenic, a member of the omega-3 family, is found in soy, canola, and flaxseed oils. It is also found in leafy green vegetables, fatty fish, and fish oils.

STEROLS AND PHOSPHOLIPIDS IN FOODS

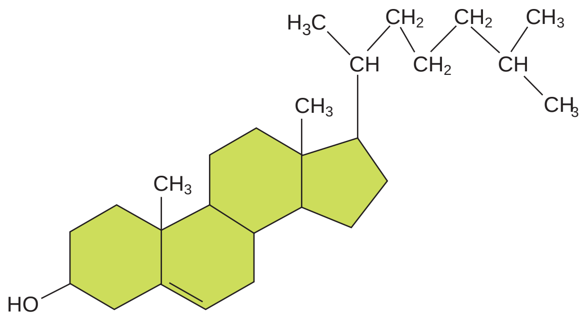
Almost 95 percent of the fat found in foods is in the form of triglycerides; the remaining fats in food are either sterols or phospholipids. Fatty acids are chains of carbon, but sterols have a different chemical composition. Sterols belong to a group of fats whose core structure is made up of four rings. This four-ringed nucleus is known as a steroid. Various side chains can be added to the steroid nucleus and many different compounds can be made, including cholesterol, vitamin D, and the steroid hormones, including the sex hormones (see Figure 6.7). If the steroid-based compound has one or more **hydroxyl** (OH) groups attached and no **carbonyl** (=C=O) or carboxyl (COOH) groups, then the compound is known as a sterol.

The most common sterol found in food is cholesterol. Cholesterol is only found in animal foods such as meat, egg yolks, and milk and milk products in which the fat has not been removed. Cholesterol is an important component of human cell membranes. No plant foods contain cholesterol. However, plants do contain other sterols, known as phytosterols, including **estrogens** similar to human sex hormones. Phytosterols are an important structural component of plant cell membranes.

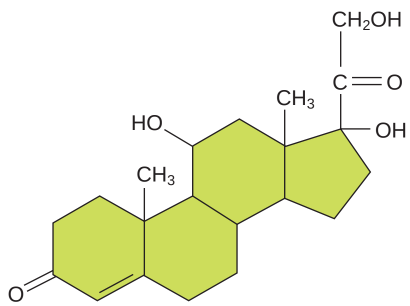
Phospholipids are similar in structure to triglycerides but are distinguished by the inclusion of phosphate. They are a structural component of all living tissues, especially the cell membranes of animal cells. Lecithin is an example of a phospholipid. Although sterols and phospholipids are physiologically important, the primary nutritional focus in this chapter is the predominant fat found in foods and in the body—triglycerides.

FATS AND THEIR INFLUENCE ON PERFORMANCE AND HEALTH

While the chemical differences between the various fats may be obvious, the impact of these differences on performance or health may not be immediately clear. From a performance perspective, fat intake is important because fat is metabolized to provide energy for



Cholesterol



Cortisol

Figure 6.7 Structure of Sterols

Note the four-ring nucleus (steroid) in these sterols.

low- to moderate-intensity exercise. The vast majority of fat used to provide this energy will come from triglycerides stored either in adipose tissue or muscle cells. The adipose and muscle triglycerides are manufactured from fatty acids originally found in food. From a purely metabolic perspective, the original source of the fat (saturated or unsaturated fatty acids found in food) is not important. What is important to the body is that it can metabolize the triglycerides for immediate energy or store them for future use as energy.

From a health perspective, there are certain fats that should be emphasized because they have been shown to lower the risk of cardiovascular disease. Unsaturated fatty acids (i.e., mono- and polyunsaturated fats) and omega-3 fatty acids are examples. Conversely, it is recommended that the consumption of saturated fatty acids be limited and that *trans* fatty acids be eliminated from the diet, as excessive amounts of both may be detrimental to health. In some people, excess saturated fats and dietary cholesterol raise blood cholesterol concentration, and therefore, limiting these fats in the diet is recommended. The role that the various fats play in the development of cardiovascular and other chronic diseases is discussed in Chapter 12.

Because performance and health are both important, athletes first determine the total amount of fat appropriate in their daily diet. Then they can choose foods that contain certain kinds of fatty acids (e.g., almonds are high in monounsaturated fat). The appropriate amount of fat intake for the athlete will depend on two factors: 1) overall energy (caloric) need and 2) **macronutrient** balance (i.e., meeting carbohydrate, protein, and fat recommendations within the context of energy needs). These two factors will be explained later in this chapter.

What's the point? Triglycerides are the most abundant type of fat in both food and in the body. A triglyceride contains three fatty acids attached to a glycerol molecule. Differences in the fatty acids are due to their chemical composition.

Digestion, Absorption, and Transportation of Fats

Digestion is the breakdown of foods into smaller parts. Absorption involves taking these smaller parts through the cells of the intestine where they will then be transported to other parts of the body. Fats present a particular digestion and absorption challenge because they are large molecules. Additionally, they do not mix well with water, the main component of blood, so transport in the blood requires fat to be bound to protein.

DIGESTION OF FATS

The process of fat digestion begins in the mouth and continues in the stomach to a small degree, but digestion of fat occurs predominantly in the small intestine. Undigested fat in the stomach has two effects: 1) it delays the emptying of the stomach contents (known as the gastric emptying rate) and 2) it results in a feeling of fullness (known as satiety). Athletes limit their fat intake temporarily in certain situations when they do not want gastric emptying delayed, such as during endurance events when rapid movement of carbohydrate-containing fluids into the intestine is beneficial. Conversely, athletes may include fat-containing foods in their meals when they want to avoid feeling hungry for several hours.

Fats are large and complex molecules that do not mix easily with water. Therefore, fats must be exposed to digestive enzymes before they can cross the membranes of the intestinal cells. An important digestive enzyme is

Linoleic acid: An essential fatty acid.

Alpha-linolenic acid: An essential fatty acid.

Hydroxyl group: Formed when oxygen attaches to hydrogen (OH).

Carbonyl group: A group of atoms (=C=O).

Estrogen: A steroid hormone associated with the development of female sex characteristics.

Macronutrient: A nutrient needed in large amounts such as carbohydrate, protein, or fat.

pancreatic lipase. As the name implies, this enzyme is secreted by the pancreas into the small intestine and helps to break down the large fatty acids into smaller components. Recall that all but 5 percent of the fat found in food is triglyceride (i.e., triacylglycerol), which is composed of three fatty acids attached to a glycerol molecule. These three-unit fats are broken down by enzymes to two-unit fats known as **diglycerides** (i.e., **diacylglycerols**) and to one-unit fats, **monoglycerides** (i.e., **monoacylglycerols**). Phospholipids are involved in a similar digestive process, although the enzymes are different. Cholesterol is not broken down at this point. The process of digestion reduces the size of the fat particles and readies them for absorption by the mucosal cells of the intestine.

ABSORPTION OF FATS

The fat particles enter the mucosal cells by passive diffusion, a process in which molecules move from an area of higher concentration to an area of lower concentration. Recall that the original triglyceride had three fatty acids and that each fatty acid could be a different length (from four to 24 carbons). Once in the mucosal cells, one-unit fats (monoglycerides) are resynthesized into triglycerides. The enzymes that assist in the resynthesis prefer to incorporate long-chain fatty acids (those with 12 to 18 carbons) into the newly synthesized triglycerides. The short- (four carbons) and medium- (six to 10 carbons) chain fatty acids will be unchanged as they pass through the mucosal cell. The majority of dietary triglycerides are long-chained fatty acids (usually 16 to 18 carbons); thus, the majority of fat eaten is broken down and then reincorporated into triglycerides by the mucosal cells. The newly synthesized triglyceride then becomes part of a large protein and fat molecule known as a **chylomicron.** A chylomicron is one example of a **lipoprotein.** Lipoproteins transport fat throughout the body. Cholesterol and the partially digested phospholipids also become part of the chylomicron. The chylomicrons and the short- and medium-chain fatty acids are then ready to be transported out of the mucosal cells of the intestine.

TRANSPORTATION OF FATS

To understand how fats are transported, one must understand the body's main transport fluids: blood and **lymph.** Blood consists of water, red and white blood cells, and many other constituents, including oxygen and nutrients. Blood enters tissues through arteries, leaves tissues through veins, and circulates within the tissues via the capillaries. Some components of blood are filtered out of the capillaries into the spaces of the tissue. This fluid is known as **interstitial fluid.** Most of the interstitial fluid is returned to the capillaries but some is not. That which is not returned is referred to as lymph. Lymph consists of white blood cells (which play an important role in immune function), proteins, fats, and other compounds. Lymph moves through its own set of vessels (the lymphatic system) that are separate from capillaries. Eventually, the lymph and blood vessels are joined near the heart.

The chylomicrons formed in the mucosal cells will be released slowly into lymphatic vessels. The release of the chylomicrons is an intentionally slow process that prevents a sudden increase in fat-containing compounds in the blood. Blood lipid (fat) levels are usually highest about three hours after fat consumption, but it may take as long as six hours for the dietary fat to be transported into the blood. The short- and medium-chain fatty acids in the mucosal cells that are not incorporated into chylomicrons will be released directly into the blood via the **portal** (liver) **vein,** where each will immediately be bound to a plasma protein, albumin.

The majority of the dietary fat consumed will have been incorporated into chylomicrons. This chapter will focus only on the transport and cellular absorption of the triglycerides contained in the chylomicrons, although fatty acids that are attached to albumin are absorbed in a similar manner. The transport and cellular absorption of the cholesterol found in the chylomicrons are more complicated and an explanation is included in the discussion of the development of **atherosclerosis** in Chapter 12.

The chylomicrons circulate through all the tissues, but adipose, muscle, and liver tissues play very important roles in fat metabolism. The triglyceride portion of the chylomicron can be absorbed by adipose and muscle cells. As the chylomicron circulates in the blood, it comes in contact with **lipoprotein lipase** (LPL), an enzyme. LPL is found on the surface of small blood vessels and capillaries within the adipose and muscle tissues. This enzyme stimulates the release of the fatty acids from the triglyceride, which are then rapidly absorbed by the fat and muscle cells.

The absorption of fatty acids into the fat and muscle cells is of great importance to the athlete and will be the focus of the metabolism section that follows. However, the liver also plays a substantial role that deserves mention here. In the liver, the triglyceride portion of the chylomicron is broken down and becomes part of the fatty acid pool, which will provide the fatty acids for the lipoproteins that the liver manufactures. Recall that a chylomicron is one example of a lipoprotein. Chylomicrons transport dietary (exogenous) fat. Other lipoproteins transport endogenous fats, that is, fats that are manufactured in the body by liver and other tissues. The functions of these lipoproteins, which include **low-** and **high-density lipoproteins,** are explained further in Chapter 12.

Metabolism of Fats

Once fats are digested, absorbed, and circulated, they are stored in the body largely in the form of triglycerides. The main sites of fat storage in the body are adipose tissue (in **adipocytes** [fat cells]), liver, muscle (as intramuscular triglycerides), and to a small degree in the blood. As has been previously discussed in Chapter 3, fats are metabolized for energy through oxidative phosphorylation, the aerobic energy system. In order to be metabolized, fats must be removed from storage, transported to cells, and taken up into mitochondria. There they are oxidized via the Krebs cycle and ATP is produced via the electron transport chain.

FAT STORAGE

The process of triglyceride formation is called **esterification**. The enzyme lipoprotein lipase exists in the walls of the capillaries that **perfuse** fat cells. When this enzyme is activated, it results in the breakdown of circulating triglycerides from lipoproteins, freeing fatty acids for uptake into the fat cells. Once taken up into adipocytes, the fatty acids are re-formed into triglycerides for storage. The activity of LPL and the process of triglyceride formation are primarily stimulated by the hormone insulin. The pancreas secretes insulin in response to food consumption, particularly a meal containing carbohydrate. Therefore, in the hours after a meal (particularly a meal containing fat and carbohydrate), the body has the hormonal environment and the substrates that favor triglyceride formation and fat storage. An abundance of adipocytes can be found just beneath the skin **(subcutaneous fat)** and deep within the body surrounding the internal organs **(visceral fat).**

Muscle can also store fat, referred to as intramuscular triglycerides. Fat storage in muscle occurs primarily in muscle that is highly aerobic, for example, heart (myocardial) muscle and slow-twitch (Type I) skeletal muscle. LPL in the capillary walls in muscle initiates this process in the same way that it does in adipocytes. Circulating lipoproteins are stimulated to break down the triglycerides they contain and release the fatty acids. The fatty acids are then taken up by muscle cells and reassembled into triglycerides for storage.

Fats are an excellent storage form of energy for several reasons. Compared to carbohydrates and proteins, fats contain more than twice the number of kcal per unit of weight—9 kcal/g for fat versus 4 kcal/g each for carbohydrate and protein. Therefore, fats are a very "energy dense" nutrient. When carbohydrate is stored in the form of glycogen, approximately 2 g of water are stored along with every gram of glycogen, increasing the weight without increasing the energy content. Fat is anhydrous, meaning it does not have water associated with it, making it an even more efficient storage form of energy on a per unit weight basis.

The importance of fat as a storage form of energy can be seen in comparison to carbohydrate storage. As discussed in Chapter 4, an average-sized person stores approximately 500 g of carbohydrate in the form of muscle glycogen, liver glycogen, and blood glucose. At 4 kcal/g, these carbohydrate reserves can provide approximately 2,000 kcal of energy. To illustrate this point, assume that a runner could use purely carbohydrate as a fuel source during an endurance run. These carbohydrate reserves would be essentially depleted in about 1½ hours. This same athlete, however, has in excess of 100,000 kcal of energy stored as fat in adipocytes and as intramuscular triglycerides, enough energy to fuel more than 100 hours of running (assuming the runner could rely solely on fat metabolism).

FAT UTILIZATION IN METABOLISM

Fat is an excellent storage form of energy, and the metabolism of fat provides a high yield of ATP. However, there are a number of steps in the metabolism of fats that make the process complex and relatively slow. Fats must be mobilized from storage, transported to the appropriate tissues, taken up into those tissues, **translocated** (moved from one place to another) and taken up by mitochondria, and prepared for oxidation. At the onset of moderate-intensity, **steady-state** exercise,

Pancreatic lipase: An enzyme secreted by the pancreas that helps to break down large fatty acids.

Diglyceride: A two-unit fat, known technically as a diacylglycerol.

Diacylglycerol: A two-unit fat.

Monoglyceride: A one-unit fat, known technically as a monoacylglycerol.

Monoacylglycerol: A one-unit fat.

Chylomicron: A large protein and fat molecule that helps to transport fat.

Lipoprotein: A protein-based lipid (fat) transporter.

Lymph: A fluid containing mostly white blood cells.

Interstitial fluid: Fluid located between organs and systems. Not blood or lymph.

Portal vein: The vein that carries blood to the liver; usually refers to the vein from the intestine to the liver.

Atherosclerosis: Narrowing and hardening of the arteries.

Lipoprotein lipase: An enzyme that releases fatty acids from circulating triglycerides so the fatty acids can be absorbed by fat or muscle cells.

Low-density lipoprotein: A lipid carrier with an affinity to deposit cholesterol on the surface of arteries.

High-density lipoprotein: A lipid carrier with an affinity to remove cholesterol from the surface of arteries and transport it to the liver where the cholesterol can be metabolized.

Adipocytes: Cells that store fat.

Esterification: The process of forming a triglyceride (triacylglycerol) from a glycerol molecule and three fatty acids.

Perfuse: To spread a liquid (e.g., blood) into a tissue or organ.

Subcutaneous fat: Fat stored under the skin.

Visceral fat: Fat stored around major organs.

Translocation: Moving from one place to another.

Steady-state: Exercise or activity at an intensity that is unchanging for a period of time.

it may take 10–20 minutes for fat oxidation to reach its maximal rate of activity.

Fat Mobilization, Circulation, and Uptake. In order for fats to be used in metabolism, triglycerides must first be taken out of storage. Triglycerides stored in adipocytes are broken down into the component parts—glycerol and the fatty acid chains. This process of **lipolysis** is catalyzed by an enzyme found in fat cells, **hormone-sensitive lipase** (HSL). Hormone-sensitive lipase is stimulated by catecholamines (epinephrine and norepinephrine), growth hormone, glucocorticoids (cortisol), and thyroid-stimulating hormone (TSH), and is inhibited by insulin. Therefore, mobilization of stored fat is inhibited after meals have been consumed when insulin is high, and is encouraged during the post-absorptive state (the period from approximately three to four hours after eating until food is eaten again), fasting, starvation, and when stressed. Stress, such as exercise, stimulates the sympathetic nervous system, which releases epinephrine and glucocorticoids such as cortisol from the adrenal glands, and growth hormone from the anterior pituitary gland into the blood. These hormones then interact with fat cells to promote lipolysis. Norepinephrine is released by nerve endings of sympathetic nervous system cells and also contributes to the activation of HSL and the mobilization of fat.

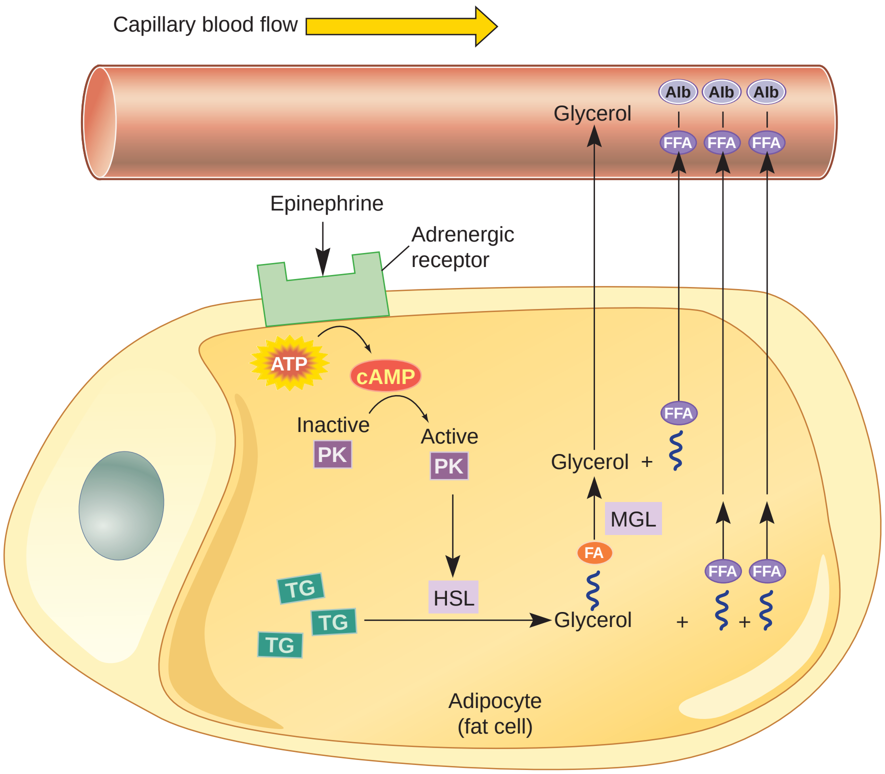
Following lipolysis, the fatty acid chains and glycerol circulate in the blood. Glycerol, a sugar alcohol, is water soluble and is easily carried in the blood. The liver contains the enzymes necessary to metabolize glycerol, so the liver takes up most of the glycerol that enters the circulation. There it can be converted to glucose via **gluconeogenesis** or eventually reassembled into triglycerides. The fatty acid chains liberated in lipolysis are not water soluble, however, and must be attached to a carrier to be transported in the blood. The carrier is typically a plasma protein, the most common of which is albumin. When mobilized and circulated, these fatty acid chains are often referred to as free fatty acids (FFA), which is somewhat of a misnomer, as very few of them exist "free" in the circulation. Transport in the blood by albumin is crucial to the metabolism of fat. Disruption of the ability of albumin to transport fatty acids impairs fat metabolism, particularly during higher-intensity exercise, and will be discussed later in the chapter. The mobilization and transport of stored triglyceride is illustrated in Figure 6.8.

Once in the blood, fatty acids can be distributed to other tissues throughout the body for use in metabolism. A key element for the utilization of fat as a fuel is the delivery of adequate amounts of fatty acids to the tissue. Some fat-utilizing tissues have a greater number of receptor sites and transport mechanisms embedded in the cell wall that are unique for fatty acids and facilitate the movement of fatty acids from the blood into the cells. For example, heart muscle cells have a higher capacity for fat utilization than slow-twitch muscle fibers, which in turn have a higher capacity than fast-twitch muscle fibers. Certain tissues also have a more extensive network of capillaries that allow a more effective delivery of fatty acids, and therefore enhanced fat oxidation. Examples again include heart muscle and slow-twitch muscle fibers, particularly compared to fast-twitch muscle fibers, which have a less dense capillary network.

Activation and Translocation Within the Cell. After mobilization, circulation, and uptake into the cells, the fatty acids must go through an activation step before being transported into the mitochondria. Similar to the beginning of glycolysis where two ATP are used in the first three steps to initiate the process, one ATP is used along with coenzyme A (CoA) to convert the fatty acid chain to a compound called fatty acyl-CoA, and one ATP is used to ensure that the reaction is irreversible. This process takes place in the outer mitochondrial membrane prior to the translocation of the fatty acid into the mitochondrial matrix. As with the beginning steps of glycolysis, this initial investment of energy is recouped by the subsequent production of ATP.

Once the fatty acid chain has been converted to fatty acyl-CoA in the mitochondrial membrane, it must be transported into the mitochondria where it goes through the process of β-oxidation and is eventually metabolized aerobically. Fatty acyl-CoA is translocated into the mitochondria by a carnitine transport mechanism, catalyzed by a group of enzymes, known collectively as carnitine acyl transferases (e.g., CAT I and CAT II). This process involves removing the CoA, translocating the long fatty acid chain that is attached to carnitine into the mitochondria, then removing the carnitine and replacing the CoA (see Figure 6.9). Each fatty acid chain has a specific carnitine acyl transferase. Palmitate, for example, is translocated into the mitochondria through the use of carnitine palmitate transferase (CPT1). Because this important transportation step involves carnitine, one approach that has been used to attempt to increase fat metabolism to improve endurance exercise performance has been the use of dietary carnitine supplements, which are discussed later in the chapter.

Because fatty acids are ultimately metabolized inside mitochondria, translocating the fatty acids into the mitochondria is a critical and potentially limiting step. Cells that have a large number of and large-sized mitochondria, such as slow-twitch muscle fibers, have an increased capacity to take up and metabolize fat. Athletes with a genetic disposition for a greater number of slow-twitch muscle fibers have an increased ability to metabolize fat. Regular endurance exercise training also results in an increase in the number and size of mitochondria in the trained muscles, which further enhances an athlete's ability to metabolize fat.



Alb = albumin | HSL = hormone sensitive lipase | FFA = free fatty acid
cAMP = cyclic AMP | TG = triglyceride (triacylglycerol) | MGL = monoacylglycerol lipase
PK = protein kinase | FA = fatty acid | ATP = adenosine triphosphate

Figure 6.8 Mobilization and Transportation of Stored Triglyceride

Within an adipocyte, hormone-sensitive lipase will break down a stored triglyceride into glycerol and three fatty acids, which diffuse into the capillary circulation. The fatty acids are bound to albumin for transport. This process is initiated with the stimulation of adrenergic receptors on the cell membrane by stress hormones such as epinephrine and norepinephrine.

Beta Oxidation. There is an additional series of steps that must be completed before fatty acids can be metabolized to produce ATP—beta oxidation. Beta oxidation is a series of four chemical steps during which two-carbon segments are cleaved off the fatty acid chain, and converted to acetyl CoA. In a fatty acid chain, the first carbon is labeled alpha (α) and the second is labeled beta (β)—the carbons are clipped off the chain at the location of the second carbon, therefore the name β oxidation. Once the two-carbon segment has been converted to acetyl CoA it can enter the Krebs cycle as previously explained in Chapter 3. Each acetyl CoA that is derived from a fatty acid chain can be oxidized to eventually form 12 ATP. Each fatty acid that is metabolized contains an even number of carbons, so a series of acetyl CoA can be formed by β oxidation. The final two carbons of the fatty acid chain are already formed as acetyl CoA, so they do not have to go through the process of β oxidation and can proceed directly to the Krebs cycle. In addition to forming acetyl CoA that can be oxidized, the process of β oxidation involves two oxidation-reduction reactions, during which one NAD (nicotinamide adenine dinucleotide) and one FAD (flavin adenine dinucleotide) pick up electrons that can be shuttled through the electron transport chain to produce ATP. A detailed figure of β oxidation can be found in Appendix K.

The value of fat metabolism can be seen in the number of acetyl CoA that are formed and oxidized, leading to a very large number of ATP produced. Palmitate, a 16-carbon fatty acid, is used as an example. Metabolism of palmitate results in a total of eight acetyl CoA available for oxidation. After accounting for the ATP utilized in the activation steps, the complete oxidation of the acetyl CoA, and the additional electrons from β oxidation, the final ATP production from the complete

Lipolysis: The breakdown of a triglyceride (triacylglycerol) releasing a glycerol molecule and three fatty acids.

Hormone-sensitive lipase: An enzyme found in fat cells that helps to mobilize the fat stored there.

Gluconeogenesis: The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

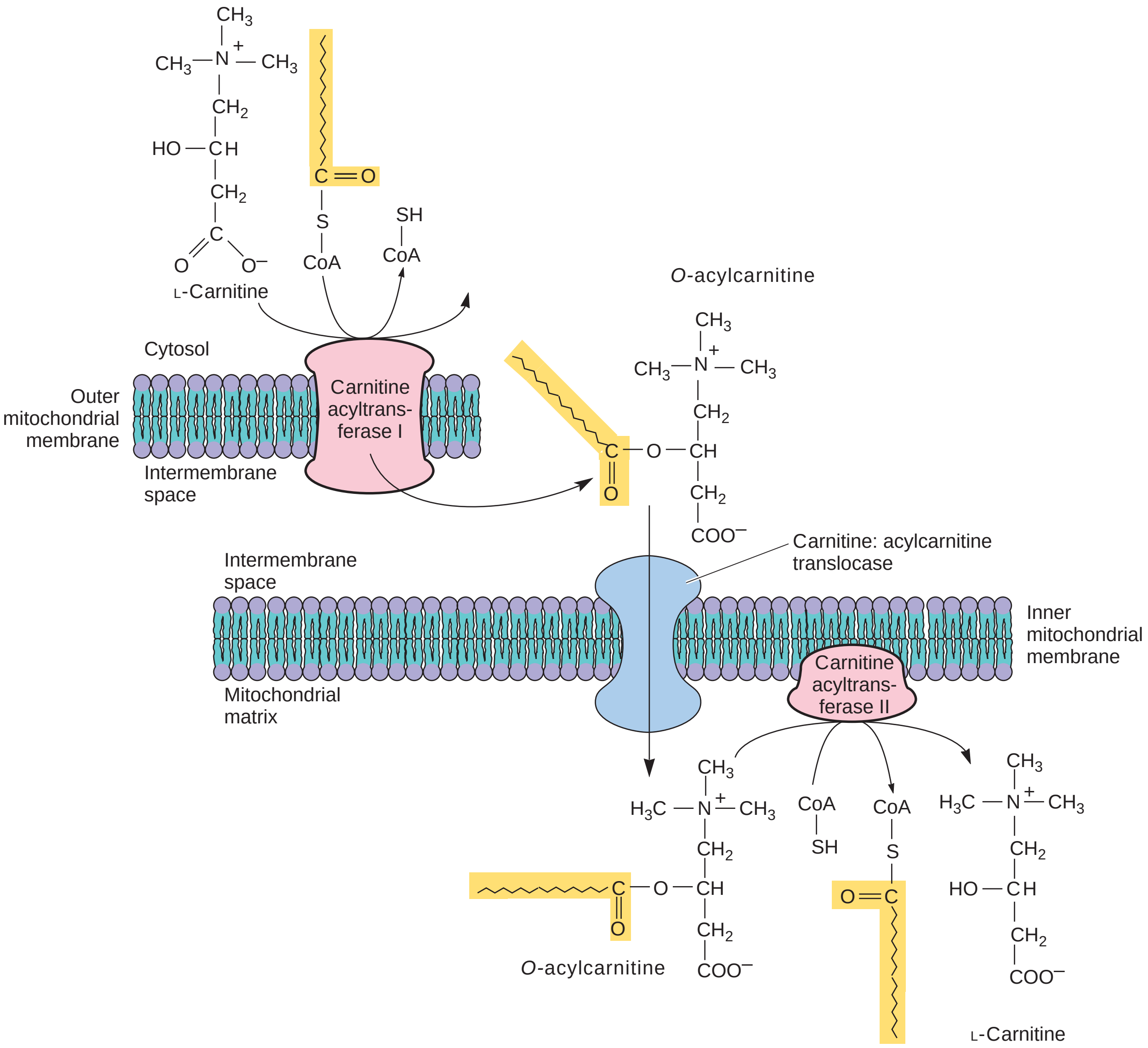


Figure 6.9 Mitochondrial Transfer of Fatty Acyl-CoA

In the outer mitochondrial membrane, the CoA of fatty acyl-CoA is removed and joined to carnitine via carnitine acyltransferase. The acylcarnitine is then translocated into the mitochondria where the fatty acid is separated from the carnitine and is rejoined with a CoA.

metabolism of palmitate is 129 ATP. When compared to the two ATP obtained from glucose by anaerobic glycolysis or even the 36 ATP from glucose by aerobic metabolism, fat metabolism has a substantial advantage in the provision of energy. The major disadvantages of fat metabolism are the numerous steps involved and the necessity to consume additional oxygen.

Ketosis. Fat is primarily metabolized as described above, but acetyl CoA may also be catabolized to produce ketone bodies—acetoacetate, β-hydroxybutyrate, and acetone. This is a normal metabolic pathway that is sometimes referred to as an "overflow" pathway. It is estimated that the liver can produce as much as 185 g of ketones daily and that after an overnight fast ketones supply ~2 to 6 percent of the body's total energy needs. The normal blood ketone concentration is less than 0.05 mmol/L, with the highest concentration being present after an overnight fast. The normal urine ketone concentration is typically zero (VanItallie and Nufert, 2003).

Ketone production is increased when fatty acid oxidation is accelerated. This can occur when carbohydrate intake is low due to self-restriction or involuntary starvation. It can also occur when carbohydrate metabolism is impaired, which is the case for those with diabetes mellitus. For medical purposes, ketosis is defined as an abnormal increase in ketone bodies or a blood ketone concentration >0.06 mmol/L. In someone with diabetes, ketosis is a potentially dangerous complication because it can result in ketoacidosis, a condition in which the pH of the blood is more acidic than the body tissues. Ketoacidosis can result in diabetic coma and death. However, ketosis in those without diabetes rarely leads to ketoacidosis. In discussions of ketosis it is very important to distinguish between individuals that have diabetes and those that do not have diabetes.

To understand how ketones are formed, a brief review of carbohydrate metabolism is needed (see Chapter 4 for details). Glycolysis is the process that converts glucose to pyruvate. Pyruvate is transported into the mitochondria where it is metabolized to acetyl CoA. Acetyl CoA joins with oxaloacetate, the first step in the Krebs Cycle. With a low carbohydrate intake, the body must find other sources of acetyl CoA, namely fatty acids and some amino acids. As more fatty acids are broken down to provide acetyl CoA, it begins to accumulate because of a low supply of oxaloacetate. In response to the accumulating acetyl CoA, ketone bodies are produced. The ketones become especially important as a source of energy for the brain because its usual energy source, glucose, is declining and fatty acids cannot cross the blood-brain barrier.

In the first two to three days of carbohydrate and energy restriction, the body produces glucose from alternative sources, such as lactate and amino acids provided by muscle. At this point, approximately two-thirds of the fuel used by the brain is glucose with the remaining one-third provided by ketones. Sustaining this alternative metabolic pathway would be untenable because too much muscle protein would need to be degraded to provide fuel for the central nervous system. As carbohydrate and energy restriction continues past a few days (referred to as starvation), more metabolic adaptations take place. Glucose will be primarily manufactured from glycerol (obtained from the breakdown of fatty acids) and ketones will become the primary source of fuel for the brain. After six weeks of starvation, about 70 percent of the brain's energy sources will be ketones, with less than 30 percent provided by glucose (Gropper et al., 2005).

Starvation also produces changes in skeletal muscle. Restricted carbohydrate intake results in the muscle cells using a fuel source other than glucose, which is now in short supply since muscle glycogen has been depleted and dietary carbohydrate is not providing glucose for glycogen resynthesis.

A low-carbohydrate, calorie-restricted diet that results in ketosis is one popular method for weight loss used by overweight and obese individuals (see Chapter 12). Athletes may wonder if such a diet plan is appropriate for them. Ketosis is a result of both restricted energy (caloric) and carbohydrate intakes, dietary manipulations that would likely have a negative effect on an athlete's training. Some loss of muscle protein would occur, although a high dietary protein intake may help to **attenuate** muscle degradation. While ketosis in a nondiabetic athlete will not likely result in ketoacidosis, the disadvantages (e.g., low glycogen stores, inability to sustain training and/or train at higher intensities) seem to outweigh the advantages (e.g., loss of weight as fat) when viewed from the perspective of optimal performance.

What's the point? Fats are complicated to absorb, transport, and metabolize. When compared to carbohydrates, fats yield a large amount of ATP via aerobic metabolism, but additional oxygen is needed.

Fats as a Source of Energy During Exercise

Fat is an important fuel source for energy production at rest and during exercise. As mentioned in previous chapters, carbohydrate and fat are the two major fuel sources, with protein playing a much smaller role. The degree to which either of these fuel sources may contribute to the body's energy needs is dependent upon a variety of factors that will be discussed in this section, with an emphasis on the factors that influence fat oxidation (Jeukendrup, Saris, and Wagenmakers, 1998a,b).

The use of fat as a fuel has a number of important advantages: Fat is abundant in the food supply, energy dense (high caloric content on a per unit weight basis), stored in substantial amounts in adipose tissue, and when metabolized, provides a large number of ATP. Disadvantages, however, include the many steps and the time involved in metabolizing fat. In addition, it should be recalled that fat can only be used in aerobic metabolism. Its use as a fuel is therefore limited to activities and exercise that can be supported by oxidative phosphorylation (e.g., low to moderate intensity). This is in contrast to carbohydrate metabolism—glucose and glycogen can either be metabolized via oxidative phosphorylation or used anaerobically through anaerobic glycolysis to support higher-intensity activities. As shown in the example with palmitate, the complete metabolism of one molecule of a fatty acid results in the rephosphorylation of a large number of ATP compared to the metabolism of glucose. The metabolism of fatty acids requires significantly more oxygen, however. When the ATP yield is analyzed relative to the amount of oxygen consumed, fat metabolism is less efficient than carbohydrate because it requires more oxygen for each ATP replenished.

RELATIVE AND ABSOLUTE FAT OXIDATION

To understand the use of fat as a fuel at rest and during exercise, it is important to understand how the utilization of this fuel is determined and expressed. Recall

Attenuate: To reduce the size or strength of.

Table 6.1 Energy Expenditure and Fuel Utilization

Run Pace (min/mile)	Heart Rate (bpm)	RER	Percent Energy from Fat	Percent Energy from CHO	Total Energy Expenditure (kcal/min)	Fat (kcal/min)	CHO (kcal/min)
Rest	72	0.77	78.2	21.8	1.4	1.1	0.3
9:30	127	0.88	40.8	59.2	11.5	4.7	6.8
9:00	138	0.89	37.4	62.6	13.4	5.0	8.4
8:30	144	0.91	30.6	69.4	14.2	4.4	9.8
8:00	153	0.92	27.2	72.8	15.3	4.2	11.1

Heart rate, RER, and relative and absolute energy expenditure from fat and carbohydrate at rest and at four different running paces for a 49-year-old male marathon runner.

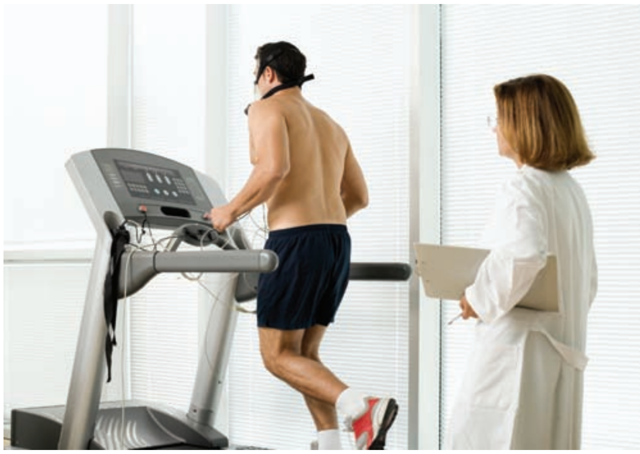
Legend: min = minutes; bpm = beats per minute; RER = respiratory exchange ratio; CHO = carbohydrate; kcal = kilocalories

from Chapter 3 that the most common way of determining fuel utilization during aerobic exercise or activity is through indirect calorimetry and the use of the respiratory exchange ratio (RER). The RER is the ratio of carbon dioxide produced to the amount of oxygen consumed. Metabolism of carbohydrate requires the utilization of an amount of oxygen equal to the amount of carbon dioxide produced to give a higher RER, approaching or equal to 1.0. Because oxidation of fat requires a larger consumption of oxygen than the carbon dioxide produced, the RER during fat metabolism is lower, approaching 0.70.

The respiratory exchange ratio that is determined during a steady-state aerobic activity gives an indication of the percentage of the energy expenditure that is derived from fat oxidation relative to the percentage derived from carbohydrate oxidation. This is an expression of the fuel sources in a relative fashion, as a percentage of the total energy expenditure. Because only nonprotein sources of fuel are typically considered, fat and carbohydrate can be expressed as a percentage relative to the other. Sometimes it is important to know the percentage of energy expenditure provided by fat and carbohydrate oxidation (see case study below).

The expression of fuel utilization in a relative fashion is useful, but does not provide any information about the actual amount of energy being expended; in other words, the total amount of energy that is being provided by fat and carbohydrate. An expression of the total amount of energy expenditure is termed absolute. A common way of expressing energy expenditure is the use of rate, the number of kilocalories (kcal) expended each minute (min).

If one knows both the absolute energy expenditure (kcal/min) and the relative contribution of each fuel (percentage from fat and carbohydrate), the absolute caloric expenditure (kcal/min) from fat and carbohydrate can be determined. The case study presented here will illustrate a number of important concepts about



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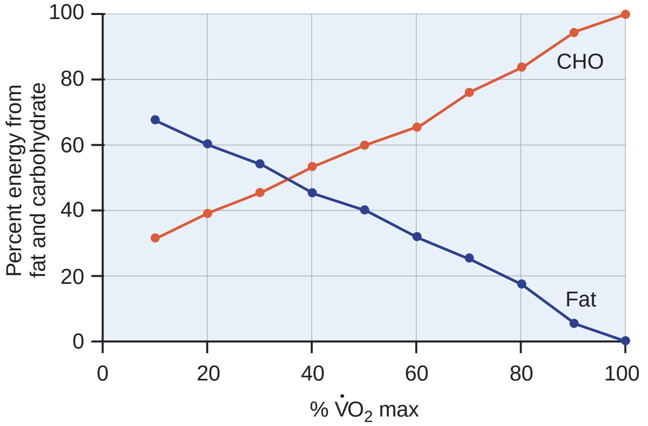
Energy expenditure and fuel utilization during running can be measured.

fat metabolism during exercise and the relationship of fat and carbohydrate as fuel sources.

Consider the case of a 49-year-old male who is in the process of training for his first marathon to celebrate his 50th birthday. He had some previous recreational running experience and had run several 10-kilometer races and two half-marathons. At 5′6″ (168 cm) and 182 lb (82.5 kg), he realizes that losing weight and body fat will help him accomplish his goal of running a marathon. He participated in an indirect calorimetry study at rest and while running on a treadmill to learn more about his energy expenditure and fuel utilization at different running paces (see Table 6.1).

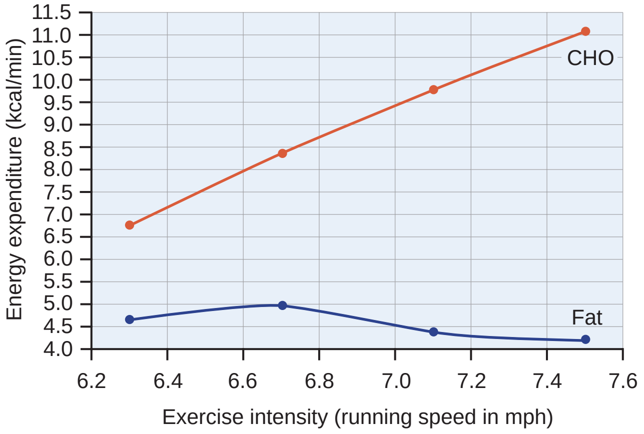
First, observe the results from the metabolic study at rest. Heart rate is low (72 bpm), RER is low (0.77), and total energy expenditure is low (1.4 kcal/min). The low RER indicates that a large proportion (78.2 percent) of energy at rest is provided by fat oxidation, and a relatively small percentage (21.8 percent) is provided by metabolizing carbohydrate. Of the total energy



CHO = carbohydrate
$\dot{V}O_2$max = maximum oxygen consumption

Figure 6.10 Percentage of Fat and Carbohydrate Used as Exercise Intensity Increases

As exercise intensity increases (as a percentage of $\dot{V}O_{2max}$), the percentage of energy provided by fat metabolism decreases and the percentage of energy from carbohydrate metabolism increases.



CHO = carbohydrate
kcal/min = kilocalories per minute
mph = miles per hour

Figure 6.11 Absolute Fat and Carbohydrate Oxidation

Absolute energy expenditure from carbohydrate oxidation increases as exercise intensity increases and is higher than fat oxidation at all running paces. Absolute fat oxidation increases as the exercise intensity increases from a running speed of 6.3 to 6.7 mph, but then declines as the exercise intensity continues to increase.

expenditure of 1.4 kcal/min, 1.1 kcal/min is provided by fat. This is a typical metabolic response at rest, particularly if it has been several hours since the last meal—long enough for any food to be completely digested and absorbed (i.e., postabsorptive state).

Fat Oxidation During Exercise. Next, observe the metabolic response when he begins running at a steady pace of 9 minutes and 30 seconds (9:30) per mile, a modest exercise intensity for this athlete. As one would expect, heart rate increases above resting (127 bpm) and total energy expenditure increases substantially to 11.5 kcal/min. In other words, he burns 11.5 kcal every minute he runs at this pace. The RER rises to 0.88, indicating the percentage of energy derived from fat has dropped to 40.8 percent while that provided by carbohydrate has increased to 59.2 percent. Even at this fairly modest exercise intensity, fat is no longer the predominate source of energy for running. However, even though the percentage of energy from fat has declined, the absolute number of kcal from fat metabolism has increased dramatically over what was seen at rest. This makes perfect sense—although the percentage is less (40.8 percent compared to 78.2 percent at rest), it is a smaller percentage of a much larger number—the total energy expenditure has increased 10-fold, from 1.1 kcal/min at rest to 11.5 kcal/min during exercise.

Finally, observe the metabolic response as exercise intensity continues to increase as the running pace gets faster, to 9:00, 8:30, and finally 8:00 minutes per mile. Again as expected with increasing exercise intensity, the heart rate increases and the total energy expenditure increases. The RER also increases with each successive increase in exercise intensity, indicating a continuing decline in the percentage of energy that is supplied by fat metabolism and a continuing increase in that provided by carbohydrate metabolism. The pattern of response is also illustrated in Figure 6.10. There is a point in exercise intensity when carbohydrate increases and becomes the predominant source of energy and the utilization of fat declines to a lesser percentage. This point has been described as the "crossover concept" by Brooks, Fahey, and Baldwin (2005).

The *relative* expression of fuel utilization only provides a portion of the true picture, however. To complete the story, one must examine the *absolute* energy expenditure from fat and carbohydrate. As the running pace increases from 9:30 to 9:00 minutes per mile, there is an increase in absolute fat oxidation, from 4.7 to 5.0 kcal/min (see Table 6.1). Even though the percentage of energy from fat has declined, the larger total energy expenditure indicates that the total absolute amount of fat being metabolized each minute has actually increased. There is a maximum point of absolute fat oxidation, however, and as speed continues to increase beyond this point the absolute amount of fat metabolism goes down (in this case, from 5.0 to 4.4 then 4.2 kcal/min) along with a consistent decline in the percentage of energy derived from fat. The patterns of response of absolute fat and carbohydrate oxidation by the marathon runner to increasing exercise intensity are shown in Figure 6.11.

If fat is such a good energy source, why does fat metabolism decline as exercise intensity increases?

Again, understand that there is an initial increase in absolute fat oxidation with lower-intensity exercise. The body responds to the exercise by stimulating lipolysis through sympathetic nervous system stimulation of hormones such as epinephrine, norepinephrine, and growth hormone. The free fatty acids that are mobilized are delivered to exercising muscle fibers by the increase in blood flow that occurs with exercise activity. Increases in oxygen consumption by muscle are made possible by increases in breathing and circulation of oxygen-laden blood to the exercising muscle, so aerobic metabolism increases, including an increase in fat oxidation.

As exercise intensity continues to increase, however, a number of changes occur that may reduce the body's ability to metabolize fat. Increased exercise intensity means an increased reliance on fast-twitch muscle fibers. These fibers rely more on anaerobic energy systems, particularly anaerobic glycolysis, and have a relatively poor ability to oxidize fat. As these fibers use anaerobic glycolysis, they produce lactate. Lactate in the blood is known to inhibit the ability of the plasma protein albumin to bind and carry free fatty acids in the blood. Without this carrier mechanism available to transport the fatty acids, they essentially become "stuck" in the fat cells, unable to be transported anywhere else in the body. In addition, when the exercise intensity is higher, a successively larger proportion of the body's blood flow is diverted to exercising muscle, and may not be as available to circulate through adipose tissue to pick up fatty acids. Because fat oxidation requires greater oxygen consumption than carbohydrate oxidation to produce the same number of ATP, it is more energetically efficient to oxidize carbohydrate under conditions when oxygen consumption is very high, that is, during higher-intensity exercise.

Fat Oxidation During Prolonged Steady-State Exercise. The subject in this case study had a goal to run a marathon, a prolonged distance run of 26.2 miles. The data from the metabolic study show what happens to energy expenditure and fuel utilization if the athlete runs at different intensities, but what metabolic response occurs when he runs at a steady pace for several hours? This runner did indeed complete a marathon in celebration of his 50th birthday. His final time for the marathon was 3 h, 55 min, 48 seconds, an average pace of 9:00 minutes per mile. Reviewing the metabolic study data, at a pace of 9:00 minutes per mile this runner was obtaining approximately 37.4 percent of his energy from fat metabolism and 62.6 percent from carbohydrates. As a runner continues to exercise for a prolonged period of time, however, carbohydrate stores are reduced significantly, eventually leading to muscle glycogen depletion. As the available carbohydrate stores are diminished, the body has no choice but to rely more on fat oxidation. Therefore, a very common metabolic response to prolonged

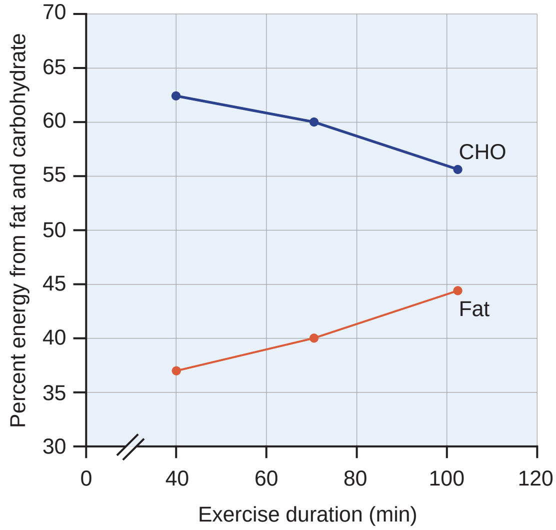


Figure 6.12 Percentage of Fat and Carbohydrate Used as Exercise Duration Increases

As steady-state exercise continues for a prolonged period of time, the percentage of energy derived from fat may increase slightly as the percentage of energy derived from carbohydrate oxidation declines.

exercise is a slight, gradual rise in the RER, indicating a reduced reliance on carbohydrate and an increased dependence on fat oxidation. This metabolic response to exercise duration is illustrated in Figure 6.12.

Do You Have to Burn Fat to Lose Fat? Like many people, the subject of this case study wanted to lose body fat by exercising. Because fat can be used as a fuel source during exercise, it seems logical to focus on fat "burning" as a primary way to reduce the body's fat stores. This idea has unfortunately led to erroneous recommendations by some people in the fitness industry. A common recommendation is to exercise at a "fat-burning" intensity. Commercial exercise equipment such as treadmills even come programmed with "fat-burning zones." This recommendation to "burn fat to lose fat" is faulty on at least two levels.

The recommended "fat-burning zone" is typically lower-intensity aerobic exercise, with the rationale that people burn more fat at lower exercise intensities. It is true that RER is typically lower during lower-intensity exercise (see Table 6.1), but this only indicates that fat burning is higher *as a percentage of the total energy expenditure*. If having the highest possible *percentage* of fat burning were the key factor in losing body fat, the best strategy would be to lie on the couch all day! A person typically has the lowest RER and highest *percentage* of fat utilization when they are at rest. The marathon runner in the case study was getting nearly 80 percent of his energy from fat metabolism while resting, but total energy expenditure (1.4 kcal/min) and the absolute number of fat calories (1.1 kcal/min) being burned were very low.

To find the exercise intensity that results in the highest *amount* of fat being burned, look again at the metabolic study of the marathon runner. The highest rate of absolute fat oxidation (5 kcal/min) was reached at a running pace of 9:00 min/mile, even though as a percentage, the relative contribution of fat had dropped to approximately 37 percent. If this subject runs for an hour at this pace, he would burn 804 kcal, 300 kcal of which are from fat. If he runs for an hour at a lower intensity (e.g., slows down to 9:30 minutes per mile) he would burn only 690 kcal, 282 kcal of which are from fat. It is clear that a low exercise intensity does not necessarily result in a greater amount of "fat burning."

The second level of faulty reasoning behind these recommendations is based on the incorrect assumption that in order to lose body fat, a person must burn fat *during* exercise. Casual observation of athletes such as sprinters, weight lifters, and bodybuilders reveals that these athletes can be very lean with low levels of body fat, yet their exercise activities are very high intensity, relying mostly on anaerobic energy systems during which very little fat is utilized. Research studies, such as that by Grediagin et al. (1995), demonstrate the most important factor in weight and fat loss is total caloric expenditure, not exercise intensity or the source of the fuel used during exercise. In this study half of the subjects exercised at a lower intensity, but the duration of the exercise was increased to equal the total amount of kcal expended by the other half of the subjects that exercised at a higher intensity. Both groups lost weight and both lost an identical amount of body fat. If exercise time (duration) is limited, the most appropriate strategy for weight/fat loss is to not worry about the source of the fuel, but to exercise in a way that maximizes caloric expenditure during the allotted time.

Returning to the example of the marathon runner, if he were to increase his running pace from 9:00 to 8:00 min/mile for his one-hour run, he would expend 918 kcal instead of 804 kcal. The number of kcal expended from fat would decline from 300 to 250, but the total energy expenditure during the same amount of time is over 100 kcal greater. To summarize and answer the question—Do you have to burn fat to lose fat?—no, you do not need to burn fat during a short-term exercise session to accomplish long-term body fat loss.

EFFECTS OF TRAINING ON FAT USAGE

Endurance exercise training results in an enhanced ability to oxidize fat. This is potentially advantageous to endurance athletes—if they can rely more on fat metabolism during an endurance event they may be able to "spare" the body's limited carbohydrate stores (i.e., muscle glycogen) for use later in the event and improve their performance.

The regular stimulus of chronic exercise training taxes the oxidative phosphorylation energy system and the oxidative pathways of fat and carbohydrate metabolism. Over time a number of physiological adaptations occur that enhance the body's fat oxidation capability. Fatty acids are mobilized from adipocytes more easily and are taken up into muscle cells more readily. Cardiovascular adaptations include an increase in the capillary network in muscle, which allows for an enhanced delivery of fatty acids. One of the most important adaptations to endurance training that aids fat oxidation is an increase in mitochondrial mass in the muscle due to an increase in both the number and size of these important oxidative organelles. Mitochondrial mass can double in response to endurance training and results in an overall increase in activity of oxidative enzymes, once again enhancing the body's ability to metabolize fat.

The enhanced ability to metabolize fat during exercise can be seen at the same absolute exercise intensity and to a lesser degree at the same exercise intensity relative to the athlete's maximum. In other words, an athlete running at the exact same pace after months of training will be able to oxidize more fat due to the increase in fat oxidation capability. This is the same absolute exercise intensity, but because the athlete's maximal exercise capacity has increased, it now represents a lower percentage of his or her maximum. For example, if a 9:00 min/mile running pace was 75 percent of the runner's $\dot{V}O_{2max}$ before training, it may now be only 65 percent of the new, higher $\dot{V}O_{2max}$. To a certain degree, the ability to oxidize fat increases at the same relative exercise intensity in response to endurance training. If this runner increases the running pace to the point that it represents 75 percent of the new, higher $\dot{V}O_{2max}$, fat oxidation will be slightly higher after training than at the same percentage of maximum before training. This increased ability to metabolize fat during exercise may be beneficial to the endurance athlete during training and during some periods of lesser effort during competition; however, during a competitive event the intensity of exercise at "race pace" means that the predominant fuel source will be carbohydrate.

High-Fat Diets/Fat Loading. Long-term consumption of a diet that is high in fat will result in a metabolic adaptation to favor fat oxidation at rest and during exercise of certain intensities. As a strategy to increase fat metabolism and potentially spare carbohydrate usage, the use of high-fat diets has been studied to determine if endurance performance can be improved.

The study of Phinney et al. (1983) is often referenced in support of this strategy. In this study a group of cyclists were fed a high-fat ketogenic diet for four weeks that provided less than 20 g of carbohydrate each day. Endurance ability was tested before and after the high-fat diet period by having the cyclists ride as long as they could on a cycle ergometer in the lab at an intensity of approximately 60 percent of $\dot{V}O_{2max}$. The RER was significantly lower, indicating an enhancement in fat oxidation, and the "ride-to-exhaustion" time was four minutes longer on average after a month on the high-fat diet. The results of this study are sometimes used erroneously to suggest high-fat diets improve performance, although the four-minute difference was not statistically significant. This study is also sometimes used to suggest that adaptation to a high-fat diet at least does not hurt endurance performance. However, this study used a small sample size, only five cyclists, and in the post-test of endurance only three of the subjects increased their endurance time while two decreased their time. Most relevant to the question of performance for the endurance athlete was the intensity of the performance task. The cyclists were asked to ride at a relatively low percentage of their maximum for as long as they could—a measure of endurance time that fails to mimic the demands of an endurance event. The exercise intensity was also one that was far below that of an athlete actually competing in an endurance race event.

Subsequent research studies (Carey et al., 2001) and reviews (Helge, 2000) show that consumption of a high-fat diet can indeed alter the metabolic response at rest and during light- to moderate-intensity exercise in favor of fat oxidation. However, there does not appear to be any practical benefit when it comes to endurance performance.

Effect of Caffeine on Fat Usage. Some endurance athletes use caffeine to enhance performance. The rationale for its use is based on the fact that caffeine enhances free fatty acid utilization during endurance exercise and therefore theoretically reduces muscle glycogen usage. In other words, caffeine is purported to have a glycogen-sparing effect. In long endurance events, such as marathons or triathlons, low muscle glycogen levels are associated with fatigue and negatively affect performance; it would be advantageous to spare glycogen and prevent muscle glycogen levels from dropping too low.

To achieve the desired effect of elevating plasma free fatty acid levels, users must have a large amount of caffeine in their blood. The dose at which caffeine is effective is estimated to be 5 to 6 mg/kg body weight. For a 110-lb (50-kg) person, the recommended dose would be 250 to 300 mg of caffeine, equivalent to about 3 cups of strongly brewed coffee. This amount of caffeine could be consumed in a variety of ways, including the consumption of strongly brewed coffee, other caffeine-containing beverages, or caffeine-containing pills. The latter are widely used because they contain a known concentrated dose.

A review of the considerable research literature on the effects of caffeine ingestion on endurance performance reveals a consensus view that caffeine may be an effective ergogenic aid, but not for the metabolic rationale outlined above (Spriet, 1995). While caffeine may enhance free fatty acid mobilization above normal levels during endurance exercise, fat oxidation is not significantly increased, nor is muscle glycogen "spared."

The major ergogenic benefit of caffeine use may be more closely related to its role as a central nervous system stimulant. Caffeine's role in improvement in endurance athletic performance is associated with a heightened sense of awareness and a decreased perception of effort. People who are not habituated to using caffeine on a regular basis experience these benefits more readily.

The use of caffeine to improve performance is not limited to endurance athletes, as caffeine's stimulatory effects may also enhance strength performance. Some strength athletes use caffeine for the purpose of activating muscle fibers. Caffeine may have an effect on recruitment of muscle for exercise by reducing the motor unit recruitment threshold and enhancing nerve conduction velocity. It may also have direct effect on muscle by altering calcium release kinetics by the sarcoplasmic reticulum (Graham, 2001).

Caffeine is legal and socially acceptable throughout the world as a compound found in many beverages. At certain concentrations caffeine is a banned substance by some sports-governing bodies (e.g., National Collegiate Athletic Association [NCAA]). For example, in a postcompetition urine analysis, urinary caffeine levels exceeding 15 mcg/ml would subject an NCAA athlete to disqualification. However, such levels would be very difficult to reach via food or beverage intake (i.e., the equivalent of 6 to 8 cups of caffeinated coffee two to three hours prior to competition), and the equivalent amount of caffeine-containing tablets would likely impair performance in other ways (e.g., shaking, rapid heartbeat, nausea).

Caffeine is considered safe for use by most adults, although it has several known side effects. Blood pressure is increased both at rest and during exercise, heart rate is increased, gastrointestinal distress can occur, and insomnia may result. The side effects are more likely to occur in those people who are caffeine naïve (i.e., don't routinely consume caffeine). For routine users, caffeine is addictive and sudden withdrawal can result in severe headaches. To summarize, caffeine does elevate free fatty acid levels but caffeine's influence on endurance performance is due to its stimulatory effects and not its

What's the point? Fats are the predominant fuel source at rest and during lower-intensity exercise. As exercise intensity increases, the *absolute* amount of fat used increases then declines, but the *relative* amount decreases, because more carbohydrate is used than fat. Endurance training enhances the body's ability to use fat but caffeine does not. Caffeine's positive effect on endurance performance is due to central nervous system stimulation.

The Internet Café

Where do I find reliable information about fat metabolism and exercise?

Athletes who search for information about fat metabolism on the Internet will often be directed to commercial sites that are selling "fat-burning" supplements or weight loss diets. For those who wish to read research articles about fat metabolism, one of the most comprehensive resources is to search the biomedical journals indexed in Medline at **www.pubmed.gov.** Sports-governing bodies and sites directed towards coaches and athletes in particular sports may include information on fat metabolism that is written by experts. Some of these articles are well referenced. Consumers should check the scientific credentials of the authors of articles about the metabolism of fat.

effect on fat metabolism or usage. More information on caffeine is found in Chapters 7, 10 and 11.

FAT-RELATED DIETARY SUPPLEMENTS

Supplements that are involved in "fat burning" are marketed to both athletes and nonathletes. Some, such as carnitine, are associated with the oxidation of fatty acids, and are often marketed as ways to enhance the metabolism of fat. Others are specific types of fat, such as conjugated linoleic acid (CLA) and medium-chain triglycerides (MCT). Supplements sold as an adjunct to weight loss (e.g., advertised as "fat burning") typically contain stimulants, such as caffeine, guarana, and ephedrine. The supplements reviewed in this chapter, carnitine and MCT, are those that affect fat metabolism and performance; those that affect body fat loss are discussed in Chapter 11.

Carnitine. Carnitine is essential to transport fatty acids into the mitochondria where they can be broken down for energy. Whenever a substance is known to have a direct role in metabolism, an intriguing question is raised: Would a concentrated amount, such as that found in a supplement, enhance the normal metabolic process?

Carnitine is found in food and can be synthesized in the body from the amino acid lysine. Deficiencies have been reported in humans but they are rare. As would be expected, in carnitine-deficient individuals supplementation normalizes long-chain fatty acid metabolism. Healthy adults are not carnitine deficient and exercise does not result in the loss of carnitine in the muscle. Studies have shown that carnitine supplements do not increase the carnitine content of muscles, probably because the transport of carnitine into the muscle is well controlled and only very small amounts are needed for proper fatty acid metabolism (Brass, 2004; Muller et al., 2002).

Two small studies, one in healthy adults and one in athletes, concluded that fat oxidation was increased with carnitine supplementation (Muller et al., 2002; Cha et al., 2001). In the study of athletes, the supplement was ingested with caffeine so it is impossible to draw conclusions about a carnitine supplement without caffeine. A study of 36 moderately obese women who combined carnitine supplements with regular exercise showed no difference in weight loss or endurance (Villani et al., 2000). Volek et al. (2002) studied 10 healthy active men who supplemented carnitine for three weeks. This study reported statistically significant improvement in recovery from high-repetition squat exercises. At the present time, there is not enough evidence to suggest that carnitine supplementation is effective for increasing fat oxidation, improving performance, or inducing body fat loss. On the other hand, carnitine supplementation has not been shown to be detrimental to performance (Brass, 2004).

Carnitine supplements are sold in pill or liquid form. Supplement manufacturers recommend a dose of 2 to 4 g/day, which is the dose used in most scientific studies. Carnitine supplementation appears to be safe at these doses. As with most supplements, purity and potency is not assured.

Medium-Chain Triglycerides. As described earlier in the chapter, medium-chain triglycerides contain six to 10 carbon atoms. They are rapidly absorbed via the portal vein and are easily transported into the mitochondria. For these reasons, MCT are sometimes advertised as being an energy source that is as readily available as carbohydrate. It is important to know if the use of MCT by endurance athletes could increase fat oxidation during moderate- to high-intensity exercise, reduce reliance on muscle glycogen stores, or enhance performance (Hawley, 2002; Horowitz and Klein, 2000).

Several studies of well-trained endurance athletes have found that MCT ingestion does not alter fat metabolism, spare muscle glycogen, or improve performance (Goedecke et al., 2005; Misell et al., 2001; Horowitz et al., 2000; Angus et al., 2000). In fact, Goedecke et al. (2005) found that ingestion of MCT by ultraendurance cyclists compromised sprint performance—high-intensity, short-duration cycling bouts required as part of some ultraendurance competitions. The negative effect on sprint performance may have been due to gastrointestinal upset from the MCT solution. This is an example of a supplement that not only fails to improve performance but also may actually impair it.

Fat Recommendations for Athletes

The appropriate amount of dietary fat for the athlete will depend on two factors—overall energy (caloric) need and macronutrient balance. Recall that the four energy-containing nutrients are carbohydrate, fat, protein, and alcohol. While each nutrient can be considered separately, the relationships among them are also important. Typically only carbohydrate, fat, and protein are included in macronutrient balance discussions. Alcohol is usually not included in general recommendations for athletes because it contains no essential nutrients and many athletes cannot legally consume alcohol due to age restrictions.

RECOMMENDED TOTAL DAILY FAT INTAKE FOR ATHLETES IN TRAINING

To determine the amount of dietary fat required, one must also know how much carbohydrate, protein, and total energy (kcal) the athlete needs. This discussion assumes that the athlete is in energy balance. In other words, the athlete does not want to change body weight or composition and energy intake is equal to energy output. How much dietary fat does such an athlete need to consume?

In some respects this is a mathematical problem. Since the athlete wishes to remain in energy balance, the daily number of kcal needed to match energy expenditure must be determined. The amount of carbohydrate necessary to support the demands of the sport and the goals of the training cycle must be established. The daily protein goal is also important information. Once those figures are obtained, the amount of fat can be calculated. The recommended fat intake will be determined within the context of energy and macronutrient balance.

Emily, a 140-lb (~64 kg) elite 800-m runner, needs approximately 2,700 kcal (~42 kcal/kg) daily to maintain energy balance. To restore the glycogen used during her most demanding training mesocycle, she needs a carbohydrate intake of 7 g/kg (~445 g daily). Her goal for protein intake is 1.4 g/kg (~89 g daily). Together, carbohydrate and protein provide approximately 2,136 kcal. With an estimated total energy need of 2,700 kcal, fat needs to provide about 564 kcal or approximately 63 grams of fat daily.

The carbohydrate and protein recommendations are expressed on a gram per kilogram body weight basis (g/kg). In other words, carbohydrate and protein recommendations are stated as an absolute amount. They are not stated as a relative amount, such as a percent of total energy intake (e.g., 60 percent of total calories as carbohydrate). Although carbohydrate and protein recommendations are commonly expressed on an absolute basis in the planning of athletes' diets, fat recommendations have not usually been expressed this way. It is common to express fat as a percentage of total energy intake, even though this method is inconsistent with carbohydrate and protein recommendations. However, that is changing as some sports dietitians are beginning to state fat recommendations on a g/kg basis.

A very general guideline for daily fat intake by athletes is approximately 1.0 g/kg. This figure is also consistent with the range recommended by the Dietary Reference Intakes (DRI) and the Dietary Guidelines (20 to 35 percent of total caloric intake). Endurance athletes may need up to 2.0 g/kg to adequate replace intramuscular triglycerides (Horvath, Eagen, Fisher et al., 2000). When energy needs are exceptionally high, as is the case with ultraendurance athletes, the amount of fat in the diet may be as high as 3.0 g/kg (Seebohar, 2005). These g/kg guidelines are based on observations of the amount of fat trained athletes consume when they are in energy and macronutrient balance, not on research studies that have examined optimal dietary fat intake. In the example above, Emily's fat intake was approximately 1.0 g/kg or 21 percent of total energy intake.

Many athletes wonder if their diet must be "low fat." For most well-trained athletes, the diet is relatively low in fat because the intake of carbohydrate and protein is relatively high. However, fat intake typically falls within the DRI and the Dietary Guidelines. Although fat may be limited to accommodate higher carbohydrate and protein needs, athletes' diets do not need to be overly restrictive or devoid of fat. One study has shown that male and female distance runners (minimum 35 miles/wk) who consumed low-fat diets (16% of total energy intake as fat) for four weeks also consumed significantly fewer kilocalories when compared to medium to high-fat diets of 31 percent and 44 percent of total energy, respectively. Interestingly, the low-fat diet that resulted in the consumption of 19 percent fewer kilocalories was also associated with a statistically significant decrease in endurance performance (Horvath, Eagen, Fisher et al., 2000).

In general, people believe that a high intake of dietary fat results in increases in body fat. Because of this belief, fat is perceived negatively and fat intake is often restricted (Wenk, 2004). However, increases in body fat are due to the excess consumption of total energy (kcal). The overconsumption of any of the energy-containing compounds—carbohydrate, fat, protein, and/or alcohol—can result in increased body fat. Dietary fat intake is not the sole determinant of the extent of body fat stores. Athletes should not consider fat a forbidden nutrient or be misled by the erroneous belief that all fat is unhealthy (see Spotlight on Enrichment: Must an Athlete's Diet Be a "Low-Fat" Diet?).

ADJUSTING FAT INTAKE TO ACHIEVE ENERGY DEFICITS

Many athletes do not wish to be in energy balance; instead they wish to maintain an energy deficit for some period of time. The reason for the deficit is to force the body to use stored body fat for energy. The athlete's goal is to attain a lower percentage of body fat, which presumably will translate to a performance advantage. A low percentage of body fat may be advantageous to performance depending on the sport. For example, there is a potential performance advantage for a 10,000-m (6.2-mile) runner to attain a low percentage of body fat because there is less body mass (weight) to be moved. Extra body fat is "dead weight"—it does not produce any force to help with the exercise task and is extra weight that must be carried. However, performance and health can be negatively affected when body fat stores are too low or when dietary fat intake is severely limited. Given that a loss of body fat would be advantageous, how does the athlete best achieve an energy deficit?

Again, the athlete must consider the four energy-containing nutrients—carbohydrate, fat, protein, and alcohol. If the athlete is consuming all four of these nutrients, then the obvious nutrient to reduce is alcohol because its intake is not essential and may be counterproductive. If alcohol is not a part of the athlete's diet, then only the three remaining energy-containing nutrients could be adjusted. Sufficient carbohydrate is needed to adequately replenish glycogen stores and sufficient protein is needed to maintain muscle mass. Since both of these nutrients are directly or indirectly related to performance, fat often becomes the nutrient to reduce by default.

Although athletes in many different sports may want to maintain an energy deficit to produce a change in body fat, the sport of bodybuilding provides an excellent illustration. Six to 12 weeks prior to a contest, bodybuilders change their diets so they are deficient in energy on a daily basis. Protein intake is kept at a relatively high level, since they want to maintain the

Kevin Dodge/Masterfile

The fat intake of a bodybuilder will vary depending on the training cycle.

maximum amount of muscle mass, and weeks of low energy intake will result in some protein being used as an energy source. Carbohydrate intake must be adequate to replenish glycogen used during weight lifting and for aerobic activities. By design, precontest diets are low in fat, which results in an energy deficit when compared to energy intake in previous months. Adding or increasing aerobic exercise achieves a further energy deficit (Lambert, Frank, and Evans, 2004).

Consider the case of Kevin, a 220-lb (100-kg) body builder who routinely consumes about 5,500 kcal (55 kcal/kg). His usual fat intake is about 1.5 g/kg or 150 g daily (~25 percent of total energy intake). Two to three months before a big contest he will reduce his energy

SPOTLIGHT ON ENRICHMENT

Must an Athlete's Diet Be a "Low-Fat" Diet?

Many athletes wonder if they must routinely consume a low-fat diet. Before answering this question, the term *low-fat* must be clarified. For the general population, a low-fat diet has been defined historically as one that contains less than 30 percent of total calories as fat. This definition was developed in the mid-1960s when the average fat intake in the U.S. diet was 40 to 42 percent of total calories, a level associated with health risks (Chanmugam et al., 2003). Using this typical definition, athletes usually consume a "low-fat" diet because fat intake is often less than 30 percent of total calories.

Because Americans are normally very sedentary, the typical diet consumed in the United States is too high in fat and calories. Today people eat more grams of fat, on average 76 g daily, and more calories than they did in the 1960s. The public health message is still the same—reduce intake of dietary (saturated and *trans*) fat. However, this message does not automatically apply to athletes because of their high level of activity.

Although a low-fat diet can be appropriate for athletes, they should be aware that a very-low-fat diet can be detrimental to training, performance, and health. A very-low-fat diet is typically defined as less than 15 to 20 percent of total calories as fat. In most cases, such diets are also too low in energy over the long term to support training and can result in impaired performance. A low-fat diet can result in a lower caloric intake that can lead to a lower intake of other nutrients (Horvath, Eagen, Ryder-Calvin et al., 2000).

The reality for athletes is that their diets are usually lower in fat than those of the general population who are not attempting to lose weight, but they do not need to be exceptionally low in fat. In fact, very-low-fat diets may be detrimental for athletes.

intake to approximately 3,500 kcal. In addition to reducing caloric intake, he will slightly increase protein intake, slightly reduce carbohydrate intake, and substantially reduce fat intake. His precontest fat intake will likely be about 65 g daily or 0.65 g/kg, less than half of his usual fat consumption. During the seven days before the contest he will reduce fat intake even more in an effort to lose as much body fat as possible without sacrificing muscle mass or the ability to maintain training. After the contest he will return to his usual intake of 5,500 kcal, which includes a routine fat intake of about 1.5 g/kg daily.

ACUTE AND CHRONIC FAT AND ENERGY DEFICITS

Reductions in fat and energy intake can be either **acute** (short term) or chronic (long term). Acute deficits are usually made to reduce body fat or body weight to meet an immediate or short-term goal. Examples include a wrestler trying to "make weight" (i.e., not exceed the maximum weight in a given weight classification) or a bodybuilder preparing for a contest. Acute reductions in dietary fat and energy usually last several days to two or three months. At the end of this period, fat and energy intakes are restored to usual levels.

Chronic fat and energy deficits are those that last several months or years. Male and female distance runners and jockeys and female figure skaters, gymnasts, and dancers are examples of athletes who often exhibit chronic fat and energy deficits. Severe fat restriction can be a routine part of an energy-restricted diet adopted by an athlete to attain or maintain a low percentage of body fat. This is particularly true for the athlete who struggles to maintain a low percentage of body fat. The ultimate degree of leanness possible is largely determined by genetics, and forcing the body to maintain a very low percentage of body fat may only be achievable with long-term energy deficits (i.e., semi-starvation state). In some cases chronic, severe fat restriction is a result of a fat phobia—an irrational fear that dietary fat will become body fat. Any time that fat and kilocalories are severely restricted, athletes need to ask important questions about the effect on training, performance, and health. Dietary and psychological counseling can be beneficial.

EFFECTS OF AN INADEQUATE FAT INTAKE ON TRAINING, PERFORMANCE, AND HEALTH

Inadequate fat intake, and the energy restriction that usually accompanies it, has the potential to negatively affect training, performance, and health. These effects may include: 1) inadequate replenishment of intramuscular fat stores, 2) inability to manufacture sex-related hormones, 3) alterations in the ratio of high- and low-density lipoproteins (HDL:LDL), and 4) inadequate fat-soluble vitamin intakes.

Intramuscular fat stores, such as muscle triglycerides, are reduced after endurance exercise and even more so after ultraendurance exercise. These muscular fat stores must be replenished. A routine very-low-fat diet may not be sufficient for the resynthesis of muscle triglycerides, just as a routine low-carbohydrate diet does not provide enough carbohydrates for the resynthesis of muscle glycogen (Pendergast, Leddy, and Venkatraman, 2000).

Chronic fat restriction may negatively impact the manufacture of sex-related hormones such as **testosterone.** Some studies of healthy men have shown that a low-fat diet (between 18 and 25 percent of total calories) with a high ratio of polyunsaturated to saturated fat lowered testosterone concentration (Dorgan et al., 1996; Hamalainen et al., 1984). There have also been reports of lowered testosterone concentration in wrestlers who consumed fat- and energy-restricted diets (Strauss, Lanese, and Malarkey, 1985). These studies did not examine the effect that low testosterone concentration may have on muscle mass, but they have been interpreted to mean that chronic and severe fat restriction is not desirable for male athletes because of the potential effect on testosterone production (Lambert, Frank, and Evans, 2004).

The effect of chronic fat restriction by females on the manufacture of sex-related hormones such as estrogen has been hard to ascertain. Female athletes with exercise-related menstrual irregularities tend to have both low-fat and low-energy intakes (De Cree, 1998). For some, their fat and energy restriction is one aspect of an eating disorder, **anorexia athletica** (Sudi et al., 2004). Because there are several interrelated factors, it is not known if and how one factor, the chronic low intake of dietary fat, influences the low estrogen concentrations that are observed. However, increasing both dietary fat and caloric intake is one facet of the treatment for those with anorexia athletica.

As part of the Dietary Reference Intakes for fat intake, it is recommended that daily dietary fat intake not be below 20 percent of total energy intake. Studies have shown that very-low-fat diets in healthy individuals can result in declines in high-density lipoprotein (HDL) concentrations. HDL is a lipid carrier that tends to remove cholesterol from the surface of arteries and transports it back to the liver where the cholesterol can be metabolized. Low HDL concentrations are a risk factor for cardiovascular disease as explained in Chapter 12 (Institute of Medicine, 2002).

Inadequate fat-soluble vitamin intake is a concern when dietary fat intake is low (i.e., <0.75 g/kg). Four vitamins are fat-soluble: Vitamins A, D, E, and K. These vitamins are found in foods that contain fat and a small amount of fat must be present for their proper absorption. Surveys of athletes with low fat and energy intakes suggest that vitamin E is consumed in low amounts, often less than one-third of the recommended intake

(Ziegler, Nelson, and Jonnalagadda, 1999; Leydon and Wall, 2002).

Linoleic and alpha-linolenic are essential fatty acids that cannot be manufactured by the body. Essential fatty acid deficiencies have been reported in humans that have diseases that result in fat malabsorption. However, in healthy adults essential fatty acid deficiencies are unlikely even among people who chronically consume low-fat diets. The reason is that about 10 percent of the fat stored in adipose cells is linoleic acid. This protects the adult body against essential fatty acid deficiencies that are a result of long-term fat and energy deficits (Institute of Medicine, 2002). Although essential fatty acid deficiencies are not likely, for the other reasons stated above, chronically low fat intake can be detrimental to performance and health.

Translating Daily Fat Recommendations to Food Choices

Many athletes fail to consume an appropriate amount of fat. For some, fat intake is too high and for others fat consumption is too low. In addition to the total amount of fat needed, athletes should also be aware of the kinds of fatty acids that are associated with good health. Unsaturated fatty acids may help to reduce heart disease risk, while excess saturated fatty acids are associated with an increased risk for cardiovascular disease.

A frequent recommendation for both athletes and the general population is the inclusion of "heart-healthy" fats—oils such as olive, canola, or flaxseed, nuts, and fatty fish or fish oils. These are often referred to as "good" fats, although this may not be the best terminology. A better way of communicating the point is that these foods should be emphasized in the diet. Foods that have large amounts of saturated fatty acids or cholesterol are not inherently "bad," but they should not represent the predominant types of fat consumed. *Trans* fatty acids have no known health benefits and their consumption should be limited. This can be achieved by primarily eating foods that contain naturally occurring fats, since naturally occurring fats are in the *cis* formation. Foods that contain **hydrogenated** vegetable oils (e.g., snack foods such as crackers, chips, and cookies or stick margarine) are usually sources of *trans* fatty acids.

AMOUNT AND TYPES OF FATS IN FOOD

When planning a diet from scratch, athletes generally begin by determining the amount of carbohydrate and protein needed followed by the need for fat. Similarly, when translating recommendations to food choices, athletes often choose carbohydrate and protein foods first. If this is the case, the amount of fat contained in these foods must be accounted for. The remaining fat needed to meet total energy needs then tends to come from fats that are added to foods (e.g., butter, margarine, or salad dressings). Athletes may also analyze their current food intake and make adjustments to their present diet instead of planning a diet from scratch. In either case, athletes should be aware of the amount and types of fats found in food.

Table 6.2 lists foods that are 100 percent fat or nearly 100 percent fat, such as oils and margarine, and the amount of fat in one serving. The predominant fat contained (e.g., monounsaturated, polyunsaturated, or saturated) is noted. Most of these fats are added to foods or used for food preparation. Table 6.3 lists fat-containing foods that also have some carbohydrate and/or protein, such as nuts and seeds. The amount of energy, fat, carbohydrate, and protein are listed. The predominant type of fat is also noted. Notice that there are substantial differences in the foods collectively called fats and oils. For example, some oils contain a high percentage of monounsaturated fatty acids (olive oil has the highest concentration), while others are predominantly polyunsaturated. The fatty acid content of margarines differs, depending on whether the margarine is liquid, soft, or hard. Although it won't affect athletic performance, the type of fat may affect long-term health.

The amounts of carbohydrate and protein required by athletes are substantial; thus, fat intake is comparatively low, especially if an energy (caloric) deficit is desirable. Low-fat or nonfat versions of foods may better fit into an athlete's diet plan. In particular, lean meat, fish, and poultry and modified-fat dairy products are often chosen. Table 6.4 compares high-, medium-, and low-fat versions of similar foods.

What may not be readily apparent is the amount or type of fat that is in a processed food. This is sometimes referred to as "hidden fat." Reading food labels is necessary if athletes want to discover a processed food's nutrient composition. The Nutrition Facts label is required to show the amount of total fat, saturated fat, *trans* fat, and cholesterol, and the percentage of total calories from fat. The amount of monounsaturated or polyunsaturated fat may be included, but listing these values is voluntary. Table 6.5 lists the amount of total and saturated fat found in some snack foods.

Acute: Brief or quick. Opposite of chronic.

Testosterone: A steroid hormone associated with the development of male sex characteristics.

Anorexia athletica: An eating disorder unique to athletes. May include some elements of anorexia nervosa and bulimia and excessive exercise.

Lucas, a Cross Country Runner

As in previous chapters, a one-day dietary intake of Lucas, a collegiate cross country runner, is analyzed. Recall that the appropriate amount of dietary fat for an athlete depends on two factors—overall energy (caloric) need and macronutrient balance. Lucas' need for energy is approximately 3,400 kcal (~ 54 kcal/kg) daily. Due to the demands of his training (running 75 to 80 miles per week), his daily goal for carbohydrate is 8 g/kg. His daily protein goal is 1.5 g/kg. It is in this context that his fat intake should be evaluated. An analysis of the one-day diet that Lucas consumed is shown in Figure 6.13.

According to the dietary analysis, Lucas consumed approximately 3,333 kcal, 532 g of carbohydrate (~ 8.5 g/kg), and 124 g of protein (~ 2 g/kg). His fat intake was 94 g or 1.5 g/kg (~ 25 percent of total energy intake). His total energy intake was neither too high nor too low. He exceeded his goals for carbohydrate and protein intake. His fat intake allowed him to achieve macronutrient and energy balance. From a performance perspective, Lucas' fat intake was appropriate. An evaluation of Lucas' diet from a health perspective is included in Chapter 12.

It should be pointed out that Lucas included a number of nonfat and low-fat foods in his diet. For example, the smoothie that he had for breakfast was made from nonfat milk and low-fat yogurt. The lunchtime burritos were made from low-fat tortillas and low-fat refried black beans. For dinner he drank nonfat milk and chose white meat turkey for his sandwich. Because Lucas began running cross country in high school, he had already made adjustments to his diet. Had he eaten full-fat versions of these foods he would have exceeded his fat and energy goals.

Nutrient	DRI	Intake	0% 50% 100%
Energy			
Kilocalories	3365 kcal	3332.8 kcal	99%
Carbohydrate	379–547 g	532.15 g	
Fat, total	75–131 g	93.86 g	
Protein	84–294 g	124.09 g	
Fat			
Saturated fat	<10%	36.63 g	
Monounsaturated fat	no rec	19.45 g	
Polyunsaturated fat	no rec	11.65 g	
Cholesterol	300 mg	195.79 mg	65%
Essental fatty acids (efa)			
Omega-6 linoleic	17 g	1.9 g	11%
Omega-3 linolenic	1.6 g	0.47 g	30%

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	Goal*	Actual	% Goal
Grains	10 oz. eq.	11.8 oz. eq.	118%
Vegetables	4 cup eq.	1.2 cup eq.	30%
Fruits	2.5 cup eq.	1.7 cup eq.	68%
Milk	3 cup eq.	5.4 cup eq.	180%
Meat & Beans	7 oz. eq.	8.8 oz. eq.	126%
Discretionary	648	1152	178%

*Your results are based on a 3200 calorie pattern, the maximum caloric intake used by MyPyramid.

Figure 6.13 Dietary Analysis of 24-Hour Diet of a Male Collegiate Cross Country Runner

Table 6.2 Fats and Oils

Food*	Amount	Energy (kcal)	Fat (g)	Predominant Type of Fat**
Olives, black	6 medium	30	3	Monounsaturated
Olives, green	4 medium, stuffed	40	3	Monounsaturated
Olive oil	1 T	120	13.5	Monounsaturated
Canola oil	1 T	120	13.5	Monounsaturated
Peanut oil	1 T	120	13.5	Monounsaturated
Safflower oil, >70% oleic	1 T	120	13.5	Monounsaturated
Safflower oil, >70% linoleic	1 T	120	13.5	Polyunsaturated
Corn oil	1 T	120	13.5	Polyunsaturated
Soybean oil	1 T	120	13.5	Polyunsaturated
Flaxseed oil	1 T	115	13	Polyunsaturated
Margarine, liquid (squeezable)	1 T	100	11	Polyunsaturated
Margarine, soft (tub)	1 T	100	11	Polyunsaturated/ Monounsaturated
Margarine, hard (stick)	1 T	100	11	Saturated
Mayonnaise	1 T	100	11	Polyunsaturated
Salad dressing, oil and vinegar	1 T	85	8	Depends on the type of oil used
Salad dressing, Ranch type	1 T	73	8	Polyunsaturated
Coconut oil	1 T	117	13.5	Saturated
Bacon grease	1 T	112	12	Saturated/ Monounsaturated
Butter, stick	1 T	108	12	Saturated
Butter, whipped	1 T	82	9	Saturated
Coconut oil	1 T	120	13.5	Saturated
Cream, half and half	1 T	20	1.5	Saturated
Lard	1 T	114	12.5	Monounsaturated/ Saturated
Shortening	1 T	110	12	No one type is predominant

Examples of foods that are 100 percent, or nearly 100 percent fat and the predominant type of fat they contain.

Legend: kcal = kilocalorie; g = gram; T = Tablespoon; oz = ounce

*All foods listed are either 100% fat or nearly 100% (contain <1 g of protein and carbohydrate).

**When two fats are listed, both are found in approximately equal amounts.

Table 6.3 High-Fat Foods That Also Contain Carbohydrate and Protein

Food	Amount	Energy (kcal)	Fat (g)	Predominant Type of Fat*	CHO (g)	Protein (g)
Avocado	One (173 g)	306	30	Monounsaturated	12	3.5
Peanuts	¼ c, oil roasted	213	18	Monounsaturated	6	10
Almonds	¼ c, dry roasted	206	18	Monounsaturated	7	8
Hazelnuts (filberts)	¼ c, dry roasted	183	18	Monounsaturated	5	4
Pecans	¼ c, dry roasted	187	19	Monounsaturated	4	2.5
Pistachios	¼ c, dry roasted	183	15	Monounsaturated	9	7
Walnuts	¼ c	196	19.5	Polyunsaturated	4	4.5
Sesame seeds	1 T	51	4	Polyunsaturated/ Monounsaturated	2	1.5
Tahini (sesame seed paste)	1 T	89	8	Polyunsaturated/ Monounsaturated	3	2.5
Sunflower seeds	¼ c, oil roasted	208	19	Polyunsaturated	5	7
Pumpkin seeds	¼ c, oil roasted	296	24	Polyunsaturated	8	19
Flax seeds	1 T	59	4	Polyunsaturated	4	2
Bacon	2 slices	70	6	Monounsaturated/ Saturated	0	4
Canadian-style bacon (pork sirloin)	2 slices	50	1.5	Saturated	0	8
Coconut, sweetened, shredded	2 T	58	4	Saturated	5.5	0
Coconut milk	¼ c	138	14	Saturated	3	1

Legend: kcal = kilocalorie; g = gram; CHO = carbohydrate; c = cup; T = Tablespoon

*When two fats are listed, both are found in approximately equal amounts.

FAT AND THE TYPICAL AMERICAN DIET

The typical American diet is characterized by a high intake of red meat, processed meat, high-fat dairy products, French fries, refined grains, sweets, and desserts. Large portions of these foods are frequently served in restaurants and at home. With the exception of sweets that are pure sugar, all of these foods can contribute substantial amounts of fat and kilocalories to the diet. This dietary pattern has been shown to contribute to chronic diseases such as cardiovascular disease, type 2 diabetes, and metabolic syndrome (see Chapter 12) (Hu et al., 2000).

Traditional Mediterranean, Asian, and Latin American diets differ from the typical American diet in that meats, sweets, and eggs are used sparingly (often on a monthly or weekly basis) and fruits, vegetables, fish, beans, whole grains, and oils are eaten daily. Portion sizes are also smaller. However, traditional Mediterranean, Asian, and Latin American meal patterns are being replaced by the typical American diet pattern in many parts of the world.

The typical American diet is too high in fat for most athletes, so they look for alternatives for both performance and health reasons. Athletes may gravitate to traditional dietary patterns, often referred to as ethnic diets, which are plant- and fish-based and relatively low in fat. Some athletes adopt a nonmeat, nonanimal-product (vegan) diet and in doing so lower their intake of fat, particularly saturated fats. However, meat and animal products do not have to be excluded. Hu (2003) noted that a dietary pattern that includes poultry and low-fat dairy products is also consistent with a reduced risk for cardiovascular disease. In other words, an athlete does not have to become a vegetarian or vegan to lower the risk for chronic diseases. There are various ways to modify the typical American diet to one that supports training, performance, and long-term health.

Table 6.4 High-, Medium-, and Low-Fat Meat, Fish, Poultry, and Dairy Products

Food	Preparation Method	Amount	Fat (g)
Ground beef, regular	Broiled	3 oz	17.5
Ground beef, lean	Broiled	3 oz	16
Ground beef, extra lean	Broiled	3 oz	14
Tuna salad	Mayonnaise added to tuna	¾ c	20
Light tuna, canned in oil	Drained	2 oz	7
Light tuna, canned in water	Drained	2 oz	0.5
Chicken wing (meat and skin), flour coated	Fried	3 oz	19
Chicken wing (meat and skin)	Roasted	3 oz	16.5
Chicken leg (dark meat)	Roasted	3 oz	7
Chicken breast (white meat)	Roasted	3 oz	3
Whole milk (3.3% butterfat)		8 oz	8
Reduced fat milk (2% butterfat)		8 oz	5
Low-fat milk (1% butterfat)		8 oz	2
Nonfat (skim) milk		8 oz	0.2
Creamed cottage cheese (4% butterfat)		½ c	5
Low-fat cottage cheese (2% butterfat)		½ c	2
Low-fat cottage cheese (1% butterfat)		½ c	1
Dry curd cottage cheese (0.4% or less butterfat)		½ c	~0.5

Legend: g = gram; oz = ounce, c = cup

Table 6.5 Amount of Total and Saturated Fat in Selected Snack Foods

Food	Amount	Energy (kcal)	Total fat (g)	Saturated fat (g)
Oreo cookie ice cream	5 oz	355	20.5	12
Glazed donut	1	350	19	5
Reese's peanut butter cups	2 pieces	250	14	5
Oreo cookies	6 cookies	318	14	3
Nestle plain milk chocolate candy bar	1 (1.45 oz)	210	13	8
Trail mix	¼ c	173	11	2
Milky Way candy bar	1	270	10	5
Fritos	1 oz	160	10	1.5
Brownie	1 piece (1.5 oz)	170	8	1.5
Cheese whiz	2 T	90	7	5
Wheat thins	16 crackers (1 oz)	140	6	1
Hostess Twinkie	1	150	5	2
Pop-tart (frosted toaster pastry)	1	200	5	1

Legend: kcal = kilocalorie; oz = ounce; c = cup; g = gram

Nutrient	DRI	Intake	0%	50%	100%
Energy					
Kilocalories	2427 kcal	3540.98 kcal			146%
Carbohydrate	273–394 g	406.75 g			
Fat, total	54–94 g	176.99 g			
Protein	61–212 g	99.2 g			
Fat					
Saturated fat	<10%	60.03 g			
Monounsaturated fat	no rec	34.5 g			
Polyunsaturated fat	no rec	13.36 g			
Cholesterol	300 mg	666.58 mg			222%
Carbs					
Dietary fiber, total	38 g	20.01 g			53%
Sugar, total	no rec	179.14 g			

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	Goal*	Actual	% Goal
Grains	8 oz. eq.	8.5 oz. eq.	106%
Vegetables	3 cup eq.	1.3 cup eq.	43%
Fruits	2 cup eq.	0 cup eq.	0%
Milk	3 cup eq.	2.4 cup eq.	80%
Meat & Beans	6.5 oz. eq.	6.2 oz. eq.	95%
Discretionary	362	1816.7	502%

*Your results are based on 2427 calorie pattern (sedentary male)

Figure 6.14 Dietary Analysis of a Typical American Diet (See text below for foods included)

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The Americanization of traditional ethnic meals often results in the addition of fat.

To begin to modify their diets, individuals need to analyze their current dietary intake. Figure 6.14 illustrates the macronutrient content of a diet containing many foods that Americans commonly consume—bacon and eggs for breakfast; a ham-and-cheese sandwich, potato chips, and cookies for lunch; a super-sized cheeseburger and fries at a fast-food restaurant for dinner; and chocolate ice cream for dessert. One can easily see how many Americans consume high-fat, high-calorie diets.

Most Americans are sedentary and their energy consumption exceeds their energy expenditure. As shown in Figure 6.14, estimated caloric need for a sedentary male Lucas' age is approximately 2,400 kcal, but the caloric value of the foods analyzed is more than 3,500 kcal. Note that fiber intake is low and that cholesterol and saturated fat intakes are excessive, which can be associated with some chronic diseases (see Chapter 12). The MyPyramid analysis clearly shows the low fruit and vegetable intake that is typical of many Americans.

For illustration purposes, now assume that this dietary analysis represents Lucas' alter ego and former high school teammate, Luke. Luke has never much cared about his diet because he didn't think it was all that important. In high school he ate whatever was convenient, which included fast foods most days, and he was still the best cross country runner in his region. He also figured that his diet was fine as long as he didn't gain any body fat. But a dietary analysis reveals some interesting facts. Luke's diet has an excess of energy by about 140 kcal (3,541 kcal consumed compared to 3,400 kcal needed). His carbohydrate intake is ~6.5 g/kg, 1.5 g/kg lower than his daily goal of ~8 g/kg. His fat intake is 177 g or ~2.8 g/kg. He does not meet recommended goals in three crucial areas: energy, carbohydrates, and macronutrient balance. If this one-day diet reflects his usual intake, over time he could fail to meet his training and performance goals. His carbohydrate intake is insufficient to adequately restore muscle glycogen levels depleted by prolonged endurance training and he could expect to gain 15 lb (~7 kg) of body fat over the course of the year if he consumes an excess of 140 kcal daily. From a health perspective, his intake

Table 6.6 Burger Meals Compared

Meal	Energy (kcal)	Fat (g)
Big Mac®	540	29
Large French Fries (6 oz)	570	30
TOTAL	**1,110**	**59**
Quarter Pounder® (no cheese)	410	19
Medium French Fries (4 oz)	790	78
TOTAL	**890**	**46**
Cheeseburger	300	12
Small French Fries (2.6 oz)	250	13
TOTAL	**550**	**25**

Ordering a smaller-sized meal results in lower total fat and energy intakes.

Legend: kcal = kilocalorie; g = gram; oz = ounce

Used with permission from McDonald's Corporation.

of total fat, saturated fat, and cholesterol exceeds the recommendations made to help reduce cardiovascular disease risk (see Chapter 12).

WAYS TO MODIFY THE TYPICAL AMERICAN DIET

Sports dietitians frequently counsel athletes about ways to modify their current diet to lower fat intake. Strategies include reducing portion sizes, preparing and buying foods with less fat, adding less fat to food, choosing lower fat meat and poultry, consuming low-fat or nonfat dairy products, and substituting high-fat refined grains and desserts with fresh fruits and vegetables. There is no one strategy that must be used. Instead, sports dietitians help athletes create an individualized diet plan utilizing some or all of these strategies.

- **Reduce portion size.** Reducing the portion size of high-fat foods is one obvious way to reduce fat and energy intake. Table 6.6 compares small, medium, and large meals containing a cheeseburger and French fries sold at McDonald's. These meals range from a high of 59 g of fat and 1,110 kcal to a low of 25 g of fat and 550 kcal. When high-fat foods are the only option, one strategy to reduce fat and energy intake is to simply order a smaller size.
- **Prepare foods with less fat.** Much fat can be added to food when it is prepared. Ways to prepare food that minimize the amount of fat used for cooking include grilling, roasting, broiling, baking, steaming, or poaching. Deep fat frying adds substantial amounts of fat to the original food. For example, a 3-oz piece of fish that has been coated with flour and fried has about 11 g of fat. The same fish prepared by steaming or baking has about 1 g of fat.

Anthony Blake Photo Library/Photolibrary

Grilling and steaming are preparation methods that do not require additional fat.

- **Add less fat to foods.** Some people add substantial amounts of fat to food, such as butter or margarine on bread or potatoes. Potatoes naturally contain very little fat so a baked potato contributes less than 1 g of fat when eaten plain. But what about the addition of butter, sour cream, or cheese sauce? All of these can be sources of substantial amounts of fat, depending on how much is added. A baked potato with sour cream and chives, which is available at several fast-food restaurants, has approximately 14 g of fat, all coming from the sour cream. Most baked potatoes with cheese sauce sold at fast-food restaurants have about 28 g of fat. The baked potato prepared at home can be equally fat laden, depending on how much fat is added.
- **Be aware of "hidden fats."** The fat content of some foods is surprising. A Caesar salad served in a restaurant can have 30 to 40 g of fat. A Mrs. Fields peanut butter cookie has 16 g of fat. Beverages as sources of fat should not be overlooked. A Double Chocolate Chip Frappuccino® Blended Crème with whipped cream (16 oz) from Starbucks contains 22 g of fat. Many processed snack-type foods such as crackers and chips and desserts such as pastries contain much more fat than one might realize. Reading nutrition labels and looking up nutrition information on commercial websites are ways of finding out how much fat is in a particular food.
- **Consume lower-fat cuts of meat or poultry and low-fat or nonfat dairy products.** White meat chicken, water-packed tuna, flank steak, skim milk, and low-fat cottage cheese are examples of foods that often become the staples of many athletes' diets because these foods are low in fat. Eating the lower-fat version of a product is a strategy frequently used by athletes because these foods taste good and are widely available.
- **Choose lower-fat versions of high-fat processed foods.** There are at least 5,000 foods on supermarket shelves that are lower-fat versions of full-fat foods. Consumers have tremendous choice when it comes to buying foods with a lower fat content. A word of

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Beverages may be a source of fat.

caution: these lower-fat foods may not be lower in kilocalories (energy) than the full-fat version. This is because the fat content of the food may be replaced with carbohydrate, often in the form of sugar.

• **Substitute fruits and vegetables for fat-containing snack foods.** One strategy that athletes may find helpful is to substitute a food that is naturally low in fat, such as most fruits and vegetables, for a high-fat food. This may also result in a lower energy intake, which is a goal for some athletes.

FAT SUBSTITUTES AND FAT BLOCKERS

Fat imparts some of the most appealing flavors and textures found in foods. It is also the most concentrated source of energy in the diet at 9 kcal/g. Because dietary fat is so desirable, there have been many efforts made to find acceptable **fat substitutes** and compounds that block fat absorption.

Fat Substitutes. During the 1990s, when the rates of overweight and obesity were steadily climbing in the United States, the government encouraged the food industry to create more than 5,000 reduced-fat foods. At one point more than a thousand such products were introduced each year (Wylie-Rosett, 2002). Some of these foods simply had the fat removed (e.g., skim milk), but many of the products involved fat substitutes.

Fat substitutes are most often made from carbohydrate sources, although some are derived from fat and at least one is protein-based. Carbohydrates are used because fibers and starches retain water and they add body and texture to the food when the fat is removed. Such foods have much less fat but often a similar amount of kilocalories when compared to the original product.

Protein-based fat substitutes are egg or milk proteins that have been ultracentrifuged to produce extremely small particles. The microparticles roll over each other in the mouth so the product has the same feel and texture as the full-fat product. Protein-based fat substitutes are used in dairy products, such as ice cream, and baked goods.

Many reduced-fat bakery products contain monoglycerides and diglycerides. These fats are derived from vegetable oils and have been emulsified with water. Although all fats contain 9 kcal/g, a gram of

KEEPING IT IN PERSPECTIVE

Fat Is for Fuel and Fun

Angelina looked solemnly at the piece of cake that she had been served. To the others in the room it was simply a small piece of birthday cake, but to her it was 10 g of fat. Even though she had run 5 miles that morning and had a figure that others said they envied, Angelina couldn't bring herself to eat the cake. She feared that "a minute on the lips" meant "a lifetime on the hips." So she said that she was a bit nauseated and didn't eat it, even though it was her birthday.

Fat is a calorie-dense nutrient and there are problems associated with excessive intake. However, it is very important for athletes to be able to keep their fat intake in perspective. On the fat intake continuum athletes should stay centered and not restrict fat too severely or consume fat excessively. They should view fat as a nutrient, not as something that is inherently "bad." At times they must limit fat intake, such as during a training mesocycle or microcycle when energy and fat is restricted in an effort to lose weight. But they also need to be flexible with fat intake, such as eating and enjoying a piece of cake on their birthday.

Fat is an excellent fuel source. When energy, carbohydrate, protein, and fat intakes are balanced there is no need to fret about fat. Fat also imparts a wonderful flavor and texture to food and there is a joy and satisfaction that comes with eating fat-containing foods. Backpackers often stop at the top of a steep pass and enjoy a chocolate bar. Getting to the top of the mountain gives them perspective because they can look at the world from afar. That same kind of perspective is necessary for athletes to evaluate their fat intake and discover that fat, at least in part, is for fuel and fun.

monoglyceride or diglyceride contains a considerable amount of water, so the total amount of fat is reduced when these compounds replace other fats on a per weight basis.

Caprenin and salatrim are fatty acids that are used in baked goods and dairy products because of their similar textural properties to cocoa butter. These fatty acids essentially contain 5 kcal/g because they are only partially digested and absorbed. Substituting these for traditional fats reduces the fat content by almost half. However, gastrointestinal symptoms, such as nausea and cramps, have been reported, especially as the amount consumed increases.

In a class by itself, both structurally and for regulatory purposes, is **Olestra** (Olean®). Olestra is a nonabsorbable fat substitute composed of sucrose polyester, a compound made up of sucrose with six to eight carbon fatty acids attached. Because of its chemical structure, Olestra is resistant to pancreatic lipase and remains unabsorbed in the gastrointestinal tract. When first approved, all products containing Olestra were required to carry a warning label: "This Product Contains Olestra. Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added." In 2003, the Food and Drug Administration removed the warning label requirement.

Similar to artificial sweeteners, fat substitutes are not the weight loss panacea that both industry and consumers had hoped they would be. Many "fat-free" products do not have fewer kilocalories than the full-fat product, just more sugar. Controlled randomized trials have shown that individuals who choose foods with fat substitutes consume less total fat and less saturated fat but only to a small degree. In one study of Olestra, total dietary fat intake was reduced by 2.7 percent and saturated fat intake was reduced by 1.1 percent (Wylie-Rosett, 2002).

Fat Blockers. **Fat blockers**, compounds that prevent fat absorption, are appealing because, theoretically, high-fat foods could be eaten and enjoyed but blocked before they are absorbed. One such compound is **chitosan,** which is sold as a dietary supplement and advertised as an aid to weight loss.

Chitosan is derived from chitin, a compound extracted from the exoskeletons of crustaceans (i.e., shellfish such as shrimp and crabs). It is a polysaccharide similar to cellulose and is considered a dietary fiber. Studies conducted in rats found that chitosan can bind to fats in the intestine and block their absorption. The chitosan-fat complex is excreted in the feces.

The initial evidence in rats held promise that chitosan may be an aid to weight loss in humans.

Fat substitute: Compounds that replace the fat that would be found naturally in a food. Most are made from proteins or carbohydrates.

Olestra: A fat substitute that cannot be absorbed by the body.

Fat blocker: A compound that prevents fat found in food from being absorbed.

Chitosan: A dietary supplement derived from shellfish that is advertised as an aid to weight loss.

THE EXPERTS IN. . .

Fat Metabolism and Exercise

Many exercise physiologists study the metabolism of fat during exercise and the interactions between carbohydrate and fat metabolism. This basic knowledge of metabolism can lead to applied research that tests dietary manipulations of carbohydrate and fat intake to determine their effects on metabolism and performance. A natural extension of this information is the application it may have to disease states such as diabetes and obesity. George A. Brooks, Ph.D., is an expert in the area of metabolic adjustments to exercise. One of his research interests is the use of carbohydrate, fat, and protein to fuel endurance exercise and his research has led to the identification and better understanding of the "crossover concept." Asker Jeukendrup, Ph.D., a Registered Sport and Exercise Nutritionist in Europe, has published numerous research articles about the interactions between fat and carbohydrate metabolism during exercise. Having competed in Ironman distance events, Jeukendrup has a special interest in conducting applied research to improve performance and reduce gastrointestinal distress in endurance athletes. Joseph A. Houmard, Ph.D., conducts research on lipid metabolism with a focus on obesity, weight loss, and exercise. This type of work helps health professionals to better understand the metabolic basis of obesity and the impact exercise and diet may have on weight loss.

However, when tested in double-blind, randomized clinical trials, there was no significant difference between the weight of those who received chitosan supplements and those who received the placebo. Some participants who received chitosan experienced gastrointestinal distress such as constipation. Systematic reviews of the clinical trials, the strongest level of scientific evidence, conclude that chitosan supplements are not an effective aid to weight loss (Pittler and Ernst, 2004).

Summary

Fat is the most energy-dense nutrient found in food. The predominant fat in food and in the body is the **triglyceride (triacylglycerol)**, which is made up of three fatty acids attached to a **glycerol** molecule. The fatty acids, which are chains of carbon and hydrogen, vary in length and chemical composition. Fats are large molecules and their digestion, absorption, and transport is complicated because they must be broken down into smaller components.

Once absorbed, triglycerides must be re-formed. The main sites of fat storage are **adipocytes** (fat cells), liver, and muscle cells. After a meal, particularly a meal containing fats and carbohydrates, the hormonal environment is such that triglyceride formation and fat storage are favored. To be used in metabolism, fats must be taken out of storage. An enzyme, **hormone-sensitive lipase,** catalyzes **lipolysis** of triglycerides stored in adipocytes.

Fat is the primary energy source at rest and during low-intensity activity. The advantages of fat include its abundance in food, energy density, ability to be easily stored, and ability to produce a large amount of ATP. However, fat usage is limited to rest and low-intensity activity because of the time it takes to metabolize fatty acids and the oxygen necessary for metabolism.

Because the need for carbohydrate and protein is relatively high, athletes find their diets tend to be relatively low in fat and usually lower than the typical American diet. Heart-healthy fats, oils such as olive, canola, or flaxseed, nuts, and fatty fish or fish oils should be emphasized. Athletes can reduce the amount of fat in their diets by reducing portion sizes, preparing and buying foods with less fat, adding less fat to food, choosing lower fat meat and poultry, consuming low-fat or nonfat dairy products, and substituting high-fat refined grains (e.g., snack foods and desserts) with fresh fruits and vegetables. Caution should be used when restricting fat since athletes can reduce the fat in their diets too much.

Post-Test — Reassessing Current Knowledge of Fats

Now that you have more knowledge about fats, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. A low-calorie, low-carbohydrate diet that results in ketosis is dangerous for athletes because it leads to the medical condition known as ketoacidosis.
2. At rest, the highest percentage of total energy expenditure is from fat and not carbohydrate.
3. To lose body fat, it is best to perform low-intensity exercise, which keeps one in the fat-burning zone.
4. To improve performance, endurance athletes should ingest caffeine because more free fatty acids are oxidized for energy and muscle glycogen is spared.
5. Athletes typically need to follow a very-low-fat diet.

Review Questions

1. What might people mean when they say "too much fat?"
2. Why is consuming enough dietary fat important for athletes?
3. What are the differences between saturated, monounsaturated, and polyunsaturated fatty acids? Name foods in which each type predominates.
4. What is the chemical difference between *cis*- and *trans* fatty acids? Why might people be advised to eat whole (less processed) foods?
5. What is a triglyceride? Where are triglycerides found in food? In the body?
6. Explain the two major factors that dictate the appropriate amount of dietary fat intake for an athlete.
7. Briefly explain the digestion, intestinal absorption, and transportation of fats.
8. Briefly explain the major steps in the metabolism of fatty acids in the body.
9. What happens to the use of fat as a fuel as exercise intensity increases? What happens to the use of fat as a fuel when steady-state exercise progresses in duration?
10. Explain relative and absolute fat oxidation. Does a person need to burn fat during exercise in order to lose body fat?
11. Why do athletes acutely and chronically restrict fat intake?

12. In what ways may severe, chronic fat and energy restriction affect performance and health?
13. What are the recommended guidelines for fat intake for athletes?
14. Describe some strategies that athletes could use to reduce the fat content of their diets.
15. What are fat substitutes?
16. Is the dietary supplement chitosan effective for blocking fat absorption or for weight loss in humans? Why or why not?

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7 Water and Electrolytes

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Learning Objectives

1. Describe the approximate amount, distribution, and roles of body water.
2. Discuss the processes by which water movements occur between compartments in the body.
3. Define euhydration, hyperhydration, hypohydration, and dehydration.
4. Identify avenues of water and sodium loss and intake.
5. Discuss the effect of exercise on fluid balance and outline strategies for maintaining fluid balance before, during, and after exercise.
6. Identify the role fluid plays in body temperature regulation during exercise and on performance and health.
7. Discuss the effect of caffeine on hydration status.
8. Explain the phenomenon of hyponatremia and outline a strategy for prevention in endurance and ultraendurance athletes.

Pre-Test Assessing Current Knowledge of Water and Electrolytes

Read the following statements about water and electrolytes and decide if each is true or false.

1. The two major aspects of fluid balance are the volume of water and the concentration of the substances in the water.
2. Now that sports beverages are precisely formulated, it is rare that water would be a better choice than a sports beverage for a trained athlete.
3. Athletes should avoid caffeinated drinks because caffeine is a potent diuretic.
4. A rule of thumb for endurance athletes is to drink as much water as possible.
5. Under most circumstances, athletes will not voluntarily drink enough fluid to account for all the water lost during exercise.

Water is often considered the most important nutrient. Failure to consume other nutrients may result in harmful deficiencies over a span of weeks, months, or years, but humans can only live for a few days without water. It is the most abundant substance in the body, comprising approximately 60 percent of an average person's body weight. Water provides the **aqueous** medium for chemical reactions and other processes within cells, transports substances throughout the body, facilitates **thermoregulation** (maintenance of body temperature), and is critical to most other physiological processes. Because of the additional physiological stress generated by physical activity, exercise, and sport, fluid balance is an important consideration for athletes and active people.

Loss of body water can be detrimental to both performance and health, as can excessive water consumption. In extreme cases, these situations can be fatal. The challenge for athletes, especially those exercising in hot and humid environments, is to adequately replenish water that is lost during (if possible) and after exercise. Some simple postexercise assessments, such as scale weight, urine color, and degree of thirst, can help athletes monitor if fluid has been adequately restored. The loss and intake of **electrolytes** (e.g., sodium) must also be balanced.

Each athlete needs an individualized plan for fluid and/or electrolyte intake before, during, and after exercise under normal training conditions. The plan will need to be adjusted to reflect changing environmental conditions (e.g., increasing temperature, stress of competition). The amount and timing of fluid and/or electrolyte intake are critical elements of the plan. For many athletes, carbohydrate intake will also be critical and the amount, type, and concentration of carbohydrate are included as part of the plan because fluid is often used as a vehicle for carbohydrate delivery.

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Sports beverages may be part of the athlete's individualized plan for fluid and/or electrolyte intake before, during, and after exercise.

Overview of Water and Electrolytes

There are two major aspects to fluid balance that must be considered and understood: 1) water volume and 2) the concentration of **solutes** in body fluid. First, the body must have an adequate volume of water to meet physiological demands, a condition referred to as **euhydration.** An excess amount of water is generally a temporary condition in healthy people and is called **hyperhydration,** while an insufficient volume of water in the body is termed **hypohydration.** The term **dehydration** refers to the process of losing body water and moving from a state of euhydration to hypohydration. Dehydration is often used interchangeably with hypohydration, but these terms have different meanings.

Second, because of the potential for water to move from one area to another by **osmosis** due to concentration differences, the overall concentration of substances dissolved in body water must be considered as well. This is the concept of **tonicity;** body fluids are considered to be **hypotonic, isotonic,** or **hypertonic** if they have a concentration of solutes that is less than, the same as, or greater than the concentration of solutes in the cells, respectively. Although a number of substances are osmotically active, the tonicity of body fluids is due largely to the concentration of electrolytes, electrically

Table 7.1 Electrolytes Involved in Fluid Balance

Cations	Anions
Sodium (Na^+)	Chloride (Cl^-)
Potassium (K^+)	Bicarbonate ($HC0_3^-$)
Calcium (Ca^{2+})	Phosphate (PO_4^{3-})
Magnesium (Mg^{2+})	Protein

Cations are positively charged electrolytes and anions are negatively charged electrolytes.

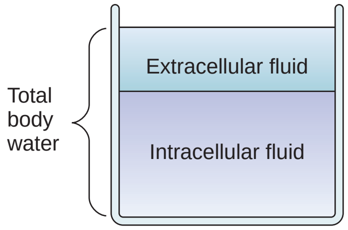


Figure 7.1 Body Water Compartments

Approximately two-thirds of body water is found in the intracellular fluid (ICF) compartment and approximately one-third is found in the extracellular fluid (ECF) compartment.

charged **cations** such as sodium (Na^+) and potassium (K^+), and **anions** such as chloride (Cl^-) and phosphate (PO_4^{3-}). Table 7.1 lists the cations and anions involved in fluid balance.

Body Water and Electrolytes

The amount of water in the body depends on a variety of factors, including body size, gender, age, and body composition. In general, larger people have more body water compared to those of smaller stature and males have more water than females because men typically have more muscle mass and less body fat than women. Body water percentage has an inverse relationship with both age and body fatness; it declines with advancing age and increasing body fatness. On average, an adult's body is approximately 60 percent water by weight, but individuals may range from 40 to 80 percent. An average 70-kg (154-lb) male has approximately 42 liters (L) of total body water, and the average female approximately 30 L. Expressed as a nonmetric measurement, the average female and male have approximately 8 and 11 gallons of body water, respectively. Different body tissues contain varying proportions of water. For example, blood **plasma** is largely fluid and consists of approximately 90 percent water. Muscle and other organ tissue can range from 70 to 80 percent water, while bone contains much less water, about 22 percent. Lipids are **anhydrous,** therefore, fat tissue contains very little water—approximately 10 percent.

DISTRIBUTION OF BODY WATER

Water is distributed throughout the body. This distribution is often separated into two major compartments: intracellular fluid (ICF) and extracellular fluid (ECF). Intracellular fluid consists of all the water contained within the trillions of cells in the body. Some cells have higher concentrations of water than others. All of these cells maintain their integrity because of their cell membranes, which separates the fluid inside the cells from the extracellular fluid. The ECF is further divided into subcompartments. One subcompartment is the plasma, the watery portion of the blood. Another is the **interstitial fluid,** the fluid that is found between the cells. Approximately two-thirds of total body water is in the ICF, leaving approximately one-third in the ECF (Figure 7.1).

Intracellular Fluid. The body contains trillions of cells, many with different structures, composition, and functions. The water content of cells may vary dramatically. For example, myocytes or muscle cells may contain as much as 75 to 80 percent water by weight, while osteocytes or bone cells may consist of as little as 22 percent water. Collectively,

Aqueous: Consisting mostly of water.

Thermoregulation: Maintenance of body temperature in the normal range.

Electrolyte: A substance that will dissociate into ions in solution and is capable of conducting electricity.

Solute: A substance dissolved in a solution.

Euhydration: "Good" hydration (eu = good); a normal or adequate amount of water for proper physiological function.

Hyperhydration: A temporary excess of water; beyond the normal state of hydration.

Hypohydration: An insufficient amount of water; below the normal state of hydration.

Dehydration: The process of going from a state of euhydration to hypohydration.

Osmosis: Fluid movement through a semipermeable membrane from a greater concentration to a lesser concentration so the concentrations will equalize.

Tonicity: The ability of a solution to cause water movement.

Hypotonic: Having a lower osmotic pressure than another fluid.

Isotonic: Having an equal osmotic pressure to another fluid.

Hypertonic: Having a higher osmotic pressure than another fluid.

Cation: A positively charged ion.

Anion: A negatively charged ion.

Plasma: Fluid component of blood or lymph; does not include cells.

Anhydrous: Containing no water.

Interstitial fluid: Found between cells, tissues, or parts of an organ.

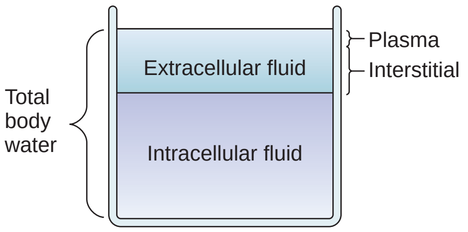


Figure 7.2 Extracellular Water Compartments

The two main components of the Extracellular Fluid (ECF) compartment are the interstitial fluid, composing approximately 80 percent of the ECF, and the plasma, which is approximately 20 percent of the ECF.

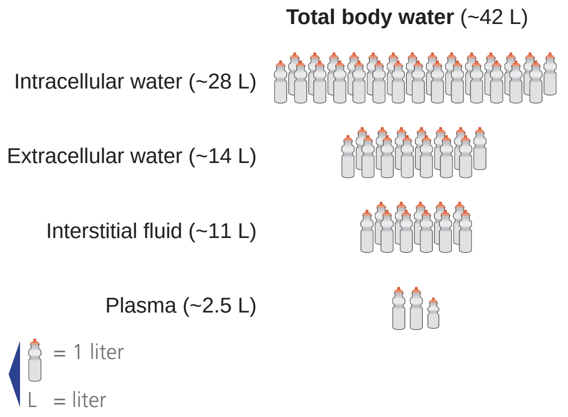


Figure 7.3 Total Body Water Distribution

though, the cells of the body contain approximately two-thirds of the body's total water volume, and all cells together are considered the intracellular fluid compartment. If an average male has 42 L of body water, approximately 28 L (~7.5 gal) is contained in the cells or about 40 percent of total body weight.

Extracellular Fluid. All of the water in the body not contained inside cells is considered a part of the extracellular fluid compartment. This is approximately one-third of the total body water, or about 14 L (~3.5 gal) in the average male. As shown in Figures 7.2 and 7.3, the ECF can be further subdivided into discrete areas such as the plasma (~2.8 L or ~3 qt) and the interstitial fluid (11.2 L or 3 gal).

The plasma serves as the fluid transportation medium to transport red blood cells, gases, nutrients, hormones, and other substances throughout the body. It is a major reservoir of fluid and plays a critical role in thermoregulation, particularly for activity in hot and humid environments. Of the total ECF volume, plasma accounts for approximately one-fifth, or 20 percent. The plasma is contained within the vascular system and is separated from the interstitial fluid by the walls of the blood vessels. The thicker walls of the larger blood vessels (e.g., arteries and veins) provide a substantial barrier to fluid movement, while the smaller and thinner walls of the capillaries are very permeable and can allow considerable movement of water between compartments.

The major component of the ECF compartment (approximately 80 percent) is interstitial fluid. The interstitial fluid surrounds the cells and provides protection and an avenue for exchange with the cells of the body. The remaining ECF compartments are considered negligible compared to plasma and interstitial fluid because they are so small. Lymph is fluid contained in the lymphatic system, which returns fluid from the interstitial space to the blood. Transcellular fluids are found in specialized cells such as the brain and spinal column (cerebrospinal fluid), joints (synovial fluid), areas surrounding the internal organs, heart, and lungs (peritoneal, pericardial, and intrapleural fluids, respectively), eyes (intraocular fluid), and digestive juices. While these fluids play critical functional roles, the total amount of water contained in these fluids is small and generally stable, so these fluid compartments are usually not included in discussions of body fluid balance. Figure 7.3 illustrates total body water distribution.

Water Movement between Compartments. The water that is found in ICF and ECF is not **static.** Water can be added to or removed from these compartments, and although there are barriers separating the various compartments, fluid moves between compartments relatively easily. Because intracellular fluid exists in isolated cells, water must pass through the extracellular fluid compartment in order to reach cells. The ECF therefore acts as a gateway for water entry into the body, initially through the plasma.

All cells are freely permeable to water so water can move through cell membranes easily, but there must be some force that stimulates the movement of water. The two major forces that result in the movement of water are fluid (hydrostatic) pressure and osmotic pressure.

Fluid or hydrostatic pressure is created when there is a difference in fluid pressure between two areas. For example, the cardiovascular system uses hydrostatic pressure to move blood throughout the body. When the heart contracts, it squeezes the blood that fills it, increasing blood pressure. This increase in blood pressure creates the driving force to propel blood through the blood vessels in the pulmonary and **systemic circulation.** This type of pressure can also result in water moving from the area of higher pressure (blood plasma), to areas of lower pressure (interstitial spaces). In another example of the fluid shifts resulting from hydrostatic pressure, feet and ankles may swell if a person stands for long periods of time. When a person stands upright, blood rushes towards the feet due to gravity. This increase in hydrostatic pressure inside the blood vessels in the lower extremities results in more movement of water to the interstitial spaces in the feet and lower legs, resulting in swelling or **edema.**

The second cause of water movement is due to osmosis, the tendency of water to move from areas of high solute concentration to areas of lower solute concentration. This would not be a factor if the fluid in the various

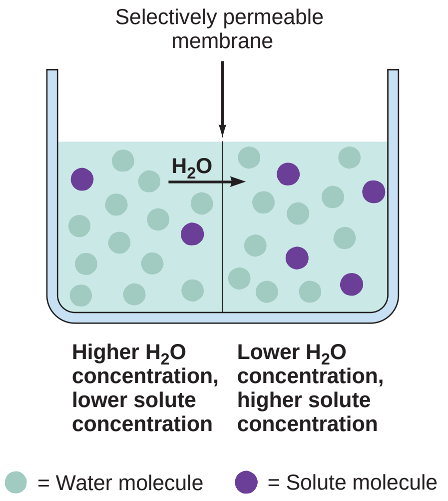


Figure 7.4 Osmosis

Water will move by osmosis across a selectively permeable membrane from an area of lower solute concentration to an area of higher solute concentration.

compartments contained only water. However, fluids in the body contain a wide variety of solutes dissolved in the water. Figure 7.4 illustrates the net movement of water by osmosis from an area of lower to higher solute concentration across a selectively permeable membrane.

The membranes of cells are selectively permeable, allowing free movement of water but often maintaining differences in the distribution of solutes.

Osmotic pressure is measured in milliosmoles (mOsm). When the number of particles (solute) is measured per *kilogram* of **solvent,** the correct term is **osmolality;** when measured per *liter* of solvent, the correct term is **osmolarity.** In nutrition and medicine, *osmolarity* is the standard term, whereas in exercise physiology the term *osmolality* is more commonly used because osmolality is not affected by temperature (Gropper, Smith, and Groff, 2005). In this textbook, the term osmolarity will be used.

The two major subcompartments of the ECF—plasma and interstitial fluid—have a nearly identical composition and distribution of electrolytes (see Figure 7.5). In

Static: Not moving or changing.

Systemic circulation: Circulation of blood to all parts of the body other than the lungs.

Edema: An abnormal buildup of fluid between cells.

Solvent: A substance (usually a liquid) in which other substances are dissolved.

Osmolality: Osmoles of solute per kilogram of solvent.

Osmolarity: Osmoles of solute per liter of solution.

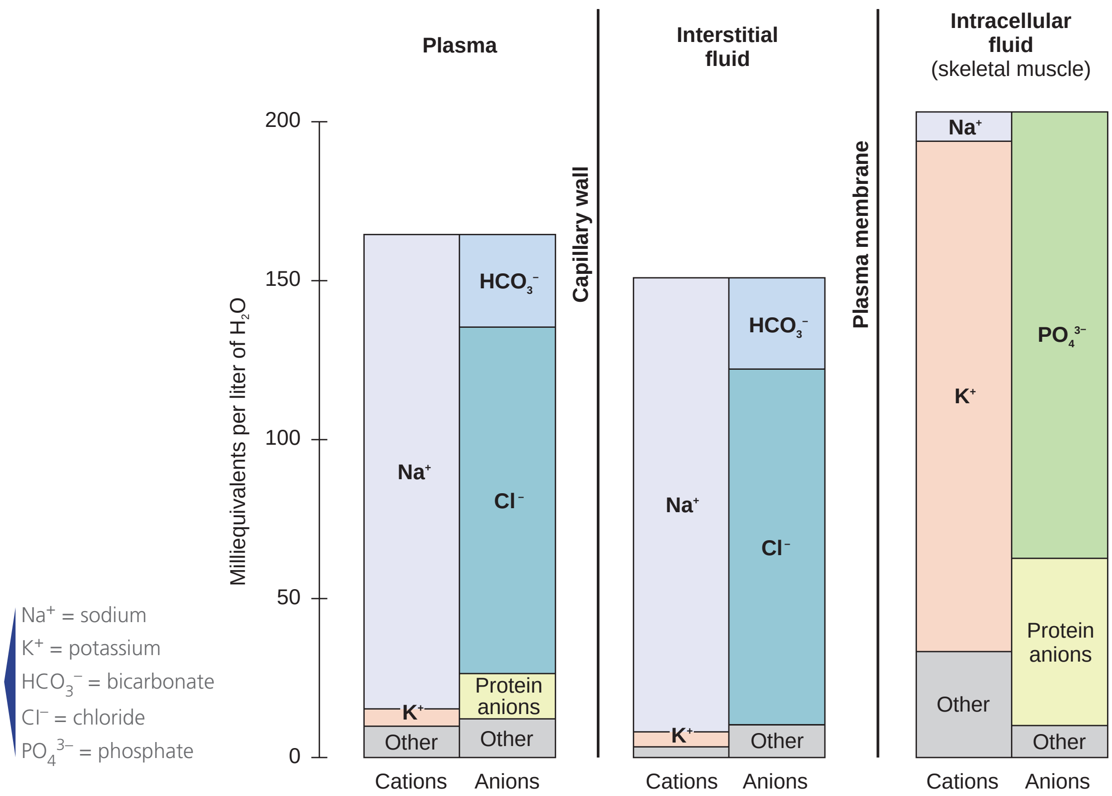


Figure 7.5 Electrolyte Distribution in Body Fluid Compartments

extracellular fluid the major cation (positively charged ion) is sodium. The amount and concentration of potassium and other cations are much smaller. The major anions (negatively charged ions) are chloride and bicarbonate. In addition, there are some negatively charged proteins in plasma (e.g., albumin) that are typically not found in the interstitial fluid, but the amount is small compared to chloride and bicarbonate.

The composition and distribution of electrolytes inside the cells are quite different from those found in the extracellular fluid (see Figure 7.5). Potassium is the primary cation in the ICF, with sodium being present but at a much lower concentration. This distribution is opposite that of the ECF, and represents an important concentration differential for each ion. Because of these concentration differences, there is constant pressure for sodium to leak into cells and for potassium to leak out of cells. Normal intracellular and extracellular concentrations are maintained by the action of the sodium-potassium pumps located in the cell membranes, which constantly pump sodium ions out of the cells, while simultaneously pumping potassium ions back into the cells. The major anions inside the cells are phosphate and the negatively charged intracellular proteins.

It is important to note that while the ionic composition differs between the ICF and the ECF, the osmolarity or total concentration of all solutes in those compartments is generally the same. Shifts in fluid between the ECF and ICF occur solely due to osmosis, the movement of water from an area of lower concentration to an area of higher concentration. Under normal homeostatic conditions, the osmolarities of the ECF and ICF are the same, and there is no net movement of water. However, if the concentration in either compartment changes, a fluid shift may occur. If sodium increases in concentration in the extracellular fluid, water would move by osmosis out of the cells and into the ECF in an attempt to dilute the extracellular fluid and restore balance. For example, heavy sweating can cause a large loss of plasma volume due to water loss, resulting in an increased concentration of sodium in the plasma. This stimulates movement of water out of the cells (i.e., ICF) and into the plasma (i.e., ECF), causing the cells to shrink. Conversely, if the concentration of sodium in the extracellular fluid is decreased, the osmolarity of the ECF would be less than that in the cells, and water would move by osmosis into the cells in an attempt to correct the concentration imbalance. The resulting movement of water into the cells would cause the cells to expand.

The concentration of solutes, or osmolarity, in a particular fluid is not static, and it can sometimes change relatively quickly. The concept of tonicity describes this change in solute concentration. Recall that isotonicity refers to a concentration of solutes that are equal to each other. Water will pass in and out of the cell, but the net movement of water will be zero. When a fluid has a higher concentration of solutes compared to another fluid, it is said to be hypertonic. For example, when a person sweats heavily, there is a loss of water from the extracellular fluid and the ECF becomes hypertonic in relation to the intracellular fluid. The opposite concentration difference is called hypotonic, when a fluid has a lower osmolarity than the reference fluid. If a person consumes a large amount of water very quickly, this water is absorbed into the extracellular fluid, resulting in a dilution of the ECF and making it hypotonic compared to the intracellular fluid (see Figure 7.6).

If one understands how water moves by osmosis, one can easily understand how fluid shifts in the body. The movement of fluid occurs as a result of controlling the amount of water in the ECF and the osmolarity of the ECF. The amount of water and the osmolarity in the ECF is controlled by water intake and loss, sodium intake and loss, and by compensatory regulatory mechanisms in the kidney and gastrointestinal tract.

What's the point? Water will move from an area higher to lower pressure or from an area of lower to higher solute concentration.

WATER LOSS AND WATER INTAKE

Fluid balance in the body is partially a result of the daily balance of water intake and water loss. There are a limited number of avenues for water intake, but a wider variety of ways that water may be lost from the body (see Figure 7.7).

Water Loss. Water loss from the body is generally categorized as either **insensible** or **sensible.** Insensible refers to avenues of loss that are not normally noticed by the individual, including water lost through ventilation and through nonsweat diffusion through the skin. With each breath, the inspired (i.e., inhaled) air is humidified to protect delicate lung tissues from drying. The water vapor that is added is then lost with the subsequent expiration, because the water is not recaptured before the air is exhaled from the body. This water loss is typically not noticed except on cold days when we can "see our breath." When warm, humid air from the lungs is rapidly cooled by the cold air outside, water vapor condenses into water droplets that can be readily seen. Water losses by this route can increase in environments in which the air is colder and drier, as more water vapor needs to be added to the inspired air. Increased levels of ventilation as a result of exercise may also cause an increased insensible loss of water.

Skin must be kept moist to prevent drying and cracking, and some of the water that diffuses into the

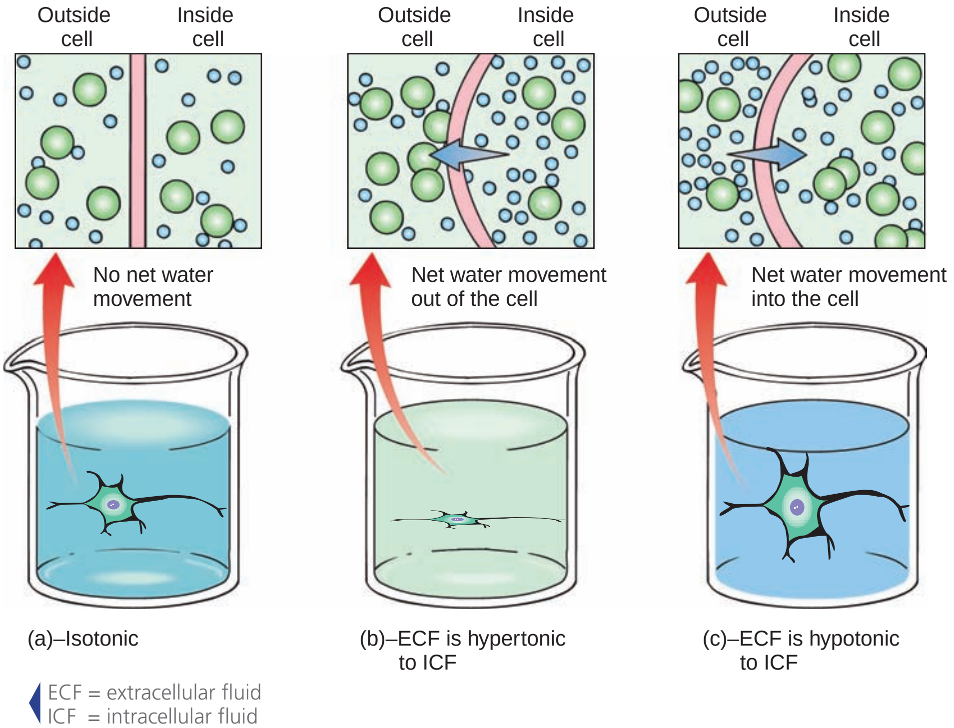


Figure 7.6 Isotonicity, Hypertonicity, and Hypotonicity

One avenue of water loss is through ventilation.

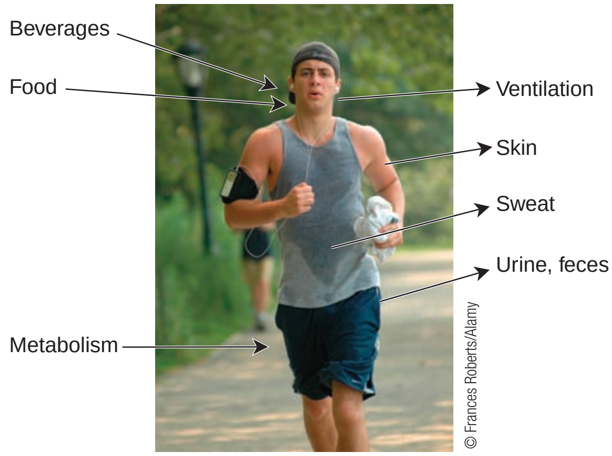


Figure 7.7 Avenues of Water Gain and Loss

Water can be gained by the body through the consumption of food and/or beverages, and as a result of metabolism. Water can be lost via ventilation, insensible loss through the skin, sweating, and urine and fecal losses.

skin is lost from the body. Water loss by this mechanism may also increase in dry environments with low humidity. Total insensible water losses average approximately 1,000 milliliters (ml) or ~36 oz (~4.5 cups) per day for the average person.

The three major areas of sensible water loss are the fluid lost in urine, feces, and sweat (see Figure 7.7). The amount of water in feces is variable, but daily loss by this route averages approximately 100 ml (~3.5 oz) per day. This is not typically a major avenue of water loss by the body, unless an individual has a disease such as dysentery that results in large volumes of watery diarrhea.

The renal system provides the major physiological mechanism for controlling fluid balance in the body via the production and excretion of urine. Urine output can vary dramatically, but for the average person under homeostatic conditions it approximates 1,500 ml per day (~54 oz or 6–7 cups). The amount of renal water loss

Insensible: Imperceptible.

Sensible: Perceptible.

is highly variable, and can be influenced by the amount of fluid and salt intake, renal function, the action of various hormones, and by the consumption of compounds that have a **diuretic** effect.

A diuretic is a substance that increases urine output. All fluids can have a diuretic effect. Water is a diuretic if a person is in fluid balance and ingests a large volume of water. However, the focus is generally on substances that exert a diuretic effect by a mechanism in addition to an increased volume of fluid. For example, alcohol has a mild diuretic effect because it inhibits the production of antidiuretic hormone (ADH). Nearly 200 herbs are known to have a diuretic effect. Some diuretics are prescription medications (e.g., Lasix™) and can block the reabsorption of fluid and/or electrolytes from the renal tubules. These substances may have a substantial effect on hydration status, and athletes are cautioned about their use especially if they are already hypohydrated.

Caffeine (found in caffeinated coffee and some soft drinks) and theophylline (found in tea) increase urine output by increasing the blood flow in the kidneys and increasing sodium and chloride excretion. In the past, athletes were cautioned about consuming these beverages because they are mild diuretics, but avoidance is no longer recommended. Armstrong (2002) reviewed studies of caffeine ingestion and the effect on fluid and electrolyte imbalance. Based on the current body of scientific literature, a daily caffeine intake of 300 mg or less does not have a negative effect on fluid or electrolyte balance. The caffeine content of brewed coffee can vary, but a rule of thumb measurement is that an 8-oz cup of caffeinated coffee contains approximately 100 mg of caffeine. Thus, 1 to 3 cups of caffeinated coffee daily (or the equivalent from other beverages) as part of a normal diet is not considered detrimental to euhydration, and it is no longer recommended that caffeine be completely avoided by athletes. This level of caffeine intake would also be unlikely to result in a positive urinary caffeine test when caffeine is listed by a sports-governing body as a banned substance. More information about caffeine and alcohol can be found in Chapter 10.

Another highly variable avenue of water loss is sweating, one of the body's major thermoregulatory mechanisms. Sweat is water that is secreted from sweat glands onto the surface of the skin. When this water evaporates (i.e., changes from water to water vapor), it results not only in a loss of water, but in a transfer of heat away from the body. If an individual is not in a hot environment, sweating is minimal and water loss by this mechanism averages approximately 100 ml (~3.5 oz) daily. As environmental temperatures rise and/or activity increases, thermoregulatory demands increase, and water loss via sweating increases. It would not be uncommon for active adults in hot and/or humid environments to lose several liters of water each day through sweating. The effect of exercise and activity on water loss will be discussed in greater detail later in this chapter.

In many athletes the loss of water through sweating is very visible, but in others it may not be as noticeable. Athletes that compete and train in the water, such as swimmers and water polo players, may sweat as part of their thermoregulatory response, but this avenue of water loss is not readily apparent. One study of elite male water polo players showed an average sweat rate of 287 ml per hour during training and 786 ml per hour during competitive matches. The same study showed elite male and female swimmers having an average sweat rate during training of 138 ml and 107 ml per kilometer swum, respectively (Cox et al., 2002). The hydration needs of these athletes should not be overlooked.

Water Intake. The addition of water to the body is primarily accomplished through the fluid content of beverages and foods consumed each day, and secondarily through metabolism (see Figure 7.7). On average, an adult will take in approximately 2,350 ml (~84 oz or 10.5 cups) of water each day from beverage and food sources, but there can be considerable variation depending on how much an individual eats and drinks. The water content of foods can vary dramatically, as can be illustrated by comparing watermelon (~90 percent water) and bran cereal (~2 percent water). Beverages also vary in their water content. Water, coffee (black), and tea (plain) are 99 percent water with a small amount of minerals and other compounds accounting for the remaining 1 percent. A sports beverage such as Gatorade Thirst Quencher® contains 93 percent water and fruit juice is approximately 88 percent water (the remainder is mostly sugar). Milk, depending on the fat content, ranges from 88 to 91 percent water, with the remainder being substances such as proteins and minerals. All beverages are predominately water, but each can have a different effect on fluid balance and osmolarity because of the other substances contained.

Another source of water is a result of aerobic metabolism. As explained in Chapter 3, in the metabolic pathway of oxidative phosphorylation, oxygen is required in the mitochondria to be the final electron acceptor at the end of the electron transport chain. Oxygen (O) molecules pick up the electrons in the form of hydrogen (H) molecules, and are thus converted to water (H_20). Aerobic metabolism contributes approximately 350 ml (~12.5 oz) of water each day. For the average adult in homeostasis, approximately 2,700 ml (~96 oz or 12 cups) of water are consumed or produced by the body each day via food and beverage intake and metabolism.

WATER BALANCE AND IMBALANCE

The amount of water in the body is constantly changing, with fluid being added and removed through the mechanisms discussed above. The body is said to be in fluid balance if a sufficient amount of fluid is present that allows for the body to function normally. Although

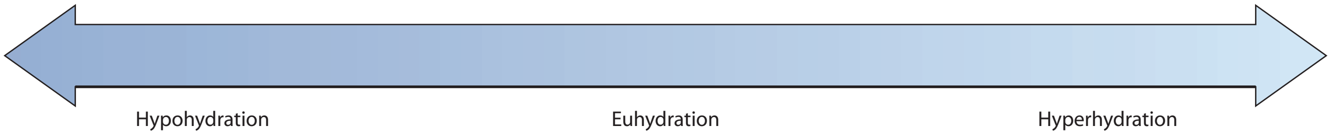


Figure 7.8 The Fluid Continuum

The amount of water in the body lies along a continuum, from hypohydration (too little) to hyperhydration (too much), with the optimal amount called euhydration.

the body has sensitive mechanisms to maintain fluid balance over time, it is possible to exceed the capabilities of these mechanisms either in the short or long term. In general, the amount of fluid consumed is not carefully matched to the body's daily needs. The usual overall strategy is to drink an excess of water, retain what is needed to maintain fluid balance, and excrete the excess. Deviations from this basic strategy can result in imbalances.

Euhydration, Hypohydration, and Hyperhydration. The amount of water in the body lies along a continuum, from too little to too much. Euhydration, hypohydration, and hyperhydration are terms that describe the status of body water, although these terms refer to a general condition rather than to a specific amount of water (see Figure 7.8). Because of the difficulties of measuring total body water and the variability between individuals, specific dividing lines between these conditions on this continuum have not been identified. The discussion that follows assumes that a person is healthy and has normal kidney function.

Euhydration refers to a "normal" amount of water to support fluid balance and to easily meet required physiological functions. Enough water is present to maintain osmolarity of the extracellular fluid, prevent large water shifts between compartments, and support critical processes such as cardiovascular function and thermoregulation. As previously discussed, this optimal level of hydration is typically achieved by consuming fluids in excess of need and allowing the renal system to excrete the unneeded amount.

Hyperhydration refers to body water above that considered normal and is typically a short-term condition. Acute hyperhydration can be achieved by consuming excess fluids, but the renal system usually acts quickly (within minutes to hours) to excrete the excess water by forming greater volumes of urine. For example, a person who drinks 500 ml (~ 18 ounces or 2.25 cups) of water with lunch will usually need to urinate by the middle of the afternoon.

Consumption of certain osmotic substances such as glycerol along with excess water may slightly prolong the state of hyperhydration. This induced hyperhydration is a strategy that may be employed by athletes to aid thermoregulation when competing in hot environments, and is discussed later in this chapter.

Consumption of large amounts of water very quickly (e.g., 3,000 ml or ~ 104 oz or ~ 13 cups in four hours, as some slow marathon runners have done) can result in a state of hyperhydration that can actually be dangerous to one's health, and can even result in death (Almond et al., 2005). The excess water dilutes the concentration of solutes in the extracellular fluid. Before the kidneys have a chance to excrete the extra water, the reduced osmolarity in the ECF provokes a shift of water from the ECF into the cells, causing them to swell. Nerve cells, especially those in the brain, are particularly sensitive to this swelling and may cease to function properly, resulting in impaired brain function, coma, or even death. This condition can occur during certain types of endurance exercise and is discussed later in this chapter (see Hyponatremia).

Hypohydration is the term used to describe body fluid levels that are below normal or optimal. It is the result of either an inadequate intake of water, excessive loss of water, or a combination of both. Hypohydration is a relative term (compared to euhydration) and is not defined as a certain amount of body water below euhydration. Hypohydration occurs initially in the ECF, which results in an increased concentration of solutes in the ECF due to a relative lack of water. Because the osmolarity of the ECF increases, water shifts from the cells to the ECF in an attempt to balance the solute concentrations between these two fluid compartments. When water levels decline in the cells, the cells shrink and this shrinkage may impair cellular function. Hypohydration may have severe adverse effects on exercise performance and thermoregulation, so athletes need to be especially conscious of ways to prevent excessive hypohydration. The term dehydration is commonly used interchangeably with hypohydration, but it is more accurate to use the term dehydration to describe the *process* of moving from a state of euhydration to a state of hypohydration.

SODIUM INTAKE AND EXCRETION

Fluid levels in the body are regulated by both the volume of water and the osmolarity of the extracellular fluid. Sodium is the most important electrolyte in the

Diuretic: Causing an increased output of urine.

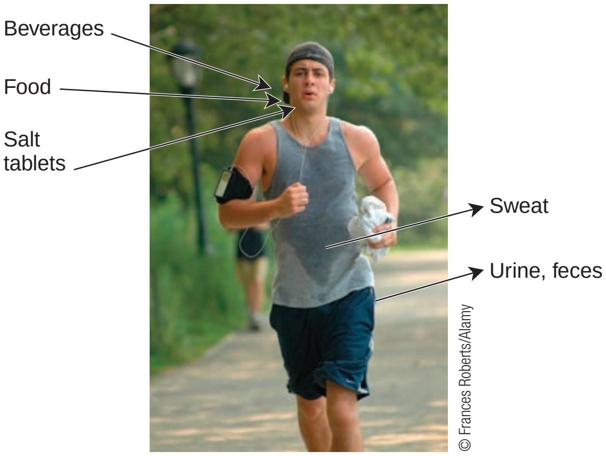


Figure 7.9 Routes of Sodium Intake and Excretion

Sodium intake occurs with the consumption of sodium-containing foods and beverages, or rarely, salt tablets. Sodium can be lost via sweat, urine, and feces.

extracellular fluid because it exists in the largest amount and directly affects osmolarity. The body must respond to changes in the amount of sodium in the ECF by adjusting water volume. An increase in sodium in the ECF will increase the volume of water and a decrease in sodium will result in a decrease in ECF water volume.

The only route of intake for sodium is by ingestion, either through foods, fluids, or rarely, salt tablets (sodium chloride). Similar to water, sodium is generally consumed in excess of the body's requirements and the body relies on the renal system to excrete what is not needed (see Figure 7.9). Many factors influence the amount of sodium in the diet, but the largest factor in industrialized countries is the consumption of processed foods at home and at restaurants. For the average American adult, processed food is the source of 77 percent of daily sodium intake. The addition of table salt (i.e., sodium chloride) to foods accounts for approximately 11 percent of daily sodium intake. The remaining sodium (~12 percent) occurs naturally in water and in foods such as milk, vegetables, and grains (Institute of Medicine, 2004).

There is considerable variation in sodium intakes among men and women in the United States and around the world. Consumption can be reported as either sodium or salt intake, which often causes confusion because these terms are not the same. Intakes are routinely reported in both milligrams and grams, which adds to the confusion.

The highest reported consumption worldwide is in Northern Japan where intake of sodium is estimated to be more than 10,000 milligrams (mg), or 10 g, daily due to the salting and pickling of foods. The average daily intake of sodium in the United States is approximately 4,200 mg (4.2 g) for men and 3,300 mg (3.3 g) for women.

For most people in the United States, sodium is consumed in the form of sodium chloride (e.g., salt added to food) and this sometimes leads to the reporting of salt intake rather than sodium intake. One gram (i.e., 1,000 mg) of salt contains ~40 percent sodium or ~400 mg of sodium. One-fourth teaspoon is the equivalent of 1.5 g of table salt, thus, this amount of salt contains 590 mg of sodium. It is easy to see how adding salt to food results in a high sodium intake. Reported salt intake by U.S. men is approximately 10 g per day, but for some salt intake may be as high as 25 g daily.

The Dietary Reference Intake for sodium for adults under the age of 50 is 1,500 mg (1.5 g) daily. The Tolerable Upper Intake Level is 2,300 mg (2.3 g) daily. These recommendations are made to the general population to reduce the prevalence of high blood pressure associated with aging. However, the Institute of Medicine (2004) clearly states that these recommendations do not apply to highly active individuals who lose large amounts of sweat daily. Sodium intake and hypertension are discussed in Chapter 12.

Sodium intake by athletes varies, based on caloric intake and choice of foods. Low caloric intake may mean lower sodium intake. For example, the daily energy intake of 19 New Zealand jockeys was approximately 1,500 kcal while the average sodium intake was approximately 1,900 mg (1.9 g) (Leydon and Wall, 2002). As caloric intake increases, sodium levels rise, so even an athlete who is careful about avoiding high-sodium foods (e.g., soy sauce, fast foods, salty-tasting snacks) may find that sodium intake is above 3,000 mg (3 g) daily. Some athletes consume fairly high levels of sodium (e.g., ≥5,000 mg or 5 g), especially if they add table salt to their food.

While sodium intake may not be carefully matched to need, urinary sodium excretion is precisely controlled to maintain proper ECF osmolarity. Sodium is regulated by the kidneys and can either be reabsorbed or excreted in the urine. Because sodium intake usually far exceeds daily needs, a large amount of sodium is excreted in the urine to maintain sodium balance. Average urinary sodium excretion is approximately 1 to 5 g per day. More information about renal function can be found in a human physiology text such as Sherwood (2007).

A small amount of sodium is lost each day in sweat and feces. This obligatory loss amounts to approximately 0.5 g (500 mg) per day. Sodium loss can increase substantially if there is heavy sweating and will be discussed later in this chapter.

Popcorn, pretzels, nuts, and chips typically have salt (sodium chloride) added, although low-salt varieties are available.

POTASSIUM INTAKE AND EXCRETION

Potassium, the primary intracellular cation, is consumed via foods and beverages or occasionally, through the use of salt substitute (i.e., potassium chloride). Potassium is abundant is unprocessed foods such as fruits, vegetables, whole grains, beans, and milk. Low dietary potassium intake in the United States is a reflection of a low daily fruit and vegetable intake, a pattern that is typical of approximately two-thirds of the adult population. It is also a result of the high intake of processed foods; processing results in substantial potassium losses. Examples of foods with a high potassium content include bananas, orange juice, and avocadoes. Potassium found in food is well absorbed from the gastrointestinal tract (greater than 90 percent absorption).

An Adequate Intake (AI) for adults is 4,700 mg daily. The average daily intake in the United States is approximately 2,200 to 2,400 mg for women and 2,800 to 3,300 mg for men. With such low average intakes, it is likely that some adults in the United States will have a moderate potassium deficiency. Such a deficiency is associated with increased blood pressure (see Chapter 12) and increased bone turnover due to an increase in urinary calcium excretion. However, a moderate potassium deficiency is hard to detect with laboratory tests because blood potassium concentration will remain within the normal range (3.5 to 5.0 mmol/L) (Institute of Medicine, 2004).

Athletes who are concerned about the potential for a moderate potassium deficiency should focus on consuming a variety of fruits and vegetables daily. Self-prescribed potassium supplements are not recommended because of the potential for hyperkalemia (i.e., elevated blood potassium concentration), which has been occasionally reported in bodybuilders (Perazella, 2000; Appleby, Fisher, and Martin, 1994; Sturmi and Rutecki, 1995).

Hypokalemia, a severe deficiency state, is defined as a blood potassium concentration less than 3.5 mmol/L and would be a rare occurrence in an otherwise healthy individual. Symptoms include muscle weakness and cardiac arrhythmias, which can be fatal. Hypokalemia is *not* a result of low dietary intake because the amount consumed in food is high enough to prevent this condition. Rather, hypokalemia is a result of substantial potassium loss, usually through severe and prolonged vomiting or diarrhea or the use of potassium-depleting diuretic drugs without adequately replenishing potassium.

Under normal conditions the primary pathway for potassium loss is urinary excretion, while small amounts are lost in the feces and sweat. The kidneys precisely control the amount of potassium either reabsorbed or excreted. Problems occur when potassium is lost atypically. For example, an athlete who is struggling with an eating disorder may frequently self-induce vomiting, which over time could result in hypokalemia, cardiac arrhythmias, and death.

While there are several electrolytes involved in fluid and electrolyte balance, the initial dietary focus tends to be on sodium and potassium. Two other cations—calcium and magnesium—are discussed in Chapter 9. The corresponding anions, such as chloride and phosphate, receive little dietary attention. The chloride content of the diet can be reasonably well predicted from salt intake and phosphorus is widely found in food. A dietary deficiency of either would be extremely rare.

Effect of Exercise on Fluid Balance

Under normal conditions, most healthy sedentary individuals regulate their fluid balance (i.e., achieve homeostasis) relatively easily. Thirst and hunger mechanisms usually lead people to consume water in excess of the body's daily needs, with the excess being excreted. If there is a shortfall in fluid consumption, the body can respond in the short-term by reducing urine excretion, which conserves water and maintains fluid balance.

Exercise challenges fluid homeostasis because of the critical role that body fluids play in thermoregulation (maintaining an appropriate body temperature). Exercise causes an increase in body temperature, and a major mechanism for lowering body temperature is the evaporation of sweat. The loss of fluid through sweat may have a large impact on fluid balance, both in the short and long term. Physical activity or exercise, especially in hot and humid conditions, represents a substantial challenge for the regulation of body temperature, fluid homeostasis, and, subsequently, performance (Armstrong and Epstein, 1999).

In contrast to sedentary individuals who can regulate their fluid balance easily, athletes may have a difficult time preventing dehydration and severe hypohydration. These conditions can negatively impact training, performance, and health (Hargreaves and Febbraio, 1998).

WATER LOSS DURING EXERCISE

Exercise can result in water shifting between compartments within the body and in accelerated loss of body water. As the cardiovascular system adjusts to the demands of exercise to increase blood flow and oxygen delivery, the increased pressure in the blood vessels results in some of the fluid leaking into the surrounding interstitial space. This fluid is lost from the plasma and plasma volume therefore declines slightly as the water shifts within the extracellular fluid compartments. This decrease in plasma volume occurs within the first few minutes after exercise begins with the amount being largely dependent upon the exercise intensity. The decline may be up to approximately 5 percent of plasma volume if the exercise is intense. As explained earlier, an average adult male has approximately 2.8 L of plasma. A 5 percent loss would be approximately 140 ml (5 oz) of water, an amount that would not likely impair exercise performance. However, plasma volume losses up to 10 to 20 percent can occur with prolonged exercise, and losses of this magnitude may compromise cardiovascular function and ultimately reduce exercise performance (Convertino, 1987).

Exercise can cause substantial dehydration through increased sweating. The increase in energy expenditure associated with physical activity and exercise results in an increase in heat production. To prevent this heat load from causing an excessive increase in body temperature, heat loss mechanisms must be activated, one of which is sweating. As the internal (core) temperature of the body rises, sweat glands are stimulated to secrete sweat to reduce the heat load. A review of thermoregulation may be beneficial at this point (see Sherwood, 2007), but in short, when sweat evaporates from the surface of the skin, heat is transported away from the body. It is not uncommon for body temperatures to rise to 39° or 40°C (102°F to 104°F) during exercise, even in temperate climates (see Figure 7.10) (Hamilton et al., 1991).

The rate at which the body loses water through sweating depends upon a variety of factors. Exercise intensity can influence sweat rate through its independent effect on core temperature. At any given room temperature, increased exercise intensity results in higher body temperatures, and higher body temperatures will stimulate higher sweat rates. Increased exercise intensity requires higher energy expenditure, which results in a greater amount of metabolic energy being converted to heat.

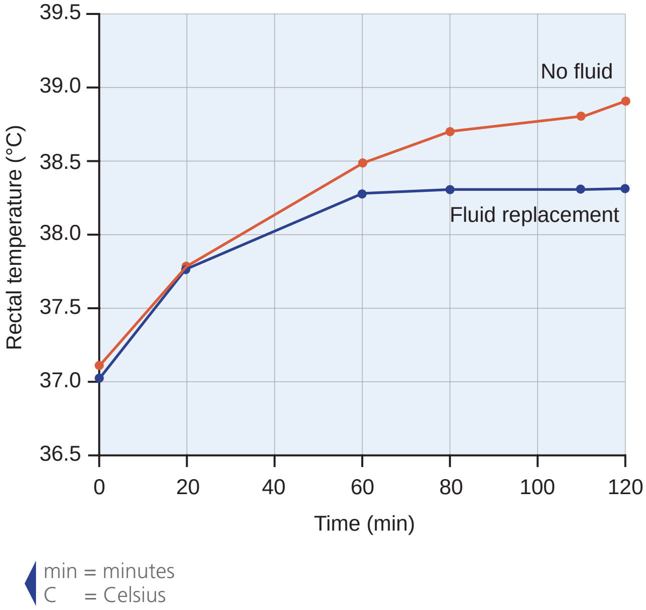


Figure 7.10 Rise in Rectal Temperature during Exercise.

Body temperature rises with exercise, but replacing fluid to prevent dehydration prevents the excessive rise in body temperature that occurs when no fluid is consumed.

Environmental conditions can also dramatically influence sweat rate. Independent of exercise intensity, higher **ambient** temperatures result in higher core temperatures and higher sweat rates. The relative humidity, or amount of water vapor in the air, can also influence sweat rate and can make fluid loss by sweating more visible. Increased water vapor in the air reduces the ability of sweat secreted onto the skin to be evaporated, and it is the *evaporation* of sweat, not just the process of sweating that leads to heat transfer. When conditions are more humid, sweating is a less effective means of thermoregulation and body temperatures may be higher, resulting in a stimulus for an even higher sweat rate.

Clothing, uniforms, and protective gear may further influence the rate of sweating by providing a barrier to heat loss. This type of clothing may provide an insulating effect, trapping more heat in the body or it may adversely affect the evaporation of sweat by reducing the surface area of the skin that is exposed. Athletes in sports with certain uniform traditions or requirements may be at greater risk for heat injury and fluid imbalances. Football uniforms provide an excellent example. They generally cover most of the skin and have thick padding in many places that can have an insulating effect. Protective gear such as helmets, arm wrappings, padding, and gloves add to the thermoregulatory challenge and may result in

Imagestate Ltd/Photolibrary

Firemen work in high temperature environments and wear protective clothing that adversely affects the evaporation of sweat.

Nick Laham/Getty Images

This heavily favored Olympic marathoner was unable to finish the race, which was held in hot and humid conditions.

greater fluid loss through sweat. Other examples include the fire protection gear worn by firefighters, hazardous materials suits worn by public safety workers, and chemical warfare protection suits worn by military personnel.

The training status of the athlete and the degree of acclimation to the heat are also important factors affecting sweat rate. Because of regular training and the increased demands for thermoregulation, trained athletes typically have higher sweat rates than do sedentary individuals (Armstrong, Costill, and Fink, 1987). Trained athletes will start sweating sooner as body temperature begins to increase and will sweat at a higher rate, so they have a greater potential for water loss through sweating. The advantage, of course, is that they have a more effective mechanism for controlling their body temperature. Exposure to higher ambient temperatures during training (e.g., a hotter climate) results in a number of adaptations that improve thermoregulation, one of which is an increased sweat rate.

Obviously, there are a variety of factors that can influence sweat rate, either alone or in conjunction with one another. Just how much fluid can a person lose through sweating? As discussed earlier, an adult that is performing usual occupational activities throughout the day in a temperate (normal room temperature) environment may lose approximately 0.1 L (100 ml or ~ 3.5 oz) of water each day as sweat. If that person performs those same daily activities in a hotter, more desertlike environment (high temperature but low relative humidity), sweat loss will increase into a range of 0.3 to 1.2 L (300–1,200 ml or ~ 10–43 oz or ~ 1–5 cups) per *hour*. The addition of protective clothing such as the firefighter's suit can result in sweat rates of 1.0 to 2.0 L (1,000–2,000 ml or 36–71 oz or ~ 4.5–9 cups) per hour. Sweat rates in excess of 2.5 L (2,500 ml or ~ 89 oz or ~ 11 cups) per hour have been observed in athletes competing in team sports (e.g., soccer) and in individual athletes engaged in prolonged endurance sports (e.g., marathon running) in hot environments (Armstrong and Maresh, 1998).

Consider a world-class female runner competing in the Olympic Marathon, which is contested during the Summer Games, often in hot and humid conditions. She will run for a little over two hours and could lose approximately 2 L of sweat per hour or a total of 4 L of water! This may approach 10 percent of total body water or almost 10 pounds of water weight loss in a 100-pound runner if she were to consume no fluids. With such a sweat rate, it is easy to see how large amounts of fluid can be lost very quickly under certain exercise or environmental conditions. Because fluid homeostasis is a balance of water intake and loss, fluid intake is essential. But can an athlete prevent overall fluid loss when sweating heavily by drinking water or other fluids?

Unfortunately, it is very difficult to match water intake with water loss when exercising in hot and humid conditions for several reasons. Most people will experience "voluntary dehydration" and will not consume enough fluid during the activity to match the amount of fluid being lost. Voluntary dehydration occurs because the human thirst mechanism responds too slowly and does not have enough precision to stimulate drinking enough fluids to compensate for the high rate of fluid loss. If fluid loss exceeds fluid intake, athletes will gradually dehydrate, but they do not feel thirsty initially.

Even if athletes are encouraged to consume more fluid than they would likely take in of their own volition, the rate at which the water can be emptied from the

Ambient: In the immediate surrounding area.

stomach and absorbed from the gastrointestinal tract may be less than the rate of fluid loss due to sweating. The maximal rate of gastric emptying (how fast the fluid leaves the stomach) appears to be less than the maximal rate of absorption from the intestines, and therefore limits the overall rate of fluid intake (Sawka and Coyle, 1999). The maximal rate of gastric emptying for an average-sized adult male is approximately 1.0–1.5 L per hour. This rate may be slightly reduced with high-intensity exercise and with an increased heat load.

Some level of activity or movement may actually aid gastric emptying through agitation of the stomach contents, and exercise up to approximately 70 percent of an athlete's maximal oxygen consumption generally does not have an adverse effect on fluid uptake. More intense exercise may impede gastric emptying, though, and delay the replacement of water and carbohydrate. Compared to bouts of low-intensity exercise (walking), athletes that performed intermittent, high-intensity exercise that mimicked the intensity of a soccer match showed a significant decline in the gastric emptying of a beverage that contained carbohydrate as well as a noncarbohydrate beverage (Leiper et al., 2005).

Therefore, even if athletes are encouraged or even forced to consume fluids in an attempt to match fluid loss, there is usually a gradual fluid loss because intake and absorption cannot keep pace with loss. It is not uncommon for athletes exercising under these conditions to lose 2 to 6 percent of their body weight during the activity. It is important to attempt to match the amount of fluid lost during exercise with appropriate fluid intake strategies. It is also very important to pay attention to rehydration strategies after the activity to ensure a return to euhydration.

What's the point? Athletes should plan their fluid intake strategies with the goal of replacing fluid losses during exercise; however, it may not be possible to replace fluid as fast as it is being lost.

While much attention is paid to exercising in hot and humid environments, substantial fluid loss can occur with exercise in cold climates as well (e.g., winter sports, mountain climbing). Water loss from ventilation is usually greater in cold environments because the air is dry (low relative humidity) and the body must add more water vapor to the cold, dry air that is inspired. If the individual's ventilation is elevated during exercise, a large portion of this water is lost through exhalation. Activities requiring a high energy expenditure will result in elevations in body temperature even in cold temperatures. Participants need to carefully consider the clothing they wear, as clothing that is sufficiently warm at rest may prove to be too warm during exercise or activity, resulting in increased sweating and fluid loss.

EFFECT OF HYPOHYDRATION AND REHYDRATION ON CORE TEMPERATURE

Dehydration, or moving to a state of hypohydration as a result of fluid loss, can have an adverse impact on core temperature and ultimately on exercise performance (Sawka et al., 1998). When there is a loss of body water, the majority of the water comes initially from the ECF, specifically from the plasma. Therefore, as body water is lost through heavy sweating, there is a gradual loss of blood volume, a condition known as **hypovolemia.** Because sweat is hypotonic in relation to blood, fewer electrolytes and other solutes are lost in sweat in proportion to the amount of water lost. In this case, the plasma that remains is more concentrated and its osmolarity increases. Both of these conditions may adversely affect thermoregulation and exercise performance.

The main function of blood flow is to deliver oxygen-laden blood to tissues and the need for oxygen delivery is greatly increased during exercise, particularly in the exercising muscles. Blood flow also helps to control body temperature, and this thermoregulatory function is used to a greater extent during exercise in the heat. A finite and relatively small amount of blood is available to fulfill both these functions, and exercise in the heat sets up a competition for this limited resource. The situation gradually becomes worse as the athlete dehydrates because total blood volume continues to decline.

A state of hypohydration will result in an increased core temperature during exercise, in the heat and even in normal ambient conditions. A loss of only 1 percent body weight as water can result in measurable increases in body temperature, and the greater the loss of body water, the greater the increase in temperature. It is estimated that for every 1 percent of body weight that is lost as water, core temperature will be elevated 0.1°C–0.23°C (Sawka and Coyle, 1999).

It is critical for performance that athletes remain well-hydrated, because the adverse effects of hypohydration may offset the benefits gained by having a higher aerobic fitness level or by becoming acclimated to the heat. When hypohydrated, heat dissipation ability is impaired, resulting in higher body temperatures. At the same body temperature (i.e., same level of stimulus) the hypohydrated athlete will experience a decrease in whole-body sweating rate and a decrease in skin blood flow, which can substantially narrow the two main avenues of heat loss.

In addition to the declining blood volume, fluid loss may also adversely affect body temperature through the increase in osmolarity of the blood. The portion of the brain that controls the body's thermoregulatory responses is in the hypothalamus. The blood becoming hypertonic may have a direct effect on the cells in this region of the brain and their ability to maintain body temperature. The worst-case scenario of increasing core temperature and deteriorating thermoregulatory control is **hyperthermia** (abnormally high body temperature), which may lead to coma and death (e.g., heat stroke).

Some athletes manipulate fluid intake and fluid balance in an effort to "make weight." For example, wrestlers may restrict fluid and food intake while engaging in excessive exercise, wearing clothing while exercising that increases body temperature and sweating, and taking diuretics. While the goal may be weight loss through dehydration, the result may be hyperthermia. Tragically, some wrestlers have died from hyperthermia because of these practices (Centers for Disease Control and Prevention, 1998). (See Spotlight on Enrichment: Intentional, Rapid Dehydration.)

Hypovolemia: Less than the normal volume.

Hyperthermia: Abnormally high body temperature.

SPOTLIGHT ON ENRICHMENT

Intentional, Rapid Dehydration

Athletes who must meet certain weight classifications and have their weight certified before competition include wrestlers, boxers, and lightweight rowers. There is a long history in these sports of using dehydration as a rapid weight loss method. In 1990, Steen and Brownell surveyed college (n = 63) and high school (n = 368) wrestlers to assess weight loss practices and concluded that traditional practices used to "make weight" were still being employed. Some of the common practices were dehydration, fasting, and restriction of food intake. Practices that were less common but used by some wrestlers included vomiting and the use of laxatives and diuretics. The survey documented what had long been suspected: "weight" loss was rapid, large, and frequent, and after the target weight was met, rapid weight gain followed. Forty-one percent of the collegiate wrestlers reported weight fluctuations of ~11 to 20 pounds (~5 to 9 kg) each *week* throughout the season. For high school wrestlers the weekly losses were smaller, ~6 to 10 pounds (2.7 to 4.5 kg), and reported by fewer athletes (23 percent), but suggested that such practices had their roots early in the athletes' competitive careers.

In 1994, Scott, Horswill, and Dick found that collegiate wrestlers competing in the season-ending NCAA tournament gained a substantial amount of weight between weigh-in and competition (approximately 20 hours apart). In this study wrestlers gained an average of 4.9 percent of body weight, with the wrestlers in the lower weight categories gaining the most weight. In 1996, the American College of Sports Medicine (Oppliger et al., 1996) published a Position Stand on weight loss in wrestlers, in which concern was expressed about rapid and large weight losses and the methods used to achieve them and called for rule changes that would help to limit these losses.

During a one-month period in 1997, three collegiate wrestlers, ages 19, 21, and 22, died from hyperthermia. The accounts of their precompetition preparation were remarkably and tragically similar. They restricted food and fluid intake, wore vapor-impermeable suits under their warm-up clothing to promote sweating, and engaged in excessive exercise. In the case of the 19-year-old, his preseason weight was 233 lb (105.9 kg) and he was attempting to "make weight" to compete in the 195-pound weight class. He needed to lose 15 lb (6.8 kg) over a 12-hour period. The 22-year-old wrestler's preseason weight was 178 lb (80.9 kg). He had lost 8 lb (3.6 kg) in the four previous days but was attempting to lose 4 additional pounds (1.8 kg) in four hours. Rectal temperature at the time of death was 108°F (42°C). The third victim had a preseason weight of 180 lb (81.8 kg) and had lost 11 lb (5 kg) over a three-day period. He was attempting to lose 6 additional pounds (2.7 kg) in three hours so he could wrestle in the 153-pound weight class. When he began his attempt he weighed 159 lb (72.2 kg). After 90 minutes of exercise he had lost 2.3 lb (1 kg) and lost an additional 2 lb after another 75 minutes of exercise. After a short rest he began exercising again in an effort to lose the remaining weight, 1.7 lb. He collapsed and died from cardiorespiratory arrest. A postmortem laboratory analysis indicated that blood sodium concentration was 159 mmol/L, far above the normal range (136 to 146 mmol/L) and a sign of severe dehydration (Centers for Disease Control and Prevention, 1998).

These deaths were the first documented collegiate wrestling deaths, and they did for the sport what no amount of research studies, position stands, or previously expressed concerns could do—raise awareness at all levels of the sport and promote change in wrestling rules. For example, the NCAA instituted new rules for collegiate wrestlers in the 1997–98 season and high schools have since adopted rules to prevent rapid, large weight (water) losses and large weight fluctuations. By measuring specific gravity in urine and monitoring percent body fat changes over the course of the season, these sports-governing bodies are making good on their promises to try and stop the use of large and rapid fluid losses as a method of weight loss. These new rules are reducing the prevalence of rapid and large weight losses (Oppliger et al., 2006).

Hypohydration clearly affects body temperature, but what effect does it have on exercise performance? In general, a loss of more than 2 percent of body weight can be detrimental, especially when exercising in the heat, because physical and mental performance is reduced. However, there are individual variations that result in some people being more or less tolerant to changes in hydration status (Sawka et al., 2007).

Maximal aerobic power ($\dot{V}O_{2max}$) and endurance performance are reduced when an athlete is hypohydrated. With a loss of 3 percent or more of body weight as water, measurable reductions in $\dot{V}O_2$ can be observed. Losses of body water less than 3 percent of body weight are not typically associated with decreased $\dot{V}O_{2max}$ when the athlete is tested in normal ambient temperatures. When tested in the heat, however, modest fluid losses of 2 to 4 percent of body weight can result in significant declines in maximal oxygen consumption (Sawka, Montain, and Latzka, 2001).

In addition to maximal aerobic performance, endurance exercise performance is impaired when an athlete is hypohydrated (Cheuvront, Carter, and Sawka, 2003, Von Duvillard et al., 2004). The decline in performance is larger with increased distance or duration of the endurance activity. For example, performance in a marathon will decline more than in a 10-kilometer race when a runner is hypohydrated. Hypohydration can also impair performance of lesser-intensity activities such as walking or hiking in the heat. A hypohydrated athlete exercising in the heat becomes fatigued more quickly compared to an athlete exercising in a euhydrated state. Body temperatures will rise in both athletes, but the hypohydrated athlete will fatigue at a lower body temperature. When hypohydrated, thermoregulation is impaired and the athlete cannot tolerate the same amount of increase in body temperature without fatiguing.

There is good evidence to suggest that a loss of 3 to 5 percent of body weight does not reduce anaerobic performance or muscular strength (Sawka et al., 2007). However, this magnitude of body water loss does affect thermoregulation and increases the risk for potentially fatal heat illnesses such as heat stroke.

ELECTROLYTE LOSS DURING EXERCISE

Fluid loss through sweating is the major concern for the exercising athlete, but sweat is composed of more than water. Sweat contains the electrolytes sodium, potassium, and chloride; small amounts of minerals such as iron, calcium, and magnesium; and trace amounts of urea, uric acid, ammonia, and lactate. Of these, sodium is present in the largest amount. During light sweating, sodium and chloride are reabsorbed from the tubule of the sweat gland and are not lost in large amounts. During heavy sweating, however, the sweat moves through the tubule at a rate that is too fast for substantial reabsorption, so sodium and chloride losses are proportionally greater.

The sodium content of sweat ranges from 10–70 mEq per liter with the average concentration of approximately 35 mEq/L (Sawka et al., 2007). One mEq of sodium is equal to 23 mg of sodium, thus, the upper end of the range, 70 mEq/L, is equivalent to 1,610 mg or 1.6 g of sodium per liter. This rate and amount of sodium loss typically does not pose a problem for the athlete if the exercise duration is not over an hour or two. During exercise lasting less than two hours, the athlete would need to pay more attention to fluid replacement to address the water loss through sweating than to sodium replacement. Water works well as a fluid replacement beverage under these conditions. The duration is short enough that excessive electrolyte loss is not likely, and therefore electrolyte replacement is not a priority. The duration of the activity is also within the range that endogenous carbohydrate (i.e., muscle and liver glycogen) stores are not likely to be depleted, so the inclusion of carbohydrate in the beverage for exercise of this duration is likely not a necessity. Consumption of beverages that do contain carbohydrate and electrolytes are not likely to pose any problems for the athlete.

More than two hours of continuous exercise typically marks the transition when the use of fluids that contain sodium and carbohydrate becomes appropriate. As explained earlier, it is possible for athletes engaged in prolonged moderate- to high-intensity exercise in hot environments to sustain sweat rates of 1 L to over 2 L per hour, resulting in substantial sodium loss (~ 1.5–3.0 g per hour). In such cases, sodium replacement should begin during exercise by including sodium in beverages or eating salty-tasting snacks. The addition of sodium may also encourage greater voluntary drinking and may aid in the uptake of water from the small intestine. Athletes that train and compete at these distances and durations should experiment during training to determine the need for sodium and carbohydrate replacement during exercise. For example, an athlete that is a heavy sodium excreter can look for accumulation of salt on skin or clothing after training and experiment with various replacement strategies during and after exercise (Maughan, 2001). Although the focus of this chapter is water and electrolytes, the intensity and length of time of activities such as marathon running and Olympic distance triathlons also result in substantial utilization of carbohydrate stores, and the ingestion of carbohydrates to maintain the availability and use of this fuel is also important (Sawka et al., 2007).

Very-long-duration activities (i.e., >4 hours), such as ultramarathon running or Ironman®-length triathlons, may also result in substantial sodium loss even in athletes who are not "heavy" sweaters (Rehrer, 2001). Much lesser amounts of potassium, magnesium, calcium, and chloride are lost, even at high sweat rates (up to 0.5, 0.02, 0.04, and 2.1 g per liter, respectively). More careful consideration of both fluid and electrolyte replacement (particularly sodium) must be made by the athlete during prolonged activities. Sweat is hypotonic in relation to blood, so as water and electrolytes are lost in sweat, there is a proportionally greater loss of water. Therefore, as the athlete dehydrates, the blood becomes more hypertonic. The combination of dehydration and hypertonicity may significantly impair performance, so the athlete must have a strategy to prevent or delay these, and the fatigue that can accompany them, from occurring.

One strategy for sodium replacement during prolonged exercise when there are large sodium losses through sweating is the use of sodium supplements in the form of salt tablets. Triathletes competing in Ironman®-length events may be exercising vigorously in a thermally challenging environment for eight to 12 hours or more, experiencing substantial fluid and sodium loss. As these athletes have become aware of the dangers of hyponatremia that may occur in these events (see section on hyponatremia), some have attempted to counter the sodium loss by consuming it in the more concentrated form of salt tablets (Speedy et al., 2003). A number of commercial products are marketed for this purpose; examples include Lava Salts™ and Succeed! Caps. A 1-gram capsule of Succeed! contains 314 mg of sodium and 21 mg of potassium, with a recommended dose of not more than two capsules per hour. Research on the effectiveness of this strategy for preventing the occurrence of hyponatremia is not extensive, although the results of two studies (Hew-Butler et al., 2006; Speedy et al., 2003) suggest athletes supplementing with salt tablets during an Ironman™-length triathlon do not have significantly different serum sodium concentrations than athletes that consumed a placebo. As an alternative to salt tablets, ultraendurance athletes may consume sodium as part of a carbohydrate-containing beverage. An example is the consumption of Gatorade Endurance Formula™. Eight ounces of this product provides 200 mg of sodium as well as 90 mg each of chloride and potassium, 6 mg of calcium, and 3 mg of magnesium.

EXERCISE-RELATED MUSCLE CRAMPING

Athletes may experience painful muscle cramps during or immediately after exercise, technically known as exercise-associated muscle cramping (EAMC). It has long been believed that such cramping is due to dehydration, changes in electrolyte concentrations, or both. Potassium, calcium, and magnesium supplements are advertised to athletes as a way to prevent or recover from muscle cramps. Despite a widespread belief that EAMC in all athletes is caused by dehydration and electrolyte loss, there is no body of scientific literature that supports this theory. The American College of Sports Medicine (ACSM) (Sawka et al., 2007) position paper notes that recommendations to avoid dehydration and sodium deficits to prevent muscle cramps is based on consensus and usual practice (i.e., Evidence category C) not experimental evidence (i.e., Evidence categories A and B).

Schwellnus et al. (2004) studied 72 male ultramarathon (56 km) runners to determine if hydration status or changes in electrolyte concentrations were associated with EAMC. Twenty-one of the runners experienced muscle cramps (often in hamstring and quadriceps muscles) during the ultramarathon. When compared to runners who had no muscle cramps, there were no significant differences in hydration status or sodium, potassium, calcium, and magnesium concentrations in the blood. The authors suggest that EAMC in ultradistance athletes have a different cause than dehydration or electrolyte imbalance.

Case studies of tennis and football players suggest that heat cramps (total body cramping when exercising in the heat) may be the result of rapid and large losses of fluid and sodium. The cramping appears to be caused by sodium depletion and dehydration as well as muscle fatigue. Those who fall into this group, known as "salty sweaters," appear to benefit from sodium-containing beverages during exercise and the consumption of an adequate amount of sodium and water after exercise (Bergeron, 2003; Eichner, 2002). As there are many causes of EAMC, including nonnutritional causes (e.g., lack of stretching), each athlete should determine the likely causes of their cramping and, through trial and error, institute strategies that are known to prevent the causative factors.

Replenishment of Water and Electrolytes

Exercise and physical activity can have a substantial impact on fluid balance. Water and electrolyte loss must be compensated for to maintain long-term fluid homeostasis. Single events or bouts of exercise may cause large disruptions in fluid balance and need immediate attention. However, many athletes experience small deficits on a daily basis and these small cumulative deficits become more pronounced deficits over several days or weeks. Athletes should develop a practical approach to monitoring their hydration status and a strategy for water and electrolyte replacement to maintain a status of euhydration and appropriate osmolarity.

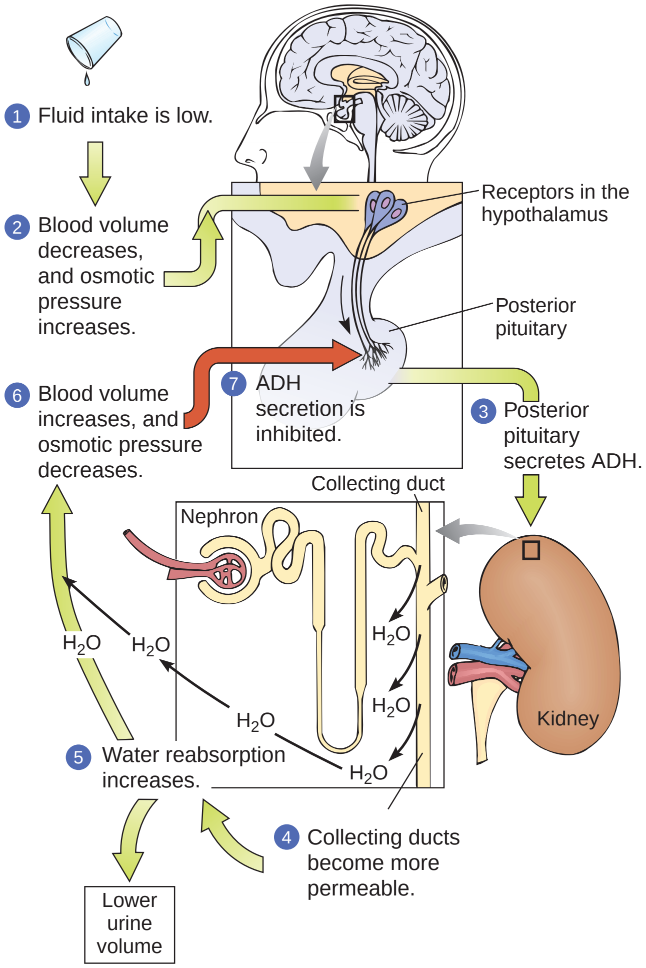
MONITORING HYDRATION STATUS

There are a variety of ways to monitor the body's hydration status. These methods have varying degrees of accuracy, difficulty, and expense. Typically, the methods that are the most accurate are also the most difficult and time-consuming to perform and the most expensive. These methods are best suited for use in research studies and are rarely practical for day-to-day use by athletes or those who exercise or compete recreationally. Daily monitoring requires an approach that is practical, and easy to administer and understand (Armstrong, 2005).

To precisely determine an individual's hydration status, the amount of total body water and the osmolarity of the plasma must be known. Accurate measures of total body water are often determined using isotope dilution, most commonly deuterium oxide (also discussed in Chapter 2). When a known volume of water having a known radioactivity level is consumed, it is diluted as it is absorbed and distributed throughout the water compartments of the body. After distribution and equilibration, a sample of body water can be taken and analyzed for its radioactivity. Total body water volume can then be determined from the degree of dilution of radioactivity. This method, while accurate, is expensive and time-consuming, requires trained personnel, and is not suitable for daily monitoring.

A second method of testing fluid balance involves measuring plasma solutes. The plasma osmolarity level associated with euhydration is 285 mOsm/kg (Institute of Medicine, 2004). In order to determine this value, however, a blood sample is needed, as well as access to a clinical laboratory for analysis. This method is also not very practical or desirable for frequent monitoring because of the time, expense, and necessity for drawing blood, but it is often used in research settings.

Because the renal system is the major physiological mechanism for regulating fluid balance (see Figure 7.11), an analysis of urine can also provide information about hydration status. When an individual becomes hypohydrated, the amount of urine produced is often lower than usual due to water conservation by the body. A 24-hour urine collection can easily measure volume, but this can be a time-consuming and unpleasant task and one that is not practical for an athlete to perform on a regular basis. However, in the hypohydrated individual the urine also has a higher specific gravity (concentration of particles), higher osmolarity, and a darker color. Urine specific gravity of ≤ 1.020 and urine osmolality of ≤ 700 mOsm/kg are considered consistent with euhydration (ACSM, 2007). In the past, such measurements required specific equipment or a clinical laboratory, but the availability of inexpensive urine testing strips now allows athletes to easily test urine for specific gravity as well as the presence of other compounds (e.g., glucose, protein).



ADH = antidiuretic hormone

Figure 7.11 Regulation of Urine Volume

Observation of urine color is more subjective and may not be as precise as laboratory measures, but is a more practical approach that can be easily conducted whenever the athlete urinates (Armstrong et al., 1998). It is typically recommended that athletes observe the color of the first void (urination) of the day after awakening from a night's sleep. Armstrong (2000) has suggested the use of a urine color scale (Figure 7.12) to estimate the degree of hypohydration. Although it lacks precision, urine color may be an easy, practical marker that an athlete can use in conjunction with other markers to assess hydration status. Urine color may be affected by diet (e.g., consumption of beets), dietary supplements, or medications and these reduce the accuracy of a color test.

Weight loss that occurs as a result of a single exercise bout is likely due to fluid loss; thus, changes in body weight can be used as a marker of short-term fluid loss and as a benchmark for subsequent rehydration. Changes in body fat or lean body mass over time complicate the use of this marker, but daily weight loss or gain over the course of a single workout can be used to determine

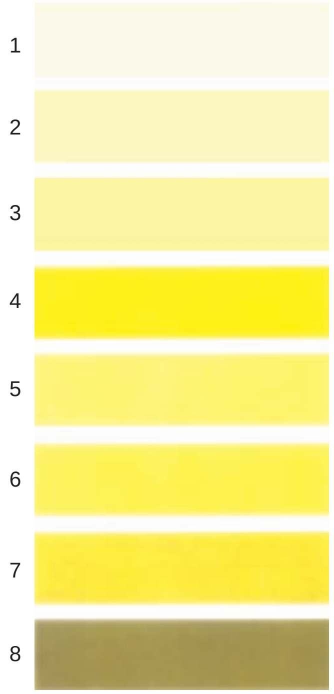


Figure 7.12 Urine Color Chart

A urine color chart can be used as a general assessment of hydration status. A urine sample collected the first thing in the morning can be viewed against a white background in good light and the color compared to the chart. A lighter urine color, in the 1, 2, or 3 range can be considered well-hydrated, while a darker urine color, in the 6, 7, or 8 range can be considered hypohydrated. Other factors, such as the use of medications or vitamins may also affect urine color; therefore, this method should be used cautiously and in conjunction with other methods such as acute changes in body weight.

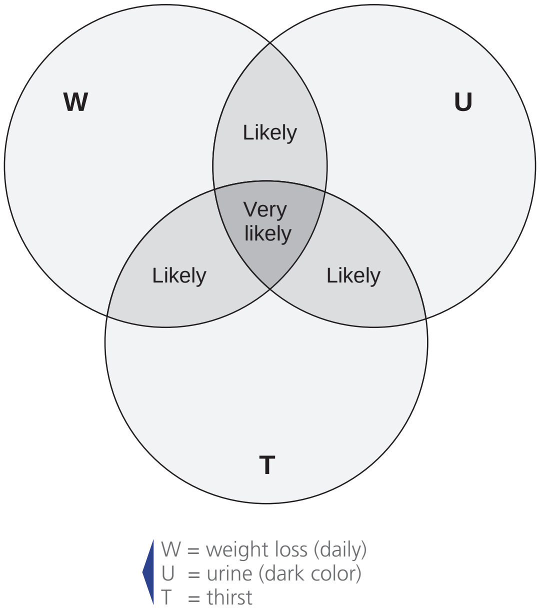


Figure 7.13 Hydration Assessment Tool

Each morning, athletes need to evaluate whether: 1) they are thirsty, 2) their urine is dark yellow, and 3) their body weight is noticeably lower than the previous morning. If one of these conditions is present, then they *may* be hypohydrated; if two conditions are present, then it is *likely* they are hypohydrated, and if all three conditions are present, then it is *very likely* they are hypohydrated.

water loss with reasonable accuracy. One liter of water weighs approximately 1 kg (2.2 lb). If an athlete completes a hard workout lasting approximately one hour and loses 2 kg (4.4 lb) of body weight, it can be assumed that approximately 2 L of fluid have been lost (2 kg × 1 L/kg). If this athlete takes a scale weight the next morning and has gained back only 1 kg (2.2 lb), it is likely that not enough fluids were consumed over the intervening day. Weight is easy to track and when used in conjunction with other markers may provide a reasonably accurate and practical method for monitoring hydration status. However, checking body weight every day may be detrimental if an athlete is struggling with disordered eating, an eating disorder, or anxiety related to degree of body fatness. These athletes may misinterpret a 1-kg (2.2-lb) weight gain as a gain in body fat and not an increase in body water. In such cases, taking daily weights would be discouraged and urine color may be the most appropriate measure of hydration status.

Cheuvront and Sawka (2005) have suggested a simple, logical approach using a combination of factors: thirst, body weight loss, and dark urine color (see Figure 7.13). The presence of any one of these factors may not provide sufficient evidence of inadequate hydration, but there is increasing probability with the overlap of two or all three factors. Each morning, athletes need to evaluate whether: 1) they are thirsty, 2) their urine is dark yellow, and 3) their body weight is noticeably lower than the previous morning. If one of these conditions is present, then they *may* be hypohydrated; if two conditions are present, then it is *likely* they are hypohydrated, and if all three conditions are present, then it is *very likely* they are hypohydrated. Rehydration strategies can then be pursued accordingly.

TYPE, TIMING, AND AMOUNT OF FLUID AND ELECTROLYTE INTAKE

Each athlete should have an individualized plan for consuming water and/or electrolytes before, during, and after exercise (Shirreffs, Armstrong and Cheuvront, 2004). Many athletes also need to consume carbohydrate during these periods, and having carbohydrate in a beverage makes doing so convenient. It is critical that each athlete plan a strategy for obtaining the nutrients needed and then test that plan during training under various environmental conditions. Because heat and humidity are substantial factors influencing fluid loss, athletes need to determine usual losses and successful rehydration strategies under different environmental conditions. A plan for adjusting fluid intake is especially important if competition is held in an environment with higher heat and humidity than the usual training setting. A basic plan, with adjustments for changing environmental conditions and the stress of competition, helps the athlete to be proactive in preventing or delaying dehydration and other nutrient-related problems. Trial and error is important for determining the ways in which the athlete will meet the ultimate goal: proper consumption of fluids, electrolytes, and/or carbohydrates.

Intake Prior to Training and Performance. Athletes should be conscious of being adequately hydrated at the beginning of an exercise session or competitive event by consuming adequate fluids throughout the previous day. Pre-exercise fluid consumption should begin at least four hours prior to training or performance, if possible. Assuming that the athlete has adequately re-hydrated from the previous day's exercise, the slow intake of fluids is recommended. Although the amount will depend on the individual, a rule of thumb for fluid intake is ~5–7 ml/kg at least four hours prior to exercise (Sawka et al., 2007). For example, a 50-kg (110 lb) female may establish a goal of consuming 250–350 ml (~8–12 oz or 1–1½ cups) of fluid before exercise. This amount of fluid four hours prior should be sufficient to maintain euhydration and allow for urination prior to training or competition. When this same rule of thumb measure is applied to larger athletes, such as a 260-lb (118 kg) male, an appropriate goal may be ~600–800 ml (~20–27 oz), highlighting the difficulty in making general recommendations for athletes.

The pre-exercise fluid intake strategy is different if the athlete is not euhydrated. Entering exercise in a state of hypohydration may be due to inadequate restoration of fluid from the previous day's exercise, multiple exercise bouts in hot and/or humid conditions, or the voluntary restriction of fluid to reduce body weight prior to weight certification. In such cases a more aggressive approach to pre-exercise fluid intake is needed. In addition to the rule of thumb recommendation outlined above, ~3–5 ml/kg two hours prior is recommended. Using the previous example, a 50-kg (110 lb) female might want to consume an additional 150–250 ml (5–12 oz), while the 260-lb (118 kg) male may need ~350–600 ml (~12–20 oz) more.

In most cases, water is sufficient. However, sodium does help to stimulate thirst, retain body water, and encourage people to drink more, so a pre-exercise source of sodium may be beneficial. If obtained in a beverage, the recommended amount is 20–50 mEq/L or 460–1,150 mg/L of sodium. If the athlete is also attempting to optimize carbohydrate stores, the ingestion of a carbohydrate-containing beverage or a small carbohydrate meal may be beneficial.

The amount and timing of the fluid ingestion prior to exercise should be determined on an individual basis during training by trial and error. Too little fluid intake may leave the athlete with a suboptimal hydration status and may allow for a greater degree of dehydration during the activity, predisposing the athlete to potentially poorer performance. Ingesting too much fluid may pose problems as well. The athlete may feel too full or bloated, potentially leading to gastrointestinal disturbances during exercise. An overabundance of fluid intake may also lead to excess urine production, discomfort, or interruption of training or competition. Each athlete's situation is really an experiment of one and he or she needs to determine the most appropriate amount and timing of fluid consumption before exercise. The stress of competition may result in a need to alter one's usual pattern of intake before exercise.

Intake During Training and Performance. As athletes lose fluid during exercise they should attempt to replace these losses to maintain fluid balance (Sawka and Montain, 2000). This is the easy and logical answer, but replacing fluids equal to those lost during exercise is not always possible, at least during the activity. Voluntary fluid replacement often falls short of fluid losses, in part due to "voluntary dehydration." Athletes may not be able to, or may not want to take time from their sporting activity to drink fluids. Certain activities, such as cycling, provide the means to carry more fluids and greater opportunity to consume them during the activity. Contrast this with activities such as running, during which fluid and/or food consumption is difficult. Some team sports may have time-outs, substitutions, or other breaks in the action that provide an opportunity to drink, but often voluntary fluid intake does not compensate for large fluid losses.

There is also a physiological reason that makes it difficult to avoid hypohydration—the inability to empty water from the stomach and absorb it into the blood as fast as it is being lost. While the maximal rate of gastric emptying and fluid uptake in adults approximates 1 L (~36 oz (~4.5 cups) per hour, water may be lost in sweat at rates twice that (over 2 L of sweat per hour) with very heavy sweating. In some situations it is not physically possible to take in enough fluid to match what is lost. A recognized goal is to prevent *excessive* dehydration (i.e., >2 percent of body water loss) and *excessive* changes in electrolyte balance (Sawka et al., 2007).

In the past, a recommended guideline for fluid replacement during exercise was to consume 150 to 350 ml (~6–12 ounces) of fluid at 15- to 20-minute intervals, beginning at the onset of exercise (Convertino et al., 1996). The ACSM (Sawka et al., 2007) now recommends a customized plan that considers sweat rate, sweat composition, duration of exercise, clothing, and environmental conditions. Recognizing that the lack of

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Paul Spinelli/Getty Images

Some athletes can more easily consume fluids during competition than others.

recommendations regarding specific amounts to be consumed make it difficult for many athletes to determine the amount of fluid needed, the ACSM recommends as a starting point that marathon runners consume 0.4–0.8 L of fluid per hour. To avoid overconsumption of water and hyponatremia, it is further recommended that the lower end of the range would be more appropriate for slower paced, lighter weight runners competing in cooler environmental temperatures while the upper end of the range would be more appropriate for faster paced, heavier weight athletes running in hotter, more humid conditions. This range is only a guideline, and it is well recognized that the lower or upper ends of the range could result in over or under consumption of fluid by a particular runner. The need for an individualized plan for fluid replacement cannot be overemphasized.

Guidelines have not been developed for sports other than marathon runners but the principles used to establish the guideline for marathon runners do have application for other athletes. For example, an interior lineman in the National Football League may need the equivalent of 0.8 L of fluid per hour because of a large body size, a high sweat rate, clothing that prevents the evaporation of sweat, and environmental conditions at the competition site that are hotter and more humid than the athlete is accustomed to.

From a practical perspective, the amount of fluid consumed will vary depending upon the rate of fluid loss and the individual's tolerance for fluid intake during the activity. Liquids that are cool are generally better tolerated than those that are warmer (although their coldness has no noticeable effect on body temperature). People can also generally better tolerate small amounts of fluid consumed more frequently than large amounts consumed less frequently. Frequent drinking of small amounts of fluid will maintain an amount of fluid in the stomach that will stimulate gastric emptying and fluid uptake by the body. However, each athlete must find his or her "gastric tolerance." Again, the frequency and volume of fluid replacement should be determined during training so as not to introduce a new, unfamiliar process during competition.

If the athlete consumes a typical amount of dietary sodium, there is little need for the fluid replacement beverage to contain sodium unless the exercise duration is more than two hours and there is a very high sweat rate. In such cases, it is recommended that 1 g of sodium per hour be consumed. This recommendation is made to endurance athletes who sweat heavily and whose sweat contains a large amount of sodium (i.e., "salty sweaters") (Murray, 2006). However, a sodium content of 20–30 mEq/L (460–690 mg/L) may be beneficial for endurance athletes exercising in the heat who do not sweat heavily because the sodium stimulates thirst, stimulates voluntary consumption of more fluid, increases the palatability of a beverage, and promotes body water retention (Sawka et al., 2007).

Similarly, if the athlete has adequate carbohydrate stores, there is little need for the fluid to contain carbohydrate if the exercise duration is less than two hours. If exercise is in excess of two hours, however, it is recommended that carbohydrate be consumed as well as sodium.

If consuming carbohydrate, the carbohydrate content of the beverage should be less than 10 percent ($<$10 g of carbohydrate in 100 ml of water) for more effective fluid replacement and thermoregulation. Many sports beverages contain 6 to 8 percent carbohydrate, a concentration that does not induce gastric distress for many people. However, some athletes find that they need more dilute solutions based on their individual tolerances. Carbohydrate concentrations greater than 10 percent may slow gastric emptying and fluid uptake if consumed during exercise. However, there may be times that the carbohydrate concentration of the beverage may be greater than 10 percent. For example, ultraendurance athletes may benefit from large amounts of glucose during competition because the need for carbohydrate is so great. These athletes will need to experiment with more concentrated carbohydrate solutions during training. Trial-and-error experimentation will help ultraendurance athletes test their gastric tolerance for beverages containing more than 10 percent carbohydrate. More information about carbohydrate intake during exercise is found in Chapter 4.

Replenishment after Training and Performance. Fluid balance is typically compromised during exercise training or performance, so athletes must pay particular attention to rehydration strategies after exercise is complete (Shirreffs and Maughan, 2000; Shirreffs, 2001). It is recommended that athletes drink approximately 1.5 L (~ 50 oz or ~ 6 cups) of fluid per kg body weight lost, beginning as soon after exercise as is practical. In other words, a 2.2 lb loss of scale weight requires ~ 1.5 L fluid intake (Sawka et al., 2007). In the past, a rule of thumb for rehydration was "a pint, a pound," a catchy way of reminding athletes to consume 1 pint (2 cups) of fluid for each pound of scale weight lost. However, a pint is ~ 480 ml and is not enough to restore a 1 lb water loss, which requires ~ 700 ml to replenish. "A pint, a pound" is typically not enough, especially if the athlete began the exercise session in a mild state of hypohydration. Water is not as effective in achieving euhydration as a beverage that contains some sodium, because sodium increases the body's drive to drink and results in a temporary decrease in urine output (Murray, 2006). The sodium in beverages and foods consumed after exercise also help to replenish electrolytes lost during exercise. It is recommended that athletes who lose large amounts of sodium in sweat salt their food or consume salty-tasting snacks after exercise.

Is the Athlete Generally Euhydrated?

If yes, 24-hour fluid intake appears to be appropriate.

If no, total daily fluid intake should be evaluated and adjusted.

What Are the Athlete's Goals prior to Exercise?

If euhydration only, water intake is sufficient.

If carbohydrate is needed, choose between a sports beverage, carbohydrate gel and water, or carbohydrate-containing food and water.

What Are the Athlete's Goals during Exercise?

If only fluid is needed, water may be sufficient

If carbohydrate is also needed, choose a sports beverage or carbohydrate gel and water, or carbohydrate-containing food and water.

If sodium is also needed, choose a sodium-containing sports beverage or sodium-containing food and water.

What Are the Athlete's Goals after Exercise?

Replenish water, carbohydrate, and sodium as needed with a combination of foods and beverages.

Figure 7.14 Assessment and Establishment of a Fluid, Electrolyte, and Carbohydrate Replenishment Plan

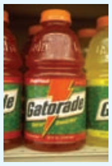
APPLICATION OF FLUID AND ELECTROLYTE GUIDELINES

One of the challenges for athletes and professionals who work with them is to translate scientifically based recommendations into practice. Athletes have many questions about water, sports beverages, and foods that may be used to replenish fluid, electrolytes, and carbohydrates. No single strategy or product is "best" for all athletes. An analysis of the athlete's needs and knowledge of the ingredients in beverages and foods provide important information for developing an individualized plan.

Some evaluation questions are listed in Figure 7.14. For example, is the athlete generally euhydrated? If yes, an appropriate plan for fluid replenishment may already be established and only fine-tuning is needed as conditions change. In many cases, however, athletes are in a routine state of hypohydration and overall daily fluid intake needs to be increased. One simple adjustment may be to drink more water during the course of a day. Some substantial adjustments may also need to be made.

Prior to exercise, some athletes are concerned only about maintaining euhydration and not about consuming additional carbohydrate. In such cases water is an appropriate pre-exercise beverage. As an example, a sprinter may drink only water during the warm-up period and while waiting for the competition to begin. Athletes engaged in prolonged exercise may choose a carbohydrate-containing beverage, because both carbohydrate and fluid are needed during exercise. These athletes will experiment during training with various carbohydrate concentrations, finding the sports beverage or food-and-water combination that provides sufficient carbohydrate without creating gastrointestinal distress. Similarly, a sports beverage can also provide sodium, a nutrient that may be needed during prolonged or ultraendurance exercise. Postexercise intake should reflect the water and nutrients lost during exercise and beverages play an important role. Since each athlete has different requirements, it is important to determine the amount of fluid and other nutrients needed and then choose foods and beverages accordingly.

For illustration purposes, consider two marathon runners who have the same fluid and carbohydrate goals during the race but achieve them in different ways. The first runner prefers to consume only a sports beverage throughout the race. This preference is based on convenience (e.g., always available along the course, easy to consume while running), taste, and predictability (e.g., known nutrient content, no history of gastrointestinal distress, no disruption to mental routine). The second runner prefers to consume a variety of carbohydrate and fluid sources—sports beverages, sports gels, bananas, and water (see Figure 7.15). This runner experiences taste fatigue and voluntary dehydration if limited to just sports beverages and prefers a variety of tastes and textures during the marathon. She also wants to be able to match food and beverage intake to how she is feeling during the run (e.g., blood glucose concentration and



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8 ounces of a 6% carbohydrate beverage provides: ~7.5 ounces of water, 50 kcal, 14 g carbohydrate, 110 mg sodium, 30 mg potassium.

Christina Micek

1 packet of GU® plus 8 ounces of water provides: ~8 ounces of water, 100 kcal, 25 g carbohydrate, 40 mg sodium, 35 mg potassium.

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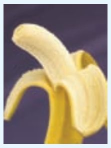
1 large juicy orange provides: ~5 ounces of water, 86 kcal, 22 g carbohydrate, 0 mg sodium, 333 mg potassium.



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7- to 8-inch banana plus 6 ounces of water provides: ~8 ounces of water, 105 kcal, 27 g carbohydrate, 5 mg sodium, 422 mg potassium.

Figure 7.15 Comparison of Selected Food/Water Combinations to a Sports Beverage

Legend: kcal = kilocalorie; g = gram; mg = milligram

degree of gastrointestinal stress), and increasing or decreasing fluid, semisolid, and solid food intake is part of her racing strategy. Each of these athletes has developed an individualized plan that appropriately meets their fluid and carbohydrate goals, but the plans are very different even though they are in the same sport.

Fluid, electrolyte, and carbohydrate guidelines are often given as ranges and athletes use these ranges to create and fine-tune an individualized plan through trial and error. The nutrient composition of food and beverages is important information needed to make wise decisions about the specific foods and beverages to include. All beverages provide water, but athletes must check the label to determine carbohydrate (amount and source), electrolyte (e.g., sodium, potassium), caffeine, and energy (kcal) content. Additionally, athletes may need information about carbohydrate concentration or glycemic response, which is not on the label but may be stated in promotion materials. The athlete that wants to consume ~15 g of sugar and some sodium in 8 oz of water can choose from a number of traditional carbohydrate/electrolyte beverages. However, if the athlete wants the carbohydrate source to be a glucose polymer to provide a slower glycemic response, then fewer choices will be available.

Athletes frequently consume four types of fluids: water, sports beverages, fruit juices, and soft drinks. The advantages and disadvantages of each are listed in Figure 7.16. Carbohydrate-electrolyte beverages (the original sports beverages) provide water, carbohydrate, sodium, chloride, and potassium. In addition to traditional ingredients, sports beverages may also contain some of the following in varying amounts: proteins, fats, electrolytes such as magnesium or calcium, antioxidant vitamins, B-complex vitamins, glycerol, and central nervous system stimulants, such as caffeine. Fruit juices provide water, carbohydrate, and potassium, but the concentration of carbohydrate is much greater than a traditional sports beverage. Soft drinks, also concentrated carbohydrate sources, are carbonated, which may cause gastrointestinal discomfort. Fruit juices and soft drinks are usually not consumed during exercise but can be part of overall daily fluid intake. An important point is that athletes choose beverages that provide water and nutrients in the quantities they need and do not contain unwanted or excess substances. Various beverages are compared in Table 7.2. A detailed discussion of the need for carbohydrate before, during, and after exercise is found in Chapter 4.

Two areas of concern may be the sugar and caffeine content of beverages, especially of "energy" drinks (see Spotlight on Enrichment: "Energy" Beverages: What Are Athletes Getting?). Sport beverages and energy

Advantages	Disadvantages
Advantages of Water	**Disadvantages of Water**
Noncaloric Refreshing taste Widely available (bottled, drinking fountains, hoses) Depending on hardness or softness, may provide some electrolytes	Provides no carbohydrate Electrolyte content of unbottled water not known and variable
Advantages of Sports Beverages	**Disadvantages of Sports Beverages**
Provide carbohydrate Sweet taste Contain electrolytes in known quantities Rapid rate of absorption due to sugar and sodium content Convenient	Could provide unwanted calories if overconsumed
Advantages of Fruit Juices	**Disadvantages of Fruit Juices**
Provide carbohydrate Sweet taste Often high in potassium May contain vitamins, minerals, and phytochemicals	High concentration of carbohydrate May cause some gastrointestinal distress Could provide unwanted calories if overconsumed In children, may displace milk intake
Advantages of Soft Drinks	**Disadvantages of Soft Drinks**
Provides carbohydrate Sweet taste Widely available Provide stimulatory effect if caffeinated	High concentration of carbohydrate Carbonation may contribute to gastrointestinal distress Low nutrient density A source of excess calories for many adults and children In children, may displace milk intake Provide unwanted stimulatory effect if caffeinated

Figure 7.16 Advantages and Disadvantages of Popular Beverages

SPOTLIGHT ON ENRICHMENT

"Energy" Beverages: What Are Athletes Getting?

"Energy" drinks are marketed to individuals who are mentally or physically fatigued. Trained and recreational athletes, as well as people with demanding work schedules can experience fatigue. The athlete's fatigue may be caused by insufficient caloric (energy) or carbohydrate intake, hypohydration, iron-deficiency anemia, lack of sleep, overtraining, increased body temperature, or a combination of these factors. Athletes routinely struggle with fatigue, so it is very tempting to buy a drink that simply promises more "energy."

Table 7.2 includes the energy, carbohydrate, and caffeine content of some popular energy drinks. Most provide about 28 to 35 g of carbohydrate and 110 to 140 kcal in an 8-oz serving. For an athlete whose source of fatigue is low kilocalorie and carbohydrate intake, such beverages can provide both. However, the immediate feeling of "energy" is most likely due to the presence of a neurological stimulant, usually caffeine. The stimulant(s) is often from herbal sources, such as guarana, kola nuts, or maté. U.S. law does not require the amount of caffeine to be stated on the label, but the caffeine content of an 8-oz "energy" drink is frequently 75 to 80 mg, although it may be considerably more.

For those who are caffeine-naïve (never or rare users) or caffeine-sensitive, a large dose of caffeine can cause a jittery, nervous response. They feel "overstimulated" rather than "energized," which may be detrimental to training, performance, or sleep. In some individuals, caffeine can cause an irregular heartbeat. Athletes should be aware of their caffeine threshold for adverse side effects and cognizant of their daily intake. A 12-oz caffeinated soft drink provides approximately 30 to 50 mg of caffeine, less caffeine than an "energy" beverage. The caffeine content of an 8-oz cup of black caffeinated coffee can vary considerably and may be as low as 35 mg and as high as 225 mg (Center for Science in the Public Interest, 2007).

Although the exact mechanisms are not known, caffeine may impact performance because of central nervous system stimulation that alters perception of fatigue. But altering perception will not offset substantial contributors to fatigue such as low muscle glycogen stores or iron deficiency anemia in endurance athletes. Athletes who mask fatigue with stimulants are encouraged to determine and address the fundamental causes of their fatigue (Dunford, 2002).

drinks fall along the sweetened beverage continuum that runs from flavored water to highly concentrated carbohydrate solutions (see percent carbohydrate [CHO %] column in Table 7.2). Many drinks contain high-fructose corn syrup and have a low nutrient density. In some cases, the drinks are a source of excess kilocalories and water may be a better choice because it is noncaloric. This may be the case for those participating in low-energy-expenditure sports and includes athletes (e.g., pinch hitter in baseball), occasional exercisers, and children (e.g., T-ball). Not everyone engaged in a "sport" needs a "sports beverage."

Table 7.2 Composition of Selected Beverages

Beverage	Serving Size (oz)	Energy (kcal)	CHO (g)	CHO (source)	CHO (%)	Cations (mg)	Caffeine (mg)	Other
Carbohydrate-electrolyte beverages (4–7% carbohydrate)								
Hydrade	8	55	10	HFCS	4	Na^+: 91 K^+: 77	0	5.1% glycerol; some vitamin C
Gatorade Original Thirst Quencher	8	50	14	Sucrose syrup; glucose–fructose syrup	6	Na^+: 110 K^+: 30	0	
Gatorade Endurance Formula	8	50	14	Sucrose syrup; glucose–fructose syrup	6	Na^+: 200 K^+: 90	0	Some calcium and magnesium
Accelerade	8	80	14	Sucrose, maltodextrin, fructose	6	Na^+: 133 K^+: 43		Some magnesium, vitamin C, E; 5 g protein
All Sport Body Quencher	8	60	16	HFCS	7	Na^+: 55 K^+: 50	0	Vitamin C; some B vitamins
POWERade	8	64	17	HFCS, glucose polymers	7	Na^+: 53 K^+: 32	0	Some B vitamins
Lightly sweetened waters with vitamins added								
Propel Fitness Water	8	10	3	Sucrose syrup	1	Na^+: 35 K^+: 0	0	Some B vitamins; May have added calcium; Contains sucralose*
Vitamin water	8	50	13	Fructose	5.5	Na^+: 0 K^+: 0	0	Vitamins A, C, and some B vitamins; lutein
Soft drinks								
Coca Cola	8	97	27	HFCS	11	Na^+: 33 K^+: 0	23	
Pepsi	8	100	27	HFCS and/or sugar	11	Na^+: 25 K^+: 10	25	
Mountain Dew	8	110	31	HFCS, orange juice concentrate	13	Na^+: 50 K^+: 0	37	
Fruit juices								
Orange juice	8	110	27	Sucrose, fructose, glucose	11	Na^+: 15 K^+: 450	0	Naturally occurring vitamins and minerals
Unsweetened apple juice	8	116	28	Primarily fructose, some glucose and sucrose	11.5	Na^+: 8 K^+: 296		Naturally occurring vitamins and minerals

continued

Table 7.2 Composition of Selected Beverages (continued)

Beverage	Serving Size (oz)	Energy (kcal)	CHO (g)	CHO (source)	CHO (%)	Cations (mg)	Caffeine (mg)	Other
Energy drinks								
AMP Energy Drink	8	110	29	HFCS and/or sugar	12.5	Na^+: 65 K^+: 7	71 (guarana)	Some B vitamins, taurine, ginseng
Red Bull	8.3	110	28	Sucrose, glucose, glucuronolactone	11	Na^+: 200	80	Some B vitamins
Rock Star Energy	8	140	31	Surcose, glucose	13	Na^+: 40	80 (25 mg guarana)	Some B vitamins, taurine, herbs (e.g., milk thistle, ginseng, ginkgo)
SoBe Adrenaline Rush	8.3	140	37	HFCS	15	Na^+: 115 K^+: 20	86 (50 mg guarana)	Vitamin C; 50 mg ginseng
Venom Energy Drink	8.3	130	29	HFCS	11.5	Na^+: 10 K^+: 28	~100 (250 mg mate 50 mg guarana	Vitamin C, some B vitamins, taurine, bee pollen, ginseng
Other								
Extran	6.75	320	80	Glucose syrup	42	Na^+: 20 K^+: 50		Concentrated CHO source for ultradistance events

Nutrient information obtained from company websites and product labels.

Legend: oz = fluid ounces; kcal = kilocalories; CHO = carbohydrate; g = grams; mg = milligrams; HFCS = high fructose corn syrup; Na^+ = sodium; K^+ = potassium

*Sucralose (Splenda) is an artificial sweetener.

HYPONATREMIA

A potentially serious medical complication that may occur in endurance athletes during prolonged exercise such as ultramarathons or triathlons is hyponatremia (Noakes et al., 1985; Armstrong et al., 1993). Clinically, hyponatremia occurs when plasma sodium concentration falls below 135 mmol/L (from a typical level of 140 mmol/L). Exercise-associated hyponatremia is often characterized by a rapid drop to 130 mmol/L or below and is particularly serious when it drops rapidly and remains low. Because of the important role sodium has

SPOTLIGHT ON A REAL ATHLETE

Hyponatremia in a Boston Marathon Runner

The *Wall Street Journal* (2005) recounted the harrowing story of a 27-year-old male running his first Boston Marathon. The projected temperature for the 2004 race was 90°F and his goal was to finish the race in less than four hours. The runner knew that he sweated heavily in warm weather and was concerned that he would dehydrate quickly. He drank more than a gallon of water prior to the race and water at every rest stop. He was on pace at mile 19 when he developed nausea and leg cramps. By mile 23 he was unable to run but walked to the finish line. After finishing he drank approximately 2 quarts of water but felt worse and experienced vomiting and diarrhea. On the subway ride home, the vomiting continued so he continued to drink water and a carbohydrate-electrolyte beverage. At home he became unconscious and fell (breaking his shoulder). Relatives called 911 and he was transported to the hospital, during which time he was given IV fluids as he was incorrectly diagnosed as being hypohydrated. He lapsed into a coma and was placed on life support for four days. In the hospital he was correctly diagnosed as having hyponatremia. Happily, this condition was reversed and he recovered.

in maintaining osmotic and fluid balance between body water compartments and in the electrochemical gradient necessary for the transmission of nerve impulses, large disruptions in plasma sodium concentration can have serious physiological and medical consequences. Low sodium concentration in the extracellular fluid will stimulate the movement of water by osmosis from the plasma into the intracellular spaces, causing cells to swell. If nerve cells swell too much they cease to function properly, which can result in symptoms of dizziness, confusion, seizure, coma, and even death (see Spotlight on a Real Athlete: Hyponatremia in a Boston Marathon Runner).

Although rare in occurrence in shorter events, hyponatremia has been reported in up to 10 percent of runners in certain ultraendurance running events and in as many as 29 percent of triathletes in the Ironman Triathlon (Speedy, Rogers, Noakes, Thompson et al., 2000). Note that these events involve endurance exercise lasting over seven hours of duration, often in conditions of high heat and humidity, resulting in significant sweat loss. The physiological mechanism of this exertional hyponatremia is not completely understood, but a leading hypothesis is that it is due to a combination of loss of sodium through heavy sweating and an overconsumption of hypotonic fluids, particularly water (Noakes et al., 2005; Noakes, 1992, Speedy, Rogers, Noakes, Wright et al., 2000). When dehydration is prevented by copious consumption of water, sodium lost in sweat is not replaced, leading to a dilution of the sodium in the extracellular fluid. Hyponatremia can also occur in slow marathon runners, who are on the course for five or more hours, all the while consuming water or other beverages with a low sodium content (Almond et al., 2005).

The strategy to prevent hyponatremia is twofold: replacement of sodium and prevention of fluid overload or overdrinking. If exercise is to extend beyond two or three hours, sodium replacement should be considered along with fluid replacement, either in a beverage, as a supplement, or with salty-tasting foods. The recommended amount is 0.5 to 0.7 g of sodium per liter of fluid (American College of Sports Medicine, American Dietetic Association and Dietitians of Canada, 2000). Athletes may simply add salt to traditional sports beverages. For example if an athlete adds ¼ teaspoon of table salt to 32 ounces (~960 ml or 4 cups) of a sports beverage, 590 mg of sodium will be added. The additional sodium is ~0.6 g of sodium per liter of fluid, the midpoint of the guideline.

Athletes should be encouraged to consume enough fluid to match fluid loss and prevent performance-attenuating hypohydration, while not exceeding the amount of fluid lost. A substantial reduction in the incidence of hyponatremia in an ultradistance triathlon was observed after participants were educated about appropriate fluid intake and access to fluids during the race was decreased slightly by reducing the number of fluid stations and increasing the distance between them (Speedy, Rogers, Noakes, Thompson, et al., 2000) Because the body's fluid balance mechanisms can be temporarily overwhelmed, an athlete's fluid and sodium intake is an important part of fluid homeostasis.

What's the point? Most athletes do not need to be concerned with hyponatremia; however, this condition cannot be overlooked because it is potentially fatal. The keys are to avoid overdrinking and to replace sodium lost in sweat.

THE EXPERTS IN. . .

Fluid and Electrolyte Balance

Lawrence E. Armstrong, Ph.D., conducts research of athletes performing in extreme environments. Some of these research data have been collected in the medical tents of major marathons. In addition to his scientific studies, Dr. Armstrong has written extensively for consumer audiences and has created practical tools for athletes to assess hydration status. Timothy D. Noakes, M.D., heads an exercise science and sports medicine research unit in South Africa. He has conducted extensive research, including elucidating the factors associated with hyponatremia.

Michael N. Sawka, Ph.D., is an expert in heat stress physiology. His research focuses on the effect of heat, cold, and altitude on exercise physiology, including temperature regulation, blood volume response, and fluid and electrolyte balance. Robert Murray, Ph.D., is an exercise physiologist whose specialty is the effect of fluid and carbohydrate intake on performance. As the director of the Gatorade Sports Science Institute, he oversees the work of many researchers in the area of fluid and electrolyte balance. Suzanne Nelson Steen, D.Sc., R.D., is a sports nutritionist at an NCAA Division I school. Dr. Steen works with athletes from many sports but has developed special programs for wrestlers and athletes who sweat heavily and lose large amounts of water and sodium. As head of sports nutrition services and an adjunct faculty member, Dr. Steen is an example of a person who both conducts research and develops effective individualized fluid and electrolyte plans for athletes.

HYPERHYDRATION

Dehydration can have an adverse effect on training and performance, thus athletes have attempted to manipulate body fluid levels prior to exercise by hyperhydrating. The idea is to increase the amount of body water prior to exercise so when fluid is lost during exercise, a critical level of hypohydration is not reached as quickly. Theoretically, this could prevent or delay a decline in performance.

Short-term hyperhydration can be achieved relatively easily by fluid overload, the consumption of excess fluids in the hours before exercise. This overconsumption results in an increase in total body water, an increase in plasma volume, and a potential improvement in thermoregulation and exercise performance in the heat. Because the kidneys react quickly to an overload of fluid, urine production is increased and the resulting full bladder and need to urinate may be an interfering factor for the upcoming exercise. Consumption of large quantities of fluid may also result in gastric discomfort. Hyponatremia may also be a concern if very large volumes of hypotonic fluid are consumed.

Glycerol Loading. Another strategy for hyperhydrating involves the ingestion of an osmotically active, water-retaining molecule along with the increased amounts of fluid prior to exercise. One such compound is glycerol. Glycerol is easily absorbed and distributed throughout fluid compartments in the body where it exerts an osmotic force to attract water.

A typical glycerol loading regimen is to consume 1.0–1.2 g of glycerol per kg body weight along with 25–35 ml of water per kg body weight. For a 150-lb (~68 kg) runner this would be approximately 80 g of glycerol and 2 L (2,000 ml or ~71 oz or ~9 cups) of water. This approach generally results in fluid retention and hyperhydration of approximately 500 ml (~18 oz or ~2¼ cups) more than with fluid overload alone. However, it is unclear if this additional water "storage" prior to the onset of exercise improves

The Internet Café

Where Do I Find Reliable Information about Water and Electrolytes?

Several organizations have published position papers on the replenishment of water and electrolytes by athletes. These position papers outline general recommendations for fluid and electrolyte intake before, during, and after exercise. However, since body size varies tremendously among athletes, these guidelines must be individualized so that the amount of fluid consumed is well matched to the amount of fluid lost.

American College of Sports Medicine Position Stand, "Exercise and Fluid Replacement," **www.acsm-msse.org/**

American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada Position Statement, "Nutrition and Athletic Performance," **www.acsm-msse.org/**

USA Track and Field, "Proper Hydration for Distance Running—Identifying Individual Fluid Needs," **www.usatf.org/**

The Gatorade Sports Science Institute **(www.gssiweb.com/)** produces a large amount of excellent materials intended for professional audiences such as exercise physiologists, sports dietitians, strength and conditioning coaches, and athletic trainers. This is a commercial website and features products made by Gatorade.

KEEPING IT IN PERSPECTIVE

Fluid and Electrolyte Balance Is Critical

Athletes must keep many aspects of nutrition in perspective, including their intake of energy, carbohydrates, proteins, fats, alcohol, vitamins, and minerals. What makes the fluid and electrolyte perspective different is that balance can change to imbalance quickly and the impact on health can be immediate and potentially fatal. There is no "one size fits all" approach to fluid balance, so each athlete must consider fluids and electrolytes from an individual perspective. Well-meaning advice—"drink as much as you can"—does not consider the case of the slow-paced endurance athlete. "Reduce sodium intake" does not consider the athlete who loses large amounts of sodium in sweat. "Drink a pint, a pound" does not consider the athlete who was hypohydrated before exercise began. "Just sweat it out and you'll make weight" does not consider the athlete's body temperature or degree of dehydration.

The proper perspective is to match fluid and electrolyte intake with fluid and electrolyte losses, although an exact "match" is often not possible or necessary. Part of maintaining a proper perspective is to recognize changing environmental conditions and needs and adjust accordingly. There can be a lot of trial and error involved; however, severe errors (e.g., hyponatremia, elevated core temperature) can be fatal. That makes the fluid and electrolyte perspective more time-critical and an everyday concern for the athlete who is training and competing.

performance. Theoretically, the additional body water would provide extra fluid for sweating and maintaining blood volume to enhance the control of body temperature without unduly compromising the cardiovascular function needed to sustain exercise performance. While a small number of studies have shown this to be the case, the scientific literature lacks a sufficient number of studies with similar results to support a strong consensus opinion (Burke, 2001).

The potential adverse effects that may accompany glycerol loading must be considered, particularly the weight gain that results from hyperhydration. Excess body weight may negatively affect performance, particularly in weight-bearing activities such as running. Consumption of glycerol may also result in gastrointestinal upset and nausea, as might the ingestion of large amounts of fluid. This hyperhydration strategy may have some benefit, but should only be attempted by an athlete under the supervision of a sports medicine professional. This practice should first be instituted during training to ascertain the potential effects, both positive and negative, on performance.

Summary

Water is critical to the normal physiological functioning of the body. Optimal fluid balance is of further importance to the athlete, as exercise can place severe demands on the body to maintain fluid homeostasis. Substantial water losses can occur during exercise and activity, particularly if the environmental conditions are severe. Water losses can compromise the body's ability to regulate body temperature, which may in turn impair training, performance, and health. Extreme losses of water and electrolytes may be dangerous or fatal due to severe **hypohydration** and an inability to keep body temperature from rising. Athletes should be conscious of water losses and employ strategies to ensure adequate hydration and electrolyte replacement before, during, and after exercise. Water in excess of need can also be problematic, as in the case of hyponatremia.

Recommendations for fluid and electrolyte consumption before, during, and after exercise are good guidelines for intake but must be individualized. Many sports beverages provide a convenient way to consume water and sodium, as well as carbohydrate, although food and water combinations are also used. Trial and error during training helps athletes determine the most appropriate fluid and electrolyte intake before and during competition. The athlete's usual rehydration strategy may need adjustment when environmental conditions change, especially increases in heat and humidity.

Post-Test: Reassessing Knowledge of Water and Electrolytes

Now that you have more knowledge about water and electrolytes, read the statements and decide if each is true or false. The answers can be found in Appendix O.

1. The two major aspects of fluid balance are the volume of water and the concentration of the substances in the water.
2. Now that sports beverages are precisely formulated, it is rare that water would be a better choice than a sports beverage for a trained athlete.
3. Athletes should avoid caffeinated drinks because caffeine is a potent diuretic.
4. A rule of thumb for endurance athletes is to drink as much water as possible.
5. Under most circumstances, athletes will not voluntarily drink enough fluid to account for all the water lost during exercise.

Review Questions

1. Why is water so critical to athletic performance?
2. How is water distributed throughout the body? How does the body maintain fluid balance between the extracellular and intracellular compartments?
3. Compare and contrast euhydration, hypohydration, and hyperhydration. Discuss the reasons athletes might attempt to be hypohydrated or hyperhydrated and the ways in which they achieve these states. What are the dangers associated with hypohydration and hyperhydration?
4. Compare and contrast the intake, physiological roles, and excretion of sodium and potassium.
5. What effect does exercise have on fluid balance? What effect does hypohydration have on exercise performance? On health?
6. Outline the ways that hydration status can be monitored. Which ways are easy and practical for athletes to use?
7. Choose an athlete in a sport that you are familiar with and devise a plan for fluid and/or electrolyte intake before, during, and after exercise. What are the important considerations given the demands of the sport and the environmental conditions under which training and performance occur? Why might an athlete not like the plan that you created?

8. What is the current recommendation for caffeine intake by athletes?
9. What is hyponatremia? In which sports are athletes at risk for developing hyponatremia? How can this condition be prevented?

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8 Vitamins

Learning Objectives

1. Classify vitamins and describe their general roles.
2. Explain how vitamin inadequacies and excesses can occur and why either might be detrimental to performance and health.
3. Explain how the Dietary Reference Intakes (DRI) and the Tolerable Upper Intake Levels (UL) should be interpreted.
4. Describe if, and how, exercise increases the need for or accelerates the loss of a particular vitamin.
5. Compare and contrast the average intake of vitamins by sedentary adults in the United States and athletes, particularly those who restrict energy intake.
6. Explain the differences between a clinical and subclinical vitamin deficiency.
7. Name the vitamins associated with energy metabolism and blood formation and summarize the results of studies conducted with athletes.
8. Compare and contrast vitamins A, C, and E, particularly their antioxidant functions.
9. Compare and contrast vitamins based on their source—naturally occurring in food, added to foods during processing, and found in supplements.
10. Evaluate the need for vitamin supplements based on food intake.

Pre-Test Assessing Current Knowledge of Vitamins

Read the following statements and decide if each is true or false.

1. Exercise increases the usage of vitamins, so most athletes need more vitamins than sedentary people.
2. Vitamins provide energy.
3. The amount of vitamins an athlete consumes is generally related to the amount of kilocalories consumed.
4. When antioxidant vitamins are consumed in excess, they act like pro-oxidants instead of antioxidants.
5. Vitamin supplements are better regulated than other dietary supplements because the U.S. Food and Drug Administration sets a maximum dose (amount) for each vitamin.

Because vitamins are a common topic of discussion, it may be surprising that **vitamins** were only "discovered" approximately 100 years ago. In the early 1900s scientists first began to identify the chemical composition of these essential nutrients. Foods were analyzed and it was determined if certain foods were excellent or poor sources of particular vitamins. Biochemical knowledge of specific vitamins helped identify and rectify vitamin deficiencies that were prevalent in many countries, including the United States. The scientific discovery of vitamins proved to be monumental to improving the health of all people.

Interestingly, people had knowledge of vitamins before they were discovered. For example, in the 1700s British sailors on long voyages across the Atlantic were given a small amount of lime juice as part of their daily rations. The lime juice contained "something" that helped the sailors avoid one of the dangers of months on the oceans—the disease scurvy. This practice also gave rise to the nickname "Limeys." As scientists later discovered, scurvy is a result of a severe lack of vitamin C. Vitamin C is found in citrus fruits such as limes, oranges, and grapefruits. The physician who convinced the British navy to require lime juice on all trans-Atlantic voyages did not know the nutrient in the food that prevented scurvy, but he knew that nutrient was essential and was not being provided in the sailors' usual diet.

Today, knowledge of vitamins and the impact of their deficiencies is extensive. Scientists have identified many vitamins that are essential, the amount that is needed to prevent deficiencies, and the approximate amounts contained in food. In the United States and other industrialized countries, vitamin deficiency diseases are rare. One of the reasons is that many foods are "fortified" with vitamins. The bigger scientific challenge today is determining how much is too much and how vitamins in quantities greater than that found in food might interact with each other and the body's biochemical pathways.

It may seem odd that something that is so essential in small quantities may be detrimental when taken in large quantities. The amount of any vitamin needed by the body is small—measured in milligrams (mg) or micrograms (mcg). The body can tolerate much larger amounts than the minimum amount needed, but this tolerance is not without limits. For example, in small amounts the vitamin **beta-carotene** (a form of vitamin A) is an **antioxidant** but in large amounts it is a **pro-oxidant.** In other words, at low doses beta-carotene helps protect cells from the destructive effects of oxygen but at high levels beta-carotene enhances the destructive effects. Anyone who ingests high doses of antioxidant vitamin supplements should be aware that there could be potential problems.

Vitamins are essential nutrients needed for the proper functioning of the body. Some are involved in energy metabolism, red blood cell production, and antioxidant functions, so it is natural that athletes would look at the functionality of vitamins and their potential to improve these exercise-related processes. Athletes should develop strategies for consuming enough of all the vitamins without consuming too much. Endurance exercise may increase the need for some vitamins and may result in small losses of others via urine or sweat. An increase in exercise also requires that more energy be consumed to maintain energy balance and body composition. If the additional foods eaten to support exercise and training are nutrient dense, then vitamin-rich foods can easily provide the additional vitamins needed. But many athletes don't consume nutrient-dense foods, particularly vitamin-rich foods such as fruits, vegetables, and whole grains. Athletes may also be limiting caloric intake in an effort to reduce body fat. In these cases vitamin intake may be inadequate unless the diet is planned with nutrient density in mind. As with all nutrients, adequate vitamin intake requires analysis and judgment of the foods routinely consumed before determining if, and how much, of a supplement might be needed.

Vitamin supplements, especially a one-a-day type formulation, are among the most popular of all the dietary supplements athletes choose to take (Morrison, Gizis, and Shorter, 2004). There is no evidence that athletes who consume a diet that is adequate in energy and nutrients need vitamin supplementation. However, many athletes choose to supplement. For some, supplementation is needed because caloric intake is very low or the nutrient density of foods is poor. These athletes are often restricting caloric intake for long periods of time and a multivitamin supplement likely helps prevent vitamin deficiencies. It is important to remember that vitamin supplements do not address other nutrient inadequacies such as low carbohydrate or low protein intakes, conditions that can affect training, performance, and health.

For other athletes, daily vitamin supplements act as an insurance policy—sufficient coverage to prevent vitamin deficiencies because vitamin intake from food is less than optimal. However, athletes who consume enough kilocalories are likely to consume many foods that have been fortified with vitamins. In fact, foods and beverages frequently consumed by athletes, such as energy bars, ready-to-eat breakfast cereals, and sports beverages, have seen an increase in the amount of vitamins being added, probably serving as an additional insurance policy. Most people who take vitamin supplements do so to enhance their health but many do not realize that excessive intake can also be detrimental to health. Vitamin supplements should be evaluated based on their safety and effectiveness. Vitamins, like most other nutrients, are much more complicated than one might initially think.

Classification of Vitamins

Vitamins are essential nutrients needed in small quantities for the proper functioning of the body. Table 8.1 lists 13 vitamins that have been identified as essential. Vitamins are often classified based on their solubility. Those vitamins that are fat-soluble include vitamins A, D, E, and K. All of the B vitamins (thiamin, riboflavin, niacin, pantothenic acid, biotin, folate, B_6, and B_{12}) and vitamin C are water soluble. Some of the characteristics associated with vitamins are related to their solubility.

The fat-soluble vitamins are absorbed and transported in the same way as fat (see Chapter 6). Absorption may take several hours and transport in the blood requires that they be bound to a carrier. Fat-soluble vitamins are stored in liver and adipose (fat) cells. Although each fat-soluble vitamin has a recommended daily intake, the ability to store these vitamins means that daily intake can vary without immediate risk for deficiency. For example, on days when vitamin E intake is lower than usual, the body has a ready store of vitamin E for use. On days when vitamin E intake is adequate (i.e., meets the Dietary Reference Intake [DRI]), stores that have been reduced can be increased. This ability to store fat-soluble vitamins helps the body to guard against deficiencies but it also means that toxicities can occur if excessive amounts are consumed over long periods of time. These toxicities, although rare, can cause substantial health problems, especially in a major organ such as the liver. Optimal intake—not too little, not too much—is an important goal.

In contrast to fat-soluble vitamins, water-soluble vitamins are easily absorbed and circulate in the blood without the need for a carrier. There is no designated storage site. Instead, tissues can become saturated with the vitamin and when the saturation point is reached the excess is excreted via the urine. For some water-soluble vitamins,

Table 8.1 Fat- and Water-Soluble Vitamins

Fat Soluble	Water Soluble
Vitamin A	Vitamin B_1 (Thiamin)
Vitamin D	Vitamin B_2 (Riboflavin)
Vitamin E	Vitamin B_3 (Niacin)
Vitamin K	Pantothenic acid
	Biotin
	Folate (Folic acid, folacin)
	Vitamin B_6
	Vitamin B_{12}
	Vitamin C

Choline is sometimes listed as a water-soluble vitamin but it is technically an amine (a derivative of ammonia). It is included with the B vitamins as part of the Dietary Reference Intakes (DRI).

Vitamin: Essential organic (carbon-containing) compound necessary in very small quantities for proper physiological function.

Beta-carotene: One form of carotene, a precursor to vitamin A.

Antioxidant: Substance that inhibits oxidative reactions and protects cells and tissues from damage.

Pro-oxidant: Compound that increases the formation of reactive oxygen species or free radicals.

such as B_1 (thiamin), B_2 (riboflavin), B_{12}, pantothenic acid, or biotin, this saturation/excretion system works exceptionally well and no **toxicity** symptoms have been reported. However, toxicity symptoms have been reported for some other water-soluble vitamins when excessive amounts are consumed. For example, excessive amounts of vitamin B_6 can damage the nervous system and result in headaches, difficulty with reflexes or walking, and numbness. A moderate intake helps prevent both deficiencies and toxicities (Gropper, Smith, and Groff, 2005).

Solubility is one way of classifying vitamins, but another classification method uses physiological function. In many cases several vitamins are needed for a physiological process to occur. Some common classifications include 1) vitamins related to energy metabolism, 2) vitamins needed for red blood cell formation, 3) antioxidant vitamins, and 4) miscellaneous functions. When classified this way, water- and fat-soluble vitamins may be in the same category. For example, vitamins with antioxidant properties include the fat-soluble vitamins A (as beta-carotene) and E as well as the water-soluble vitamin C.

In many cases the vitamins are not classified together, but are addressed individually. For each of the 13 vitamins listed in Table 8.1 there is a tremendous amount of information known. This information has been summarized in Table 8.2. For each vitamin the following appears: common and alternative names, major physiological functions, solubility, the deficiency and/or toxicity disease, symptoms associated with deficiency and/or toxicity, food sources, and miscellaneous information. More detailed information on vitamins can also be found in basic nutrition textbooks or at the Food and Nutrition Information Center at www.nal.usda.gov/fnic.

Recommended Daily Vitamin Intake

Vitamins play an important role in overall health. Because each vitamin plays a specific role that cannot be replaced or substituted by another vitamin, it is important to consume an adequate amount of each vitamin. Consumption of excessive amounts of vitamins should be avoided since toxicities, even of certain water-soluble vitamins, can occur. Two sets of guidelines have been created that help quantify adequate but not excessive amounts. As discussed in Chapter 1, the Dietary Reference Intakes is a set of values that helps answer the question, "How much [of a nutrient] is needed each day?" The Tolerable Upper Intake Levels (UL) helps address the question, "How much is too much?"

Toxicity: State or relative degree of being poisonous.

Table 8.3 is a quick and easy reference when considering these questions. The complete DRI and UL for vitamins are listed in the gatefold located in the back of this textbook, but the values for adult males and adult, nonpregnant females have been repeated in Table 8.3. Notice that the DRI are the same for adult males and females of any age for some of the vitamins. However, the recommended intake of several vitamins is higher based on male gender (e.g., vitamins A, C) or increasing age (e.g., vitamins D, B_6). Observe that upper intake levels have been established for only eight of the 14 vitamins listed; UL have not been established for the other six vitamins because of a lack of scientific data. Excessive amounts of these vitamins may cause adverse effects, however, at the present time the amounts at which adverse effects may occur is not known.

The Dietary Reference Intakes are the current standard used to determine nutrient goals for individuals. The standard was developed using scientific studies of healthy people who are moderately active. A reasonable question raised by athletes is whether exercise that is greater than moderate, especially endurance exercise, substantially changes nutrient needs. For example, do athletes need more of a particular vitamin to meet the demands of moderate or rigorous training? Do athletes lose more vitamins through sweat or urine than sedentary individuals? Unfortunately, these questions are not easily answered because the body of literature is small, and in some cases, nonexistent.

THE INFLUENCE OF EXERCISE ON VITAMIN REQUIREMENTS

There are a number of ways in which exercise could alter vitamin requirements. Exercise could decrease absorption from the gastrointestinal tract or increase the loss of vitamins via sweat or urine. Limited study data suggest that exercise may increase the loss of vitamins B_1 and B_6, although any increased losses would likely be small (Volpe, 2006). Metabolic pathways stressed by exercise and the maintenance of tissues that are altered with training could also increase vitamin requirements. For example, one of the adaptations the body makes to endurance exercise is to increase the number of mitochondrial enzymes, most of which contain a vitamin cofactor. Several vitamins are also involved in rebuilding muscle. From a theoretical perspective, there are a number of ways vitamin requirements could be increased. Alternatively, there are a number of adaptations the body can make to the stress of exercise that might preserve vitamins. Exercise may cause the body to decrease excretion, as has been shown in the case of vitamin B_6 (Crozier, Cordain, and Sampson, 1994). Exercise could also result in effective recycling of vitamins, as has been postulated for vitamin C (Peake, 2003). Because the body has so

Table 8.2 Summary of Fat- and Water-Soluble Vitamin Characteristics

Vitamin A	
Names	In animal sources: retinol, retinal, and retinoic acid In plant sources: beta-carotene (a precursor to vitamin A)
Major physiological functions	Overall health of cells and membranes (proper vision, reproduction, bone and tooth development, immune system); beta-carotene is an antioxidant
Solubility	Fat soluble
Deficiency disease	Hypovitaminosis A
Symptoms of deficiency	Night blindness, permanent blindness, more frequent and severe infections, lack of growth, inability to reproduce
Toxicity disease	Hypervitaminosis A (from animal sources)
Symptoms of toxicity	Blurred vision, lack of growth, birth defects, hemorrhaging, liver failure; can be fatal
Food sources	Animal (preformed vitamin A): Liver; fish oil; milk, and milk products (fortified) Plant: Dark-green leafy vegetables (e.g., spinach); orange fruits and vegetables (e.g., carrots, cantaloupe, tomatoes)
Other	Excess of beta-carotene from supplements is associated with pro-oxidant not antioxidant functions. May promote tumor growth in smokers. The yellowing of the skin that occurs is thought to be harmless but is indicative of a high level of intake.
Vitamin D	
Names	Calciferol, cholecalciferol
Major physiological functions	Regulates bone mineralization
Solubility	Fat soluble
Deficiency disease	Rickets, osteomalacia
Symptoms of deficiency	Bowing of the legs, demineralization of bones, joint pain, muscle spasms
Toxicity disease	Hypervitaminosis D
Symptoms of toxicity	Calcification of tissues including blood vessels; kidney stones; general gastrointestinal and nervous system complaints
Food sources	Fish oil; some fish such as salmon, mackerel, tuna, and shrimp; milk (fortified); margarine (fortified)
Other	Ultraviolet light (sunshine) can activate a vitamin D precursor in the skin
Vitamin E	
Names	Tocopherol (e.g., alpha-tocopherol, beta-tocopherol)
Major physiological functions	Antioxidant; proper red blood cell formation
Solubility	Fat soluble
Deficiency disease	Deficiencies are rare
Symptoms of deficiency	Anemia, muscle weakness
Toxicity disease	None; toxicities are rare
Symptoms of toxicity	General symptoms such as fatigue or nausea
Food sources	Oil; soybeans; almonds and other nuts; sunflower seeds; wheat germ

continued

Table 8.2 Summary of Fat- and Water-Soluble Vitamin Characteristics (continued)

Vitamin K	
Names	Phylloquinone
Major physiological functions	Normal blood clotting; role in bone mineralization
Solubility	Fat soluble
Deficiency disease	Vitamin K deficiency
Symptoms of deficiency	Hemorrhaging; poor bone mineralization
Toxicity disease	None
Symptoms of toxicity	Not known
Food sources	Green leafy vegetables
Other	Synthesized by bacteria in the intestine; Vitamin K supplements are prescription only since excessive vitamin K could interfere with medications that prevent clotting of the blood
Vitamin B_1	
Names	Thiamin
Major physiological functions	Release of energy from carbohydrates, proteins, and fats via thiamin-containing enzymes; normal nervous system function
Solubility	Water soluble
Deficiency disease	Beriberi
Symptoms of deficiency	Muscle wasting, weight loss, cardiovascular problems
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Whole grain breads and cereals; bread and cereals made from processed grains or flour (fortified); dried beans, pork
Other	Deficiencies seen in the U.S. are usually due to alcohol abuse or gastric bypass surgery
Vitamin B_2	
Names	Riboflavin
Major physiological functions	Release of energy from carbohydrates, proteins, and fats via riboflavin-containing enzymes; normal skin development
Solubility	Water soluble
Deficiency disease	Riboflavin deficiency disease
Symptoms of deficiency	Changes to the mouth, lips, and tongue; skin rash
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Milk; leafy green vegetables; whole grain breads and cereals

Table 8.2 Summary of Fat- and Water-Soluble Vitamin Characteristics (continued)

Vitamin B_3	
Names	Niacin, nicotinic acid, nicotinamide
Major physiological functions	Release of energy from carbohydrates, proteins, and fats via niacin-containing enzymes
Solubility	Water soluble
Deficiency disease	Pellagra
Symptoms of deficiency	Diarrhea, mental changes, skin rash
Toxicity disease	Not named; usually referred to as niacin toxicity
Symptoms of toxicity	Flushing, itching, rash, sweating
Food sources	Meat, fish, poultry, and eggs; milk; nuts; whole grain breads and cereals; bread and cereals made from processed grains or flour (fortified)
Other	Tryptophan, an amino acid found in foods, is a precursor to niacin. Niacin rush (flushing, itching, rash) may be a result of a high intake of supplemental vitamin B_3 in a short period of time
Vitamin B_6	
Names	Pyridoxine
Major physiological functions	Release of energy stored in muscle glycogen; role in gluconeogenic processes (e.g., manufacture of glucose from protein fragments); red blood cell formation
Solubility	Water soluble
Deficiency disease	Not named
Symptoms of deficiency	Microcytic (small cell) anemia
Toxicity disease	Not named; usually referred to as vitamin B_6 toxicity
Symptoms of toxicity	Nervous system impairment including fatigue, difficulty walking, numbness, depression
Food sources	Whole grain breads and cereals; dried beans; leafy green vegetables; bananas; meat, fish, and poultry
Other	Not all symptoms of vitamin B_6 toxicity are reversed after supplementation is withdrawn
Vitamin B_{12}	
Names	Cobalamin, cyanocobalamin
Major physiological functions	Synthesis of new cells; nervous system; red blood cell formation; activation of folate
Solubility	Water soluble
Deficiency disease	Not named
Symptoms of deficiency	Fatigue; nerve cell degeneration; numbness; lack of vitamin B_{12} absorption results in pernicious anemia
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Animal foods only; specially formulated yeast (fortified)
Other	Intrinsic factor (IF), which is produced in the stomach, is needed for vitamin B_{12} absorption in the intestine. Lack of IF may require vitamin B_{12} injections

continued

Table 8.2 Summary of Fat- and Water-Soluble Vitamin Characteristics (continued)

Folate	
Names	Folic acid, folacin
Major physiological functions	Synthesis of new cells; red blood cell formation
Solubility	Water soluble
Deficiency disease	Not named
Symptoms of deficiency	Megaloblastic (large cell) anemia; depression; in pregnancy, increased risk for neural tube defects
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Leafy green vegetables; whole grain breads and cereals; dried beans; bread and cereals made from processed grains or flour (fortified); orange juice
Other	Folate supplementation can mask the symptoms of vitamin B_{12} deficiency and can delay diagnosis
Pantothenic Acid	
Names	No other name
Major physiological functions	Release of energy from carbohydrates, proteins, and fats via acetyl CoA
Solubility	Water soluble
Deficiency disease	Not named; rare
Symptoms of deficiency	Fatigue
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Widely distributed in food
Biotin	
Names	No other name
Major physiological functions	Release of energy from carbohydrates, proteins, and fats
Solubility	Water soluble
Deficiency disease	Not named; rare
Symptoms of deficiency	Fatigue; loss of appetite
Toxicity disease	None
Symptoms of toxicity	None known
Food sources	Widely distributed in food
Vitamin C	
Names	Ascorbic acid
Major physiological functions	Collagen synthesis; antioxidant; immune function; aids absorption of iron
Solubility	Water soluble
Deficiency disease	Scurvy

Table 8.2 Summary of Fat- and Water-Soluble Vitamin Characteristics (continued)

Vitamin C (continued)	
Symptoms of deficiency	Poor wound healing; bleeding gums, small blood vessel hemorrhages
Toxicity disease	Not named
Symptoms of toxicity	Diarrhea, fatigue, kidney stones in some people
Food sources	Oranges, grapefruit, and other citrus fruits; strawberries, cabbage, broccoli, peppers, tomatoes

Gropper, S.S., Smith, J.L. and Groff, J.L. *Advanced Nutrition and Human Metabolism*. Thomson/Wadsworth, Belmont, CA, 2005.

Table 8.3 DRI and UL for Adult Males and Adult, Nonpregnant Females

Vitamin	Dietary Reference Intakes (DRI)	Tolerable Upper Intake Level (UL)
Vitamin A	700 mcg (females) 900 mcg (males)	3,000 mcg*
Vitamin D	5 mcg (ages 19 to 50) 10 mcg (ages 51 to 70) 15 mcg (over age 70)	50 mcg
Vitamin E	15 mg	1,000 mg**
Vitamin K	90 mcg	Not established
Thiamin	1.1 mg (females) 1.2 mg (males)	Not established
Riboflavin	1.1 mg (females) 1.3 mg (males)	Not established
Niacin	14 mg (females) 16 mg (males)	35 mg
Vitamin B_6	1.3 mg (ages 19 to 50) 1.5 mg (females over 50) 1.7 mg (males over 50)	100 mg
Vitamin B_{12}	2.4 mcg	Not established
Folate	400 mcg	1,000 mcg
Pantothenic acid	5 mg	Not established
Biotin	30 mcg	Not established
Choline	425 mg (females) 550 mg (males)	3,500 mg
Vitamin C	75 mg (females)*** 90 mg (males)***	2,000 mg

Legend: mg = milligrams; mcg = micrograms

Dietary Reference Intakes.

*Refers to preformed vitamin A, not beta-carotene.

**Via supplements or fortified foods.

***Values are increased for smokers. Female smoker, 110 mg; Male smoker, 125 mg.

Athletes can improve their vitamin status by increasing their intake of fruits, vegetables, and whole grains.

many adaptive mechanisms in response to exercise, an increase in utilization does not necessarily mean an increase in dietary need.

Research in this area has been limited because it is difficult to conduct. To determine the effect of exercise on vitamin requirements both trained and untrained subjects are needed. These subjects would need to consume sufficient energy and controlled amounts of the vitamin being studied. Extensive measurements are required to determine the effect of training on vitamin absorption, excretion, metabolism, and utilization. It is not surprising that the body of scientific literature in this area is small (Akabas and Dolins, 2005).

At the present time the effect that exercise has on vitamin requirements is presumed to be relatively small and adequately covered by the requirements set forth for sedentary humans. Perhaps the most striking feature of the scientific literature in this area is not evidence of an increased demand for vitamins imposed by the stress of exercise, rather it is the marginal dietary intake of vitamins by some athletes. These marginal intakes are a result of low energy intake and limited consumption of

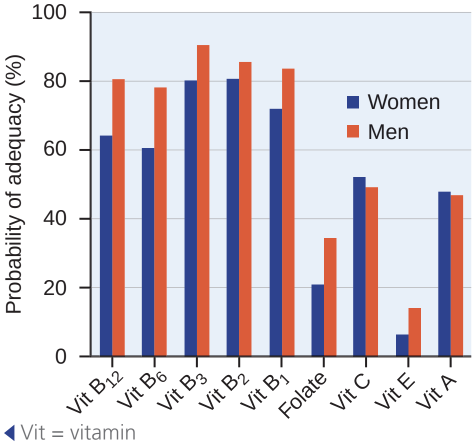

Figure 8.1 Probability of Adequate Vitamin Intake for Adult Males and Females

Many adults likely consume inadequate amounts of several vitamins, and in particular, low amounts of folate and vitamins A, C, and E.

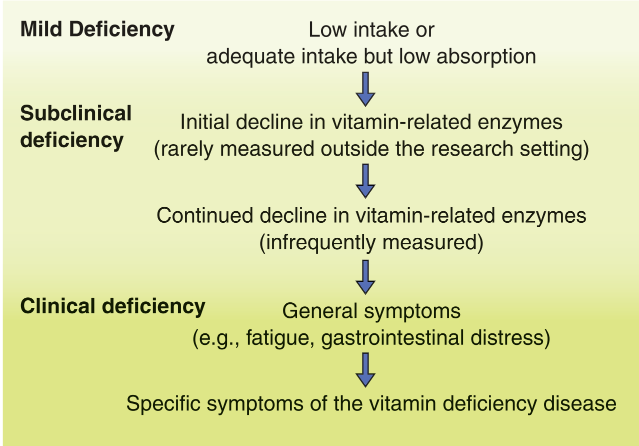

Figure 8.2 Stages Associated with Vitamin Deficiency

Vitamin deficiencies progress from mild to moderate (subclinical) to severe (clinical). The progression through the mild and moderate deficiency stages is difficult to monitor and recognize.

nutrient-dense foods (Lukaski, 2004; Manore, 2000). For many athletes, improving dietary intake, particularly of fruits, vegetables, and whole grains, may be the best initial action to improve their vitamin status.

AVERAGE VITAMIN INTAKES BY SEDENTARY ADULTS AND ATHLETES

Figure 8.1 shows the probability of adequate vitamin intake from food for U.S. adult males and females. For example, only 14.1 percent of men and 6.8 percent of women are likely to receive an adequate amount of vitamin E from their diets. These figures are from data obtained between 1994 and 1996 (2005 Dietary Guidelines Advisory Committee Report). A dietary analysis would need to be performed for an individual to know the approximate amount of vitamins he or she consumes daily, but these average values are telling. This chart illustrates three important points: 1) many U.S. adults do not eat as nutritiously as they should and therefore do not meet daily vitamin recommendations, 2) the intake of folate and the antioxidant vitamins A, C, and E are particularly low, and 3) some adults are likely to have mild subclinical vitamin deficiencies because of long-term low intake of some vitamins.

Perhaps the single most important factor in obtaining excellent nutritional status is adequate energy intake. Many studies have shown that for both male and female athletes, inadequate energy intake is associated with inadequate nutrient intake (Jonnalagadda, Ziegler, and Nelson, 2004; Leydon and Wall, 2002; Papadopoulou, Papadopoulou, and Gallos, 2002; Ziegler et al., 2002 and 1999; Lukaski, 2004). Energy-restricted athletes such as female gymnasts, ballet dancers, wrestlers, and jockeys often consume low dietary intakes of one or more vitamins. Low vitamin E intake may reflect a low-fat diet, a common dietary pattern for athletes such as distance runners who must emphasize higher carbohydrate and protein consumption because of the demands of training and competition (Horvath et al., 2000).

Although energy intake is often associated with vitamin intake, it is not always a predictor. Sometimes energy intake is adequate, or even excessive, but vitamin intake is low. This is most likely a result of poor food choices. When fruit and vegetable intake is lower than recommended, as is the case for the majority of adults (Centers for Disease Control and Prevention, 1988) and presumably many athletes in the United States, intakes of vitamins A and C are typically low. Low intake of vitamins from food is the first step toward a vitamin deficiency.

VITAMIN DEFICIENCIES AND TOXICITIES

Vitamin deficiencies do not occur overnight, especially in previously well-nourished adults. Any vitamin deficiencies will progress through stages—at first mild, then moderate, and ultimately, severe. Severe deficiencies are termed **clinical deficiencies** while mild and moderate deficiencies are called **subclinical deficiencies.** These terms describe indistinct points on a continuum. There are no clear-cut divisions between mild and moderate and moderate and severe deficiencies. The stages are outlined in Figure 8.2.

Developing Mild Deficiencies. Mild deficiencies can develop if vitamin intake is poor or absent. As discussed previously, many adult diets are lacking sufficient amounts of vitamins and, over time, mild vitamin deficiencies can develop. In a few cases the intake of a vitamin could be zero. For example, vegans do not consume any animal-derived products and their diets could be devoid of vitamin B_{12}, which is only found in animal foods. Vitamins must also be properly absorbed and utilized by the body, which is the case for most people, but poor vitamin absorption can be a consequence of some gastrointestinal diseases. Inadequate vitamin intake from the diet is one of the few factors associated with vitamin deficiencies that can be easily documented. The first step in determining a potential vitamin deficiency is an assessment of usual vitamin intake.

Developing Subclinical Deficiencies. If poor intake or absorption is not reversed or resolved, a subclinical deficiency can develop over time. With a subclinical vitamin deficiency the person shows no medical signs of a disease. However, the lack of a particular vitamin can begin to affect functionality. For example, a lack of vitamin A ultimately results in blindness, a sign of a clinical vitamin A deficiency. However, long before blindness appears problems with normal vision are present, such as difficulty in being able to see in the dark or adjusting vision to low light conditions. Any subtle changes are hard to detect early, and in most cases there are few reliable tests to determine whether a subclinical vitamin deficiency exists (Tanumihardjo, 2004).

Vitamin status can be assessed through biochemical measurements of the vitamins or their metabolites (i.e., a by-product of the vitamin's metabolism). These tests involve the analysis of blood or urine. Although such tests are used in scientific studies, they are rarely performed outside a research setting because of the expense and the difficulty in getting accurate measurements (small changes in vitamin-related biochemical pathways are hard to detect).

An important question is how prevalent are subclinical vitamin deficiencies in U.S. adults, including athletes? That is a difficult question to answer because of a lack of studies, particularly of athletes. Nutrition scientists suspect that some people in the general population have subclinical vitamin deficiencies because the intake for some vitamins is well below recommendations, but only vitamin D and vitamin B_{12} subclinical vitamin deficiencies have been well documented (see below). Many physically active people consume a sufficient amount of vitamins and those athletes who do not are often restricting caloric intake. Low intake can result in marginal body stores and subclinical vitamin deficiencies (Manore, 2000). These deficiencies can lead to impaired biochemical function (e.g., reduced enzyme activity), but evidence is lacking that performance is impaired (Lukaski, 2004).

Ultraviolet light (e.g., sunshine) can activate a precursor to vitamin D in skin cells. People who have no sunshine exposure may manifest a subclinical vitamin D deficiency if their vitamin D intake from food is low. Cultural, as well as dietary factors, can contribute to vitamin D deficiency. For example, women who are completely clothed and veiled when outside and who do not consume any foods containing vitamin D can develop a subclinical vitamin D deficiency (Hatun et al., 2005). Similarly, people who live at high latitudes during the winter lack exposure to ultraviolet light.

Vitamin B_{12} is only found in animal foods. Vegans, who eliminate all sources of animal products from their diets, are at risk for a subclinical vitamin B_{12} deficiency because of a chronically low intake for many years. Vegetarians may also be at risk. Herrmann and colleagues (2003) found that more than 75 percent of the vegetarians they studied who consumed milk or milk and eggs had laboratory test results that suggested a subclinical vitamin deficiency. Although the subjects consumed some vitamin B_{12} from the milk or eggs, their intake over time was probably too low. It is recommended that vegetarians, particularly vegans, consume supplemental vitamin B_{12} or vitamin B_{12} fortified foods (Antony, 2003).

Developing Clinical Deficiencies. As has been shown throughout human history, the lack of a particular vitamin can lead to a vitamin deficiency disease. Several vitamin deficiency diseases were common and widespread throughout the world, including the United States, until the 1950s. Examples include rickets, a bone malformation disease in children caused by a lack of vitamin D, and beriberi, a disease of the nervous system caused by a deficiency of thiamin. Some of these diseases are still common today in some countries.

With a clinical vitamin deficiency the person shows medical signs of a disease. For example, someone suffering from pellagra, which is due to a lack of the B vitamin niacin, would have changes in skin similar to sunburn, a red and swollen tongue, diarrhea, and mental confusion. In the United States and other developed nations, clinical vitamin deficiency diseases are rare because of an abundant food supply, vitamin fortification of foods, and use of vitamin supplements. The chances of young or middle aged, active U.S. adults manifesting a clinical vitamin deficiency are slim. One exception, which may apply to some athletes, is an individual with a severe eating disorder (see Chapter 13). A clinical vitamin deficiency that is due to poor intake can be treated and reversed by administering the missing vitamin, usually in the form of a supplement.

Developing and Reversing Toxicities. Vitamin deficiencies do not occur overnight; neither do vitamin toxicities. Most vitamin toxicities take months or years to develop.

Clinical deficiency: Severe lack of, resulting in recognizable medical signs and symptoms.

Subclinical deficiency: Mild to moderate lack of; medical signs and symptoms are typically not present or are difficult to recognize.

Initially, the symptoms of vitamin toxicity are usually vague—a general feeling of **lethargy,** also known as **malaise.** With continued exposure to high amounts, more specific symptoms emerge, often related to major organ systems such as the liver or nervous system. Vitamin toxicities are rare but they can occur and have been reported for vitamins A, D, E, and B_6 (Hathcock et al., 2005; Bendich, 2000; Vieth, 1999).

Vitamin A toxicity, known as **hypervitaminosis** A, provides an excellent example of the many issues related to vitamin overdose. Myhre et al. (2003) conducted a meta-analysis of all vitamin A toxicities reported in the medical literature between 1944 and 2000. Recall from Chapter 1 that a meta-analysis is a powerful statistical method used to compare similar research studies and review the collective body of scientific research on a particular topic. These researchers found that there were 259 reported cases of vitamin A overdose worldwide. The largest number of cases, 105, was from the United States. This meta-analysis confirms that while the number of cases is extremely small, vitamin A toxicity does occur.

The researchers found evidence of hypervitaminosis A with both acute (short-term) and chronic (long-term) excessive intake of **retinol,** a form of vitamin A. Those who developed an acute toxicity did so within a few weeks. In contrast, the chronic toxicity was the result of months or years of excessive ingestion. The key finding was the form of the supplement consumed. Those who developed an acute toxicity took water-**miscible, emulsified,** and solid preparations, while those who developed a chronic toxicity consumed an oil-based supplement. Retinol in water-miscible, emulsified, and solid preparations is very readily absorbed; faster absorption led to acute toxicity. Therefore, the form of the vitamin supplement can be important as well as the dose consumed.

The widespread use of multivitamin supplements in the United States raises the question of whether the consumption of such supplements results in toxicities. The accumulated data from U.S. Poison Control Centers for 2003 indicate that there were 57,801 human poison exposure cases reported from the ingestion of multivitamins (including some that contained the mineral iron). More than 45,000 of these cases were in children under the age of six; 6,931 cases involved adults. Of the more than 57,000 reports, four resulted in death and 63 in major medical conditions. These data further underscore the fact that vitamin toxicities do occur, although serious health consequences are rare (Watson et al., 2004).

Once vitamin toxicity is diagnosed, the usual treatment is to curtail the use of that supplement. When the body is no longer exposed to high doses, tissue concentrations decrease over time and symptoms generally subside. The best prevention of vitamin toxicities is for individuals to not consume doses higher than the Tolerable Upper Intake Levels, which are discussed in more detail later in this chapter.

What's the point? The Dietary Reference Intakes (DRI) and the Tolerable Upper Intake Level (UL) are guidelines for obtaining sufficient, but not excessive, amounts of vitamins. In healthy adults, vitamin deficiencies and toxicities are typically slow to develop and difficult to detect initially.

The Roles of Vitamins in the Body

Each vitamin has a unique chemical composition as well as specific biochemical roles. Vitamins with similar functions are often grouped together. Vitamins associated with energy metabolism are differentiated from vitamins needed for blood formation or antioxidant functions. Athletes are particularly interested in these functions since each plays a role in training and performance.

VITAMINS AND ENERGY METABOLISM

Thiamin (B_1), riboflavin (B_2), niacin (B_3), vitamin B_6, pantothenic acid, and biotin are often referred to as the B-complex vitamins. These vitamins are primarily involved in the production of ATP as they are part of the enzymes that regulate these reactions. Enzymes are a two-part molecule; one part of which is a coenzyme. The coenzyme typically contains a vitamin, also known as a cofactor. Without vitamins, the enzymes could not function and the energy found in carbohydrates, fats, proteins, and alcohol could not be converted to ATP. Table 8.4 briefly list some of the vitamins and their associated coenzymes and biochemical functions, while Figure 8.3 highlights the vitamin-containing compounds involved in energy metabolism.

Thiamin. Thiamin (B_1) is part of a coenzyme involved in the release of energy from carbohydrates, proteins, and fats. The majority of the thiamin in the body (~80 percent) is found as thiamin diphosphate (TDP), which is also known as thiamin pyrophosphate (TPP). TDP **catalyzes** reactions involving pyruvate and α-ketoglutarate (see Figure 8.3) and the branched chain amino acids (leucine, isoleucine, and valine). TDP is one of several enzymes needed in these biochemical reactions. Half of the thiamin in the body is found in skeletal muscle, where many of these reactions occur (Gropper, Smith, and Groff, 2005).

Given the link between thiamin and ATP production, a logical question is whether an increase in thiamin intake above that which is normally needed could result in an increase in TDP and energy production. An athlete might ask, "Does taking more thiamin give me

Table 8.4 Vitamins and Associated Coenzymes

Vitamin	Coenzyme	Biochemical Pathway
Thiamin (B_1)	Thiamin pyrophosphate (TPP); also known as thiamin diphosphate (TDP)	Decarboxylation (removal of –COOH group to form CO_2) of pyruvate and alpha-ketoglutarate
Riboflavin (B_2)	Flavin mononucleotide (FMN); Flavin adenine dinucleotide (FAD)	Numerous oxidation-reduction reactions (can accept and release a pair of hydrogen atoms)
Niacin (B_3)	Nicotinamide adenine dinucleotide (NAD and NADH); Nicotinamide adenine dinucleotide phosphate (NADP and NADPH)	NAD and NADH transfer electrons in the electron transport chain; NADP and NADPH are involved in reduction reactions in many parts of the cell
Vitamin B_6 (pyridoxine)	Pyroxidoxal phosphate (PLP)	Needed for amino acid metabolism, including transamination, transferring and removing sulfur, cleavage, and synthesis
Pantothenic acid	Component of acetyl CoA	Critical intermediate compound in energy production (carbohydrates, proteins, and fats)

Gropper, S.S., Smith, J.L. and Groff, J.L. *Advanced Nutrition and Human Metabolism*. Thomson/Wadsworth, Belmont, CA, 2005.

JJ/Taxi/Getty Images

Nutrient-dense carbohydrate-containing foods, such as breads, cereals, and grains, are excellent sources of thiamin.

more energy?" The answer is no. Consuming the recommended amount of thiamin likely results in tissues being saturated with thiamin. Enzymes and coenzymes function at maximum velocity when saturated with a substrate. After the point of saturation, more substrate will not result in a greater number of enzymes or greater speed. When enzymes and tissues are saturated with water-soluble vitamins, any excess is excreted in urine. Energy production is not increased with excess thiamin intake because the extra thiamin is not utilized and is excreted when it exceeds the point of saturation.

Athletes in training produce more ATP than nonathletes, so another logical question is whether athletes need more thiamin than sedentary individuals. The link between increased ATP production and a sufficient amount of thiamin is the consumption of sufficient carbohydrate foods. Athletes who expend large amounts of energy for training and competition need to consume sufficient energy (kilocalories) from food to support their high levels of physical activity. A large part of that energy should come from carbohydrate foods, since carbohydrates are needed to resynthesize muscle glycogen on a daily basis. Nutrient-dense carbohydrate-containing foods, such as breads, cereals, and grains, are excellent sources of thiamin. When energy expenditure is high, many athletes increase their caloric intake and their intake of high-quality carbohydrates. In doing so, they consume sufficient thiamin and meet or exceed the DRI.

Low thiamin intake in athletes is associated with energy restriction and consumption of low nutrient-dense carbohydrates (e.g., food or beverages high in sugar and low in fiber and vitamins). Dietary intake studies of female gymnasts and collegiate wrestlers have confirmed that these athletes restrict energy intake and as a result have low thiamin intakes. Short-term (4 to 12 weeks) low intake of thiamin does not appear to affect performance in the few studies that have examined the effects, but it is assumed that fatigue and related effects on training and performance could occur with severe or prolonged thiamin restriction (Lukaski, 2004).

Lethargy: Physically slow or mentally dull.

Malaise: A general feeling of sickness but a lack of any specific symptoms.

Hypervitaminosis: Excessive intake of one or more vitamins.

Retinol: Preformed vitamin A.

Miscible: Two or more liquids that can be mixed together.

Emulsified: Suspending small droplets of one liquid in another liquid, resulting in a mixture of two liquids that normally tend to separate, e.g., oil and water.

Catalyze: Increase the rate of, such as speeding up a chemical reaction.

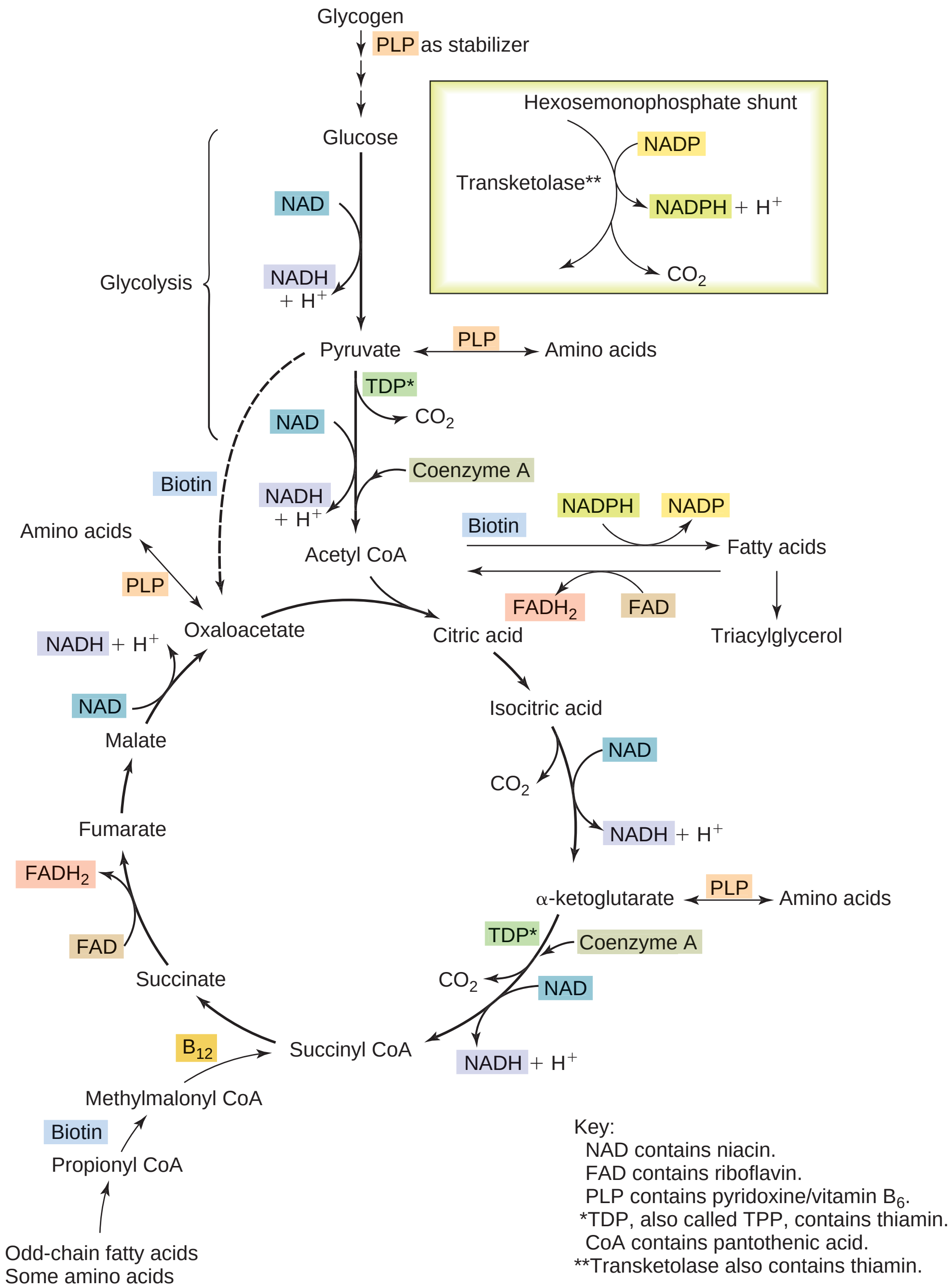

Figure 8.3 Vitamin-Containing Compounds Involved in Energy Metabolism

Riboflavin. Riboflavin is part of two coenzymes involved in ATP production, flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD). These coenzymes are necessary for the numerous oxidation-reduction reactions that occur because they can accept or release hydrogen atoms (see Figure 8.3). The synthesis of these enzymes is under hormonal control. Although a sufficient amount of riboflavin must be consumed, excessive amounts are excreted in the urine (Gropper, Smith, and Groff, 2005).

Most athletes consume sufficient riboflavin although there have been reports of low intake by athletes, typically by those who consume too few kilocalories. Fatigue and related effects on training and performance could occur with severe or prolonged riboflavin restriction (Lukaski, 2004). However, riboflavin is found in a wide variety of foods such as breads and cereals, vegetables, meat, and dairy products such as milk, and athletes consuming a sufficient amount of energy would not likely be deficient.

Anthony Blake Photo Library/Photolibrary

Riboflavin is found in a wide variety of foods, with dairy products being excellent sources.

Anthony Blake Photo Library/Photolibrary

Green leafy vegetables and protein-containing foods are excellent sources of vitamin B_6.

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Excellent sources of niacin include protein-containing foods such as chicken, tuna, and pork.

Niacin. Niacin is part of two coenzymes, nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP). These coenzymes are involved in numerous reactions and are part of almost 200 enzymes in the body. NAD/NADH play critical roles in the production of ATP (see Figure 8.3), including the transfer of electrons in the electron transport chain. In addition, NADP/NADPH are needed in a variety of reactions such as synthesis of fatty acids and the oxidation of the amino acid glutamate. Many cellular reactions involve niacin as a cofactor.

Severe or prolonged deficiencies could occur, but evidence of subclinical deficiencies affecting performance is lacking. Athletes who consume sufficient energy also consume sufficient niacin (Lukaski, 2004). Excellent sources of niacin include protein-containing foods such as chicken, tuna, and pork. Cereal, because it has niacin added, is also high in niacin.

Vitamin B_6. Vitamin B_6 (pyridoxine) is involved in amino acid metabolism and the release of glucose from glycogen (see Figure 8.3). Pyroxidoxal phosphate (PLP) is one of the coenzymes that catalyze reactions that transform amino acids (e.g., amino acid cleavage and synthesis, transamination). For example, the synthesis of the conditionally indispensable amino acid cysteine from the indispensable amino acid methionine requires PLP. PLP is also part of the enzyme that helps release glucose from glycogen stores, and most of the vitamin B_6 in skeletal muscle is found as PLP. Limited studies suggest that a vitamin B_6 deficiency may impair exercise capacity (Manore, 2000).

Vitamin B_6 is found in both plant and animal sources and surveys have shown that most athletes consume an adequate amount daily. A food that is a favorite of many athletes, bananas, contains a large amount of vitamin B_6, as do green, leafy vegetables. Not surprisingly, given the vitamin's role in amino acid metabolism, protein-containing foods such as meat, fish, and poultry are good sources of vitamin B_6.

Pantothenic Acid and Biotin. Many people are somewhat familiar with thiamin, riboflavin, niacin, and vitamin B_6 but may be unfamiliar with the remaining B-complex vitamins, pantothenic acid and biotin. While these vitamins may be mentioned less often, they are almost always included in vitamin B-complex supplements. Pantothenic acid is part of coenzyme A (CoA), an important compound in aerobic metabolism. Like other enzymes, acetyl CoA is made up of two parts, acetate (also known as acetic acid) and coenzyme A. Pantothenic acid is intimately involved in energy metabolism as a part of this compound but large amounts of pantothenic acid do not increase the rate of energy reactions. Biotin is also involved in a number of energy-related reactions (see Figure 8.3).

Not surprisingly, pantothenic acid and biotin are widely found in food. If vitamins that are so universally involved in energy metabolism were concentrated in a few select foods, it is likely that deficiencies would occur more frequently. However, pantothenic acid and biotin deficiencies in humans are extremely rare because nearly all foods contain some of these compounds.

To summarize, the B-complex vitamins are important nutrients because they are part of the enzymes that catalyze the biochemical reactions associated with energy (see Table 8.4 and Figure 8.3). They play a critical role in energy metabolism but, by themselves, do not provide "energy" (see Spotlight on Enrichment: Vitamins and "Energy"). Excessive amounts of the B vitamins do not result in more enzymes or greater enzymatic activity. A clear theme has emerged—consuming sufficient energy (kilocalories) and eating a variety of nutrient-dense foods usually ensures that enough of the vitamins needed to metabolize the energy will be ingested. Athletes who are at risk for low intake and potential subclinical deficiencies are those who restrict their caloric intake and consume foods that are nutrient poor (e.g., high in sugar and low in vitamins).

VITAMINS AND ANTIOXIDANT PROTECTION

Oxygen is needed to produce ATP from carbohydrates, fats, or proteins under aerobic conditions. The majority of oxygen used in oxidative phosphorylation reactions is reduced to water but a small percentage (~4–5 percent) is not. Instead, **free radicals** or **reactive oxygen species** (ROS) are produced. ROS are unstable chemical compounds that can destroy cells by damaging cellular membranes and DNA. ROS will always be present; the key issue is that there is a balance between rate of production and rate of clearance. The latter requires a sufficient, but not excessive, amount of antioxidants (Peake, 2003; Clarkson and Thompson, 2000). The imbalance between ROS and antioxidants that occurs with exercise is termed **oxidative stress,** which can lead to damaged cells, tissues, and organs (Urso and Clarkson, 2003).

The formation of free radicals is directly related to exercise intensity and duration. As exercise intensity and duration increases, the body makes greater use of the aerobic energy system (oxidative phosphorylation), and as a result, more ROS are formed. Therefore, endurance exercise has the potential to produce more tissue-damaging free radicals. A positive result of aerobic exercise training, however, is a buildup of the body's natural defenses against ROS, both the enzymatic and non-enzymatic antioxidants (Jackson et al., 2004).

Each cell has many antioxidant systems located predominantly in the cell membrane, cytoplasm, and mitochondria. These systems rely on sufficient amounts and types of antioxidant vitamins (e.g., vitamins E, C, and A as **carotenoids**) as well as several minerals (e.g., selenium, zinc, iron). The antioxidant vitamins can directly interact with ROS to prevent cell damage and, in some cases, may be able to repair the damage. These

SPOTLIGHT ON ENRICHMENT

Vitamins and "Energy"

Vitamins play critical roles in energy metabolism but they are *indirect* roles. The biological energy that is needed to perform work is provided by carbohydrates, proteins, fats, and alcohol and this energy is measured in kilocalories. Vitamins contain no energy but facilitate the production of energy. Why then do people say, "vitamins give me energy"? Why do ads for vitamin supplements proclaim, "vitamins for energy"? One reason is that a *clinical* vitamin deficiency of one or more of the B-complex vitamins results in physical fatigue. Theoretically, a subclinical deficiency of any one of the B-complex vitamins could also result in fatigue, although proof of this is lacking for several vitamins. Broad statements linking vitamins to energy are correct, but it needs to be understood that the roles vitamins play in energy metabolism are not simple, direct, or independent, rather, they are complicated, indirect, and in partnership with other compounds. The vitamin/energy claims are typically overstated because they are out of context for the athlete who is unlikely to have a clinical vitamin deficiency.

Athletes can be fatigued for a number of nutrient-related reasons, including inadequate energy (caloric) intake, lack of sufficient carbohydrates, hypohydration (insufficient volume of body water), and subclinical B-complex vitamin deficiencies. If the reason is a lack of B-complex vitamins as part of a low caloric intake, then consuming more nutritious foods will likely resolve both the low energy and vitamin consumption. If caloric intake is sufficient but B-complex vitamin intake is low (a scenario that is not as likely but could exist due to the high intake of foods that are calorie dense but not nutrient dense), increasing consumption of foods containing B-vitamins is a logical first step. B-complex vitamin supplements could also be considered. If an athlete's vitamin status has been compromised (e.g., poor long-term vitamin intake due to an eating disorder) and a subclinical deficiency is suspected, consumption of appropriate amounts of the deficient vitamins will restore normal levels and will address vitamin-related issues of fatigue. The consumption of B-complex vitamins above and beyond recommended amounts in an athlete who is not deficient does not provide "extra" energy.

vitamins also play an indirect role in the overall functioning of antioxidant systems. The concern for endurance athletes is that the production of ROS may outstrip the body's ability to defend against them, leading to oxidative stress (Williams et al., 2006; Evans, 2000; Powers and Lennon, 1999).

Low intake of the antioxidant vitamins impacts the body's ability to counteract the harmful effects of oxidation. For this reason, many endurance athletes consider taking vitamin A (as beta-carotene), C, and/or E supplements. However, excessive intake can also have a harmful effect. At high concentrations antioxidant vitamins can act as pro-oxidants. Pro-oxidants increase the formation of free radicals and enhance oxidative damage. Viewed on a continuum, both low and high amounts of antioxidant vitamins are harmful, but for different reasons.

Williams et al. (2006) reviewed the results of 41 studies of antioxidant supplements (primarily vitamins E, C, or A as beta-carotene) conducted in endurance athletes prior to 2005. Of the 47 trials (some studies tested more than one supplement), 20 found that exercise-induced oxidative stress was decreased with supplementation of antioxidant vitamins, while such supplements had no effect in 23 trials. Four trials reported an increase in oxidative stress. Half of the 20 trials that showed a decrease in oxidative stress involved vitamin E supplements. The authors of the review concluded that the results of antioxidant supplement studies in endurance athletes are **equivocal** (difficult to interpret) and state that there is currently insufficient evidence to recommend antioxidant supplements to endurance athletes. However, there is one area of scientific agreement—all athletes should consume a diet that is rich in antioxidant-containing foods, particularly fruits, vegetables, and whole grains (Williams et al., 2006, Urso and Clarkson, 2003; Lukaski, 2004).

A 2007 meta-analysis of the use of antioxidant supplements to prevent disease found that supplemental vitamin A, beta-carotene, and vitamin E, consumed singly or combined, was not associated with reduced mortality. In fact, the analysis indicated that antioxidant supplement use was associated with a higher rate of premature mortality. It is estimated that 10–20 percent of the adults in North America and Europe (~80–160 million people) consume antioxidant supplements (Bjelakovic et al., 2007).

Vitamin E. Vitamin E is the primary antioxidant found in cell membranes. Cell membranes contain a high proportion of polyunsaturated fatty acids, which can be oxidized by ROS. The destruction of the lipid in the cell membrane is a chain reaction requiring several steps. Vitamin E's role is to break the chain reaction. Free radicals are a thousand times more likely to react with vitamin E than with polyunsaturated fatty acids (Viitala et al., 2004). For these reasons, vitamin E is an essential vitamin because it can prevent oxidative damage and maintain the integrity of cell membranes. Severe damage to cell membranes would cause the cell to leak fluid, leading to cellular death.

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Fruits, vegetables, nuts, and whole grains are rich in antioxidants.

The Dietary Reference Intake for Vitamin E for adults is 15 mg daily. Vitamin E has a very low potential for toxicity and the Tolerable Upper Intake Level is 1,000 mg. Deficiencies are rare and are associated with fat malabsorption syndromes. Some surveys of athletes have shown that intake from food is low (Lukaski, 2004). This is particularly true when total fat intake is restricted, the case for many athletes who are restricting energy intake in an effort to attain or maintain a low percentage of body fat. Excellent dietary sources of vitamin E include oils, seeds, nuts, whole grains, and vegetables.

Free radical: An atom or group of atoms with at least one unpaired electron.

Reactive oxygen species: Oxygen ions, free radicals, and peroxides that are highly reactive because of the presence of unpaired electrons.

Oxidative stress: Damage to cells, organs, or tissues due to reactive oxygen species. Caused by an imbalance between pro-oxidants and antioxidants.

Carotenoid: A precursor to vitamin A, characterized by an orange or red pigment.

Equivocal: Open to more than one interpretation; difficult to interpret or understand.

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Excellent sources of vitamin E include oils, seeds, nuts, whole grains and vegetables.

Vitamin E is a popular dietary supplement among athletes, particularly endurance athletes (Morrison, Gizis, and Shorter, 2004). Theoretically, endurance athletes would be at greater risk for oxidative damage due to their prolonged aerobic training, which may take place under environmental conditions that generate free radical production (e.g., high altitude, exposure to ozone and ultraviolet light). It has also been postulated that resistance exercise could be associated with oxidative damage. Resistance exercise can damage muscle tissue that leads to inflammation, a process associated with an increase in ROS (Viitala and Newhouse, 2004). At the present time, antioxidant supplements for athletes are generally not recommended because the study results are inconclusive and there is some evidence that oxidative stress could be increased with antioxidant supplementation (Williams et al., 2006; Lukaski, 2004; Viitala and Newhouse, 2004; Viitala et al., 2004).

While the current body of research does not support using vitamin E supplementation as a way to enhance exercise training or performance, researchers acknowledge that not all scientists agree. Vitamin E remains a popular supplement because of the theoretical *potential* to decrease exercise-induced oxidative damage in muscle tissue. Vitamin E supplements are commonly sold in dosages of 100 or 200 mg daily, amounts that are not achievable through food alone and well above the DRI for adults, 15 mg daily. In those studies in which an increase in oxidative damage was reported, the amount of vitamin E consumed was greater than 200 mg (Williams et al., 2006). It should be noted that on supplement labels vitamin E may be listed in International Units (IU), an old unit of measurement. To receive 15 mg of supplemental vitamin E, one must choose a supplement that contains 22 IU of natural vitamin E or 33 IU of synthetic vitamin E. Some of the vitamin E found in synthetic forms is inactive, thus, more of the synthetic vitamin E is needed when compared to more active forms. The Tolerable Upper Intake Level is 1,000 mg daily, which is equivalent to 1,500 IU of natural vitamin E or 1,100 IU of synthetic vitamin E (Institute of Medicine, 2000).

In light of two large meta-analyses, questions have been raised about the effect of large doses of supplemental vitamin E on health. As mentioned previously, Bjelakovic et al. (2007) found that antioxidant supplementation, including vitamin E supplements, was associated with an increased risk of premature mortality. This analysis of trials totaling more than 230,000 people included healthy individuals as well as those with chronic diseases. Miller et al. (2005) reviewed 19 clinical trials totaling approximately 140,000 people and found that high doses of vitamin E supplements ($>$400 IU daily) were associated with increased **all-cause mortality.** The study participants were adults with chronic diseases, often heart disease or cancer. Although vitamin E appears to have a low risk for toxicity, it should not be assumed that supplementing with vitamin E is risk free. Although more studies are needed, vitamin E supplements may be detrimental, not beneficial, to health.

To judge the potential performance and health benefits of supplemental vitamins, athletes and sports medicine professionals must be critical thinkers. Athletes need to obtain correct information from unbiased sources and then draw appropriate conclusions about the safety and effectiveness of a particular supplement. Spotlight on Supplements: Applying Critical Thinking Skills to Evaluating Dietary Supplements examines one athlete's reasons for taking a vitamin E supplement and the conclusions that he draws.

Vitamin C. Vitamin C is an antioxidant vitamin that works both independently of and in conjunction with vitamin E. Vitamin C is a water-soluble vitamin, and its antioxidant activity occurs primarily in extracellular tissue. In these ways vitamin C is very different from vitamin E. However, vitamin E also depends on vitamin C. When vitamin E interacts with a free radical, it becomes oxidized; vitamin C can interact with the oxidized vitamin E, reducing the compound and regenerating the vitamin E (Gropper, Smith, and Groff, 2005). These vitamins work both separately and together, which is the reason many researchers include both vitamins in their study protocols and athletes may hear recommendations to take these supplements together.

It is very hard to study vitamin C as an antioxidant during exercise. The number of studies in athletes is small and the results are conflicting. Some researchers suggest that athletes have a greater need for vitamin C than the general population. Others suggest that the needs of athletes are not greater than the sedentary population and that supplementation does not help athletes counteract the free radicals that result from exercise (Peake, 2003). At present, this debate continues.

Vitamin C-containing fruits and vegetables include strawberries, citrus fruits, and peppers.

The DRI for nonsmoking females is 75 mg/d and 90 mg daily for nonsmoking males. Fortunately, the majority of athletes consume approximately 90 to 140 mg of vitamin C daily and meet the DRI. Many consume much more since vitamin C is one of the most frequently purchased supplements (Peake, 2003). Supplemental doses of 250, 500, and 1,000 mg daily are commonly advertised. Preliminary work in tissue cultures has suggested that vitamin C in excess does have pro-oxidant activity (Abudu et al., 2004), but the potential role of vitamin C supplements on premature mortality is not clear (Bjelakovic et al., 2007). Vitamin C supplementation and its relationship to colds and the immune system are discussed in Spotlight on Enrichment: Vitamin C and Colds.

Of the three antioxidant vitamins, vitamin C is the most crucial to consume on a daily basis because it is water soluble. Important exercise-related physiological functions include its roles in antioxidant, immune, and collagen repair systems. Athletes, particularly endurance athletes, are highly encouraged to meet the DRI daily. For all practical purposes this means consuming vitamin C-containing fruits (e.g., oranges, grapefruit, strawberries) and vegetables (e.g., cabbage, broccoli, peppers, tomatoes).

Vitamin A. Vitamin A is a broad term and includes both preformed vitamin A (e.g., retinol) and vitamin A precursors (e.g., carotenoids). Beta-carotene is the best

All-cause mortality: All deaths, not just deaths caused by a certain disease, such as cardiovascular disease.

SPOTLIGHT ON SUPPLEMENTS

Applying Critical Thinking Skills to Evaluating Dietary Supplements

Listen to an endurance athlete explain why he is taking a vitamin E supplement.

"Most people don't realize it but oxygen has both beneficial and harmful effects. I try to counter the harmful effects of free radicals by taking a vitamin E supplement. Most studies have shown that vitamin E supplementation has a positive effect on endurance performance. Besides, studies have shown that there is a health benefit to vitamin E supplements. I'm concerned that my vitamin E intake may be low since I purposefully keep my caloric and fat intakes low so I don't gain body fat. Someone told me that when you take high levels of vitamin E it actually has an opposite effect and it no longer works as an antioxidant, but I don't think that is true. That just doesn't sound right."

This athlete has drawn both correct and incorrect conclusions. Oxygen does have both beneficial and harmful effects. His vitamin E intake may be low since he restricts his intake of both energy (kilocalories) and fats. Vitamin E is a supplement that could theoretically play a role in enhancing performance. This athlete has correctly concluded some things about vitamin E supplements.

However, some incorrect conclusions have also been drawn. The majority of studies have *not* shown that vitamin E supplementation has a positive effect on endurance performance. In the past, some studies have shown that there is a health benefit to vitamin E supplementation, but more recent studies have not duplicated earlier findings and there is increasing concern that such supplements may be detrimental to health. Although it may sound illogical that an antioxidant vitamin taken in large doses produces the opposite effect (pro-oxidant activity), there is evidence to suggest that such an effect can occur.

An appropriate course of action for this athlete is to have a dietary analysis performed by a sports dietitian to determine if energy and nutrient intake is sufficient. If intake of vitamin E is insufficient, dietary recommendations can be made and the athlete could change his food intake and consume the recommended amount. If supplementation is determined to be appropriate, the source and amount of supplementation could be discussed. Vitamin supplements are not well regulated and are heavily advertised, sometimes in ways that are misleading. Supplementation requires an evaluation of dietary intake and good critical thinking skills to judge the safety, effectiveness, and potential advantages and disadvantages of use.

known and most studied carotenoid but it is a less powerful antioxidant than some of the other carotenoids such as **lycopene** and **lutein.** Compared to vitamin E, all vitamin A-related compounds are weak antioxidants. Only preliminary studies have been conducted in athletes and no conclusions about vitamin-A related antioxidant activity during exercise can be drawn at this time.

Some athletes do not consume an adequate amount of vitamin A and fail to meet the DRI, which is 700 mcg for adult nonpregnant females and 900 mcg for adult males. Again, athletes who fall short of the recommendations are often restricting energy intake (e.g., ballet dancers, female gymnasts, distance runners), but some simply lack any vitamin A-containing fruits and vegetables in their diets (Lukaski, 2004). Consuming at least five servings of fruits and vegetables daily is recommended, but approximately 75 percent of the adult population in the United States fails to meet this minimum recommendation (Centers for Disease Control and Prevention, 1998).

The antioxidant properties of vitamin A-related compounds have been studied to the greatest extent in individuals with heart disease. Vitamin A is known to protect low-density lipoproteins from oxidation and, therefore, vessel damage. Studies have shown that people who consume beta-carotene-containing foods have lower rates of heart disease. Once this association was documented, beta-carotene supplements became popular with the hope that they would provide the same benefits as beta-carotene-containing foods. Several large studies have demonstrated that this is not the case and that vitamin A and/or beta-carotene supplements may be associated with an increase in premature mortality (Bjelakovic et al., 2007). Beta-carotene supplements increase the risk of lung cancer in subjects who smoked more than one pack of cigarettes daily. This unexpected and alarming finding resulted in the studies being halted prematurely (Hasnain and Mooradian, 2004). Other studies have shown that vitamin A supplements increase the risk of skeletal fracture (Genaro Pde and Martini, 2004).

Dark green, orange, and red colored fruits and vegetables are excellent sources of vitamin A.

These studies highlight some important points. First, it cannot be assumed that a beneficial component found in food will be equally beneficial if concentrated in a pill and taken as a supplement. A likely explanation is that the component in food is found in low concentrations and works in conjunction with other compounds also found in the food. These features are lost when a single vitamin is consumed as a supplement. Secondly, apparently benign compounds can act in unpredictable ways in the body. While many supplements are safe, it cannot be assumed that all compounds sold as supplements are safe.

SPOTLIGHT ON ENRICHMENT

Vitamin C and Colds

During infection there is a rapid decline in the concentration of vitamin C in the plasma and white blood cells. This knowledge has led to the use of vitamin C supplements to self-treat upper respiratory infections such as the common cold. It is also popular for people to routinely consume vitamin C supplements in an effort to prevent colds.

A meta-analysis of 29 studies conducted between 1996 and 2004 found that the incidence (the number of new cases) of colds was not reduced with routine vitamin C supplementation greater than 200 mg daily. However, once a cold was present, the duration (number of sick days) was reduced by 8 percent in adults and the severity (extent of symptoms and confinement) was also reduced. Interestingly, in the studies in which vitamin C supplements were introduced as a treatment in those who did not routinely consume them, vitamin C supplements up to 4 g (4,000 mg) were not beneficial (Douglas et al., 2004).

In endurance athletes, the body of literature remains equivocal so it is difficult to draw conclusions at this time. A small number of studies have suggested that routine vitamin C supplementation to prevent respiratory infections might be beneficial for marathon runners, skiers, and soldiers exposed to low environmental temperatures (Douglas et al., 2004). However, other studies have not found any benefit (Gleeson, Nieman, and Pedersen, 2004).

In summary, vitamins A, C, and E have important antioxidant properties. Of the three, vitamin E is the most potent and has been the most studied in athletes. As an aid in decreasing exercise-induced oxidative damage to cells and tissues, there is some evidence of the effectiveness of vitamin E supplements, although there are a similar number of studies that show no effect. There is little scientific evidence that vitamin C supplementation, and no evidence that vitamin A supplementation, are effective for reducing oxidative stress in athletes. There is consensus that athletes should consume a diet rich in antioxidant vitamins by consuming fruits, vegetables, nuts, and whole grains. Athletes should be cautious about supplementing with high doses of antioxidant vitamins since there is preliminary evidence that each has the capability to act as a pro-oxidant, which is potentially harmful to cells and tissues. There is an accumulating body of scientific literature that antioxidant supplementation may not be as beneficial to health as once thought and some concern that such supplements may be detrimental to health.

VITAMINS AND RED BLOOD CELL FUNCTION

The human body contains approximately 30 trillion red blood cells (erythrocytes) that are primarily responsible for transporting oxygen as well as carbon dioxide. With an average life span of only 120 days, the body must replace the erythrocytes as rapidly as they die—about 2 to 3 million cells per second. Each red blood cell (RBC) contains more than 250 million molecules of hemoglobin, an iron-containing compound that is found only in RBC (Sherwood, 2007). For these reasons the mineral iron is at the center of discussions about red blood cells. Iron, its role in red blood cell formation, and the impact of iron-deficiency anemia are discussed in depth in Chapter 9.

Several vitamins are necessary to produce red blood cells, but **erythropoiesis** could not proceed without vitamin B_{12} and folic acid. These two vitamins are needed alone and in combination with each other since they activate one another. Deficiencies of these vitamins can result in anemia. Vitamin-related anemia is different from the more common mineral-related iron-deficiency anemia.

Vitamin B_{12}. Vitamin B_{12} (cobalamin) is a water-soluble vitamin but some is stored in the liver. It works in conjunction with folic acid to form a coenzyme that is needed to produce red blood cells. Other cells also require vitamin B_{12}, but deficiencies are first recognized in RBC because these cells are produced so rapidly. A deficiency of vitamin B_{12} may be a result of poor dietary intake or poor absorption, a condition associated with older adults.

The absorption of vitamin B_{12} requires a compound known as intrinsic factor (IF). IF is produced in

Vitamin B_{12} is naturally found only in foods of animal origin.

the stomach but does not bind with vitamin B_{12} until both reach the small intestine. The IF-vitamin B_{12} complex must travel to the ileum (the lowest portion of the small intestine) where it is absorbed over the next three to four hours. As people age, IF production declines. Many people over the age of 50 do not produce IF and are at risk for developing **pernicious anemia** (Gropper, Smith, and Groff, 2005).

Those who lack IF need vitamin B_{12} injections. Those who have a dietary deficiency (but normal IF production) can reverse the deficiency by consuming more vitamin B_{12}-containing foods (naturally occurring or fortified) or by taking vitamin B_{12} supplements orally. Some athletes who are not vitamin B_{12} deficient and have normal IF secretion inject vitamin B_{12} based on anecdotal evidence (i.e., personal accounts) that these injections "boost energy." There is no scientific evidence that vitamin B_{12} injections will influence energy metabolism, decrease fatigue, or affect red blood cell production in athletes without a vitamin B_{12} deficiency (Lukaski, 2004). Vitamin B_{12} injections are not recommended for athletes because there is no apparent benefit and there are some risks associated with injections (e.g., soreness, abscesses, needle contamination, presence of banned substances).

Vitamin B_{12} is found only in foods of animal origin. Examples include meat, fish, poultry, eggs, and milk and milk products. The Dietary Reference Intake for vitamin B_{12} for nonpregnant females and male adults is 2.4 mcg daily. This is a very small amount, and with some stored

Lycopene: One of the carotenoids with a red pigment.

Lutein: One of the carotenoids with an orange pigment. Also found in some animal fats such as egg yolk.

Erythropoiesis: The production of red blood cells.

Pernicious anemia: Anemia caused by a lack of intrinsic factor, which is needed to absorb vitamin B_{12}.

in the liver a deficiency due to low intake usually takes about five years to develop. Athletes at risk for low intake include vegans and those who severely restrict caloric intake. Vegans, who consume no animal-derived products, should consume a vitamin B_{12}-fortified product such as a specially formulated yeast supplement. No Tolerable Upper Intake Level has been established for vitamin B_{12} (Institute of Medicine, 1998).

Folic Acid. Folic acid is also known as folate and folacin. It works in conjunction with Vitamin B_{12} to form a coenzyme that is needed to produce red blood cells. Other cells also require folic acid to divide, but deficiencies are usually detected first in the rapidly produced RBC. At conception, folic acid is critical to support rapid cell division and prevent neural tube defects such as spina bifida (incomplete closure of spinal cord tissue). The addition of folic acid to cereals and other grain products in the United States began in 1998 in an effort to eliminate neural tube defects. The form of folic acid used in these products is well absorbed. The Dietary Reference Intake for adults is 400 mcg daily. The Tolerable Upper Intake Level is 1,000 mcg from fortified foods and supplements (sources that have highly absorbable forms of folic acid) (Institute of Medicine, 1998).

Information about folic acid intake in athletes is lacking. Prior to 1998, some surveys of athletes reported that intake was low because consumption of excellent sources of folic acid—leafy green vegetables—was low (Lukaski, 2004). Since 1998, cereals and grain products have been fortified with folic acid, and this is expected to increase average intake. Some of the foods routinely eaten by athletes—breads, cereals, beans, oranges, and bananas—are also excellent sources of folic acid. Athletes can easily meet their need for this vitamin through food alone.

A deficiency of folic acid will eventually result in **megaloblastic anemia.** A clinical deficiency will be preceded by subclinical deficiencies—a drop in folic acid concentration in the blood and a decrease in folic acid concentration in the red blood cells. Folic acid supplements will reverse a clinical deficiency but there is no evidence that supplementation will improve performance in those with subclinical deficiencies or normal blood folate concentrations (Lukaski, 2004).

The preceding pages have explained the vitamins involved in three major processes in the body: energy metabolism, protection from oxidation, and red blood cell formation. While each vitamin has been discussed according to its major function, it is important to recognize that every vitamin plays numerous important roles in the body and a vitamin deficiency can impact the body in many ways. One vitamin was not discussed—vitamin D. Vitamin D acts as a hormone (regulator) and its functions are discussed as a part of the development and maintenance of bone in Chapter 9.

Christina Micek

Breads, cereals, beans, oranges, and bananas provide folic acid.

What's the point? Vitamins have specific biochemical functions in various physiological systems, such as the metabolism of energy, the protection of oxidation-prone cells and tissues, and the production of red blood cells. There is widespread scientific agreement about the importance of consuming vitamin-rich foods such as fruits, vegetables, and whole grains. There is not scientific consensus about the effectiveness of vitamin supplements to enhance training, performance, or health.

Sources of Vitamins

Most vitamins are obtained from three sources: They exist naturally in food, they are added to foods during processing, and they are manufactured as dietary supplements. An orange is a food that naturally contains approximately 70 mg of vitamin C. A fruit punch drink with vitamin C added has about 50 mg. Vitamin C supplements come in 100-, 300-, 500-, and 1,000-mg tablets. The vitamin C found in each is the same chemical compound but the dose can vary considerably.

Food has always been a way for people to obtain nutrients. Before the discovery and isolation of nutrients in the laboratory, food stood on the merit of the nutrients it contained naturally. The word *naturally* is used to describe nutrients put in food by nature, such as the vitamin C in an orange. For each of the vitamins discussed in this chapter, there are excellent naturally occurring food sources as shown in Table 8.2.

The nutrient content of foods began to change when food processing became widespread. When raw foods are processed some nutrients are lost. For example, if an orange is juiced, the ½ cup of juice that it yields has about 60 to 65 mg of vitamin C. This is a small loss of vitamin C since the orange originally had about 70 mg. But some foods lose a considerable amount of nutrients when processed. When whole grains are processed into white flour, many of the vitamins are lost, some almost completely (e.g., vitamin B_6). Modern processing may also add nutrients to foods. Sometimes a vitamin that is lost is added back (enrichment), and sometimes vitamins that were never present before processing are added (fortification). Some foods become an excellent source of a particular vitamin because it has been added by food processors.

Vitamin supplements are concentrated sources of vitamins found naturally in food, thus the amount consumed as a supplement is often more than would be consumed from food alone. In some cases the vitamin supplement is sold in a form that has high **bioavailability.** Bioavailability refers to the degree to which a compound can be absorbed and utilized by the body and it is not necessarily greater in naturally occurring sources. Folic acid found naturally in foods has about 50 percent of the bioavailability of the folic acid added to food or found in most supplements.

Although there are three sources of vitamins—naturally occurring in food, added to foods during processing, and supplements—the lines between them are blurry. Oranges, fruit punch with vitamin C added, and vitamin C supplements are fairly clear points on a continuum. But additional vitamin C is being added to orange juice to enhance the amount naturally found and cereals are fortified with 100 percent of the DRI for many nutrients including vitamin C. Many new food and beverage products have added vitamins because this is a way to attract consumers. A popular brand of cereal, Total®, advertises "One Bowl. 100% Nutrition™." because the cereal contains 100 percent of the **Daily Value (DV)** for 12 vitamins and minerals. The differences between the amounts found in foods, added to foods, and contained in supplements are not as distinct as in the past.

NATURALLY OCCURRING, FORTIFIED, AND SUPPLEMENT SOURCES OF VITAMINS

Athletes, like other consumers, have many questions about vitamins. Can eating food alone meet the daily vitamin needs of an athlete? Are there advantages to getting vitamins from food? Are there advantages to using vitamin supplements? As is often the case in a complicated subject like nutrition, many factors must be considered before such questions can be answered.

A strong argument can be made for obtaining vitamins from foods in which they naturally occur. Throughout history, people have survived by only eating food. There is an amazing array of vitamins that occur naturally in food. An orange, which has a substantial amount of vitamin C, also contains small amounts of thiamin, riboflavin, niacin, vitamin B_6, folic acid, and vitamin A. As is often the case, a food is an excellent source of one vitamin but contributes to the overall intake of many vitamins. A diet that includes a variety of nutrient-dense foods can provide all of the vitamins that humans, including athletes, need. There is historical precedent for obtaining vitamins from "food first."

Nutrition scientists who analyze the nutrient content of food have found that nutrients that occur naturally in foods are in the right proportion to other nutrients, a factor that probably helps nutrients to be absorbed. Fruits and vegetables, foods that contain numerous vitamins, also contain other biologically active compounds (e.g., **phytochemicals**). The interactions between vitamins and these compounds may be necessary for proper biological function and protection from chronic diseases. Whole grains and beans are excellent sources of many vitamins and they come "packaged" with carbohydrates, proteins, and fiber, nutrients that are important for athletes both for training and for health. There is also scientific backing for obtaining vitamins from "food first."

Although it is true that people have survived with only the nutrients found naturally in foods, it is also true that some people who did so suffered from vitamin deficiencies. Obtaining an adequate amount of vitamins only from foods that naturally contain them requires that a wide variety of nutrient-dense foods be eaten. Athletes who restrict caloric intake may have a difficult time consuming the recommended amount for all of the vitamins needed daily. Many athletes adopt a "food first, supplements second" philosophy in which they try to obtain a sufficient amount of vitamins via their diet but take a vitamin supplement to cover any vitamin deficiencies.

Many of the foods consumed in the United States are processed foods. Food processing can strip vitamins from the food in which they naturally occurred. For example, the processing of wild rice into polished white rice or whole grains into bleached white flour reduces the vitamin content of the processed food substantially. In the United States in the 1930s and 1940s, vitamin deficiencies were widespread. These deficiencies reflected changing dietary habits, specifically the use of white bread instead of whole wheat bread. White bread had become so widely accepted that it was a staple in the diet of many Americans. To address the vitamin deficiencies

Megaloblastic anemia: A type of anemia characterized by large red blood cells.

Bioavailability: The extent to which a nutrient can be absorbed, metabolized, and utilized by the body.

Daily Value (DV): A term used on food labels; estimates the amount of certain nutrients needed each day. Not as specific as Dietary Reference Intakes.

Phytochemical: Compounds that have biological activity but are not currently known to be required for normal functioning of the body. May have a beneficial effect on health or disease prevention.

Table 8.5 Fortified Cereal and Multivitamin Supplement Compared

Vitamin	Daily Value (DV)	Fortified Cereal (% DV)	Multivitamin Supplement (% DV)
Thiamin	1.5 mg	100	100
Riboflavin	1.7 mg	100	100
Niacin	20 mg	100	100
Vitamin B_6	2 mg	100	100
Vitamin B_{12}	6 mcg	100	100
Folate	400 mcg	100	100
Vitamin C	60 mg	100	100
Vitamin A	900 mcg	15	100
Vitamin E	20 α-TE or 30 IU	100	100
Vitamin D	400 IU or 10 mcg	10	100

Legend: α-TE = alpha-tocopherol equivalents; IU = International Units; mg = milligram; mcg = microgram

that were occurring, a law was passed requiring that three vitamins lost in the processing of whole grains be added back—thiamin, riboflavin, and niacin. Other nutrients that are lost in the processing, such as vitamin B_6, are not included in that law, which is still in force today.

The addition of nutrients to food during processing is really a form of supplementation. Most Americans consume foods that contain added vitamins. Those that are required by law to be added to flour include thiamin, riboflavin, niacin, and folic acid (as well as the mineral iron). Fortification of milk with vitamin D is also a law. Such laws have helped to prevent widespread vitamin deficiencies, but the addition of selected nutrients does not necessarily make the highly processed product as nutritious as the original product. In the case of whole grain flour, some vitamins (e.g., vitamin B_6), minerals (e.g., zinc, magnesium), and fiber lost in the processing are not restored.

The natural outcome of required fortification is the voluntary addition of nutrients to foods. Some products are fortified with vitamins that would be lacking in the diet. For example, some vegetarian products (e.g., soy milk) are fortified with vitamin B_{12}, which is only found naturally in animal products. Most ready-to-eat breakfast cereals contain many added vitamins and minerals. They are often advertised to highlight the addition of these nutrients, most of which are added to a level that will provide 100 percent of the Daily Value. Daily Value is a term that is used on food and supplement labels and is an estimate of the amount of a nutrient needed each day; it is similar to but not as specific as the DRI. Consuming a highly fortified cereal is really the same as eating a food that contains a multivitamin and mineral supplement, as shown in Table 8.5.

For many years ready-to-eat cereal was one of only a handful of foods that essentially had a multivitamin and mineral supplement added. Today, vitamins (and minerals) are being added to many foods. Energy and sports bars, popular products for athletes, have many added nutrients, and manufacturers highlight the vitamin content of these products as a prominent part of their advertising. Even some bottled water has added vitamins.

Each of the vitamins found in food can also be manufactured in a laboratory and concentrated into a supplement. Supplements may be limited to one vitamin (e.g., vitamin B_1) or may contain several vitamins (e.g., multivitamin or B-complex supplements). The amount contained in each tablet or capsule can vary. Supplements that carry the USP-verified mark have been tested for purity and potency. This verification program assures consumers that good manufacturing practices have been followed during production and that the amount listed on the label is accurate. One of the best protections athletes have is to buy supplements displaying the USP-verified mark (see The Internet Café).

While many supplements contain 100 percent of the Daily Value of a particular vitamin, some contain more. A supplement with a high amount is sometimes referred to as a "megadose." Megadose does not have a standard definition but it is used to describe a supplement containing several times the DRI. Some supplements on the market contain an amount that meets or exceeds the Tolerable Upper Intake Level. Consumers should *always* be aware of and monitor the dose of any supplements consumed. In this respect, supplements are more similar to over-the-counter medications than to naturally occurring, vitamin-rich foods.

The Internet Café

Where Do I Find Information about Vitamins and Exercise?

Finding noncommercial factual information about vitamins and vitamin supplementation for athletes on the Internet can be difficult. The Australian Institute of Sport has created a series of fact sheets on supplements, including antioxidant vitamins and multivitamin supplements **(http://www.ais.org.au/nutrition/SuppFactSheets.asp).** Information about one dietary supplement verification program can be found at **http://www.usp.org/USPVerified/dietarySupplements/.**

It is time to return to the original three questions raised at the beginning of this section. Can eating food alone meet the daily vitamin needs of an athlete? The answer is yes. However, the athlete must consume enough food (i.e., adequate kilocalories) with sufficient variety and the foods chosen must be nutrient dense. This is a total diet approach that takes both time and effort. Such a diet supports training, has the potential to improve performance, and helps to prevent chronic diseases.

Are there advantages to getting vitamins from food? The answer is yes. Vitamins are found naturally in food with water, macronutrients (i.e., carbohydrates, proteins, and fats), minerals, and other biologically active compounds. In other words, vitamins are found in food with many other required nutrients. Vitamin supplements are singular in focus—they provide only vitamins. As mentioned previously, vitamins are required for energy metabolism but they do not provide energy-containing compounds—carbohydrates, proteins, or fats.

Are there advantages to using vitamin supplements? The answer is yes. However, the well-documented advantages are typically related to reversing or preventing vitamin deficiencies that result from a poor diet. Putting a Band-Aid on a cut may help the cut to heal, but the best strategy is not to get cut in the first place. Scientists are also beginning to ask another question: Are there disadvantages to using vitamin supplements, particularly the antioxidant vitamins A, C and E? The subject of a daily multivitamin supplement for adults to prevent or delay chronic diseases is controversial, but the U.S. Preventive Health Services Task Force (2003) recommends against it.

THE VITAMIN CONTENT OF HIGH- AND LOW-ENERGY-CONTAINING DIETS

In a previous section, the answer to the question, "Can eating food alone meet the daily vitamin needs of an athlete?" was yes. But each athlete must ask another question, "Does *my* diet provide the vitamins I need? The answer to that question depends on the amount and types of foods consumed. One way to estimate the nutrient content of one's diet is to record food intake for three to seven days by using a food diary (see Appendix E). All foods and beverages consumed can then be entered into a computer program that estimates the nutrient content of the diet and compares it to the DRI. In the case of vitamins, estimated intake can also be compared to the Tolerable Upper Intake Levels.

For comparison purposes, two very different dietary patterns, each containing sufficient caloric intake are examined here, and the vitamin content of these diets is compared to the DRI and to each other. Both diets contain the same amount of energy, about 2,500 kcal. Figure 8.4 shows three meals that are typical of those

2 fried eggs
2 pieces of white toast w/1 T butter
2 slices bacon
8-oz coffee w/1 T each cream, sugar
Ham & cheese sandwich
1-oz bag potato chips
16-oz soft drink
3 Oreo cookies
Cheeseburger
Medium fries
16-oz soft drink
½ cup chocolate ice cream

Figure 8.4 An Example of a High-Fat, High-Sugar, Low-Fiber Diet
Legend: T = tablespoon; oz = ounce

Table 8.6 Vitamin Intake of a High-Saturated-Fat, High-Sugar, Low-Fiber Diet Compared to the DRI

Vitamin	Intake	DRI*	% of DRI
Thiamin	1.1 mg	1.2 mg	92
Riboflavin	2.1 mg	1.3 mg	162
Niacin	13 mg	16 mg	81
Vitamin B_6	0.41 mg	1.3 mg	32
Vitamin B_{12}	2.1 mcg	2.4 mcg	88
Folate	210 mcg	400 mcg	53
Vitamin C	20 mg	90 mg	22
Vitamin A	633 mcg	900 mcg	70
Vitamin E	1.9 mg	15 mg	13

Legend: DRI = Dietary Reference Intakes; mg = milligrams; mcg = micrograms
*20-year-old male

1 cup oatmeal
1 slice whole wheat toast
1 T peanut butter
8 oz nonfat milk
8 oz orange juice
8 oz black coffee
1.5 cups lentil soup
Large (1.5 cups) green salad
1 oz avocado (~ ⅕ of an avocado)
2 T oil & vinegar dressing
2 whole wheat rolls
8 oz nonfat milk
1 banana
6 oz chicken breast
1½ cups brown rice
1 cup broccoli
1 slice whole wheat bread w/1 tsp *trans free* margarine
1 cup strawberries
Water
1 cup nonfat frozen yogurt
¼ cup dry-roasted sunflower seeds

Figure 8.5 An Example of Nutrient-Dense, Whole-Foods Diet

Legend: T = tablespoon; oz = ounce; tsp = teaspoon

consumed away from home—a bacon and fried egg breakfast; a lunch consisting of a sandwich, chips, cookies, and a soda; and dinner at a fast-food restaurant.

This high-saturated-fat, high-sugar, low-fiber dietary pattern is low in all vitamins except riboflavin (see Table 8.6). The diet came closest to meeting the recommendations for thiamin (92 percent of the DRI), vitamin B_{12} (88 percent), niacin (81 percent), and vitamin A (70 percent). Of great concern is the low intake of vitamin E (13 percent), vitamin C (22 percent), vitamin B_6 (32 percent), and folate (53 percent). This is a good example of how a diet can provide sufficient (or excess) kilocalories but is lacking in many vitamins. This diet is also high in saturated fats and sugar and low in fiber, a dietary pattern that may increase the risk for some chronic diseases as discussed in Chapter 12.

The dietary pattern featured in Figure 8.5 is nutrient dense. This diet meets the recommended daily intakes for all of the vitamins as shown in Table 8.7. Notice that the diet emphasizes fruits, vegetables, legumes, nuts, and whole grains, naturally occurring foods that are unprocessed or minimally processed. **Whole food** is a term that is used to describe such foods. Many of these foods are easy to prepare, although some planning is needed so that the refrigerator and pantry are well stocked. The colored bars in Figure 8.6 illustrate the obvious differences in the vitamin content of the two diets. The caloric intake is the same, approximately 2,500 kcal, but the vitamin intake is substantially different.

Table 8.7 Vitamin Intake of a Nutrient-Dense, Whole-Foods Diet Compared to the DRI

Vitamin	Intake	DRI*	% of DRI
Thiamin	1.9 mg	1.2 mg	160
Riboflavin	2.2 mg	1.3 mg	171
Niacin	42 mg	16 mg	264
Vitamin B_6	3.3 mg	1.3 mg	255
Vitamin B_{12}	4 mcg	2.4 mcg	168
Folate	446 mcg	400 mcg	111
Vitamin C	316 mg	90 mg	351
Vitamin A	3,410 mcg	900 mcg	379
Vitamin E	22 mg	15 mg	148

Legend: DRI = Dietary Reference Intakes; mg = milligrams; mcg = micrograms

*20-year-old male

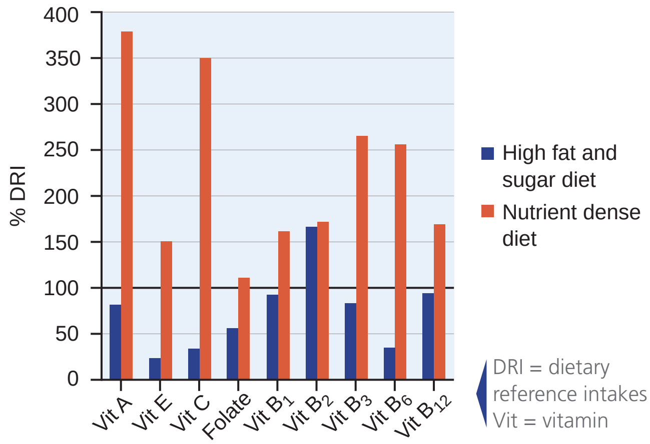

Figure 8.6 Vitamin Content of Two Diets Compared

The graph clearly shows that the whole food diet contains adequate amounts of all the vitamins shown, while the diet high in fats and sugar is lacking the recommended amounts of many vitamins. Both of these diets contain 2,500 kcal.

Figure 8.7 illustrates a diet that is very low in energy (~800 kcal), macronutrients, and most vitamins. It represents the intake of a female athlete who is trying to rapidly lose weight and who is severely restricting caloric intake for a very short period of time. In this case the athlete is eating some foods that are "healthy" such as lean turkey, green salad, and banana but drastically limiting the amount of food consumed. Because energy intake is so low, the diet

This diet consists of one 4-oz bagel with 1 T of low fat cream cheese, 2 slices of wheat bread, 2 oz of sliced turkey with 2 t mustard, 1 medium banana, 16 oz of diet cola, 1 cup green salad with 2 T low calorie dressing, 16 oz artificially sweetened iced tea, and 1 package of animal crackers. The approximate nutrient content is shown below:

Calories: 828 kcal (36% of recommended) or 17 kcal/kg

CHO: 144 g or 3.0 g/kg

Protein: 34 g or 0.7 g/kg

Fat: 14 g or 0.29 g/kg

Fiber: 13 g (52%)

Vitamins (% DRI)

Thiamin: 94

Riboflavin: 75

Niacin: 73

Vitamin B_6: 55

Vitamin B_{12}: 4

Folate: 100

Vitamin C: 78

Vitamin A: 110

Vitamin E: 8

When the caloric content of the diet is very low, it is difficult to obtain the recommended amounts of vitamins. In this example, seven of the nine vitamins analyzed were below the DRI.

Figure 8.7 Vitamin Content of a Low-Energy Diet

Legend: kcal = kilocalorie; kcal/kg = kilocalorie per kilogram body weight; CHO = carbohydrate; g = gram; g/kg = gram per kilogram body weight; DRI = Dietary Reference Intakes

lacks the recommended amounts of most vitamins with the exception of folate and vitamin A.

Athletes whose diets fall short of the recommended intake for vitamins may choose to take a multivitamin supplement. With supplementation, a low-energy (calorie) diet can meet the DRI for each vitamin that was previously lacking. For this reason, many athletes consider a multivitamin supplement to be an insurance policy. The vitamin supplement does provide insurance but only against vitamin deficiencies. Any underlying nutritional problems—low or excessive caloric, or low carbohydrate, protein, fat, and fiber intakes—are not rectified with the use of a vitamin supplement.

Table 8.8 High Vitamin Content of Diet When Highly Fortified Foods Are Consumed

Vitamin	Intake	DRI*	% of DRI	UL
Thiamin	4.9 mg	1.2 mg	406	Not established
Riboflavin	5.4 mg	1.3 mg	412	Not established
Niacin	63 mg	16 mg	394	35 mg**
Vitamin B_6	6.4 mg	1.3 mg	492	100 mg
Vitamin B_{12}	19 mcg	2.4 mcg	788	Not established
Folate	1,352 mcg	400 mcg	338	1,000 mcg**
Vitamin C	240 mg	90 mg	267	2,000 mg
Vitamin A	758 mcg	900 mcg	84	3,000 mcg
Vitamin E	64 mg	15 mg	428	1,000 mg**

Legend: DRI = Dietary Reference Intakes; UL = Tolerable Upper Intake Level; mg = milligrams; mcg = micrograms

With the exception of one vitamin, the consumption of three highly fortified foods (cereal, energy bar, and meal replacement beverage) provides two to seven times the DRI for the nine vitamins analyzed.

*26-year-old male

**The UL for these nutrients is based on the intake of fortified food and supplements only. For the remaining vitamins, the UL is based on all food (fortified and nonfortified), water, and supplements.

FOOD FORTIFICATION: CAN YOU GET TOO MUCH FROM FOOD?

Adding vitamins to food began in the United States as a way to prevent vitamin deficiencies, which were widespread in the 1930s and 1940s. In the 2000s, manufacturers began adding vitamins to foods such as meal replacement bars, energy bars, and energy beverages, products that are highly marketed to athletes. To gain market share in the highly competitive new product market, manufacturers are adding "nutrient horsepower" to foods. In other words, they are adding many vitamins in high doses so consumers perceive their products as being more nutritious than other similar products.

Table 8.8 illustrates the amount of vitamins in 1 cup of fortified breakfast cereal, one fortified energy bar, and one meal replacement beverage. These foods were chosen because they represent foods that could realistically be consumed in one day by the average athlete. As this

Whole food: Generally used to describe unprocessed or minimally processed foods.

table is limited to the vitamins found in the three fortified foods, keep in mind that the total daily vitamin intake would be much higher if all the food and beverages consumed in a 24-hour period were analyzed.

The table includes the Tolerable Upper Intake Levels. The UL for vitamins is based on the intake of all food (fortified and nonfortified), water, and supplements except for three vitamins. For vitamin E, niacin, and folate, the UL is based on fortified food and supplements only. The UL cannot be established for some vitamins because of a lack of scientific data. This example clearly illustrates that the intake of many highly fortified foods provides vitamins at levels several times higher than the DRI and, in the case of two vitamins, higher than the UL. As mentioned previously, the line between fortified foods and supplements is beginning to blur.

Table 8.9 Vitamin Content of a One-a-Day Vitamin Supplement Compared to the Daily Value (DV)

Vitamin	Intake	% of DV	UL
Thiamin	25 mg	1,666	Not established
Riboflavin	25 mg	1,470	Not established
Niacin	100 mg	500	35 mg*
Vitamin B_6	25 mg	1,250	100 mg
Vitamin B_{12}	100 mcg	1,666	Not established
Folate	400 mcg	100	1,000 mcg*
Vitamin C	150 mg	250	2,000 mg
Vitamin A (beta-carotene)	10,000 IU or 1,000 mcg	200	3,000 mcg
Vitamin E	100 mg	333	1,000 mg*

Legend: DV = Daily Value; UL = Tolerable Upper Intake Level; mg = milligrams; mcg = micrograms; IU = International Units

The vitamin content of a typical one-a-day type vitamin supplement ranges from 100 percent to over 1,600 percent of the Daily Value (DV). Daily Value is a term used on food and supplement labels and is an estimate of the amount of a nutrient needed each day; it is similar to, but not as specific as, the DRI (Dietary Reference Intakes).

*The UL for these nutrients is based on the intake of fortified food and supplements only. For the remaining vitamins, the UL is based on all food (fortified and nonfortified), water, and supplements.

CAN YOU GET TOO MUCH FROM VITAMIN SUPPLEMENTS?

It behooves athletes to look carefully at the dose of any multivitamin supplement that they are considering taking. The amounts shown in Table 8.9 and Table 8.10 are from actual supplements available for purchase. Table 8.9 is typical of the amounts shown in a one-a-day type multivitamin supplement, while Table 8.10 is typical of a high-potency vitamin supplement. The UL is provided as a basis of comparison but is not required to appear on the supplement label. Notice that the amounts contained in the high-potency vitamin supplement are very high when compared to the Daily Value. Despite the high levels, such vitamin preparations are legal to sell.

The amount and form of vitamin A is a particular concern for the supplement shown in Table 8.10 because it contains preformed vitamin A. This form of vitamin A can be toxic in high amounts. The chart clearly shows that the amount contained (3,003 mcg) is comparable to the UL. But the supplement label (see Figure 8.8) will not show either the amount in micrograms or the UL. The UL is not required by law to be on the label, and the amount of vitamin A listed on many supplement labels is an old unit of measure, IU (International Unit). The Daily Value is also based on an older, higher figure for vitamin A (5,000 IU or 1,500 mcg). The current recommended daily intake of vitamin A is lower than in the past (Penniston and Tanumihardjo, 2003). An athlete who looks at this supplement will see that it contains 200 percent of the DV and may conclude that 10,000 IU

KEEPING IT IN PERSPECTIVE

The Need for an Adequate but Not Excessive Amount of Vitamins

Moderation is the process of limiting the extremes, an important principle that can be applied to many areas, including vitamins. To obtain and maintain excellent health, both vitamin deficiencies and toxicities must be avoided. Vitamins may function as antioxidants at moderate levels but have an opposite (pro-oxidant) effect at high levels. An adequate caloric intake is typically associated with adequate vitamin intake, while the extremes are often associated with poor vitamin intake. These are just a few examples why vitamin intake should be moderate and not extreme.

There is no moderation when it comes to information about vitamins and vitamin supplements. A comprehensive Internet search of the word *vitamin* yields about 50 million matches, of which millions are for vitamin supplements. With the amount of information and advertisement about vitamins, it may be hard for consumers, including athletes, to keep vitamin needs and intake in perspective.

Table 8.10 Vitamin Content of a High-Potency Vitamin Supplement Compared to the Daily Value (DV)

Vitamin	Intake	% of DV	UL
Thiamin	50 mg	3,333	Not established
Riboflavin	50 mg	2,941	Not established
Niacin	50 mg	250	35 mg*
Vitamin B_6	50 mg	2,500	100 mg
Vitamin B_{12}	50 mcg	833	Not established
Folate	400 mcg	100	1,000 mcg*
Vitamin C	500 mg	833	2,000 mg
Vitamin A as fish liver oil, (preformed)	10,000 IU or 3,003 mcg	200	3,000 mcg
Vitamin E	400 mg	1,333	1,000 mg*

Legend: DV = Daily Value; UL = Tolerable Upper Intake Level; mg = milligrams; mcg = micrograms; IU = International Units

The vitamin content of this high-potency vitamin supplement ranges from 100 percent to over 3,300 percent of the Daily Value (DV). DV is a term that is used on food and supplement labels and is an estimate of the amount of a nutrient needed each day; it is similar to, but not as specific as, the DRI (Dietary Reference Intakes).

*The UL for these nutrients is based on the intake of fortified food and supplements only. For the remaining vitamins, the UL is based on all food (fortified and nonfortified), water and supplements.

SUPPLEMENT FACTS

Serving size: 1 tablet

Servings per container: 60

Amount per serving	% Daily Value
Thiamin 50 mg	3,333%
Riboflavin 50 mg	2,941%
Niacin 50 mg	250%
Vitamin B_6 50 mg	2,500%
Vitamin B_{12} 50 mcg	833%
Folate 400 mcg	100%
Vitamin C 500 mg	833%
Vitamin A 10,000 IU	200%
Vitamin E 400 mg	1,333%

Ingredients: Vitamin A as fish liver oil (pre-formed), asorbic acid, di-alpha tocopherol acetate, thiamin mononitrate, riboflavin, niacinamide, pyridoxine HCl, folic acid, cyanocobalamin.
Storage: Keep in a cool dry place, tightly closed.
Suggested Use: As a dietary suppliment, take one tablet daily.

Keep out of reach of children
Expiration date: Dec 2010

Figure 8.8 High-Potency Vitamin Supplement Label

Although the amount and percent of the Daily Value are required to appear on the label, this information may be difficult for consumers to interpret. In this example, consumers would need to convert the amount stated in IU to micrograms and compare it to the UL (Tolerable Upper Intake Level).

is not an excessive amount. The consumer is unlikely to be able to convert IU to micrograms, compare the amount contained to the Tolerable Upper Intake Level, or recognize that the amount contained is potentially toxic.

The UL represents decades of research and allows scientists and consumers a yardstick by which to measure adequate (i.e., DRI) and relatively safe (i.e., UL) intakes of vitamins. The UL has become particularly important as more processed foods have added vitamins and vitamin supplements usage has increased. Some nutrition scientists are beginning to question whether there are effects associated with chronic intake of highly fortified foods and routine use of vitamin supplements. There are no experimental studies in healthy active people, so the short- or long-term outcomes of such practices are not known. However, some well-designed epidemiological studies have shown an association between long-term high intake of preformed vitamin A (retinol) and increased incidence of hip

THE EXPERTS IN…

Vitamins and Exercise

Priscilla M. Clarkson, Ph.D., is an expert in human skeletal muscle and has conducted numerous studies of muscle damage, hypertrophy, and atrophy. Over the course of studying muscle, Dr. Clarkson has also become an expert on the antioxidant vitamins that may protect muscle from damage.

Melvin H. Williams, Ph.D., is Eminent Scholar Emeritus, at Old Dominion University in Norfolk, Virginia. For more than 30 years, Dr. Williams conducted research on the effect of ergogenic aids, including vitamins, on training and performance. He is one of the premier scholars in the fields of exercise physiology and sports nutrition and a recognized authority on performance-enhancing supplements.

fractures in older individuals (Melhus et al., 1998; Feskanich et al., 2002). While these studies were conducted in middle-aged and older women, they bring to light an important lesson about dosage.

The increased incidence of hip fractures was associated with a retinol (preformed vitamin A) intake of 1,500 to 2,000 mcg per day. The current DRI for vitamin A is 700 mcg for women and 900 mcg for men. It is clear that with fortified food and a daily vitamin supplement containing retinol a person could easily exceed the recommended vitamin A intake, an amount associated with an increased incidence of hip fractures, and the Tolerable Upper Intake Level (Penniston and Tanumihardjo, 2003).

Athletes must develop a plan for getting enough of each vitamin without getting too much. It is ironic that it may take less time and effort to consume too much than to consume an appropriate amount through a variety of nutrient-dense foods. Food and supplements are not mutually exclusive; rather, they are complementary. Athletes should first determine the amount of vitamins normally obtained from food and then evaluate if they need to supplement. If vitamin supplements are necessary, then decisions must be made regarding dosage. Sports dietitians, physicians, and pharmacists are professionals who can help the athlete decide whether supplements are necessary and, if so, the proper dose and form of a vitamin supplement.

What's the point? Vitamins can be obtained naturally in food, from fortified foods, and in vitamin supplements. A dietary analysis can determine whether usual vitamin intake is inadequate, adequate, or excessive. Fortified food and vitamin supplements can provide large amounts of vitamins in a concentrated form.

Summary

Vitamins are essential nutrients needed for the proper functioning of the body, particularly energy metabolism, red blood cell production, and **antioxidant** functions. Studies of the effects of exercise training on vitamin requirements have not conclusively shown that exercise increases the need for vitamins. The best-studied vitamins in athletes have been the antioxidant vitamins—**beta-carotene** (a form of vitamin A), vitamin C, and Vitamin E—and the vitamins involved with energy production—thiamin, riboflavin, and vitamin B_6. Average vitamin intakes by athletes generally reflect total energy intake. Athletes who restrict caloric intake typically consume low amounts of several vitamins, but this is not always the case. The best advice to athletes is to consume vitamins in the amounts recommended by the Dietary Reference Intakes and to not exceed the Tolerable Upper Intake Level. Presuming that absorption and utilization are normal, this strategy should prevent subclinical deficiencies and vitamin **toxicities.**

Adequate amounts of all the vitamins are needed to support training, performance, and health. A "Food First, Supplement Second" philosophy can serve athletes well. Obtaining the DRI for vitamins from food requires that athletes consume adequate energy and eat vitamin-rich foods such as fruits, vegetables, whole grains, legumes, and nuts. Athletes could meet the DRI for vitamins by taking a multivitamin supplement. Such a supplement can provide vitamins missing from the diet but does not provide carbohydrates, proteins, fats, or fiber, important nutrients to support training, performance, and health.

As more vitamins have been added to more foods and the usage of vitamin supplements has increased, scientists have begun to raise questions about possible overconsumption of vitamins and the effect on health. Athletes should read vitamin supplement labels carefully and recognize that supplements may contain potentially harmful amounts. Before choosing to supplement with any vitamin, an athlete should evaluate dietary intake and determine the supplement dose and ingredients so safety, effectiveness, and potential advantages and disadvantages of use can be judged appropriately.

Post-Test: Reassessing Current Knowledge of Vitamins

Now that you have more information about vitamins, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. Exercise increases the usage of vitamins, so most athletes need more vitamins than sedentary people.
2. Vitamins provide energy.
3. The amount of vitamins an athlete consumes is generally related to the amount of kilocalories consumed.
4. When antioxidant vitamins are consumed in excess, they act like pro-oxidants instead of antioxidants.
5. Vitamin supplements are better regulated than other dietary supplements because the U.S. Food and Drug Administration sets a maximum dose (amount) for each vitamin.

Review Questions

1. Compare and contrast fat- and water-soluble vitamins.
2. Explain the physiological and performance effects of vitamin intake that is too low, adequate, and excessive.
3. Do vitamins provide energy? Explain.
4. Explain the effects of exercise on vitamin need. Are the requirements for vitamins increased for athletes?
5. Why is it important for athletes to determine their intake of vitamins from food? How might athletes use the Dietary References Intakes (DRI) and the Tolerable Upper Intake Levels (UL) to evaluate their intake of vitamins from food and supplements?
6. Do sedentary adults consume enough vitamins? Do athletes? Explain.
7. Describe how a low vitamin intake could become a subclinical vitamin deficiency. Describe how excessive vitamin intake could become a toxicity.
8. Explain the differences between a clinical and subclinical vitamin deficiency.
9. List and explain the roles of vitamins associated with antioxidant activity, energy metabolism, and red blood cell formation.
10. Why do athletes inject vitamin B_{12}? Is this practice safe? Is it effective?
11. Are vitamin supplements helpful to athletes? If so, in which ways? Are vitamin supplements harmful to athletes? If so, in which ways?
12. Outline a process an athlete could follow to determine if a vitamin supplement is needed.

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9 Minerals

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Learning Objectives

1. Classify minerals and describe their general roles.
2. Explain how mineral inadequacies and excesses can occur and why each might be detrimental to performance and health.
3. Explain how the Dietary Reference Intakes (DRI) and the Tolerable Upper Intake Levels (UL) should be interpreted.
4. Describe if, and how, exercise increases the need for or accelerates the loss of a particular mineral.
5. Compare and contrast the average intake of minerals by sedentary adults and athletes in the United States.
6. Explain the differences between a clinical and subclinical deficiency for calcium, iron, and zinc.
7. Discuss the minerals associated with bone formation, red blood cell production, and the immune system, and explain how low intake affects performance and health.
8. Compare and contrast minerals based on their source—naturally occurring in food, added to foods during processing, and found in supplements.
9. Evaluate the need for mineral supplements based on food intake and the safety and effectiveness of mineral supplements.

Pre-Test Assessing Current Knowledge of Minerals

Read the following statements about minerals and decide if each is true or false.

1. The basic functions of minerals include building body tissues, regulating physiological processes, and providing energy.
2. In general, the body absorbs a high percentage of the minerals consumed.
3. In most cases, exercise does not increase mineral requirements above what is recommended for healthy, lightly active individuals.
4. If dietary calcium is inadequate over a long period of time, the body maintains its blood calcium concentration by reabsorbing skeletal calcium.
5. Iron-deficiency anemia has a negative impact on performance.

Vitamins and minerals are often mentioned in the same breath. While there are some similarities between these classes of nutrients, **minerals** differ from vitamins, especially water-soluble vitamins, in several ways. In chemistry, vitamins are described as organic, meaning they contain carbon in their structure. Minerals are inorganic, lacking carbon molecules. A single food may provide a substantial portion of the recommended daily intake for a vitamin, while minerals are generally found in proportionately smaller amounts even in foods considered to be excellent sources. For example, an 8-oz (240 ml) glass of orange juice provides approximately 100 mg of vitamin C, more than 100 percent of the Dietary Reference Intake (DRI) for males and nonpregnant females at any age. In contrast, an 8-oz glass of milk, considered to be an excellent source of calcium, provides approximately 300 mg of calcium, which is only 23 to 30 percent of what males or females need. Typically, water-soluble vitamins are well absorbed, crossing the mucosal cells of the gastrointestinal (GI) tract easily and being readily transported into the blood. Minerals are generally poorly or moderately absorbed and may be stranded in the cells lining the GI tract. Minerals also directly compete with each other for absorption while competition among vitamins is lower.

The margin of safety for potential adverse effects is smaller for most minerals than for most water-soluble vitamins. Once in the body, excess amounts of water-soluble vitamins are readily excreted via the urine; however, most minerals are not so easily removed. For most vitamins the Tolerable Upper Intake Level (UL) is many times higher than the DRI. For example, the UL for adults for vitamin C is 22 to 26 times higher than the DRI. In contrast, the UL for calcium is only 2 to 2.5 times higher.

In the case of two minerals, calcium and iron, there are medical tests that can help quantify the amount in the body. **Dual-energy X-ray absorptiometry (DEXA)** scans can estimate the density of bone, which is a large reservoir of body calcium, and a simple blood test can help determine if **anemia** due to iron deficiency is present. There are no imaging techniques that can determine vitamin stores and blood tests for most vitamins are not **clinically** meaningful.

Vitamins and minerals are found in a wide variety of foods. Both are added to foods and sold as dietary supplements, either singly or in combination with other nutrients. Both are essential to good health and performance, but there are more differences between vitamins and minerals than there are similarities. This chapter reviews information about minerals needed for the proper functioning of the skeletal, blood, and immune systems with an emphasis on studies conducted with athletes.

Classification of Minerals

Twenty-one minerals have been identified as essential as shown in Table 9.1. Minerals are often divided into two categories based on the amount found in the body. Those found in relatively large amounts (about 5 g in a 60-kg [132-lb] person) are termed macrominerals and include calcium, phosphorous, magnesium, sodium, potassium, chloride, and sulfur. Microminerals, also known as trace minerals, are found in comparatively smaller amounts in the body. These include well-known minerals, such as iron, as well as lesser-known ones, such as manganese and molybdenum.

Another classification method for minerals is based on function. Minerals critical to proper bone formation include calcium, phosphorus, magnesium, and fluoride. Several minerals are **electrolytes** and have either a positive or negative charge. Sodium, potassium, and chloride are prime examples of minerals that function as electrolytes and help to maintain body fluid balance. Iron is central to proper red blood cell formation. Many enzymes contain minerals such as zinc, selenium, or copper and some of these minerals are necessary for the proper functioning of the immune system.

Table 9.1 Minerals

Macrominerals	Microminerals (Trace Minerals)
Calcium	Iron
Phosphorous (phosphorus)	Zinc
Magnesium	Copper
Sodium	Fluorine (fluoride)
Potassium	Iodine
Chloride	Chromium
Sulfur	Selenium
	Manganese
	Molybdenum
	Cobalt
	Silicon
	Boron
	Nickel
	Vanadium

Macrominerals are found in relatively large amounts in the body, while microminerals are found in trace amounts.

Although some minerals have been studied more than others, basic information about each mineral is known. This information is summarized in Table 9.2. For each mineral the following appears: chemical symbol, major physiological functions, symptoms associated with a deficiency or toxicity, and food sources. More detailed information on minerals can also be found in basic and advanced nutrition textbooks or at the Food and Nutrition Information Center at www.nal.usda.gov/fnic.

Recommended Daily Mineral Intake

Dietary Reference Intakes have been established for 15 minerals (referred to as elements). Some are needed in relatively large amounts daily, such as calcium (1,000 to 1,300 mg depending on age) and potassium (4,700 mg), while others are needed in much smaller amounts, as is the case for iron or zinc (at least 8 mg). A few are needed in very small amounts. For example, the DRI for a 20-year-old woman for chromium is 25 micrograms (equivalent to 0.025 mg). Each mineral is important for proper physiological functioning and good health, although the amount needed may vary considerably.

Absorption of minerals is generally low and well regulated but toxicities can occur. Consequently, it is important to address the question, "How much is too much?" A Tolerable Upper Intake Level has been established for adults for 14 minerals. There is a lack of data about adverse effects for the other minerals and there are occasional reports of problems associated with excessive intake.

Table 9.3 lists the DRI and UL for adult males and adult, nonpregnant females. The complete DRI and UL for minerals (elements) for all ages and both genders are listed in the gatefold located at the back of this textbook. Notice that recommended daily intake is the same for both genders of the same age for several minerals including sodium, chloride, potassium, and calcium. For some minerals, such as zinc and fluoride, values differ for men and women due to differences in average body size. For females, iron recommendations reflect life cycle stage; those between the ages of 19 and 50 need more because of menstruation and the potentially large losses of iron in blood (Institute of Medicine, 2004, 2001, 2000, and 1997).

The Dietary Reference Intakes are established using scientific studies of healthy people who are moderately active. Athletes use these same standards. However,

The Internet Café

Where Do I Find Reliable Information about Minerals?

The Office of Dietary Supplements, a part of the National Institutes of Health (NIH), was established to "strengthen knowledge and understanding of dietary supplements by evaluating scientific information, stimulating and supporting research, disseminating research results, and educating the public to foster an enhanced quality of life and health for the U.S. population." Fact sheets have been created for several minerals including calcium, chromium, iron, magnesium, selenium, and zinc. Each fact sheet gives an overview of the mineral, the foods that provide it, the Dietary Reference Intakes, information about deficiencies and toxicities, information about supplementation, a thorough discussion of current issues and controversies, and a list of references. The fact sheets are written by registered dietitians at the clinical research hospital at the NIH and reviewed by expert scientific reviewers. These fact sheets, as well as a plethora of other information, can be found at: **http://ods.od.nih.gov/health_information/health_information.aspx.**

Mineral: An inorganic (noncarbon containing) compound essential for human health.

Dual-energy X-ray absorptiometry (DEXA): Imaging procedure for measuring bone mineral density.

Anemia: A condition characterized by a reduced oxygen-carrying capacity by the red blood cells.

Clinical, Clinically: Of or relating to symptoms of disease.

Electrolyte: A substance that will dissociate into ions in solution and is capable of conducting electricity.

Table 9.2 Summary of Mineral Characteristics

Boron	
Chemical symbol	B
Major physiological functions	Needed for normal calcium metabolism; most likely functions as a reaction catalyst or regulator
Symptoms of deficiency	Abnormal growth, low sperm count
Symptoms of toxicity	Gastrointestinal symptoms (nausea, vomiting, diarrhea), loss of appetite, fatigue
Food sources	Green leafy vegetables; some fruits
Other	Little is known about this mineral
Calcium	
Chemical symbol	Ca^{+2} (divalent cation)
Major physiological functions	Mineralization of bones and teeth, muscle contraction, nerve conduction, secretion of hormones and enzymes
Symptoms of deficiency	A dietary calcium deficiency is not associated with any signs or symptoms as bone mineral density declines. Spine, wrist, or hip fractures are often the first symptoms. Low calcium intake can contribute to hypertension (high blood pressure). Low blood calcium concentration, a sign of deficiency, is associated with disease states such as renal (kidney) failure
Symptoms of toxicity	Elevated blood calcium levels, impaired renal function, decreased absorption of other minerals. Could be caused by either excessive intake of calcium or vitamin D but such cases are rare. A high blood calcium concentration is usually caused by disease
Food sources	Milk and milk products; green leafy vegetables; fish with bones such as salmon or sardines; calcium-fortified products such as soy milk or orange juice
Chloride	
Chemical symbol	Cl^- (anion)
Major physiological functions	Helps to maintain fluid balance; component of hydrochloric acid (HCl) found in the stomach
Symptoms of deficiency	Failure to thrive (infants)
Symptoms of toxicity	No toxicities from chloride in food reported; rarely toxicities can occur from extremely high ingestion of sodium chloride (table salt). Symptoms would include vomiting, muscle weakness, severe dehydration, acidosis
Food sources	Table salt (sodium chloride, abbreviated NaCl); fish; meat; milk; eggs
Chromium	
Chemical symbol	Cr^{+3} (trivalent cation)
Major physiological functions	Enhances insulin sensitivity; involved in carbohydrate, protein, and fat metabolism
Symptoms of deficiency	Rare but likely to be glucose intolerance and weight loss
Symptoms of toxicity	Few side effects reported from excess chromium from food
Food sources	Whole grain breads and cereals; mushrooms; beer
Cobalt	
Chemical symbol	Co
Major physiological functions	Part of vitamin B_{12} (cobalamin)
Symptoms of deficiency	Anemia
Symptoms of toxicity	None known due to food consumption
Food sources	Same as vitamin B_{12} (animal products)

Table 9.2 Summary of Mineral Characteristics (continued)

Copper	
Chemical symbol	Cu
Major physiological functions	Part of copper-containing enzymes, role in normal hemoglobin synthesis
Symptoms of deficiency	Anemia, demineralization of bone
Symptoms of toxicity	Gastrointestinal distress; liver damage
Food sources	Seafood; nuts; seeds; whole grains; dried beans; some green leafy vegetables
Fluorine (fluoride)	
Chemical symbol	F
Major physiological functions	Component of bones and teeth. Strengthens bone crystal and resists tooth decay when taken in proper but not excessive amounts
Symptoms of deficiency	Dental caries, osteoporosis
Symptoms of toxicity	Mottled teeth, fragile bones, joint pain
Food sources	Fluoridated water; fluoridated vitamins (infants and children)
Iodine	
Chemical symbol	I
Major physiological functions	Synthesis of thyroid hormones
Symptoms of deficiency	Mental retardation, impaired growth and development, goiter (enlargement of the thyroid gland), inadequate thyroid hormone production
Symptoms of toxicity	Thyroid-related medical problems
Food sources	Iodized salt; salt-water fish; mushrooms; eggs
Iron	
Chemical symbol	Fe
Major physiological functions	Component of hemoglobin, which is necessary for iron and carbon dioxide transport; component of enzymes necessary for cellular use of oxygen; immune system functions
Symptoms of deficiency	Fatigue, loss of appetite, reduced resistance to infection
Symptoms of toxicity	Gastrointestinal distress; in those who overabsorb iron, excess iron storage in liver and subsequent liver dysfunction
Food sources	Well-absorbed (heme) sources: clams, oysters, liver, meat, fish, poultry; lesser-absorbed (nonheme) sources: dried beans and legumes, green leafy vegetables, dried fruit, iron-fortified grains
Other	Fe^{+2} = ferrous (storage) form; Fe^{+3} = ferric (transport) form
Magnesium	
Chemical symbol	Mg^{+2} (divalent cation)
Major physiological functions	Bone formation, component of more than 300 enzymes
Symptoms of deficiency	Muscle weakness, confusion, loss of appetite
Symptoms of toxicity	Diarrhea
Food sources	Green leafy vegetables; nuts and seeds; dried beans and legumes

continued

Table 9.2 Summary of Mineral Characteristics (continued)

Manganese	
Chemical symbol	Mn
Major physiological functions	Role in bone formation; necessary for proper carbohydrate, protein, and fat metabolism
Symptoms of deficiency	Not likely but could result in impaired growth and metabolism
Symptoms of toxicity	Elevated blood manganese; nervous tissue toxicity
Food sources	Nuts; dried beans; whole grains; some vegetables
Molybdenum	
Chemical symbol	Mo
Major physiological functions	Component of three enzymes
Symptoms of deficiency	No reports in humans
Symptoms of toxicity	Minimal effects in humans; impaired growth and weight loss in laboratory animals
Food sources	Legumes; whole grains; nuts
Nickel	
Chemical symbol	Ni
Major physiological functions	May be a component of some enzymes and may enhance iron absorption, but few studies have been conducted in humans
Symptoms of deficiency	Not known
Symptoms of toxicity	Low toxicity in humans; gastrointestinal distress associated with nickel poisoning from accidental ingestion of large doses
Food sources	Legumes; nuts; whole grains
Phosphorous (phosphorus)	
Chemical symbol	P
Major physiological functions	Component of bone, component of phospholipids (cell membranes), helps to maintain normal pH, part of ATP, involved in cellular metabolism
Symptoms of deficiency	Impaired growth, bone pain, muscle weakness
Symptoms of toxicity	Impaired calcium regulation, calcification of the kidney, possible reduction of calcium absorption
Food sources	Widely found in foods, especially animal foods
Potassium	
Chemical symbol	K^+ (cation)
Major physiological functions	Intracellular cation, proper cellular function
Symptoms of deficiency	Severe deficiency: hypokalemia (low blood potassium) resulting in cardiac arrhythmias and muscle weakness. Moderate deficiency: contributes to hypertension and calcium loss from bone
Symptoms of toxicity	Most people readily excrete potassium in urine so toxicity is associated with impaired potassium excretion, which results in hyperkalemia (high blood potassium) and risk for cardiac arrhythmias
Food sources	Vegetables, especially green leafy vegetables; dried beans and peas; orange juice; bananas; melons; potatoes; milk and yogurt; nuts

Table 9.2 Summary of Mineral Characteristics (continued)

Selenium	
Chemical symbol	Se
Major physiological functions	Part of antioxidant enzymes
Symptoms of deficiency	Depressed immune function. Keshan disease, which results in cardiac problems, and Keshan-Beck disease, which affects cartilage, have been reported in Asia
Symptoms of toxicity	Selenosis resulting in brittle hair and nails, gastrointestinal distress, fatigue, impaired nervous system
Food sources	Found in plants; amount varies depending on the selenium content of the soil in which they are grown
Silicon	
Chemical symbol	Si
Major physiological functions	Not known but probably involved with bone formation
Symptoms of deficiency	Not known
Symptoms of toxicity	None known due to food consumption
Food sources	Water; grains; vegetables
Sodium	
Chemical symbol	Na^{+} (cation)
Major physiological functions	Extracellular cation, helps to maintain fluid balance
Symptoms of deficiency	Not likely since sodium is widely found in foods and the body has a remarkable capacity to conserve sodium by limiting loss in urine and sweat
Symptoms of toxicity	Elevated blood pressure (depends on genetic predisposition to sodium sensitivity)
Food sources	Table salt (NaCl); addition of sodium to processed foods
Sulfur	
Chemical symbol	S
Major physiological functions	Needed for the synthesis of sulfur-containing compounds, which are essential for the synthesis of many compounds in the body
Symptoms of deficiency	Not likely in the U.S. but deficiencies could result in stunted growth
Symptoms of toxicity	Diarrhea
Food sources	Protein-containing foods and water; the majority of sulfur is provided by the breakdown of body protein and the re-use of the sulfur found in the sulfur-containing amino acids
Vanadium	
Chemical symbol	V
Major physiological functions	Not known
Symptoms of deficiency	Not known
Symptoms of toxicity	None known due to food consumption
Food sources	Mushrooms; shellfish; black pepper; parsley; dill
Other	Use vanadium with caution. There is no justification for adding vanadium to food

continued

Table 9.2 Summary of Mineral Characteristics (continued)

Zinc	
Chemical symbol	Zn
Major physiological functions	Component of hundreds of enzymes; needed for proper cellular function and proper immune system function
Symptoms of deficiency	Impaired growth, poor immunity
Symptoms of toxicity	Immunosuppression; decrease in high-density lipoproteins (HDL); impaired copper metabolism
Food sources	Animal foods (e.g., meat and milk); whole grains

1) Dietary Reference Intakes, The National Academies Press, 2) Gropper, S.S., Smith, J.L. and Groff, J.L. *Advanced Nutrition and Human Metabolism.* Thomson/Wadsworth, Belmont, CA, 2005, and 3) Office of Dietary Supplements, National Institutes of Health, http://dietary-supplements.info.nih.gov/Health_Information/Information_About_Individual_Dietary_Supplements.aspx

Table 9.3 DRI and UL for Adult Males and Adult, Nonpregnant Females

Mineral	Dietary Reference Intakes (DRI)	Tolerable Upper Intake Level (UL)
Calcium	1,000 mg (ages 19 to 50) 1,200 mg (ages 51 and above)	2,500 mg
Chromium	25 mcg (females, ages 19 to 50) 20 mcg (females, ages 51 and above) 35 mcg (males, ages 19 to 50) 30 mcg (males, ages 51 and above)	Not established
Copper	900 mcg	10,000 mcg
Fluoride	3 mg (females) 4 mg (males)	10 mg
Iodine	150 mcg	1,100 mcg
Iron	8 mg (males; females 51 and above) 18 mg (females, ages 19 to 50)	45 mg
Magnesium	310 mg (females, ages 19 to 30) 320 mg (females, ages 31 and above) 400 mg (males, ages 19 to 30) 420 mg (males, ages 31 and above)	350 mg (supplement sources only)
Manganese	1.8 mg (females) 2.3 mg (males)	11 mg
Molybdenum	45 mcg	2,000 mcg
Phosphorus	700 mg	4,000 mg (ages 19 to 70) 3,000 mg (ages 71 and above
Selenium	55 mcg	400 mcg
Zinc	8 mg (females) 11 mg (males)	40 mg
Boron	Not established	20 mg
Nickel	Not established	1 mg
Vanadium	Not established	1.8 mg

Legend: mg = milligram; mcg = microgram

Dietary Reference Intakes

exercise does influence the body's mineral status and there are athletes who lose substantial amounts of certain minerals due to a high level of training, which results in larger-than-normal losses of sweat, blood, or urine (see section below). Although some athletes have exceptional losses, most do not, and the DRI remains the standard that athletes use to judge the adequacy of their dietary mineral intake.

THE INFLUENCE OF EXERCISE ON MINERAL REQUIREMENTS

The influence of exercise on minerals has been difficult to study. Sweat and urine represent the two most likely sources of larger-than-normal losses. Sweat contains several macrominerals such as sodium, chloride, and potassium; losses of these electrolytes, including the substantial loss of sodium by "salty" sweaters, are discussed in detail in Chapter 7. The other macrominerals lost in sweat are magnesium and calcium. One study of magnesium loss in men who worked for eight hours in the heat found that the men lost approximately 4 to 5 percent of their daily magnesium intake via sweat (Lukaski, 2000). Some calcium is also lost but there is no evidence that substantial losses of magnesium or calcium occur.

Three trace minerals—zinc, iron, and copper—may be lost in sweat or urine. Acute exercise results in increased postexercise zinc blood concentration, as zinc moves from muscle cells into the **extracellular fluid.** Some of this zinc may then be excreted via the urine. A few studies have also found that the zinc concentration in sweat is increased with exercise in the heat (Lukaski, 2000). Similarly, more iron may be lost in the sweat and urine of athletes than in sedentary individuals (Gleeson, Nieman, and Pedersen, 2004; Gleeson, Lancaster, and Bishop, 2001). Copper concentrations of sweat are increased, which may help to kill bacteria on the skin (Speich, Pineau, and Ballereau, 2001). Although the number of studies is small and some of the results are contradictory, there is evidence that the loss of some minerals is greater in athletes than in the general population.

While it is recognized that mineral loss can be greater in athletes, it is also known that the consumption of excess minerals, such as zinc and iron, can be detrimental to the athlete by compromising the immune system (Gleeson, Nieman, and Pedersen, 2004). Thought must be given to the best way to compensate for larger-than-normal losses due to exercise. Moderate losses of minerals via sweat or urine can be offset by adequate mineral intake from food. Athletes who have substantial losses may need to increase their dietary intake or supplement the diet with the lost mineral(s). The best approach should be determined on an individual basis.

Mineral Deficiencies and Toxicities

Survival requires that the body be in a state of **homeostasis** and the status of minerals is no exception to this rule. One of the major ways the body maintains its mineral balance is by altering either the amount absorbed, the amount excreted, or both. In general, absorption is low or moderate for most minerals, in part, because **excretion** is normally low. For example, a male would not be expected to absorb more than 10 to 15 percent of the iron in his diet. Assuming that he consumed the DRI for iron, 8 mg, absorption would be approximately 0.8 to 1.2 mg daily. Excretion of iron in the urine and the feces generally amounts to 0.9 to 1.0 mg per day. Many minerals are similar to iron, for which both absorption and excretion are low.

Most minerals can be stored in tissues, and high or low storage levels alter the amount absorbed or excreted. For example, when iron storage is high, absorption may drop to 0.5 mg daily, whereas if iron storage is low (due to voluntary or involuntary blood loss) the body can increase absorption by 3 to 4 mg per day. High storage levels may also affect excretion. Iron is absorbed into the mucosal cells of the GI tract but it does not automatically leave the cells to be transported in the blood. When the body needs to limit iron intake, it may leave iron stranded in the mucosal cells. These cells have a very short life span—on average three days—and not transferring the iron out of the cell and into the blood means that the iron will be excreted in the feces when the dead mucosal cells are sloughed off the intestinal villa. In this example, homeostasis is maintained through the interplay of storage levels, absorption, and excretion (Gropper, Smith, and Groff, 2005).

However, mineral metabolism is much more complicated than simply adjusting intake and output. Calcium is an example of a mineral under substantial hormonal control. Its metabolism is regulated by several hormones that not only influence calcium absorption and excretion but also its deposition and **resorption** from bone. Hormonal regulation is needed because blood calcium concentration must be kept within a narrow physiologic range. The amount of calcium in the extracellular fluid must be very stable to support critical and continuous functions such as muscle contraction

Extracellular fluid: All fluids found outside cells. Includes interstitial fluid and plasma.

Homeostasis: A state of equilibrium.

Excretion: The process of eliminating compounds from the body, typically in reference to urine and feces.

Resorb, Resorption: To break down and assimilate something that was previously formed.

and nerve impulse conduction, so the body cannot depend solely on intestinal absorption and excretion to maintain calcium balance.

Calcium is also an example of a mineral that has a large storage site—bone. This allows the body to maintain calcium homeostasis even when dietary calcium intake is low over years or decades. However, removing large amounts of calcium from its storage site negatively affects the integrity and functionality of the skeletal tissue. Zinc, on the other hand, has no designated storage site. Zinc that is deposited in bone is not available for resorption, so zinc is essentially stored in the compounds that need it to function, the more than 100 zinc-containing enzymes that are found in various cells. If dietary zinc intake is low over years or decades and the body becomes deficient, then zinc is removed from those enzymes that are considered less crucial for cellular functions. These examples highlight the eventual effects of long-term poor mineral intake (Gropper, Smith, and Groff, 2005).

In summary, many mechanisms are available to the body so that it can maintain mineral homeostasis. Some of the manipulations are subtle and not easily detected, such as small increases and decreases in absorption. Changes in excretion help the body maintain balance and guard against excessive amounts in the blood or in storage. Absorption and excretion may be the bookends, but in between there are other substantial influences such as hormones, altered metabolism, or storage capacity. From the perspective of nutrition, the focus for minerals is on the consumption of an adequate amount by eating a variety of mineral-containing foods. This approach assumes adequate absorption.

MINERAL ABSORPTION

It is not possible to know exactly how much of any nutrient is absorbed from the GI tract. A number of factors can affect mineral absorption, including age, gender, stage in the life cycle, genetics, general health, and the health of the GI tract. This section will discuss factors that directly affect absorption such as the presence of a deficiency state, the amount consumed, competition from other nutrients, the presence or absence of food in the intestinal tract, and any compounds that interfere with or enhance absorption. Table 9.4 summarizes the factors that are known to influence mineral absorption.

The amount of any nutrient absorbed from food depends on whether the body is in a state of deficiency. For example, under normal conditions 70 percent of the phosphorus consumed is absorbed. When the body is deficient in phosphorus, as is the case of some elderly women, absorption can increase to about 90 percent. Notice that the body tries to compensate for a deficiency by increasing absorption but that it cannot increase absorption to 100 percent. There are limits to the body's ability to adapt. This is one reason mineral deficiencies occur.

Table 9.4 Factors Influencing Mineral Absorption

Factor	Influence on Absorption
Age	Generally decreases with age
Gender	Varies with the mineral
Life cycle stage	Growth states generally increase absorption; growth states include infancy and childhood growth, puberty, and pregnancy
Genetics	Varies with the individual; absorption could be low, normal, high, or excessive
General and gastrointestinal (GI) health	Poor health, especially poor gastrointestinal health, generally results in poorer absorption
Presence of a deficiency state	Generally results in increased absorption
Amount consumed	In food, higher intakes usually result in greater absorption
Presence of other minerals	In food, reduces absorption to a small degree; large amounts found in supplements may reduce absorption of competing minerals to a large degree
Presence of food in the GI tract	Generally enhances absorption
Compounds found in food	Phytic acid, oxalate, and insoluble fiber are known to inhibit absorption; soluble fiber enhances absorption. Some compounds enhance absorption (e.g., lactose aids calcium absorption, vitamin C aids iron absorption)
Chemical form of the mineral	Most minerals have a chemical form that results in greater absorption; some supplements and fortified foods contain highly absorbable forms

The amount consumed on a daily basis is important to prevent eventual mineral deficiencies. The percentage absorbed decreases as the amount consumed increases. However, the total amount absorbed is greater when more is consumed. For example, when 5 mg of zinc is consumed maximum absorption is approximately 40 percent or 2 mg. When 10 mg of zinc is consumed, absorption declines to about 30 percent, but the total amount absorbed is higher, about 3 mg (10 mg $\times$ 0.30) (Krebs, 2000). The best way to prevent mineral deficiencies is to consume enough of each mineral daily; in other words, the amount recommended in the Dietary Reference Intakes.

Minerals compete with each other for absorption due to chemical similarities. Minerals that are divalent

cations (i.e., 2 positively charged atoms), such as calcium, iron, zinc, copper, and magnesium, use the same binding agents and cellular receptor sites. The major factor influencing the competition appears to be the amount of each mineral consumed.

Problems can occur when intake of one mineral is excessive, such as the consumption of a large amount through supplementation. Copper, iron, and calcium absorption are all reduced when zinc intake is excessive. In the case of magnesium or calcium, if either is taken in excess, then the absorption of the other is substantially decreased. Calcium and iron are also competitors. These interactions raise questions about both the benefits and potential problems associated with supplementation of minerals, either singly or as part of a multimineral supplement. Obtaining minerals from food may be more beneficial than obtaining them from supplements that provide excessive amounts because of the effects on absorption.

Minerals taken in adequate but not excessive amounts seem to circumvent the problem of substantially reduced or favored absorption. Competition is still present because minerals normally share the same absorption mechanisms and pathways. However, when all the minerals are present in reasonable amounts, no one mineral has an overwhelming absorption advantage. In nature, calcium-containing foods, such as milk, are poor sources of iron, and iron-containing foods, such as meat, are poor sources of calcium. When eaten apart, the competing nutrient is absent. When both meat and milk are eaten as part of the same meal there will be some competition for absorption but one will not be absorbed to the exclusion of the other.

Minerals are better absorbed when food is present in the GI tract. This may be due to the slower movement of undigested food, known as an increased transit time, the presence of enzymes that are secreted as part of the normal digestive process, or a favorable pH (Sabatier et al., 2002). Some mineral supplements, such as calcium carbonate, are also better absorbed when consumed with food. However, large doses of single supplements, such as iron, may be better if taken on an empty stomach so that they do not interfere with absorption of other minerals.

A number of compounds found naturally in food are known to interfere with or enhance absorption. Those that interfere include phytic acid, oxalate, insoluble fiber, and fat. Phytic acid (phytates) and oxalates are known to inhibit the absorption of iron, zinc, calcium, and manganese by binding with the mineral and blocking absorption. These compounds are found in spinach, Swiss chard, seeds, nuts, beans, and legumes (Hurrell, 2003). Insoluble fiber, such as wheat, decreases calcium, magnesium, manganese, and zinc absorption because of a decreased transit time. In other words, the insoluble fiber causes the contents to move through the GI tract more quickly, resulting in less contact time with the mucosal cells and less opportunity for the minerals to be absorbed (Greger, 1999).

Table 9.5 Probability of Adequate Mineral Intake for Adult Males and Females

Nutrient	% Adequacy in Men	% Adequacy in Women
Calcium	58.6	45.7
Phosphorus	94.3	85.1
Magnesium	36.1	34.3
Iron	95.5	79.4
Copper	87.4	73.3
Zinc	65.7	62.0

Many men and women do not consume an adequate amount of minerals daily.

Table D1–2. Probabilities of Adequacy for Selected Nutrients on the First 24-hour Recall among Adult CSFII 1994–96 Participants. Dietary Guidelines, 2005. (www.health.gov/DietaryGuidelines/dga2005/report/HTML/D1_Tables.htm#top)

Sugars such as lactose (milk sugar) may increase calcium absorption as well as magnesium and zinc. The mechanism is not entirely known but it may be due to the effect the sugar has on increasing the permeability of the GI tract. Soluble fibers, such as pectins or gums, may also have a favorable effect (Greger, 1999). Several factors can enhance iron absorption, including ascorbic acid (vitamin C) and the presence of the meat, fish, poultry (MFP) factor (Diaz et al., 2003).

Although numerous factors have been identified as either increasing or decreasing absorption, their influences are probably subtle when considered in the larger context of daily, weekly, and yearly intake. Most reports of clinical mineral deficiencies are from poor countries where the food supply is severely limited. Eating a variety of nutrient-dense foods may be the best approach for minimizing competition and maximizing mineral absorption.

AVERAGE MINERAL INTAKES BY SEDENTARY ADULTS AND ATHLETES

Table 9.5 shows the probability of adequate mineral intakes from food for U.S. adult males and females for six minerals. Only 36 percent of men and 34 percent of women are likely to receive an adequate amount of magnesium from their diets. Calcium intake is also low for many adults with approximately 46 percent of women and 59 percent of men meeting recommended

Cation: A positively charged ion.

guidelines. Zinc consumption is adequate for 62 percent of women and ~66 percent of men. Most men meet the recommended intake for iron and phosphorus. These figures are from data obtained between 1994 and 1996.

Adequate mineral intake for athletes is generally associated with adequate energy intake. Athletes with a low energy intake are likely to be deficient in one or more of the following minerals: calcium, iron, zinc, selenium, magnesium, and copper. Energy-restricted athletes known to be at risk include distance runners, female gymnasts, ballet dancers, teenaged synchronized skaters, wrestlers, and jockeys. Some studies have shown substantial deficits, particularly of iron and zinc. Some of the trace minerals have not been assessed but it is likely that athletes who are deficient in iron and zinc are also deficient in some of the other trace minerals. These athletes are also likely to have low vitamin intakes (Ziegler et al., 2005; Jonnalagadda, Ziegler, and Nelson, 2004; Leydon and Wall, 2002; Ziegler et al., 2002 and 1999; Venkatraman and Pendergast, 2002). However, it is possible for athletes who are restricting food intake to consume a sufficient amount of some minerals if the foods chosen are highly fortified (e.g., calcium and iron added).

DEVELOPING CLINICAL AND SUBCLINICAL MINERAL DEFICIENCIES

Despite the body's adaptive mechanisms, mineral deficiencies can occur if intakes are too low over time. Any mineral deficiency will be progressive—at first mild and difficult to detect, then moderate, and ultimately, severe, if not detected and treated. As with vitamin deficiencies, mild and moderate mineral deficiencies, also called **subclinical** deficiencies, often progress over a long period of time with no visible signs or symptoms. When signs or symptoms do appear, they are usually subtle and nonspecific.

Zinc deficiency is a good illustration. A mild zinc deficiency forces the body to prioritize the functions of its zinc-containing enzymes to ensure that the available zinc is incorporated into higher-priority enzymes. Initially, a small reduction in the number and type of zinc-containing enzymes would not be noticeable and, because of limitations in measuring such activity, not likely to be detected with laboratory tests. As a mild deficiency became a moderate one, signs and symptoms would emerge but they would be nonspecific—reduced appetite, poor wound healing, or dermatitis (inflammation of the skin)—making a diagnosis of zinc deficiency difficult since many medical conditions have these same general symptoms. As a zinc deficiency became more severe (i.e., a clinical deficiency) specific signs would emerge such as impaired taste or night blindness.

Prevalence of Clinical Mineral Deficiencies. In industrialized countries where food is abundant and iodine is added to salt, clinical mineral deficiencies are typically limited to iron and calcium. In individuals with cirrhosis (scar tissue in the liver), a zinc deficiency may be present. A clinical iron deficiency results in iron-deficiency anemia. It is estimated that 3 percent of women ages 12 to 49 have iron deficiency anemia (Centers for Disease Control and Prevention, 2002). The percentage of female athletes who have a clinical iron deficiency is not known, but it is not likely to be less than 3 percent and may be considerably higher. Some males, including a few male endurance athletes, may manifest iron deficiency anemia but the prevalence is very low. Iron deficiency anemia results in fatigue and impairs performance by reducing aerobic capacity and endurance.

Normally, a clinical calcium deficiency (e.g., **osteoporosis**) develops over many decades. Based on 2002 figures, 8 million women and 2 million men in the United States have osteoporosis (National Osteoporosis Foundation, 2005). Loss of calcium from bone is exacerbated in women when **estrogen** production declines substantially. For most women this estrogen decline is a result of **menopause,** but for some female athletes low circulating estrogen is a result of a prolonged low caloric intake concurrent with the high energy expenditure of intense training. This low energy availability may be a result of disordered eating, but that is not always the case (see Chapter 13 for a full explanation). Low energy availability can result in **amenorrhea,** the cessation of menstruation. In two studies of amenorrheic female distance runners between the ages of 20 and 30, 10 to 13 percent were diagnosed with osteoporosis (Khan et al., 2002). Cobb et al. (2003) reported that of 33 well-trained distance runners (aged 18 to 26) with amenorrhea or **oligomenorrhea,** two had already developed osteoporosis. Female athletes who are not menstruating or who have infrequent menstruation should seek medical attention.

Prevalence of Subclinical Mineral Deficiencies. In the early stages of a subclinical mineral deficiency a person would show few or no outward signs that mineral status is declining. A subclinical iron deficiency is known as iron deficiency without anemia. Such deficiencies are prevalent in the United States, with estimates ranging from 2 to 5 percent of males (highest prevalence in 12 to 16 year olds), 9 to 16 percent of female adolescents, and 12 percent of nonpregnant females (Centers for Disease Control and Prevention, 2002). Malczewska, Raczynski, and Stupnicki (2000) report that 26 percent of the female endurance athletes in their study had a subclinical iron deficiency. Some researchers estimate that the prevalence is higher in vegetarians (Beard and Tobin, 2000). There is controversy about the effect of iron deficiency without anemia on human athletes because study results have been contradictory but studies in animals suggest it affects endurance capacity (Haas and Brownlie, 2001).

A subclinical calcium deficiency is known as **osteopenia** or low bone mineral density (BMD). Using 2002 data, the National Osteoporosis Foundation estimates that approximately 22 million women and 12 million men have low BMD. Those with osteopenia are at risk for developing osteoporosis. Studies of amenorrheic runners and ballet dancers found that 22 to 50 percent of the subjects had osteopenia, some mild and some substantial (Khan et al., 2002). Cobb et al. (2003) report that nearly half of the 33 oligo/amenorrheic distance runners studied had osteopenia as did a quarter of the 58 distance runners with normal menstruation. Some athletes in their 20s are experiencing bone mineral loss and they are at higher risk for fractures. While this is more prevalent in amenorrheic athletes, it is also true for some athletes with normal menstruation.

The prevalence of those in the United States who have a subclinical zinc deficiency is not known. However, a handful of studies of U.S. children and adults have shown that some people benefit from zinc supplementation, suggesting that subclinical deficiencies do exist in the United States (Hambidge, 2000). A lack of zinc could result in a depressed immune system and a higher incidence of colds (Failla, 2003).

In addition to iron, calcium, and zinc, it is reasonable to assume that some people could have subclinical deficiencies of selenium and magnesium because surveys suggest that dietary intake is below recommended levels (Ford and Mokdad, 2003). These data must be interpreted cautiously, however, because prolonged low dietary intake is suggestive but not predictive of a subclinical deficiency. Increased absorption or decreased excretion may offset low intake. For several of the trace minerals, the amount contained in food is not known; thus, dietary intake cannot be estimated and no conclusions about potential subclinical deficiencies can be made solely from dietary analysis.

Clinical mineral deficiencies negatively affect performance and undermine the athlete's health. Subclinical deficiencies are never desirable because they could theoretically impair an athlete's ability to train or perform. As is often said in sports, "the best defense is a good offense." The athlete's best defense against mineral deficiencies is an adequate intake of minerals daily through the consumption of nutrient-dense foods in sufficient quantities to meet caloric needs.

MINERAL TOXICITIES

For most of human history food was the only source of minerals. Very small amounts of trace minerals are found in food so there was little risk of consuming toxic amounts from the diet. As medical research advanced, mineral deficiencies could be detected. When a deficiency was diagnosed, it was easily reversed either with a change in food intake or short-term mineral supplementation. Supplementation was monitored as part of the medical treatment and toxic levels could be avoided. The scientific focus was on one of two points on the continuum—deficiency or toxicity.

In the last 20 years, especially in the United States, mineral supplementation by generally well-nourished individuals has increased. This has occurred because of research that has shown a relationship between various minerals and chronic diseases as well as increased advertising for mineral supplements. More foods are now fortified with minerals and more people are consuming supplements of a single mineral in amounts higher than would occur naturally from the consumption of food only. The scientific focus is now on three points on the continuum—deficiency, health benefits to well-nourished individuals, and toxicity (Fraga, 2005).

The distance between deficiency and toxicity has been fairly well defined; however, the difference between the amounts needed to prevent chronic diseases in the well-nourished individual and toxicity is poorly understood and hard to measure. The best advice for those who supplement with minerals, especially trace minerals, is to supplement carefully and monitor dosages to avoid potential toxicities. Fraga (2005) suggests that self-prescribed, poorly monitored intake of trace mineral supplements will put some people on the borderline of toxicity.

Table 9.6 lists the Tolerable Upper Intake Level that has been established for 14 of the minerals and the potential adverse affects associated with excess intake. For all of the nutrients except magnesium, the UL includes all foods, water, and supplements as mineral sources. In the case of magnesium, the established level is based on supplements only. To properly evaluate if an individual is approaching or exceeding the

Subclinical: Producing effects that are not detectable by usual clinical (medical) tests.

Osteoporosis: Disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture.

Estrogen: Female sex hormone.

Menopause: Period of time when menstruation diminishes and then ceases. Typically occurs around the age of 50.

Amenorrhea: Absence or suppression of menstruation.

Oligomenorrhea: Menstrual periods that are infrequent or sparse.

Osteopenia: Low bone mineral density. A risk factor for osteoporosis.

Table 9.6 Tolerable Upper Intake Level and Potential Toxic Effects of Minerals

Nutrient	Tolerable Upper Intake Level for Adult Males and Nonpregnant Females	Potential Toxic Effects
Calcium	2,500 mg	Kidney stone formation; hypercalcemia (high blood calcium) and renal (kidney) insufficiency; decreased absorption of other minerals
Phosphorus	4,000 mg (ages 19 to 70) 3,000 mg (ages 71 and above)	Impaired calcium regulation; calcification of the kidney; possible reduction of calcium absorption
Fluoride	10 mg	Fluorosis of the teeth and bones resulting in mottled teeth, fragile bones, and joint pain
Magnesium	350 mg (supplement sources only)	Diarrhea
Iron	45 mg	Gastrointestinal distress
Copper	10,000 mcg	Gastrointestinal distress; liver damage
Zinc	40 mg	Immunosuppression; decrease in high-density lipoproteins (HDL); impaired copper metabolism
Selenium	400 mcg	Selenosis resulting in brittle hair and nails, gastrointestinal distress, fatigue, impaired nervous system
Boron	20 mg	Low toxicity in humans; gastrointestinal distress associated with boron poisoning from accidental ingestion of large doses
Iodine	1,100 mcg	Thyroid-related medical problems
Manganese	11 mg	Elevated blood manganese levels; nervous tissue toxicity
Molybdenum	2,000 mcg	Minimal effects in humans; impaired growth and weight loss in laboratory animals
Nickel	1 mg	Low toxicity in humans; gastrointestinal distress associated with nickel poisoning from accidental ingestion of large doses
Vanadium	1.8 mg	Use vanadium with caution. There is no justification for adding vanadium to food

Legend: mg = milligram; mcg = microgram

Dietary Reference Intakes

UL, a nutritional analysis of the usual diet should be conducted to determine approximate mineral intake from food. The amounts consumed as supplements should be added to these estimates and the total intake compared to the UL. High-potency multimineral supplements can provide surprisingly high amounts of several minerals (see Spotlight on Supplements: Evaluating a High-Potency Multimineral Supplement Advertised to Athletes).

By now it should be clear that an adequate amount of each mineral is needed for proper biological function but that excessive amounts can be detrimental. Minerals are needed in every physiological system, but this chapter will focus on three that are vitally important for the athlete's health and performance—bone, blood, and immune system. Minerals involved in body fluids (e.g., sodium, potassium) are covered in detail in Chapter 7.

What's the point? Most athletes do not require more minerals than sedentary individuals and sufficient amounts can be obtained from food. Low calcium and iron intakes, which are more prevalent in females, may result in subclinical and clinical deficiencies. For those who consume a sufficient amount of minerals in food, consumption of large amounts of highly absorbable minerals found in supplements increases the risk for developing mineral toxicities.

The Roles of Minerals in Bone Formation

The strength and hardness of bones and lack of dimensional growth in adults may lead people to believe that bone has "finished growing" after adolescence and not

Evaluating a High-Potency Multimineral Supplement Advertised to Athletes

The following multimineral supplement is advertised as a "High absorbance formula for stressed people, athletes and body-builders, and cancer, AIDS, and HIV patients." The manufacturer recommends one tablet daily. Table 9.7 lists the dose found in the supplement for each mineral and compares it to the Dietary Reference Intake for a 22-year-old male. Information about the UL is also included.

This mineral supplement contains several minerals in amounts that are more than twice the DRI. Many male athletes who consume a sufficient amount of energy (kilocalories) are already obtaining the recommended amounts from food, and these doses will bring daily mineral intake several times higher than recommended. The supplement is advertised as being highly absorbable. Excessive or preferential absorption could result, although it is impossible to know how much of any mineral will be absorbed.

Five minerals contained in this supplement are of particular concern—magnesium, zinc, manganese, vanadium, and silica. The amount of magnesium exceeds the Tolerable Upper Intake Level established. The amount of zinc contained (22.5 mg) is higher than many nutrition professionals recommend. No more than 15 mg of supplemental zinc is generally recommended because high doses of zinc can interfere with iron and copper absorption and can suppress the immune system. This supplement provides 10 mg of manganese, 91 percent of the UL. When added to the amount consumed in food, intake of this nutrient could be high. It is not illegal to have high dosages in a supplement, even those that exceed the UL.

Although there is no UL for vanadium, the committee that established the UL noted that vanadium supplements should be used with caution (Institute of Medicine, 2001). The European Food Safety Authority (2004) concluded that vanadium is not an essential mineral for humans and noted that adverse effects on kidneys and reproduction have been reported in rats. The silica (silicon dioxide) in this supplement is extracted from horsetail herb and represents 20 to 50 percent of the estimated daily dietary intake of silicon. Although a UL has not been established, the Institute of Medicine also noted that silicon should not be added to food or supplements.

The label states that 2 mg of copper are contained in the supplement, but the DRI and UL are listed in micrograms, which makes it hard for the consumer to compare. Comparisons are unlikely, though, because mineral supplement labels do not require that the UL be listed.

It is curious that a supplement recommended to cancer, AIDS, and HIV-positive patients would also be recommended to athletes. Athletes are typically healthy individuals whose need for minerals is likely met by consuming amounts recommended by the DRI. Cancer and AIDS patients have wasting diseases that substantially affect nutrient intake and nutrient requirements. The use of the DRI is not appropriate with people who are ill because the DRI is established using data from healthy individuals. This supplement's advertising message was "more is better," but that conclusion is not necessarily true.

Table 9.7 Example of a High-Potency Multimineral Supplement

Mineral	Dose	DRI*	Dose Compared to DRI
Calcium	1,000 mg	1,000 mg	Equal
Iron	18 mg	8 mg	2.25 times greater
Iodine	150 mcg	150 mg	Equal
Magnesium	500 mg	400 mg	1.25 times greater; exceeds the UL (350 mg)
Zinc	22.5 mg	11 mg	2 times greater
Selenium	50 mcg	55 mcg	10% less
Copper	2 mg**	900 mcg	2.2 times greater
Manganese	10 mg	2.3 mg	4 times greater
Chromium	100 mcg	35 mcg	2.8 times greater
Molybdenum	10 mcg	45 mcg	Less than 25%
Potassium	99 mg	4,700 mg	Less than 2%
Vanadium	2 mcg	Not established	UL not established; use vanadium supplements with caution
Silica (horsetail herb)	10 mg	Not established	UL not established but report states that silicon should not be added to food or supplements

Legend: DRI = Dietary Reference Intakes; mg = milligram; mcg = microgram; UL = Tolerable Upper Intake Level

*22-year-old male

**2 mg = 2,000 mcg

metabolically active in adulthood. Bone is a dynamic tissue that is biologically active throughout life. Increases in bone length and thickness are associated with growth in childhood and adolescence, but bone mineral content can increase until about age 35, when peak bone density is achieved. After that point bone mineral loss slowly begins and continues throughout life. Loss is accelerated in females when estrogen production substantially declines such as after menopause and throughout the course of **athletic amenorrhea.**

BONE-FORMING MINERALS

Bone growth is accomplished by the balanced activity of two different types of bone cells, **osteoblasts** and **osteoclasts,** and by cartilage cells, **chondrocytes.** Osteoblasts are the bone-forming cells. They produce an organic matrix that consists of collagen fibers and a gel-like material known as ground substance, which accumulates outside of these bone cells. Calcium phosphate salts crystallize within this matrix, giving bone its rigidity and strength. Osteoclasts are bone cells that dissolve this matrix and thus remove bone tissue. This is important during bone growth in areas such as the inner surface of the marrow cavity to prevent the bones from becoming too thick and heavy. Bone length is increased by osteoblasts laying down new bone tissue at the ends of the bone where the chrondrocytes have become calcified. Once the crystallized matrix has surrounded an osteoblast, it is considered a mature bone cell and is referred to as an osteocyte (Sherwood, 2007).

Eighty to 90 percent of the mineral content of bone consists of calcium and phosphorus incorporated into **hydroxyapatite** crystals, $Ca_5(PO_4)_3OH$. Fluoride is also incorporated, increasing the size of the crystal and making it less fragile. However, too much fluoride makes the crystal too large and brittle and fragility is increased. Magnesium is not integrated into the hydroxyapatite crystal, but it sits on the surface and helps to regulate bone metabolism (Ilich and Kerstetter, 2000).

In addition to the structural minerals, several minerals play indirect roles. Iron, zinc, and copper are part of various enzymes that are needed to synthesize collagen. Sodium interacts with calcium, and studies have shown that sodium in the form of salt (e.g., sodium chloride) increases the loss of calcium in the urine. What is not yet known is whether a habitually high intake of dietary sodium chloride (i.e., table salt) reduces the amount of calcium in the bone crystal, but this effect is biologically plausible (Ilich and Kerstetter, 2000).

Nutrients other than minerals are also critical to proper bone development. Vitamin D, a general term that includes several different chemical forms, is an important influence because one form functions as a **hormone** and helps to regulate calcium absorption and excretion. Vitamin K assists with incorporation of calcium into the hydroxyapatite crystal. While all the nutrients involved in bone formation are important, calcium is emphasized because it makes up a large proportion of the hydroxyapatite crystal. Bone is a reservoir for calcium that will be tapped to provide for critical metabolic functions if dietary calcium intake is habitually low, absorption is poor, or excretion is high.

BONE REMODELING

Throughout life bone is constantly remodeled as existing bone is resorbed (broken down) and new bone is formed. This process, known as bone turnover, involves osteoclasts (cells that resorb bone) and osteoblasts (cells that form bone). Osteoclastic activity is triggered by many factors, including mechanical force (physical activity), microfractures, and changes in hormone concentrations, such as **parathyroid hormone** (PTH) and **calcitriol** (1,25-dihydroxyvitamin D_3). Once resorption begins, osteoblasts migrate to the site of resorption to begin the process of new bone formation. In children and adolescents deposition outpaces resorption. In young adults the amount of bone formed typically equals the amount of bone resorbed, but as people age, osteoblastic activity does not equal osteoclastic activity. The result is a net loss in bone density (Kenny and Prestwood, 2000).

Skeletal mass consists of both cortical and trabecular bone. Approximately 80 percent of the skeleton is cortical bone, which is found in the shafts of the long bones and on the surface of the bones. In contrast, about 20 percent is trabecular bone, which is found at the ends of the long bones and below the surface. Cortical bone is compact and is laid down in concentric circles around Haversian systems (canals) that contain blood vessels, nerves, and other tissues. In contrast, trabecular bone is a series of interconnecting plates housing the bone marrow that is the source of blood cells. Trabecular bone has much greater surface volume and a higher rate of metabolic activity and turnover than cortical bone (Compston, 2001).

One to 2 percent of the entire skeletal mass in adults is being remodeled at all times, but 20 percent of the trabecular bone is being remodeled, underscoring its high turnover. In the adult skeleton, approximately 10,000 to 20,000 new remodeling sites become active each day. At any given time, approximately 1 million sites are being actively remodeled. Over 10 years' time an adult's entire skeleton will have been remodeled (Sherwood, 2007).

Once the bone remodeling process begins at a site, the time to completion is a function of age. In children the remodeling takes several weeks, while in young adults it takes about three months. In older adults the time between bone breakdown and complete restoration can be anywhere from six to 18 months (Heaney, 2001). Most of the remodeling time is spent in bone formation, not bone breakdown (Compston, 2001).

CALCIUM METABOLISM

Calcium metabolism is hormonally controlled both on the micro level (e.g., the amount of calcium in the blood) and on the macro level (e.g., the amount of calcium absorbed, distributed, and excreted). Two critical hormones are parathyroid hormone and calcitriol (a form of vitamin D). The regulation of calcium in the blood and extracellular fluid (ECF) is referred to as calcium homeostasis and is primarily under the control of PTH. Calcium balance describes the body's total absorption, distribution, and excretion of calcium and is regulated by PTH and calcitriol. Calcium homeostasis and calcium balance describe different aspects of calcium metabolism, although the two functions are related.

Normal blood calcium concentration is between 8.5 and 10.5 mg/dl, a small physiological range. This range is tightly regulated because calcium is a cellular messenger and enzyme regulator. Approximately half of the calcium in the blood is bound to proteins and cannot leave the blood **plasma.** The remaining half is unbound and can diffuse into the extracellular fluid. On average, the extracellular fluid contains approximately 1,000 mg of calcium. The amount of calcium in the ECF directly affects the function of the nerve and muscle cells, so it must be well controlled.

Homeostasis of plasma calcium occurs because calcium can be quickly moved into the ECF from a pool of calcium in the bone fluid. Bone fluid surrounds the membranes that connect osteoblasts with osteocytes. When blood calcium concentration decreases, PTH activates calcium pumps located in the membranes surrounding the bone fluid to quickly move calcium into the blood and restore homeostasis. Known as fast exchange, the calcium is coming from bone fluid, not from mineralized bone. PTH also stimulates the kidney to resorb more calcium (so it is not lost in urine) and activate calcitriol, a hormone that increases calcium absorption in the intestine. Thus, PTH is maintaining homeostasis via fast exchange but it is also influencing calcium balance by decreasing the loss of calcium in the urine and increasing the supply of calcium from food.

Under normal conditions, a sufficient amount of calcium is consumed daily (i.e., the DRI). Calcium balance is maintained by the interplay of calcium absorption and excretion. Calcium absorption and excretion can be increased or decreased to maintain balance. Part of calcium balance also involves bone. Normally, calcium is exchanged with bone at an equal rate. Of the nearly 1,000,000 mg (1,000 g) of calcium found in bone, approximately 550 mg is exchanged daily. Obviously, bone contains a large amount of calcium, which can be used to offset a long-term low calcium intake.

Figure 9.1 illustrates the numerous tissues and hormones associated with calcium regulation. In adults, the average absorption is approximately 30 percent of the calcium entering the GI tract via food. Thus, of a 1,000-mg daily intake of calcium only about 300 mg is absorbed. The amount absorbed is regulated by vitamin D and does vary. Absorption of calcium in adults in estimated to be between 10 and 50 percent and as high as 75 percent in children (Gropper, Smith, and Groff, 2005; Heaney, 2001). Absorption from calcium supplements also varies depending on the chemical composition (e.g., calcium carbonate, calcium citrate), but typically ranges from 25 to 40 percent. The body cannot compensate for low calcium intake by increasing absorption to 100 percent.

On average, approximately 300 mg is also lost through the urine and **secretions** from the extracellular fluid into the GI tract. Under normal conditions (i.e., adequate calcium intake) the amount of calcium excreted is equal to the amount absorbed and the body can maintain calcium homeostasis and calcium balance (Gropper, Smith, and Groff, 2005).

Unfortunately, many people do not consume a sufficient amount of calcium daily, which affects calcium balance. The body must maintain calcium homeostasis, but faced with low calcium intake, it cannot do so by only using fast exchange, the PTH-stimulated calcium pumping mechanism. A second mechanism, known as slow exchange, must be relied upon to make available the calcium needed. In slow exchange, PTH stimulates the dissolution of bone by increasing osteoclast activity and inhibiting osteoblast activity. The bone crystal, $Ca_5(PO_4)_3OH$, dissolves releasing both

Athletic amenorrhea: Absence or suppression of menstruation as a result of athletic training.

Osteoblast: Bone-forming cell.

Osteoclast: Bone-removing cell.

Chondrocyte: A cartilage cell.

Hydroxyapatite: The principal storage form of calcium and phosphorus in the bone.

Hormone: A chemical compound that has a regulatory or stimulatory effect.

Parathyroid hormone: A hormone produced in the parathyroid glands that helps to raise blood calcium by stimulating bone calcium resorption.

Calcitriol: 1,25-dihydroxyvitamin D_3, a hormonally active form of vitamin D.

Plasma: The fluid portion of blood.

Secretion: The process of releasing a substance to the cell's exterior.

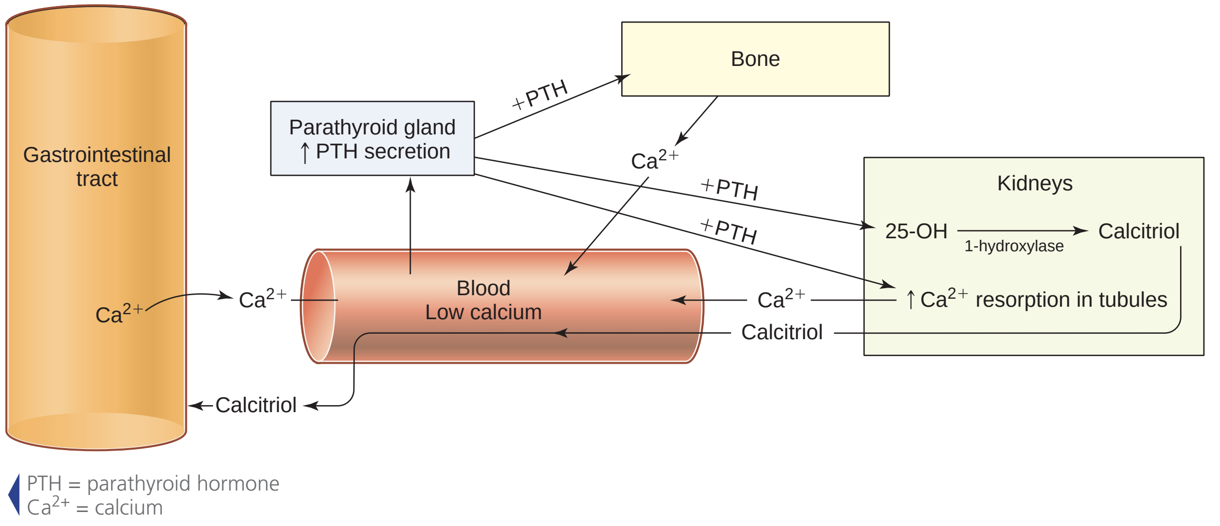

Figure 9.1 Calcium Regulation

Calcium homeostasis and balance are complex and involve the gastrointestinal tract, kidneys, bone, and blood. Two influential hormones are parathyroid hormone and calcitriol (a form of vitamin D).

Ca^{2+} (calcium) and PO_4^{3-} (phosphate). The calcium is used to maintain blood calcium within the normal range and the phosphate is typically excreted in the urine. Over time, this process undermines the integrity of the bone's structure because the mineral density of the bone is decreased (Sherwood, 2007).

PEAK BONE MINERAL DENSITY

Peak mineral density (PMD) refers to the highest bone mineral density achieved during one's lifetime. The largest amount of bone mineral is added during childhood and adolescence (45 percent of the total in each time period). Only 10 percent of bone density is accumulated between ages 20 and 35. Peak bone density of trabecular bone is achieved between the ages of 20 and 30, while cortical bone density peaks later, usually between ages 30 and 35.

Approximately 40 to 60 percent of peak bone density is genetically determined, although the exact genes are not known. Genetic factors could affect bone density capacity as well as the rate of bone deposition or resorption (Compston, 2001). To reach one's genetic potential for PMD, nutrient intake must be adequate. Although many nutrients are important in bone formation, the emphasis is put on consuming an adequate amount of calcium and vitamin D. A low calcium intake during childhood and adolescence can reduce peak bone mineral density by as much as 5 to 10 percent. This degree of peak mineral density deficit is associated with hip fracture in later life. As average life expectancy in the United States is approximately 78 years, obtaining peak bone mineral density is critical to long-term health (Centers for Disease Control and Prevention, 2004).

Physical activity or participation in sports or exercise programs has an important impact on the development of peak bone mineral density. Weight-bearing exercise or activity that exposes the body to repeated stress in excess of the normal effects of gravity is needed. This weight-bearing stress stimulates bone to increase bone mineral content over time. People who are physically active generally have greater bone mineral density than those who are sedentary. Exercise-related factors that influence peak bone density include the type, intensity, and frequency of exercise; age at which the activity is begun; and number of years that the exercise continues (Beck and Snow, 2003).

Studies in children have shown that jumping, hopping, and similar high-impact activities increase bone mineral content in the hip and spine and are safe for children to perform (Fuchs, Bauer, and Snow, 2001). A subsequent study showed that gains in bone density were sustained in the hip even after seven months of detraining (Fuchs and Snow, 2002). Childhood and adolescence are critical times for increasing bone mass and high-impact activities (e.g., jumping rope) and sports (e.g., gymnastics, volleyball, basketball) should be encouraged.

In young adults, high-impact activities and strength training such as power lifting increase bone mineral density to the greatest degree. Weight-bearing exercise at intensities of greater than 60 percent of $\dot{V}O_{2max}$ are more beneficial than weight-bearing activities performed at lower intensities. In contrast to children, bone-stimulating activities must be continued to maintain the gains made in bone density (Winters and Snow, 2000). Nonweight-bearing activities such as cycling or swimming do not stimulate gains in bone mineral

Table 9.8 Dietary Reference Intakes for Calcium and Vitamin D

Age Group (yr)	Calcium (mg)	Vitamin D (mcg)
0 to 0.5	210	5
0.5 to 1	270	5
1 to 3	500	5
4 to 8	800	5
9 to 18	1,300	5
19 to 50	1,000	5
51 to 70	1,200	10
71 and above	1,200	15

Legend: yr = year; mg = milligram; mcg = microgram

density (although these are good activities for cardiovascular fitness). Sedentary adults have lower bone mineral density than adults who are physically active. While high-impact activities have the greatest effect, weight-bearing activity, especially at higher intensities, is also beneficial. Predictably, more frequent activity has a greater effect than less frequent activity (Beck and Snow, 2003).

Recommended Dietary Intakes of Calcium and Vitamin D. Dietary intake of calcium throughout the life cycle is critical. The Dietary Reference Intakes for calcium and vitamin D for each age group are listed in Table 9.8. Calcium recommendations for infants and children increase proportionately to increasing growth. Between the ages of 9 and 18 recommended calcium intake is at its highest—1,300 mg daily. Recommendations remain relatively high throughout the life cycle. Males and nonpregnant females between the ages of 19 and 50 need 1,000 mg daily. After age 50, calcium recommendations are increased to 1,200 mg daily to help offset the loss of calcium from bone. The Tolerable Upper Intake Level for calcium is 2,500 mg daily and includes intake from food, water, and supplements.

In the United States daily calcium intakes for females peak at ages six to 11 when approximately 800 mg of calcium is consumed daily. The average dietary intake of calcium for adult women is approximately 650 mg daily, well below recommended amounts. Calcium supplements and calcium-fortified foods are consumed by some women, but consistently low calcium intakes across the life cycle are prevalent among women. Males consume approximately 925 mg daily after age nine (Morgan, 2001; Ilich and Kerstetter, 2000).

Vitamin D is a powerful regulator of calcium and phosphorus metabolism, so an adequate calcium intake should be accompanied by an adequate vitamin D intake. Vitamin D is found in a limited number of foods including fatty fish and fish oils. In industrialized countries, milk is fortified with vitamin D. Another important source is ultraviolet (UV) light. When the body is exposed to UV light (e.g., sunlight), a precursor to vitamin D in skin cells can be activated.

The Dietary Reference Intake for vitamin D is 5 mcg (200 IU) for infants, children, adolescents, and adults up to age 50. The DRI increases to 10 mcg (400 IU) for ages 50 to 69 years and to 15 mcg (600 IU) for those older than 70 years (see Table 9.8) These recommendations reflect expected reduced exposure to sunlight and a decreased conversion rate of the vitamin D precursor to the active form of vitamin D as people age. Heaney (2003), one of the world's authorities on osteoporosis, suggests that 15 mcg is too low for most elderly people and recommends 25 mcg (1,000 IU) daily for an elderly person diagnosed with osteoporosis.

Vitamin D is a fat-soluble vitamin and excessive intake could result in hypervitaminosis D, hypercalcemia (high blood calcium levels), and toxicity, although the prevalence is rare. The Tolerable Upper Intake Level is 50 mcg (2,000 IU). This level would not likely be achievable from food alone but could result from excessive vitamin D supplementation.

Vitamin D deficiency is prevalent in the older adult population. In the United States, men and women ages 50 and above have an average vitamin D intake of approximately 8 mcg (320 IU). Of this 8 mcg, approximately 5 mcg (200 IU) is obtained from food sources both fortified and naturally occurring. Exposure to UV light at all ages varies according to latitude, choice of clothing, and use of sunscreen and could be deficient (Grant and Holick, 2005).

Calcium receives most of the attention for bone formation, but bone crystal is calcium phosphate. Phosphorus is widely found in food, and 85 percent of women and almost 95 percent of men consume an adequate amount. The women with low phosphorus intakes are usually elderly. If these women take high-dose calcium supplements, the calcium may bind with the small amount of phosphorus found in the food (Heaney, 2004).

Concern has been raised about high dietary phosphorus intake due to the consumption of carbonated soft drinks, which contain phosphoric acid. At the present time the scientific research does not support an association between high phosphorus intake and osteoporosis (Heaney, 2004). However, children and adolescents are consuming more soft drinks than in the past and consumption of soda does displace milk consumption, an excellent source of calcium (Bowman, 2002). A low calcium intake by children and adolescents is a serious concern for the future bone health of the next generation of adults.

LOSS OF BONE CALCIUM

Unfortunately, many people do not consume sufficient calcium. Low dietary calcium intake results in lower contributions of calcium into the pool. For example, the average daily calcium intake for adult females is 650 mg. Assuming absorption of 30 percent, a 650-mg daily intake would likely result in 195 mg of calcium being absorbed or 65 percent of that absorbed if the recommended calcium intake of 1,000 mg was consumed (195 mg ÷ 300 mg = 65 percent). However, in adult women with low vitamin D concentrations (due to poor intake, absorption, and/or conversion to an active form), calcium absorption may be very low—approximately 10 percent—for both food and supplements. Heaney (2001) estimates that of a 750-mg calcium supplement, only 75 mg will be absorbed. Of that 75 mg, approximately 36 mg are retained (much is lost in the urine) and available to offset bone resorption. Although calcium absorption does vary and absorption can increase to some degree when an individual is deficient, it is easy to see how low calcium and vitamin D intakes negatively affect bone health.

As explained earlier, the calcium concentration in extracellular fluid must remain stable, and bone provides the calcium (via slow exchange) that would normally be provided by the diet. Calcium from trabecular bone is easily resorbed because it has much greater surface area and higher metabolic activity, but losses from cortical bone also occur. Other factors, such as estrogen, also influence bone resorption, and some loss of bone is a natural consequence of aging.

Long-term calcium deficiency is a risk factor for osteoporosis, a disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture. Osteoporotic bones are fragile and more prone to fractures, particularly in the spine (vertebrae), wrist, and hip. Assessing bone density and preventing and treating osteoporosis are discussed in more detail in Chapter 12.

Bone Loss Associated with Aging. Estimates of yearly bone loss for women between the ages of 18 and 50 years range from 0.5 to 1.5 percent per year. With the onset of menopause, estrogen deficiency results in a yearly bone loss of 1 to 2 percent, initially much of it from the vertebrae. In the decade after menopause, women can lose a total of 20 to 30 percent of bone density from trabecular bone and up to 5 to 10 percent from cortical bone (Ilich and Kerstetter, 2000). Older men lose bone density at a fairly constant rate of about 1 percent per year (Kenny and Prestwood, 2000).

Bone resorption increases with both age and estrogen deficiency. The most important mechanism appears to be the increase in the number of units that undergo remodeling. A second mechanism is the incomplete bone formation that occurs when bone resorption outpaces bone formation. Once the remodeling process is complete at a remodeling site, further modifications cannot be made. Thus, if a remodeling cycle is completed and formation did not equal resorption, then the bone loss in that remodeling unit is irreversible (Compston, 2001).

Preventing or Reducing Bone Loss Associated with Aging. During the period when peak bone mineral density can be attained, the emphasis is on adequate calcium intake and weight-bearing exercise. After this physiological period is complete, the goal is to prevent and then slow the loss of calcium from bone. This is also accomplished with adequate calcium intake and weight-bearing exercise. How effective is calcium intake in preventing loss of calcium from bone? Between the period of the attainment of peak bone mineral density and menopause, adequate calcium intake through diet or supplements helps to slow the loss of calcium by about 1 percent a year. Recall that bone loss during this period ranges from about 0.5 percent to 1.5 percent. A reasonable conclusion is that bone calcium loss is reduced or prevented in many middle-aged women, as well as men, if calcium intake is adequate.

In postmenopausal women, a meta-analysis of research studies suggests that two or more years of calcium supplementation have a small but positive effect on bone mineral density and some reduction in vertebral fractures. It is not known if supplementation reduces the incidence of nonvertebral fractures (Shea et al., 2004). When research is evaluated based on the number of years since menopause, studies of women in the early postmenopausal period (5 to 8 years after menopause) show that calcium supplementation has a small effect on slowing the loss of calcium from cortical bone but not trabecular bone. This effect appears to be greatest for the women who consumed the least amount of calcium in their diets prior to supplementation. Studies of women after the first postmenopausal decade (10 to 20 years after menopause) show that adequate calcium intake, either through food or supplementation, helps to slow the loss of calcium from bone.

In the third postmenopausal decade and beyond (studies of women ages 70 and above), calcium supplementation appears to be beneficial. Calcium deficiency, in both older men and women, can result in hyperparathyroidism. Recall that when blood calcium is low, parathyroid hormone is elevated, which stimulates bone resorption and normalizes the blood calcium concentration. Calcium deficiency may be a result of low calcium intake, vitamin D insufficiency, or both. It is common for women over 70 to have low calcium intakes, reduced vitamin D absorption and/or conversion, and increased parathyroid hormone concentrations. Calcium and vitamin D supplementation resolves the hyperparathyroidism, thus preventing the bone resorption that accompanies this medical condition (Morgan, 2001; Kenny and Prestwood, 2000).

Adequate calcium intake via calcium-containing foods or supplements after age 35 is a prudent approach and may help to slow the loss of calcium from bone in some cases, but it is limited in its effectiveness by the effects of aging on bone remodeling. Calcium intake is not the sole influence on bone mineral density; thus, food or supplemental calcium cannot be expected to offset all of the various factors that cause a decline in BMD. The important point is the need for prevention; after age 35 even a sufficient calcium intake cannot compensate for a relatively low amount of calcium in bone since peak bone mineral density is achieved in childhood, adolescence, and young adulthood.

Results of exercise studies have been mixed, but high-intensity weight-bearing activity and resistance training generally maintains or increases bone mineral density in postmenopausal women. However, these activities must be safe for older women to perform, and those who have been diagnosed with osteoporosis should discuss with their physicians the most appropriate types of exercise. Unfortunately, low-intensity weight-bearing activities, such as walking, do not put enough stress on the bone to positively impact bone density, although there are many other benefits to walking. Any exercise by older women that increases muscle strength and stability is beneficial for the prevention of falls, which cause ~90 percent of hip fractures and ~50 percent of vertebral fractures (Beck and Snow, 2003).

Bone Loss Associated with Lack of Estrogen. Estrogen deficiency is known to be a powerful factor in bone loss. Estrogen affects osteoclast number and activity, with a decrease in estrogen being associated with an increase in osteoclast proliferation and activity (Compston, 2001). The lifespan of the osteoclast appears to increase with estrogen deficiency (Seeman, 2002). Estrogen deficiency may also be associated with increased erosion depth in trabecular bone. Erosion depth affects bone strength (Compston, 2001).

Estrogen deficiency is generally associated with menopause when estrogen production naturally and substantially declines. However, estrogen deficiency can also be present in adolescent and young adult female athletes. Amenorrhea or oligomenorrhea (absent or irregular menstruation, respectively) in young female athletes can be a result of consistently low energy intake coupled with high energy expenditure (known as energy drain), inadequate nutrient intake, and the increase in exposure to stress hormones such as **epinephrine, norepinephrine,** and **cortisol** that accompanies intense training. Distance runners, ballerinas, and gymnasts are at greatest risk for delaying the onset of menstruation, experiencing irregular menstruation, or developing amenorrhea (Gordon, 2000). Some, but not all, of these athletes have eating disorders. Low bone mineral density, amenorrhea, and low energy intake, especially precipitated by disordered eating, are three interrelated factors known as the Female Athlete Triad. Each of these factors is discussed in depth in Chapter 13.

The acquired estrogen deficiency described above predisposes these young women to a failure to achieve peak bone mineral density, the loss of calcium from bone, a greater incidence of stress fractures, osteopenia (low bone mineral density), and osteoporosis (De Souza and Williams, 2005). Therein lies the danger of assuming that estrogen deficiency is only associated with age.

Two sports, distance running and gymnastics, have a high prevalence of athletes with low estrogen concentrations and/or amenorrhea. Distance runners often have significantly lower bone mineral density when compared to age-matched controls (see Chapter 13 for a review of specific studies). Gymnasts, however, have above-normal bone mineral density even when estrogen concentration and menstrual status are abnormal. The high-impact training associated with gymnastics seems to offset the negative effects on bone density associated with amenorrhea. Although amenorrhea is not a normal or desirable condition, the differences in bone density between highly trained distance runners and gymnasts highlight the substantial effect of high-impact exercise on bone mineral density (Beck and Snow, 2003).

DIETARY STRATEGIES FOR ADEQUATE CONSUMPTION OF BONE-RELATED MINERALS

It has been documented in dietary surveys that many adults, including some athletes, do not consume sufficient calcium. While calcium is not the only mineral associated with bone health, it is the one that receives the most attention.

Calcium. Milk and milk products are excellent sources of calcium. An 8-oz (240 ml) glass of milk contains approximately 300 mg, so three to four glasses a day would meet the recommended calcium intake for adults of all ages. One 8-oz cup of yogurt also contains approximately 300 mg of calcium. Athletes who are trying to limit fat and/or caloric intake often choose nonfat versions of these foods. Other dairy products, such as 1½ oz of cheese, contain the equivalent amount of calcium found in 8 oz of nonfat milk but their fat contents are higher.

Many adolescents and adults cannot digest lactose (milk sugar) because they lack sufficient lactase, the enzyme needed for lactose breakdown. They may wish

Epinephrine: Adrenaline. Primary blood pressure raising hormone.

Norepinephrine: Noradrenaline. Hormone and neurotransmitter.

Cortisol: A hormone that is elevated under conditions of physiological (e.g., exercise) or psychological stress. Has anti-inflammatory and immunosuppressive effects.

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Milk and milk products are excellent sources of calcium.

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Those with lactose intolerance may use some of the products shown, which allows them to include calcium-dense dairy foods in their diets.

to use lactase tablets, which provide the enzyme, or consume lactase-treated milk and milk products, which predigest the lactose. Some people have moderately reduced lactase production and can tolerate milk products that have been fermented, which reduces the lactose content. Examples of such products include yogurt and aged cheeses such as Parmesan, cheddar, and Gouda. These strategies help lactose-intolerant individuals to include some calcium-dense dairy foods in their diets.

Although milk and milk products contain a relatively large amount of calcium, calcium is not found exclusively in dairy foods. It is more difficult, but not impossible, to consume enough naturally occurring, nondairy calcium-containing foods. The difficulty is a result of a lack of concentrated sources of calcium and the need to consume a wide variety of foods. For example, 1 cup of cooked broccoli has about 100 mg of calcium, one-third the amount of an 8-oz glass of milk. Other vegetable

Table 9.9 Nondairy Sources of Calcium

Food and Amount	Calcium (mg)
2 pancakes	176
1 cup blackberries	46
1 whole wheat English muffin	175
2 T peanut butter	12
2 figs	54
8 oz San Pellegrino mineral water	50
4 oz canned salmon	240
1 cup broccoli	94
1 oz almonds	74
½ cup cooked acorn squash	54
1 mixed grain roll	24
1 medium orange	52

Legend: mg = milligram; T = tablespoon; oz = ounce

Together these foods total 1,051 mg of calcium.

sources of calcium include Brussels sprouts, collard greens, green cabbage, kale, kohlrabi, mustard greens, and turnip greens. Calcium is also found in some fish, beans, grains, and nuts in varying amounts. Table 9.9 lists the calcium content of some nondairy sources. Eaten over the course of a day, the foods in the amounts listed in the table would total 1,051 mg of calcium.

Some foods are calcium fortified. Soy milk, rice milk, and orange juice are beverages that *may* be fortified with calcium. Even when calcium is added the amount can vary among brands, so the label must be checked to determine the calcium content. A common level of fortification for soy milk is 300 to 350 mg in an 8-oz glass, approximately the same amount of calcium found in dairy milk. However, the form of calcium added may not be as well absorbed, so 300 mg of calcium from soy milk may only be the equivalent of 225 mg of calcium found in cow's milk (Heaney et al., 2000).

Tofu (soy bean curd) can be processed with either calcium sulfate or calcium chloride. Tofu that has been processed using these compounds contains approximately 110 mg of calcium in a ½-cup (3-oz) serving. Many other foods have calcium added, including breakfast cereals and sports bars. It may not be immediately clear how many milligrams of calcium are contained because calcium may be listed as a percentage. This percentage is calculated using the Daily Value (DV) for calcium, 1,000 mg. For example, if the label on an energy bar states that it contains 2 percent

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Dark green vegetables are good nondairy sources of calcium.

© David Young-Wolff/PhotoEdit

Soy milk and rice drinks are often fortified with calcium.

of the DV for calcium, there are 20 mg of calcium in that bar (1,000 mg × 0.02 = 20 mg).

Calcium is a critical nutrient for all people of all ages. Milk was once accepted as the ideal beverage for children, but milk consumption is declining in children due, in part, to increased soda and juice consumption. Milk consumption often declines further during adolescence and adulthood. There is no one food that must be consumed or dietary pattern that must be followed in order for calcium needs to be met. However, each person needs to consume an adequate amount, and some or all of the following strategies may be used to obtain sufficient calcium daily.

Consume:

- milk and milk products
- lactase-treated products or lactase tablets
- fermented milk products such as yogurt or aged cheeses
- calcium-containing vegetables such as cabbage, broccoli, greens
- calcium-fortified products such as orange juice, soy milk, cereal, sports bars
- calcium supplements

Phosphorus, Fluoride, and Magnesium. Phosphorus is so abundant in food and the percentage absorbed is so high that deficiencies are unlikely to occur. Fluoride is typically obtained by infants and children through the use of fluoridated vitamins and by adults through the consumption of fluoridated water. The fluoride content of tap water is available to consumers by contacting their local water agency. Magnesium is found in green leafy vegetables, nuts, seeds, and beans and legumes, such as soybeans, kidney beans, pinto beans, and lentils. It is found naturally in whole grains (e.g., wheat germ, brown rice) but is lost in the processing when grains are highly refined (e.g., white bread, white rice). Drinking water is described as "hard" if it contains minerals; one of the minerals found in hard water is magnesium.

What's the point? Adequate nutrient intake, in particular calcium and vitamin D, and weight-bearing exercise are necessary throughout life for bone health. Calcium supplementation in mid and later life has some benefit, but cannot completely offset the calcium loss from bone that accompanies aging. Athletic amenorrhea is detrimental to bone health and performance.

The Roles of Minerals in Blood Formation

A favorite adage among endurance athletes is "oxygen is everything." It is no wonder that athletes, particularly endurance athletes, look at training and nutrition strategies that result in optimal oxygen delivery. The nutrient most associated with oxygen is iron.

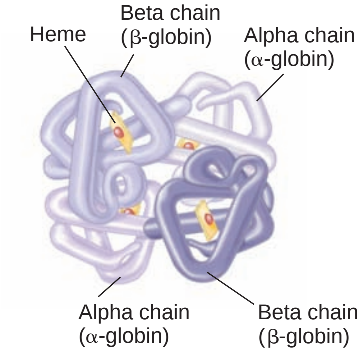
BLOOD-FORMING MINERALS

Blood consists of three types of cells—**erythrocytes** (red blood cells), **leukocytes** (white blood cells), and **platelets.** This section will focus only on erythrocytes, the blood cells whose primary function is the transport

Erythrocyte: Red blood cell.

Leukocyte: White blood cell.

Platelet: A cell found in the blood that assists with blood clotting.



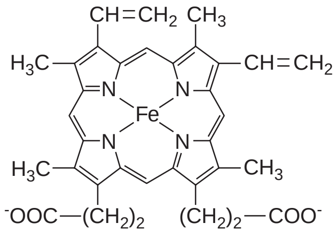


Figure 9.2 Simplified Hemoglobin and Heme Molecules

Hemoglobin consists of four polypeptide chains and four heme molecules. The iron in each heme molecule forms six bonds—four with nitrogen, one with globin (protein chain), and one with oxygen.

of oxygen. Secondary functions include carbon dioxide and nitric oxide transport. Simply stated, oxygen must be picked up from the lungs and transported to cells. Conversely, carbon dioxide must be picked up from cells and transported to the lungs. Both of these processes depend on hemoglobin, which transports 98.5 percent of the oxygen (1.5 percent is dissolved in the blood) and 30 percent of the carbon dioxide (60 percent is transported as bicarbonate and 10 percent is dissolved in blood) (Sherwood, 2007).

Hemoglobin (**heme** = iron, globin = protein) is an iron-containing protein found in the red blood cells that can bind oxygen (see Figure 9.2). At the center of the heme portion of the molecule is iron (Fe). This iron atom forms six bonds, four with nitrogen (to maintain the molecule's ring structure), one with the amino acids in the protein portion of the molecule (globin), and one with oxygen. There are four heme molecules in each molecule of hemoglobin; thus, a fully saturated hemoglobin molecule can carry four molecules of oxygen. Each red blood cell (RBC) contains more than 250 million molecules of hemoglobin. There are approximately 30 trillion red blood cells, so it is easy to see that the body has a phenomenal capacity for oxygen transport (Sherwood, 2007).

To transport oxygen throughout the body in the necessary amounts, blood must have a carrier or binding mechanism. Oxygen must bind to this carrier easily and rapidly in the lungs, remain bound as it is distributed throughout the body, yet release easily from the carrier so oxygen can be removed from the blood at sites in the body where the oxygen is needed. Iron-containing hemoglobin has unique properties that allow it to be an ideal oxygen carrier in the blood.

In areas of the body where oxygen levels are high (high **partial pressures** of oxygen), such as the lungs, hemoglobin has a high affinity for oxygen and is able to bind it readily. This is important for the fast and complete diffusion of oxygen from the lungs into the blood flowing through the pulmonary circulation. Under most circumstances, both at rest and for most people during exercise, there is nearly 100 percent saturation of oxygen on the hemoglobin molecules in the blood that passes through the pulmonary circulation. This is reflected in a common clinical test, the O_2-Hb saturation percentage, usually measured with a pulse oximeter or by the more invasive blood gas analysis.

Hemoglobin molecules have a unique ability to change their binding affinity for oxygen in areas of the body that contain less oxygen, in other words, when the partial pressure of oxygen is reduced. When the oxygen-laden blood arrives at tissues in the body that need oxygen, such as exercising muscle, the environment that has a lower partial pressure of oxygen results in hemoglobin reducing its binding affinity for oxygen, which allows the red blood cells to release oxygen molecules for transport into the cells. Iron-containing hemoglobin is critical to the effective uptake and delivery of oxygen to all tissues in the body. This process must continue constantly at rest, but is put under particular stress during exercise when oxygen demands can be dramatically increased.

Sufficient oxygen-carrying capacity is critical for all athletes, but especially endurance athletes. One measure of normal oxygen-carrying capacity is **hematocrit,** which is the amount of red blood cells expressed as a percentage of the total volume of blood plasma (the liquid portion of the blood). Normal hematocrit is approximately 42 percent for women and 45 percent for men. The general term *anemia* refers to a reduced oxygen-carrying capacity and is reflected in a hematocrit of approximately 30 percent. Another measure is the concentration of hemoglobin in the blood, which averages about 15 g/dl (dl = deciliter, or 100 milliliters) in males and slightly less, 14 g/dl, in females. Anemias

Table 9.10 Nutritional and Nonnutritional Anemias

Nutritional Anemias	Nonnutritional Anemias
Iron deficiency anemia	Aplastic anemia (RBC production depressed)
Vitamin B_{12} deficiency anemia	Hemolytic anemia (RBCs are destroyed)
Folate deficiency anemia	Sickle cell anemia (RBCs are abnormally shaped)
Anemia can result from a deficiency of any nutrient needed for RBC production (e.g., zinc, copper)	

Legend: RBC = red blood cell

can be caused by nutritional or nonnutritional factors as shown in Table 9.10.

Nutritional anemias are a result of a nutrient deficiency due to low intake or poor absorption. Some are vitamin-related (e.g., vitamin B_{12} or folic acid), but the most prevalent nutritional anemia is due to iron deficiency. Having sufficient iron stores by consuming an adequate amount of iron daily can prevent iron-deficiency anemia. Approximately 25 percent of the body's iron is found in storage in the liver, spleen, and bone marrow and this stored iron can be released and transported for incorporation into hemoglobin. On average, a well-nourished adult male has about 800 to 1,000 mg of stored iron. A well-nourished adult female has considerably less but still has sufficient stores to support normal red blood cell formation. With near-maximum iron stores, an adult male could sustain normal hemoglobin synthesis for about two years while consuming an iron-poor diet (Shah, 2004).

However, not all adults have excellent iron stores. Some may also experience higher-than-normal iron losses (e.g., large losses of blood via menstruation, small daily losses as a result of GI bleeding), low iron absorption, and low iron intake. These factors, singly or in combination, may tax an already low supply of stored iron. When iron stores are depleted and iron intake is low, then red blood cell production is negatively affected. Iron-deficiency anemia results in a decreased number of red blood cells, smaller cells, and a lower concentration of hemoglobin per cell. This results in less hemoglobin being available to transport oxygen. Not surprisingly, a common symptom associated with iron-deficiency anemia is fatigue.

Normal hemoglobin synthesis is also dependent on copper, another of the microminerals. Iron is stored in its ferrous form (Fe^{2+}) but must be converted to its ferric form (Fe^{3+}) to be transported in the blood. This conversion requires a copper-containing enzyme, ceruloplasmin. Humans can develop an anemia that is a result of a long-term copper deficiency. Excessive zinc interferes with copper absorption and can be one of the causes of this kind of anemia.

Myoglobin is an iron-containing protein found in muscle fibers that functions very similarly to hemoglobin, only in skeletal muscle. Myoglobin binds small amounts of oxygen within the muscle to provide a small reservoir for rapid increases in oxygen utilization. The body doesn't "store" oxygen per se, but myoglobin acts as an oxygen buffer when demand is increased until oxygen delivery from the blood can be increased. Myoglobin also facilitates the transfer of oxygen molecules from the red blood cells in the blood, through the muscle cells, and into the mitochondria. Highly aerobic tissues such as slow twitch (Type I) and intermediate (IIa) muscle fibers contain a higher concentration of myoglobin. Because aerobic exercise training stimulates the oxidative energy system, a common adaptation is an increase in myoglobin concentration in muscle, which helps increase the body's aerobic capacity.

Measuring the Progression of Iron Deficiency. Iron is unique among minerals in that there are a variety of blood tests that can detect normal and reduced stores and physiological function. These tests measure the amount of iron in red blood cells and estimate the level of iron storage. The most common measures are hemoglobin, hematocrit, and **serum** ferritin. When these values are within the recommended ranges, iron status is considered to be normal and red blood cell production is adequate. Normal laboratory values are listed in Table 9.11.

When iron intake is poor, iron status declines over time. Iron stores become depleted and this can be detected by measuring ferritin. **Ferritin** is the protein that stores iron in tissues (predominantly in the liver). The amount of ferritin circulating in the blood reflects the amount stored, so this blood test is a good indicator of iron storage. The normal values range from 12 to 300 ng/ml for males and 12 to 150 ng/ml for females. As the amount of storage iron declines, the amount of

Heme: Iron. Also refers to a form of iron that is well absorbed.

Partial pressure: The pressure exerted by one gas within a mixture of gases.

Hematocrit: The percentage of the volume of blood that is composed of red blood cells.

Serum: The fluid that separates from clotted blood. Similar to plasma but without the clotting agents.

Ferritin: Iron-containing storage protein.

Table 9.11 Iron-Related Blood Tests

Blood Test	Normal Values*	Explanation
Hematocrit	40.7 to 50.3% (males) 36.1 to 44.3% (females)	Measures the proportion of red blood cells in blood plasma. Values vary with altitude.
Hemoglobin	13.8 to 17.2 g/dl (males) 12.1 to 15.1 g/dl (females)	Measures the iron-containing protein in red blood cells. Values vary with altitude.
Ferritin	12 to 300 ng/ml (males) 12 to 150 ng/ml (females)	Indicates amount of iron stored.
Serum iron	60 to 170 mcg/dl	Measures the amount of iron in transferrin. Normally 30% of the available sites are carrying iron.
Transferrin saturation	20 to 50%	Indicates that there is not enough iron to fill the available sites.
Total iron binding capacity (TIBC)	240 to 450 mcg/dl	Indirect measure of transferrin.

Legend: g/dl = grams per deciliter; ng/ml = nanograms per milliliter; mcg/dl = micrograms per deciliter

*Normal values may vary by laboratory.

ferritin in the blood declines; so although the absolute value is important, repeated blood tests over time (e.g., every six months) also indicate if stores are declining. For example, an endurance athlete may have a complete blood count (CBC) two times a year for two years. The four consecutive ferritin tests are all within the normal range—120, 110, 85, and 63 ng/ml—but these "normal" values also suggest that iron stores are declining. In a moderate subclinical iron deficiency, hemoglobin and hematocrit values are in the normal range because iron-deficiency anemia develops slowly even after iron depletion. This subclinical deficiency is referred to as iron deficiency without anemia.

Hemoglobin measures the iron-containing protein found in red blood cells. Values below the normal range may indicate iron-deficiency anemia, a recognized disease, or false (runner's) anemia, which is not a true anemia. Normal hemoglobin values are 13.8 to 17.2 g/dl for males and 12.1 to 15.1 g/dl for females. Those who live or train at higher altitudes generally have hemoglobin concentrations nearer the upper end of the normal range. Values below 13.8 and 12.1 g/dl, for males and females respectively, are usually indicative of iron-deficiency anemia, but false anemia should be ruled out. In iron-deficiency anemia the body lacks the iron it needs to produce a normal amount of red blood cells. Hematocrit is also reduced because it is a measure of the proportion of red blood cells in blood plasma. In false (runner's) amemia, the slightly decreased hemoglobin value is due to plasma volume expansion associated with endurance training.

Iron Deficiency, Iron-Deficiency Anemia, and Performance. It is known that iron-deficiency anemia impairs performance. When iron-deficiency anemia is present, $\dot{V}O_{2max}$ (i.e., aerobic capacity) declines and subsequently increases with iron supplementation. The reduction in $\dot{V}O_{2max}$ is a result of impaired oxygen transport. Studies have documented that $\dot{V}O_{2max}$ can decline between 10 to 50 percent and reflects the severity of the anemia. Aerobic capacity does not seem to decline in people with an iron deficiency that has not progressed to anemia because oxygen transport is normal (Haas and Brownlie, 2001). Recall that those with iron deficiency without anemia (i.e., subclinical iron deficiency) have normal hemoglobin and hematocrit concentrations.

Iron-deficiency anemia also affects endurance capacity or the length of time until exhaustion at a given workload. This is different from aerobic capacity because endurance capacity depends on both oxygen transport and oxygen utilization. The role of iron in oxygen transport has been explained, but iron also plays a role in oxygen utilization because some oxidative enzymes contain iron.

Energy is produced either as heat or ATP from the flow of hydrogen molecules and electrons down the electron transport chain located in cell mitochondria. As part of this metabolic pathway, iron is oxidized and reduced so that the transfer of electrons can proceed. A decrease in iron-containing compounds would negatively affect oxygen utilization. Studies have documented that iron-deficiency anemia reduces endurance capacity. Studies in animals suggest that iron deficiency without anemia also affects endurance capacity, but this has not been documented in human studies. A prudent approach is to maintain normal iron status to avoid any potential problems with endurance capacity (Haas and Brownlie, 2001).

Prevalence of Iron Deficiency and Iron-Deficiency Anemia in Athletes. The prevalence of iron deficiency and iron-deficiency anemia in athletes is hard to determine. Most adult male athletes can easily meet their need for iron (8 mg daily) through diet, so the prevalence of iron-deficiency anemia is low in males. It is occasionally seen in male endurance runners and male athletes who routinely take medications that relieve pain but also induce bleeding (e.g., **aspirin, Ibuprofen**).

Some adolescent male athletes may experience iron-deficiency anemia if they lack both sufficient kilocalories and iron-containing foods in their diet. The demand for iron resulting from rapid growth during adolescence, including an expanding blood volume, can outstrip the intake of iron. Still, the prevalence is low partly because very demanding periods of physiological growth favor iron absorption.

Female athletes who are menstruating are at risk for manifesting iron-deficiency anemia. The loss of menstrual blood, thus the loss of iron, requires that iron be resupplied. This *can* be accomplished through diet alone, although the need for iron is relatively high (18 mg). Many factors may result in a poor dietary iron intake. Low caloric intake, low or absent animal protein intake, or high intake of iron inhibitors (e.g., fiber) can result in an insufficient supply of dietary iron (Beard and Tobin, 2000). Some female athletes may also have an appreciable loss of iron in sweat, feces, and urine due to the stress of heavy training.

While any female athlete may be at risk, iron-deficiency anemia is most prevalent in female distance runners, gymnasts, and other athletes who have a restricted eating style. These athletes tend to have a low caloric intake compared to their energy output and therefore a low iron intake. The energy imbalance may be substantial and is due to a high energy expenditure from a heavy training volume and a commensurate inadequate intake of energy, often in the belief that losing weight and being a lower percentage of body fat will aid performance. In addition to inadequate total energy intake, these athletes often choose high-carbohydrate, low-fat, low-protein diets that are also low in iron. Some prefer to be vegetarians, and iron found in plant sources is not as well absorbed as that found in animal foods (Beard and Tobin, 2000).

Regardless of the estimated prevalence in the general athletic population or the specific sport, each athlete should have iron status periodically assessed. This is easily accomplished with a CBC and serum ferritin as part of a yearly physical. Those who are known to be at greatest risk—female, vegetarian, low-energy intake athletes—should have their iron status assessed more frequently, often two times a year. All athletes can be proactive in avoiding declines in iron status by consuming sufficient dietary iron daily.

Christina Micek

Iron is found in many foods, but often in small amounts. Adequate dietary iron intake is associated with adequate energy intake.

DIETARY STRATEGIES FOR ADEQUATE CONSUMPTION OF BLOOD-RELATED MINERALS

Sufficient dietary iron intake is correlated with adequate energy intake. Although there are a few foods that are excellent sources of iron (e.g., oysters, clams) and some foods that contain moderate amounts (e.g., meat, dried beans, green leafy vegetables), many foods contain only small amounts. This wide distribution of small amounts of iron in food means that iron intake generally increases as caloric intake increases.

The average adult diet in the United States contains 6 to 7 mg of iron for every 1,000 kcal consumed (Beard and Tobin, 2000). Most males, especially male athletes, consume over 2,000 kcal daily. Even without emphasizing iron-rich foods in their diets, males are likely to consume at least 12 mg daily, more than the 8 mg recommended. Adequate dietary intake is one reason that males rarely manifest iron-deficiency anemia.

It is easy to see why women are at much greater risk for iron deficiency. If a woman consumed 2,000 kcal daily, then her likely intake of 12 to 14 mg of iron would be less than the recommended 18 mg. But many females, including female athletes, restrict caloric intake. A female athlete who is trying to attain or maintain a low percentage of body fat and restricts energy intake to 1,500 kcal daily would be expected to consume only 9 mg of iron daily, half the recommended amount. Females who prefer a dairy-based diet and consume high levels of milk, yogurt, and cheese also tend to have a low iron

Aspirin: Medication used to relieve pain, reduce inflammation, and lower fever. Active ingredient is salicylic acid.

Ibuprofen: Medication used to relieve pain, reduce inflammation, and lower fever.

intake since milk and milk products are relatively poor sources of iron compared to beans, grains, nuts, vegetables, and meat, poultry, and fish.

In addition to the amount of iron consumed, the form of iron is a factor because it affects absorption. Iron is found in one of two forms in food—heme or **nonheme.** Heme iron, which is found in animal foods, is well absorbed. Absorption is estimated to be 15 to 35 percent of the heme iron consumed. In contrast, nonheme iron, which is found in plant foods, has much lower absorption, in the range of 2 to 20 percent. The presence of ascorbic acid (vitamin C) enhances the absorption of both heme and nonheme iron. A compound found in meat, fish and poultry, known as MFP factor, enhances heme iron absorption. Nonheme sources of iron (e.g., grains, vegetables) may contain iron absorption inhibitors such phytates and oxalates.

How can athletes best use this information to plan a diet that is adequate in iron? Athletes should focus first on obtaining sufficient energy (kilocalories). Those who have low or marginal energy intakes should focus on including iron-rich foods in their diets. Increasing intake of iron-dense foods helps to provide more iron while not substantially increasing caloric intake. Vegetarian athletes, who do not consume the more absorbable heme iron or MFP factor, need to focus on the quantity of iron consumed as well as ensuring that a variety of plant foods are eaten. The focus on variety helps to modulate the intake of compounds that are known to inhibit iron absorption. Consuming vitamin-C-containing foods at the same meal can also be beneficial.

Table 9.12 lists iron-containing foods. The table has been subdivided into heme and nonheme sources. Foods are then listed in descending order according to the amount of iron contained. Choosing foods nearer the top of each category is recommended for athletes who are at risk for iron-deficiency anemia.

Although it receives less attention, an adequate copper intake is also important. Excellent sources of copper include seafood, nuts, and seeds. Copper is also found in whole grains, dried beans, and some green leafy vegetables. Most nutrient analysis programs do not include the copper content of foods in the database, so it is difficult to assess dietary intake. The DRI is 900 mcg for adults and the average intake by U.S. adults is more than 1,000 mcg.

What's the point? Low dietary iron intake may lead to iron-deficiency anemia, which has a negative effect on training, performance, and health. Iron supplementation can slowly help to build back iron stores. Menstruating females who restrict caloric intake are at the greatest risk for developing iron-deficiency anemia.

Table 9.12 Iron-Containing Foods

Food	Iron (mg)
Heme Sources	
3 oz steamed clams	26.6
5 steamed oysters	5 to 16.5
3 oz beef liver	5.3
3 oz beef	3
1 cup tuna fish	2.4
3 oz dark meat chicken	1.3
3 oz light meat chicken	1.1
3 oz halibut	0.9
3 oz pork loin	0.8
Nonheme Sources	
1 cup cereal (iron added, amount depends on the brand)	2 to 16
1 cup instant oatmeal (iron added)	10
1 cup soy beans	8.8
1 cup lentils	6.6
1 cup pinto beans	4.2
½ cup spinach, cooked from fresh	3.2
½ cup spinach, cooked from frozen	1.4
1 cup soy milk	1.4
½ cup tofu	1.3
1½ oz raisins	0.87
1 slice bread (iron added)	0.8
1 egg, white and yolk	0.72

Legend: mg = milligram; oz = ounce

The Roles of Minerals in the Immune System

Intense training and prolonged exercise is immunosuppressive. In other words, heavy training, especially for endurance athletes, depresses the immune system. Many endurance athletes have frequent infections, particularly upper respiratory infections, during periods of intense or prolonged training, which then undermines their ability to maintain training and negatively affects performance. The two nutritional factors most associated with proper immune system function are adequate protein and total energy intakes. However, several minerals are also involved (e.g., zinc, magnesium, selenium) and inadequate intake of these minerals impairs immune response. Conversely, excessive levels of some minerals (e.g., zinc, iron) can impair the immune system.

MINERALS AND IMMUNE SYSTEM FUNCTION

The immune system is the body's defense against disease. Effective immunity relies upon a system of tissues and organs that are supported by adequate nutrition; nearly every tissue is involved. The skin serves as a physical barrier, hairlike projections known as cilia and mucosal secretions guard against invasion via the respiratory tract, and the GI tract can kill microorganisms with hydrochloric acid, digestive enzymes, and other secretions. These are examples of nonspecific immunity, the body's first line of defense against potentially harmful microorganisms. Another form of nonspecific resistance is inflammation, which involves the release of chemicals from phagocytic cells that destroy microbes.

While nonspecific immunity is important, the body must have more specific ways to fight disease. This is known as acquired immunity, a special immune system response that forms antibodies and activates lymphocytes (white blood cells). Acquired immunity cannot occur until a specific microorganism has invaded the body (now called an antigen) and the immune system forms antibodies in response. Each antigen (microorganism) has a unique protein or large polysaccharide that the body can detect and remember. When reexposed to that specific antigen, the antibody response is rapid (within a few hours) and potent (circulating for months rather than weeks). All antibodies are immunoglobulins, compounds that are made of several polypeptide (protein) chains.

Regulation of the immune system is the responsibility of the cytokines. Cytokines are protein-containing compounds that are released in response to chronic inflammation, infections, and other disease processes. Interleukins (IL) and interferon (INF) are examples of regulatory cytokines (Guyton and Hall, 2005). Detailed information about the immune system can be found in any physiology or medical physiology textbook.

The effect of exercise on the immune system follows the "too much of a good thing may be harmful" theory. Considering just one outcome of immune function, upper respiratory tract infections (URTI), the results of a number of studies show that moderate exercise bolsters immune function as evidenced by lower risk for or incidence of URTI. However, people involved in more rigorous or prolonged exercise, such as marathon running or prolonged running training, have a greatly increased risk for upper respiratory tract infections (Nieman, 1994).

Zinc. Zinc is necessary for proper cellular function because of its role as a constituent/cofactor in more than 200 enzyme systems. It has wide-reaching effects on DNA, RNA, and cellular functions; thus many different types of immune system cells are affected when zinc is deficient or excessive. Zinc deficiency results in damaged skin cells and gastrointestinal cells, both of which are involved with nonspecific immunity. Examples of ways that zinc deficiency negatively affects specific immunity include decreased production and function of lymphocytes. An excessive zinc intake also decreases lymphocyte response and inhibits copper absorption. A copper deficiency is also immunosuppressive (Shankar and Prasad, 1998).

The Dietary Reference Intake for zinc is 8 mg for females and 11 mg for males. The Tolerable Upper Intake Level is 40 mg. The median (50th percentile) intake for adults in the United States is 9 mg for women and 13 mg for men, so clearly zinc requirements can be met through diet alone. Those who meet the DRI for zinc tend to consume sufficient kilocalories and animal foods such as red meat and milk (Institute of Medicine, 2001).

Unfortunately, it is estimated that up to 90 percent of endurance athletes do not meet the DRI for zinc. Many endurance athletes limit red meat intake and consume high-carbohydrate, relatively low protein diets (Micheletti, Rossi, and Rufini, 2001). This puts them at risk for subclinical zinc deficiencies and makes zinc supplementation attractive. But supplemental zinc can interfere with the absorption of other nutrients, especially iron and copper, and can suppress the immune system. Since caution is warranted, no more than 15 mg of supplemental zinc daily is recommended.

Recurring infections are the bane of many endurance athletes. Researchers have studied the effect of zinc supplements on prevention of upper respiratory tract infections and treatment of colds. The study results have been mixed and the evidence in support of zinc supplement use to prevent colds and infections is limited. Gleeson, Nieman, and Pedersen (2004) recommend that endurance athletes monitor their zinc status. This can be done by assessing dietary zinc intake and through a specialized blood test. Given poor intake, higher-than-normal losses in sweat and urine, and evidence of altered zinc status, low-dose zinc supplementation would be appropriate.

Selenium. At least 20 selenium-containing proteins are involved in cellular metabolism; thus selenium is an

Nonheme: A form of iron with a lower rate of absorption (see heme).

essential nutrient. Its exact roles in the immune system are not known, but depressed immunity is associated with selenium deficiency. When selenium is deficient there is less proliferation of lymphocytes, immunoglobin production is decreased, and the ability to kill pathogens is reduced (Arthur, McKenzie, and Beckett, 2003). It does not appear that athletes are selenium deficient (Speich, Pineau, and Ballereau, 2001). Food sources of selenium include meat, fish, poultry, whole grains, and nuts.

Iron. Iron has already been discussed in detail due to its role in oxygen transport. Iron also plays a role in the proper functioning of the immune system. Most studies suggest that individuals with iron deficiency are at a greater risk for infection. Iron is necessary for proper cellular function and a deficiency can affect the iron-containing enzymes of immune cells. Iron also helps to regulate the cytokines (Beard, 2001). Excess iron can impair immune system function (Gleeson, Nieman, and Pedersen, 2004).

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A nutritious diet contains adequate kilocalories and a variety of foods, such as those shown here. This dietary pattern is likely to provide sufficient carbohydrates, proteins, fats, vitamins, and minerals.

The Adequate Intake of All Minerals

At first glance, it may seem as if obtaining the proper intake of the 21 known essential minerals would be difficult. Fortunately, it is not necessary to measure and track the intake of all the macro- and microminerals in the diet. Because minerals are found in small amounts in many different foods, the best way to ensure adequate mineral status is to: 1) consume adequate kilocalories daily, 2) eat a variety of nutritious foods that have been minimally processed, and 3) consume an adequate amount of calcium and iron from food. Calcium and iron, when obtained from naturally occurring food sources, are fairly good predictors of the intake of the other minerals. In other words, when calcium and iron intake from food is adequate then the intake of the remaining 19 essential minerals is likely to be adequate.

In a nutshell, a nutritious diet contains a variety of fruits, vegetables, whole grains, beans and legumes, lean sources of proteins, heart-healthy fats, and a sufficient, but not excessive amount of energy. This dietary pattern is consistent with adequate mineral intake. This same pattern also provides athletes the

THE EXPERTS IN...

Mineral Research

Robert P. Heaney, M.D., is one of the world's experts in bone biology and calcium nutrition. His research has elucidated the physiology of calcium and helped to establish calcium requirements, such as the Dietary Reference Intakes. Much of his research has been conducted in postmenopausal, osteoporotic women, resulting in a better understanding of the causes and potential treatments of low bone mineral density. Christine M. Snow, Ph.D., is director of the Bone Research Laboratory at Oregon State University. Her research interest is the role of exercise in attaining and maintaining peak bone mass, particularly the effect of high-impact exercise on bone density in children.

John L. Beard, Ph.D., is an expert in iron metabolism. His research has focused on problems associated with iron deficiency and he has an interest in food-based strategies to help eliminate iron-deficiency-related diseases. Henry C. Lukaski supervises the Applied Physiology Laboratory at the Grand Forks Human Nutrition Research Center. The focus of his research is trace minerals, particularly iron, copper, and zinc, and their metabolism under extreme conditions such as exercise and low environmental temperatures. His work has helped to establish the amount of trace minerals needed by athletes and the benefits and potential harms of inadequate, adequate, and excessive trace minerals from dietary and/or supplement sources. Exercise scientists and sports nutritionists use the research findings of these and other scientists to better understand the metabolism of minerals and as the basis for making recommendations to athletes and nonathletes.

2 fried eggs
2 pieces of white toast w/1 T butter
2 slices bacon
8 oz coffee w/1 T each cream, sugar
Ham & cheese sandwich
1-oz bag potato chips
16-oz soft drink
3 Oreo cookies
Cheeseburger
Medium fries
16-oz soft drink
½ cup chocolate ice cream

Figure 9.3 An Example of a High-Fat, High-Sugar, Low-Fiber Diet
Legend: T = tablespoon; oz = ounce

1 cup oatmeal
1 slice whole wheat toast
1 T peanut butter
8 oz nonfat milk
8 oz orange juice
8 oz black coffee
1.5 cups lentil soup
Large (1.5 cups) green salad
1 oz avocado (~ ⅕ of an avocado)
2 T oil & vinegar dressing
2 whole wheat rolls
8 oz nonfat milk
1 banana
6 oz chicken breast
1½ cups brown rice
1 cup broccoli
1 slice whole wheat bread w/1 tsp *transfree* margarine
1 cup strawberries
Water
1 cup nonfat frozen yogurt
¼ cup dry-roasted sunflower seeds

Figure 9.4 An Example of a Nutrient-Dense, Whole-Foods Diet
Legend: T = tablespoon; oz = ounce

carbohydrates, proteins, and fats needed to support training and competition.

OBTAINING MINERALS FROM FOOD

Two diets that were discussed in Chapter 8 are repeated here in Figures 9.3 and 9.4. One is a high-fat, high-sugar, low-fiber dietary pattern that is low in most, but not all, vitamins for a 20-year-old male. The other diet emphasizes fruits and vegetables, legumes, nuts, and whole-grain, less processed foods. This whole foods diet meets the recommended daily intakes for all of the vitamins. How well do these diets fare when mineral content is analyzed? Tables 9.13 and 9.14 reveal the answers.

Table 9.13 Mineral Intake of a High-Saturated-Fat, High-Sugar, Low-Fiber Diet Compared to the DRI

Mineral	Intake	DRI*	% of DRI
Calcium	509 mg	1,000 mg	51
Iron	12.25 mg	8 mg	156
Magnesium	61 mg	400 mg	15
Zinc	3.5 mg	11 mg	32

Legend: DRI = Dietary Reference Intakes; mg = milligram
*20-year-old male

Table 9.14 Mineral Intake of a Nutrient-Dense, Whole-Foods Diet Compared to the DRI

Mineral	Intake	DRI*	% of DRI
Calcium	1,145 mg	1,000 mg	114
Iron	20.39 mg	8 mg	255
Magnesium	629 mg	400 mg	157
Zinc	16 mg	11 mg	148

Legend: DRI = Dietary Reference Intakes; mg = milligram***
*20-year-old male

Four minerals were analyzed—calcium, iron, magnesium, and zinc. Other than sodium and potassium (covered in Chapter 7), these four minerals are the only ones included in most nutrient analysis programs. The high-fat, high-sugar, low-fiber diet contains ~2,500 kcal, yet three of the four minerals assessed are low because of a lack of nutrient-dense foods. Magnesium and zinc intake are particularly low, 15 percent and 32 percent, respectively, and calcium intake is approximately 50 percent of the amount recommended for a 20 year old.

Contrast that with the nutrient-dense, whole-foods diet. This diet has approximately the same amount of energy (kilocalories), but substantially more minerals. The nutrient-dense diet provides more than 100 percent of the DRI for calcium, iron, magnesium, and zinc. In the case of iron, the diet provides 20 mg, which meets the DRI for both adult males (8 mg) and 19- to 50-year-old females (18 mg). The food with the highest iron content is lentil soup, which contains 4 mg. The remainder of the iron is gathered from the variety of foods included in this diet. With the exception of margarine and oil, all of the foods contributed iron, although no one food except the soup had more than 2 mg. An athlete consuming this dietary pattern could reasonably assume that the other minerals not analyzed are also adequate.

CONSUMING MINERAL-FORTIFIED FOODS OR A MULTIMINERAL SUPPLEMENT

By now it should be clear that adequate mineral intake can be achieved from food alone. However, this requires that a variety of nutrient-dense foods are consumed and, realistically, many people simply do not eat that way. They may wish to consume foods that have been highly fortified or enriched with minerals. Cereal is one product that has minerals added, and more mineral-fortified foods, such as energy bars, are being manufactured, in part, because people are known to consume mineral-poor diets.

Multimineral supplements are also sold. Earlier in the chapter, a supplement advertised as "high potency" was evaluated (see Spotlight on Supplements: Evaluating a High-Potency Multimineral Supplement Advertised to Athletes). But what about a mineral supplement that is not "high potency"? Another example of a product that is advertised to athletes is shown in Table 9.15. This supplement is advertised as a way to obtain the various minerals that may be missing from an athlete's usual diet. Notice that one mineral, magnesium, exceeds the Tolerable Upper Intake Level. The amount of zinc contained is 30 mg, twice as high as the 15-mg dose that is often recommended. Given that the average male consumes 13 mg of zinc daily, total zinc intake would likely exceed the UL if a male athlete consumed this supplement. This supplement also contains iron. Iron supplementation is generally not recommended for males because the risk of iron overload is greater than the risk of iron-deficiency anemia. About five of every 1,000 people in the United States, mostly Caucasian males, carry two copies of the abnormal gene responsible for overabsorption of iron, which can lead to excessive iron storage in tissues. These individuals should never take iron supplements. Before consuming any multimineral supplement, consumers should carefully check the dose of all the minerals contained.

Table 9.15 Example of a Multimineral Supplement

Mineral	Amount	% of DV	UL*
Calcium	1,000 mg	100	2,500 mg
Magnesium	500 mg	125	350 mg
Zinc	30 mg	200	40 mg
Manganese	10 mg	500	11 mg
Iron	10 mg	55	45 mg
Copper	2 mg	100	10 mg
Iodine	150 mcg	100	1,100 mcg
Selenium	200 mcg	285	400 mcg
Chromium	200 mcg	167	Not established
Molybdenum	500 mcg	667	2,000 mcg

Legend: DV = Daily Value; UL = Tolerable Upper Intake Level; mg = milligram; mcg = microgram

*The UL for minerals is based on the intake all food (fortified and nonfortified), water, and supplements except for magnesium, which is based on supplements only.

The biggest question about multiple minerals being added to food or taken as supplements is whether the minerals are well absorbed. Multimineral supplements contain too many minerals to test so this remains an unanswered question. A 2005 review article of iron and zinc supplementation together found that zinc reduced, but did not completely block, iron absorption (Fischer Walker et al., 2005). More studies are needed

KEEPING IT IN PERSPECTIVE

Minerals as Building Blocks

Remember the story of the Three Little Pigs? The first pig built his house out of straw, the second pig out of sticks, and the third pig out of bricks. The straw and stick houses were built quickly and the pigs had time to play while the third pig built his house of bricks. But the houses made of straw and sticks were not well constructed and could not withstand the huffing and puffing of the big, bad wolf.

Consuming minerals in proper balance is like building a house of bricks. The most obvious analogy is with calcium and the other bone-forming nutrients. These minerals help the bones to be dense and strong and to better withstand the loss of bone calcium that accompanies aging. Many minerals are also involved in the proper function of the immune system, which must withstand pathological microorganisms and other sources of harm on a daily basis over a lifetime. A low or unbalanced mineral diet over a long period of time is like a house of straw or sticks. Consuming enough minerals is like building and living in a house of bricks. You will be glad you did when the big, bad wolf (e.g., aging and disease) comes huffing and puffing at your door.

to determine both the potential benefits and harms associated with multiple mineral supplements.

Supplementing with Individual Minerals. Many people adopt a "food first, supplements second" philosophy. They try to obtain all of their nutrients from food if possible, but consume supplements when dietary intake is habitually low. The most frequently supplemented individual minerals are calcium and iron. Females are more likely than males to have insufficient habitual intake, increased avenues of loss, or both, potentially necessitating supplements. If both iron and calcium are supplemented, these supplements should be taken at different times if possible to reduce competition for absorption.

If a physician diagnoses iron-deficiency anemia, the appropriate treatment is iron supplementation. High doses of ferrous sulfate (325 mg of which 65 mg is iron) are often recommended. Because this form and quantity can cause GI upset, adjustments may need to be made in the supplement's dose or type. Despite high supplemental doses, the restoration of depleted iron stores is a slow process that takes three to six months. Iron supplementation should be discontinued (or started) only after consultation with a physician.

Obtaining calcium from food sources is advised, but supplemental calcium is generally absorbed as well as calcium from milk. The best absorption occurs when supplemental calcium is consumed as a 400- to 500-mg dose. The Tolerable Upper Intake Level is 2,500 mg, so supplemental calcium of up to 1,500 mg daily is probably safe for most people, although the exact amount will depend on dietary intake.

Athletes may self-prescribe other individual mineral supplements (e.g., zinc, chromium, magnesium) because they are concerned that dietary intake may be low. Although a single supplement may provide more than enough of that particular mineral, there are concerns that a single supplement, especially one containing a high dose, may be detrimental to the absorption of other nutrients. A prudent approach is to take no more than the DRI in supplement form. However, low-dose single mineral supplements are often hard to find so individual mineral supplements may need to be taken every other day or every third day to reduce exposure.

Sometimes supplements are advertised as having a higher **bioavailability** than food or another brand of supplements. The term *bioavailability* is often used interchangeably with the term absorption, but technically, bioavailability refers to absorption, utilization,

Bioavailability: The degree to which a substance is absorbed, utilized, and retained in the body.

SPOTLIGHT ON SUPPLEMENTS

How Beneficial Is Chromium Supplementation for Athletes?

Chromium is a mineral supplement sometimes taken by athletes for the purpose of increasing muscle mass and decreasing body fat. Bodybuilders and other strength athletes are frequent users. The most common supplement form is chromium picolinate. The picolinate, which makes the compound extremely stable, increases gastrointestinal absorption of the chromium. An important point is that chromium picolinate is not absorbed in the same manner as dietary chromium. It appears that chromium picolinate supplements can result in an increase in free radical (oxidant) production. More research is needed to determine if there is a long-term effect, but athletes should be aware of this possibility (Vincent, 2000).

Chromium seems to enhance insulin sensitivity by increasing the number of insulin receptors (Speich, Pineau, and Ballereau, 2001). Enhanced insulin sensitivity would improve glucose utilization. Insulin also has anabolic properties, and enhanced sensitivity could promote amino acid uptake into muscle cells. Uptake of amino acids is known to stimulate protein synthesis.

Animal studies and early studies in humans suggested that muscle mass was increased and body fat was decreased with chromium supplementation. In humans, the changes were small but significant, ~1.8 kg (~4 lb) increase in muscle mass and ~3.4 kg (~7.5 lb) decrease in body fat. Subsequent studies, with stricter methodology including better measurements of body composition, did not replicate these early results. Most studies use daily doses of chromium supplements of 200 to 400 mcg (Lukaski, 1999).

The Dietary Reference Intakes for adults range from 20 to 35 mcg daily depending on age and gender. The average daily dietary intake of chromium is approximately 25 mcg for adult females and 33 mcg for adult males. If sufficient kilocalories (energy) are consumed, a chromium deficiency would not be expected. No Tolerable Upper Intake Level has been established. Chromium supplementation of 50 to 200 micrograms daily seems to be safe. The effects of higher daily intakes are not known, but there is some suspicion that iron absorption may be decreased and that accumulated chromium in the body can damage DNA (Lukaski, 2000).

and retention. Bioavailability should be thought of as a point on a continuum. The goal should be adequate bioavailability, not poor or excess bioavailability. If bioavailability is too low, absorption or utilization would likely be poor. But excess bioavailability can be a problem, too, due to excess absorption, a high blood concentration of that mineral, and substantially reduced absorption of other minerals that use the same absorption pathways.

An example is supplemental chromium, which may be sold as chromium picolinate. The picolinate makes the compound very stable and the chromium is absorbed in much higher amounts than would be absorbed from food. Excess chromium could cause damage to cells, so highly bioavailable chromium is not as beneficial as it may sound. Chromium supplements, which are popular with athletes, are featured in the Spotlight on Supplements: How Beneficial Is Chromium Supplementation for Athletes?

What's the point? Consumption of a variety of nutrient-dense foods and sufficient caloric intake are associated with an adequate intake of minerals. Supplementation may be beneficial to provide minerals missing from the diet. Dose and extent of absorption are important issues to consider when choosing a mineral supplement.

Summary

More than 20 **minerals** are needed for the proper functioning of the body. Dietary calcium, zinc, and magnesium intakes tend to be low for both men and women in the general population. Dietary iron intake may also be low for women. Athletes' intakes of these, as well as other minerals, are likely to be low if energy intake is restricted.

Adequate calcium intake and weight-bearing exercise is needed throughout life so that peak bone mineral density is achieved and loss of calcium from bone is prevented or slowed. Bone loss is accelerated by a lack of **estrogen.** A lack of estrogen is usually associated with **menopause** but may also be present in some adolescent and young adult female athletes, putting them at great risk for low bone mineral density and fractures. Milk and milk products are concentrated sources of calcium, but calcium is found in a variety of nondairy products, although typically in lower amounts.

Iron is closely linked to athletic performance because depleted iron stores lead to iron-deficiency **anemia,** resulting in a reduced oxygen-carrying capacity of the red blood cells. Oxidative capacity at the cellular level is reduced and performance is impaired, particularly for the endurance athlete. With such clear impacts on performance, preventing iron-deficiency anemia is important for athletes. Several minerals are also involved in maintaining a healthy immune system, including iron, zinc, and selenium.

The best ways to ensure adequate mineral status is to consume enough kilocalories daily and to eat a variety of nutritious foods that have been minimally processed. While all minerals are important, there is an emphasis on obtaining adequate amounts of calcium and iron in the diet. When dietary intake of these two minerals is adequate, the intake of other minerals is likely to be adequate.

Because dietary mineral intake is low for many people, including athletes, there is much interest in taking mineral supplements. Dose is very important because large amounts of one mineral can hamper the absorption of other minerals. Large doses can also increase the risk for toxicities. Supplementation with minerals should be done thoughtfully to avoid potential problems. Mineral deficiency diseases, such as iron-deficiency anemia, are successfully treated with mineral supplementation.

Post-Test Reassessing Current Knowledge of Minerals

Now that you have more knowledge about minerals, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. The basic functions of minerals include building body tissues, regulating physiological processes, and providing energy.
2. In general, the body absorbs a high percentage of the minerals consumed.
3. In most cases, exercise does not increase mineral requirements above what is recommended for healthy, lightly active individuals.
4. If dietary calcium is inadequate over a long period of time, the body maintains its blood calcium concentration by reabsorbing skeletal calcium.
5. Iron-deficiency anemia has a negative impact on performance.

Review Questions

1. Compare and contrast minerals with vitamins. How are minerals similar to vitamins? Different from vitamins?
2. Explain the physiological and performance effects of mineral intakes that are too low or excessive.

3. Explain absorption problems associated with minerals found in food and supplements.
4. Are the requirements for minerals increased for athletes?
5. Do sedentary adults consume enough minerals? Do athletes? Explain.
6. Describe some of the potential toxic effects associated with consumption of minerals in excess of the Tolerable Upper Intake Level.
7. Explain the differences between a clinical and subclinical mineral deficiency, using either calcium or iron as an example.
8. Name the bone-forming minerals and explain why each is important for normal physiological function.
9. Briefly describe the roles of minerals and hormones in maintaining calcium homeostasis and calcium balance, including their roles in absorption, excretion, deposition, and resorption.
10. What effect does exercise have on attaining peak bone density and maintaining bone density across the life cycle?
11. How does iron deficiency, with and without anemia, affect athletic performance?
12. Explain the roles of minerals in proper immune function. Describe problems associated with both deficiencies and excesses.
13. How do athletes know if they are getting enough of all the minerals? What general dietary principles are associated with adequate mineral intake?
14. Are mineral supplements helpful or harmful to athletes? If so, in which ways?
15. What are the pros and cons of consuming a multimineral supplement daily?

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10 Diet Planning: Food First, Supplements Second


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Learning Objectives

1. Define the word *diet*.
2. Explain how energy intake and nutrient density are fundamental to diet planning.
3. Create a one-day diet plan for an athlete based on MyPyramid.
4. Explain nutrition periodization and translate sports nutrition recommendations to food choices.
5. Compare and contrast the goals of food and fluid intake prior to, during, and after exercise.
6. Discuss the safety and effectiveness of caffeine and alcohol.
7. Outline the information included on the Supplement Facts label.
8. Discuss the role of supplementation in an athlete's diet.
9. Summarize the legality, ethics, safety, and effectiveness of selected dietary supplements.

Pre-Test Assessing Current Knowledge of Diet Planning for Athletes

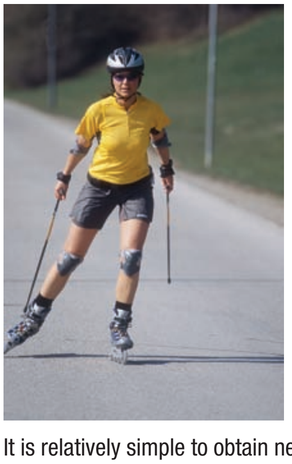
Read the following statements and decide if each is true or false.

1. When planning dietary intake, athletes should first consider how much dietary fat would be needed.
2. The key to eating nutritiously without consuming excess kilocalories is to choose foods that have a high nutrient density.
3. There is no room in the athlete's diet for fast foods.
4. After exercise, athletes should wait about an hour before consuming food or fluids.
5. To achieve optimum performance, most athletes will need to use some dietary supplements.

The word *diet* is used in two distinct ways in the English language. By definition, a **diet** consists of the food and drink that a person normally consumes. Thus, each person is always "on a diet." But the word *diet* is also used to describe a restricted intake of food and drink, usually for the purpose of weight loss. Thus, it is common to hear a person say "I need to go on a diet," "I'm on a diet," or "I've gone off my diet."

A diet is a pattern of eating. Sometimes people change their usual pattern of eating (e.g., a weight-loss diet) in an effort to change body composition. This is true for athletes, who wish to fine-tune body composition, and for sedentary people, many of whom are overweight or obese. One's usual diet may also need to change due to a medical condition, such as diabetes or heart disease. Changing one's usual pattern of eating is never easy, especially if it involves restriction.

Athletes must match their dietary intake to their training, a concept known as **nutrition periodization.** Sometimes this means increasing the carbohydrate content to restore the large amounts of glycogen used during days and weeks of hard training. Sometimes it means reducing overall energy intake to prevent excessive weight gain or to lose body fat. An athlete's diet may need to change abruptly in response to an injury. An athlete is always on a "diet," a pattern of eating, but that pattern may not always be the same.



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It is relatively simple to obtain needed nutrients with the increased caloric intake associated with regular, moderate-intensity exercise. In contrast, a person with a sedentary lifestyle needs fewer calories and should choose more nutrient-dense foods.

Planning a diet requires a broad perspective, with particular consideration given to energy intake and expenditure. The distinct nutrients are important but the need for energy provides the framework. Thus, diet planning begins with the establishment of an energy goal: energy balance or imbalance (i.e., weight loss or weight gain).

Energy: The Basis of the Diet Planning Framework

Humans are biologically designed to be physically active. When physical activity is high, a higher caloric diet is needed to maintain body weight. This higher caloric intake makes it relatively simple to obtain all the nutrients needed because larger volumes of food can be eaten. For example, a 5'7" 135-lb (170 cm 61.4-kg), 24-year-old nonpregnant female who performs 1 hour of moderate-intensity exercise five times per week would need ~2,500 kcal daily to maintain energy balance and body composition. At this caloric intake it is easy to plan a diet that meets all nutrient requirements. While predominantly nutrient-rich foods should be consumed to support her activity, some foods that are high in sugar and fat and lower in nutrients can easily be incorporated into her diet plan.

In contrast, if this same female were sedentary her daily caloric need would be approximately 2,000 kcal. All nutrient requirements can also be met at this caloric intake, but nearly all the food would need to be nutrient-dense. Nutrient-dense refers to a food that is rich in nutrients compared to its caloric content. Many popular foods, such as candy bars or ice cream, are calorie-dense instead of nutrient-dense. Large portions of calorie-dense foods and lack of physical activity are among the fundamental causes of the high

Activity	Female (kcal/kg)	Male (kcal/kg)
Sedentary (Activities of daily living [ADL] only)	30	31
Light activity (ADL + walking 2 miles per day or equivalent)	35	38
Moderate activity (ADL + moderate exercise 3–5 days/week)	37	41
Heavy activity (ADL + moderate to heavy exercise on most days)	44	50
Exceptional activity (ADL + intense training)	51	58

Figure 10.1 Estimated Daily Energy Requirements of Athletes

Legend: kcal/kg = kilocalorie per kilogram body weight

These "ballpark" figures, which are based on surveys, can be used to quickly calculate an estimate of daily energy needs, taking into account gender and activity.

prevalence of overweight and obesity in the United States and other industrialized nations.

Athletes are not usually sedentary, but their dietary intake will be influenced by relatively higher or lower energy requirements based on their training. As shown in Figure 10.1, caloric intake generally ranges from 35 kcal/kg to nearly 60 kcal/kg, largely dependent on the amount of energy expended through exercise.

An athlete's daily energy requirement varies according to the training cycle because energy expenditure from exercise can change considerably. The annual training schedule of a female rower (crew) is shown in Figure 10.2. The lowest energy expenditure is during active recovery ("off-season"), when the rower purposefully does no training. When the athlete returns to training, energy expenditure increases and continues to increase as the volume of training increases. The highest energy expenditure is during double days, when the rower engages in high-intensity and high-volume training in both morning and afternoon practices. During racing season, the total energy expenditure is similar to the beginning of the preparation period. To maintain energy balance, this rower must consume a substantial amount of food over the nine-month training period and substantially decrease caloric intake during active recovery.

Many athletes do not want to be in energy balance; rather, they want to maintain an energy deficit in an effort to reduce body fat. In such cases, each athlete must establish an appropriate daily energy intake goal. This goal essentially becomes a maximum caloric intake for the day and **macronutrient** needs (i.e., carbohydrates, proteins, and fats) must fit within this fairly strict framework. A rule of thumb recommendation is that athletes consume no less than 30 kcal/kg, because it is difficult to consume an adequate amount of nutrients, particularly carbohydrates, when energy intake is severely restricted. Conversely, some athletes want to gain weight, primarily as muscle mass, but occasionally as body fat. In the case of weight gain the athlete will need to establish a higher-than-normal daily caloric goal. Chapter 11 discusses nutrition and exercise strategies associated with changes to body composition.

Diet: The food and drink normally consumed; the restriction of food and drink for the purpose of weight loss.

Nutrition periodization: The creation of a nutrition plan to support training that has been divided into distinct periods of time.

Macronutrient: Nutrient needed in relatively large amounts. The term includes energy, carbohydrates, proteins, fats, cholesterol, and fiber but frequently refers to carbohydrates, proteins, and fats.

One-Year Training Cycle											
Preparation						Competition			Transition		
General Training			Specific Training			Racing Season			Active Recovery ("off-season")		
19.5 hr/wk with emphasis on endurance/cardiovascular training			22.5 hr/wk with emphasis on strength/power training			12 hr training/wk + 1–3 races/wk			No training		
Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
40 kcal/kg			44 kcal/kg			40 kcal/kg			33 kcal/kg		

Figure 10.2 Training Schedule and Estimated Energy Expenditure of a Female Collegiate Rower

Legend: hr = hour; wk = week; kcal = kilocalories; kg = weight in kilograms

Energy expenditure varies, depending on the intensity and volume of training over the course of a year. Similarly, the estimated daily energy requirement varies considerably. For example, "double days" (1 week of morning and afternoon practices prior to the opening of racing season and totaling 37.5 hours of training) increases daily caloric need to ~ 51 kcal/kg.

Macronutrients: Critical Elements in Diet Planning

Once the energy (kcal) goal has been established, the goals for macronutrients can be considered in the proper context and a **dietary prescription** can be developed. Because athletes may need higher carbohydrate and protein intakes than sedentary individuals (see Chapters 4 and 5), these two macronutrients are considered first. The athlete does not want to compromise the intake of these important nutrients, so their energy content is accounted for early in the diet planning process. Assume that the 24-year-old female athlete mentioned earlier needs approximately 6 g of carbohydrate and 1.2 g of protein per kilogram of body weight. Based on these goals, of the 2,500 kcal this athlete wants to consume daily, ~1,768 kcal should come from carbohydrates and proteins. The calculations for this example are shown in Figure 10.3

The diet planning process continues by considering the other energy-containing nutrients—fats and alcohol (see Figure 10.3). These contain more kilocalories per gram (9 kcal/g and 7 kcal/g for fat and alcohol, respectively) than carbohydrates and proteins (4 kcal/g). Because fat intake can be too low, a reasonable guideline for fat intake for athletes is ~1.0 g/kg of body weight.

At this point the diet has been planned to meet the macronutrient needs of the athlete. Note that after these needs have been met the caloric content of the diet in the example is too low (by ~180 kcal) to maintain energy balance (see Figure 10.3). This 180 kcal difference represents what is sometimes termed "discretionary calories." This term is used to indicate the amount of kilocalories needed to maintain energy balance after carbohydrate, protein, and fat recommendations have been met. In some cases, these "discretionary calories" are consumed in the form of alcoholic beverages. In many cases, small amounts of less nutrient-dense carbohydrate- and fat-containing foods such as soft drinks, sweets, and desserts are chosen. Because caloric requirements are high during periods of hard training, athletes may find that they need small amounts of such foods to maintain energy balance.

The 24-year-old female in this example is in energy balance when she performs moderately intense exercise five times per week and consumes 2,500 kcal daily. Now assume that she wishes to lose body fat. To reduce body fat, a rule of thumb estimate is to reduce food intake and/or increase energy expenditure by 500 kcal per day. The 500 kcal figure is used because it will likely produce a one pound per week loss of body fat. In this athlete's case (and in the case of most athletes) a 500-kcal decrease in daily food intake alone or a 500-kcal increase in daily exercise alone is not realistic or recommended. Reducing food intake by 500 kcal daily would make it hard to consume the amount of carbohydrates and proteins necessary for training and would force the athlete to consume a very low fat diet. Increasing activity by 500 kcal in a short period of time could result in overtraining, fatigue, or staleness.

A combination of food restriction and increased activity is often the best approach. For example, foods that represent "discretionary calories" could be eliminated and fat intake could be slightly reduced. Strategies to increase energy expenditure include increasing the frequency, intensity, and/or duration of exercise or including other activities into the daily lifestyle such as walking or cycling to and from work or school, using the stairs instead of elevators or escalators, stretching or performing calisthenics while watching TV, or eliminating labor-saving devices in favor of manual devices (e.g., push mowers, rakes, brooms). Together these alterations

Weight: 135 lb (61.4 kg)
Energy: 2,500 kcal/d (~40.7 kcal/kg)
Carbohydrate: 6 g/kg
Protein: 1.2 g/kg

Energy: 2,500 kcal/d
Carbohydrate (CHO): 1,472 kcal
(61.4 kg × 6 g/kg = 368 g CHO;
368 g × 4 kcal/g = 1,472 kcal)

Protein (PRO): 296 kcal
(61.4 kg × 1.2 g/kg = 74 g PRO;
74 g × 4 kcal/g = 296 kcal)

Energy from CHO + PRO: 1,768 kcal
(1,472 kcal + 296 kcal = 1,768 kcal)

Fat: 550 kcal
(61.4 kg × 1.0 g/kg = 61 g fat;
61 g × 9 kcal/g = 550 kcal)

Energy from CHO + PRO + fat: 2,318 kcal
(1,472 kcal + 296 kcal + 550 kcal = 2,318 kcal)

Energy intake not yet accounted for: 182 kcal
(2,500 kcal − 2,318 kcal = 182 kcal)

Figure 10.3 Calculating a Dietary Prescription for a 135-lb Nonpregnant Female Athlete

Legend: lb = pound; kg = kilogram; kcal/d = kilocalorie per day; kcal/kg = kilocalorie per kilogram body weight; g/kg = gram per kilogram body weight; kcal = kilocalorie; g = gram; kcal/g = kilocalorie per gram

Sports dietitians typically calculate carbohydrate and protein requirements and the energy that they provide first and then calculate fat and, if appropriate, alcohol intakes within the context of total daily energy intake.

Using the stairs instead of elevators or escalators is one strategy to increase daily energy expenditure.

to her usual food and activity patterns would result in weight loss, albeit at a slow rate. The advantages of a slow weight loss include less severe restriction of food intake, consumption of sufficient carbohydrates to support physical activity, and a sufficient protein intake to protect against the loss of muscle mass.

The naïve athlete may think that it is best to severely reduce energy intake when reducing body fat. After all, a larger restriction of energy (e.g., 1,000 kcal/d) would result in a faster weight loss. But athletes typically should not restrict food intake to a large degree because they will not be able to consume an adequate amount of carbohydrates to resynthesize muscle glycogen. They may also find it difficult to maintain a very low fat diet. Food is fuel and enough must be provided daily to support training. Additional information about weight loss strategies and weight cycling is provided in Chapters 11 and 12.

Although it is mentioned less frequently, some athletes need to increase their daily energy intake. Many people say that they would love to be in that situation! In fact, it is both difficult and frustrating for underweight athletes to increase their daily energy intake. They may have a genetic predisposition to be underweight. They may not have an appetite, so eating more food is unappealing and difficult. Additionally, some underweight athletes may be underweight because they are struggling with disordered eating and deep-seated psychological issues.

Underweight athletes benefit from nutrition counseling and the establishment of an individualized diet plan. For those who are not struggling with disordered eating, the general recommendation is to increase caloric intake by approximately 500 kcal daily (Rankin, 2002). This may be best accomplished by increasing the portion size of favorite foods and eating more frequently. Although it may seem advantageous to recommend the consumption of a calorie-dense food (e.g., milk shake), this strategy may be counterproductive because appetite can be reduced for many hours afterward and total caloric intake for the day may not exceed baseline. Some practical tips for increasing energy intake are listed in Figure 10.4.

Eat more meals and snacks daily.

Increase portion size of favorite foods.

Reduce intake of beverages that do not provide energy (kcal) but may give a feeling of fullness (e.g., coffee, tea, diet soft drinks).

Increase foods high in heart-healthy fats such as nuts, nut butters, olives, and avocadoes.

Figure 10.4 Practical Tips for Increasing Energy Intake in Underweight Athletes

Nutrient Density: The Key to Adequate Micronutrient Intake

In the area of sports nutrition, the energy-containing and muscle-related nutrients tend to be emphasized, especially carbohydrates and proteins. However, the human body requires more than just macronutrients. For optimal performance, training, and health, people need an array of other compounds, referred to as **micronutrients.** Micronutrients are substances that are needed in small quantities for normal growth, development, and maintenance of the body. Examples include all of the vitamins (see Chapter 8) and minerals (see Chapter 9). Vitamins and minerals do not contain energy so they have no caloric value. But they are found in foods that contain carbohydrates, proteins, and fats and are a necessary part of a healthy diet.

The key to eating nutritiously without consuming excess kilocalories is to choose foods that have a high nutrient density. Density, as used in this term, refers to a relatively high concentration of nutrients in relation to total kilocalories. In other words, a nutrient-dense food is rich in nutrients for the amount of kilocalories it contains. Table 10.1 compares the nutrient density of skim milk to whole milk. Both types of milk are good sources of many of the nutrients shown, in particular protein and calcium. Skim milk is a nutrient-dense food because it is rich in nutrients relative to its caloric content. Skim

Dietary prescription: An individualized plan for an appropriate amount of kilocalories, carbohydrates, proteins, fats, and alcohol daily.

Micronutrient: Nutrient needed in relatively small amounts. The term is frequently applied to all vitamins and minerals.

Table 10.1 Nutrient Density of Skim and Whole Milk

Nutrient	Skim Milk, with Nonfat Milk Solids Added (8 oz)	Whole Milk, 3.3% Milk Fat (8 oz)
Energy (kcal)	91	146
Protein (g)	9	8
Carbohydrate (g)	12	11
Fat (g)	<1	8
Cholesterol (mg)	5	24
Calcium (mg)	316	314
Iron (mg)	0.12	0.12

Legend: oz = ounce; kcal = kilocalorie; g = gram; mg = milligram

Skim (nonfat) milk is more nutrient dense than whole milk.

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Nutrient-dense foods are an important element in meeting diet planning goals.

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Skim milk is a nutrient-dense food because it is rich in nutrients relative to its caloric content.

Table 10.2 Nutrient Density of Sugar and Alcohol

Nutrient	White (table) Sugar (1 tablespoon)	Distilled Alcohol, 100 proof (1 fluid oz)
Energy (kcal)	45	82
Protein (g)	0	0
Carbohydrate (g)	12	0
Fat (g)	0	0
Calcium (mg)	<1	0
Iron (mg)	0	0.01
Thiamin (mg)	0	0
Vitamin C (mg)	0	0
Vitamin E (mg)	0	0
Folate (mcg)	0	0

Legend: oz = ounce; kcal = kilocalorie; g = gram; mg = milligram; mcg = microgram

Sugar and alcohol have a low nutrient density because they contain kilocalories but few or no nutrients.

milk is more nutrient-dense than whole milk because the whole milk contains about the same amount of nutrients as the skim milk but substantially more kilocalories. The caloric difference between the two milks is a result of the greater fat content of the whole milk. Note that the fat content of nonfat milk is not zero; a small amount of fat must be present so that the fat-soluble vitamins A and D can be added to the milk.

Fresh fruits and vegetables are typically nutrient-dense because they are rich in vitamins and minerals and low in kilocalories. Whole grains, beans and legumes, low-fat meat and poultry, fish, and nonfat or low-fat dairy products are also nutrient-dense. A food does not necessarily have to be low in kilocalories to be nutrient-dense. For example, almonds are considered a nutrient-dense food because they are rich in nutrients (e.g., vitamin E, magnesium, fiber) in relation to the amount of kilocalories that they provide. A primary goal of diet planning is to create an eating pattern that provides all the nutrients needed while providing the appropriate amount of kilocalories, and nutrient-dense foods are an important element in meeting these goals.

Sugar and alcohol have the lowest nutrient density as shown in Table 10.2. These compounds contain kilocalories but virtually no proteins, vitamins, or minerals. Sometimes these are described as having "empty" calories. Empty refers to the lack of nutrients, not the lack of kilocalories. Low-nutrient-dense foods typically have added sugar or fat. The fat and sugar provide

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It is a challenge to consume a nutritious diet when low-nutrient-dense foods are inexpensive, widely available, highly advertised, and tasty.

additional kilocalories but few or no additional nutrients. Consuming a large amount of low-nutrient-dense foods daily will usually result in overconsuming kilocalories, yet underconsuming nutrients. Thus, ironically, an obese person may be malnourished.

The athlete's diet must be adequate in both kilocalories and nutrients to support training. Because many athletes are trying to attain or maintain a low percentage of body fat, they cannot afford to overconsume energy (kcal). Therefore their diets must contain foods that are nutrient-dense. It is not difficult to determine the amount of kilocalories, carbohydrates, proteins, and fats needed by an athlete for training or competition. The challenge is to translate those recommendations into food choices while living in an environment where low-nutrient-dense foods are inexpensive, widely available, highly advertised, and tasty.

What's the point? Athletes in training need a comprehensive nutrition plan to support training, meet body composition goals, and optimize performance.

Translating Nutrient Recommendations into Food Choices

Similar to an **exercise prescription,** a diet prescription helps an athlete to know what nutrients and how much of each to consume. In the example used in the sections above, the following diet prescription was developed for a 24-year-old female who rollerblades:

Energy: 2,500 kcal/d (~40.7 kcal/kg)

Carbohydrates: 6 g/kg

Proteins: 1.2 g/kg

Fats: ~1.0 g/kg

Discretionary calories: ~180 kcal/d

Now the challenge is to translate the "numbers" into actual foods. Chapters 4, 5, and 6 explain in detail the kinds and amounts of food that contain carbohydrates, proteins, and fats. But many athletes, especially high school athletes and others who are just beginning to learn about nutrition, need some general information. Sports nutrition is a complex topic and can be overwhelming at first. Some simple tools are needed to get athletes started on the road to good nutrition.

One such tool is the Food Intake Patterns developed for MyPyramid. These intake patterns are briefly shown in Figure 10.5 (more detailed information is available in Appendix C and at www.mypyramid.gov). The foods have been grouped according to their nutrient content. The groups are fruits, vegetables, grains, meat and beans, milk, and oils, and the amounts of each group are adjusted based on caloric level. These patterns are a good starting point for use with athletes who have little nutrition knowledge. A similar approach is the use of the food exchange lists, which can be found in Appendix D.

Assume that the moderately active rollerblader has little understanding of nutrition. She does, however, have a diet prescription so she knows that she needs about 2,500 kcal daily. Notice that the Food Intake Patterns do not have a category for 2,500 kcal. This highlights one of the important limitations of using this guideline with athletes—these are general guidelines, and not individually planned diets. Also notice that the highest caloric level is 3,200 kcal. Some males, such as endurance and ultraendurance athletes and large-bodied strength athletes, will need more than 3,200 kcal daily.

The female athlete in this example should choose the 2,400 kcal pattern. This gives her a "ballpark" guideline of the kinds and amounts of foods she needs daily. In her case, she could begin to plan a diet that has approximately:

2 cups fruit

3 cups vegetables

The equivalent of 8 oz of grain products

6.5 oz of meat, poultry, or fish or the equivalent of substitutes such as beans and nuts

3 cups of milk

7 teaspoons of oil

Figure 10.6 shows a one-day diet plan developed using these food groups as a guideline. This diet

Exercise prescription: An individualized plan for frequency, intensity, duration, and mode of physical activity.

Daily Amount of Food from Each Group												
Calorie level	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200
Fruits	1 cup	1 cup	1.5 cups	1.5 cups	1.5 cups	2 cups	2 cups	2 cups	2 cups	2.5 cups	2.5 cups	2.5 cups
Vegetables	1 cup	1.5 cups	1.5 cups	2 cups	2.5 cups	2.5 cups	3 cups	3 cups	3.5 cups	3.5 cups	4 cups	4 cups
Grains	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	6 oz-eq	6 oz-eq	7 oz-eq	8 oz-eq	9 oz-eq	10 oz-eq	10 oz-eq	10 oz-eq
Meats and Beans	2 oz-eq	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	5.5 oz-eq	6 oz-eq	6.5 oz-eq	6.5 oz-eq	7 oz-eq	7 oz-eq	7 oz-eq
Milk	2 cups	2 cups	2 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups
Oils	3 tsp	4 tsp	4 tsp	5 tsp	5 tsp	6 tsp	6 tsp	7 tsp	8 tsp	8 tsp	10 tsp	11 tsp
Discretionary calorie allowance	165	171	171	132	195	267	290	362	410	426	512	648

oz-eq = ounce equivalent
tsp = teaspoon

Figure 10.5 MyPyramid Food Intake Patterns

Suggested amounts of food to consume from each food group listed, which varies according to estimated caloric needs.

1 c bran flakes cereal
1 banana
8 oz nonfat milk
8 oz orange juice
1 slice whole wheat toast
1 T margarine

Tuna salad made from 3 oz canned tuna in water, 1 T mayonnaise, and ¼ stalk celery
1 slice tomato
2 slices whole wheat bread
1 T mayonnaise
1 pear
8 oz nonfat milk
1 oats and honey granola bar

1 c green salad with 1 T oil and vinegar dressing and ½ oz almonds
3 oz chicken breast
½ c sweet potato
½ c green peas
2 whole wheat dinner rolls
2 T margarine
1 c mineral water

1 c low-fat fruit yogurt
3 sliced dried apricots

Figure 10.6 Using the Food Intake Pattern to Create a One-Day Diet Plan

Legend: c = cup; oz = ounce; T = Tablespoon

This diet plan was devised by using the suggested amounts of each food group for the 2,400 kcal pattern.

contains ~2,400 kcal (39 kcal/kg), 339 g carbohydrate (5.5 g/kg), 112 g protein (1.8 g/kg), and 75 g fat (1.2 g/kg).

How close does the one-day diet come to meeting this athlete's needs? It is in the "ballpark." The diet is slightly less than the 2,500 kcal recommended because it is based on the 2,400 kcal pattern. The diet is also a little bit too low in carbohydrates. However, if this athlete increased kilocalories to 2,500 by adding a carbohydrate-containing food, then she would nearly reach the recommended intake of carbohydrates. This example illustrates how general dietary patterns provide a good guideline from which modifications can be made.

Most general dietary guidelines are developed to contain about 5 to 6 g of carbohydrates per kilogram of body weight. Recall from Chapter 4 that the minimum recommended amount of carbohydrate for athletes in training is 5 g/kg. General dietary guidelines are not designed to provide the amount of carbohydrate that many athletes in training require (i.e., 7 or more g/kg). Trained athletes need more extensive diet planning than general guidelines can provide.

The Food Intake Patterns developed for MyPyramid are public domain documents and can be freely copied and distributed. Many health professionals use these guidelines to provide basic nutrition information to consumers, some of whom are physically active. Those who work directly with athletes in training, such as certified strength and conditioning specialists (CSCS) and certified athletic trainers (ATC), also use these tools to communicate basic nutrition information. This helps athletes receive a consistent message about the importance of nutritious foods such as fruits, vegetables, whole grains, lean proteins, beans, nuts, and heart-healthy oils. These same types of foods will be used to plan the athlete's diet, but the amount of food will be determined by the intensity and duration of training.

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Many athletes learn to cook so that they can prepare foods that are nutritious and tasty.

As pointed out earlier, trained athletes have different nutritional needs than the general population. Their diets are typically higher in kilocalories and carbohydrates than sedentary and lightly active individuals. Some athletes may be trying to reduce caloric intake but must do so without sacrificing adequate consumption of carbohydrates and proteins. Some struggle with body image and become fearful of eating. These athletes need more specific information and individually planned diets. Many sports-related personnel have basic but not advanced knowledge of nutrition. They also do not have the time or expertise to evaluate the athlete's current food and nutrient intake, recommend changes, and help create individualized diet plans. As explained in Chapter 1, when a client's needs fall outside of a practitioner's scope of practice, the appropriate response is to make a referral to a qualified practitioner. Sports dietitians are trained to evaluate and plan athletes' diets.

INDIVIDUALIZING A DIET PLAN

Many athletes can recite what has become known as the stereotypical athlete's dinner: broiled chicken breast without skin, plain baked potato, steamed broccoli, whole wheat roll, nonfat milk, and fruit for dessert. While this meal is nutritious and does provide ample carbohydrates, proteins, and nutrients, athletes may have difficulty coming up with ideas for other dinners that are equally nutritious and find themselves in a food rut. They may also not like certain foods or not be able to tolerate them (e.g., lactose intolerance). Planning and preparing varied meals is always a challenge. If they do not already know how to do so, most athletes find that they need to learn to cook.

Creating a diet that meets the athlete's needs is one way to approach diet planning. Some athletes are willing to follow a diet that has been created for them and change their dietary intake dramatically and over a short period of time. But many athletes do not take this approach; rather, they look to modify their current diet. Their current diet includes familiar foods that they enjoy and know how to prepare; however, the diet may not provide the appropriate amount of energy, carbohydrates, proteins, fats, fluid, vitamins, or minerals. The key to diet planning is individualization. Creating an elaborate diet plan that does not fit into the athlete's lifestyle or includes unappealing or unfamiliar foods does not make sense because it is not likely to be followed over the long term.

Sports dietitians work with athletes to help them identify appropriate goals and ways to modify their current diet to meet those goals. Consider the case of a freshman baseball player who eats lunch on campus every day. He has gained body fat since coming to college and he knows that eating at fast-food restaurants has contributed to his weight gain. When the health center offered a free dietary consultation he decided to meet with the sports dietitian. He expected that the dietitian would simply say to stop eating fast foods, which he does not consider an option. He was pleasantly surprised when the dietitian gave him advice on making healthier, lower calorie choices at fast-food restaurants (see Figure 10.7). He found that he could still eat fast food but that it was important to choose wisely, alter the method of preparation (e.g., grilled rather than deep fat fried), limit the portion size (e.g., 6-inch rather than 12-inch sandwiches, do not "supersize"), and ask for fewer condiments (e.g., cut down on high-fat, high-sugar sauces, mayonnaise). These are examples of ways that an athlete's current diet can be modified to meet the goal of consuming fewer kilocalories.

Smallest size adult meal or children's meal

Grilled food instead of fried (e.g., grilled chicken)

Extra lettuce and tomato substituted for mayonnaise or cheese on burgers or sandwiches

For deli sandwiches, whole wheat bread, extra vegetables, moderate amount of filling, less fatty/sugary condiments (e.g., mayo, sauces)

Salad or salad bar with dressing on the side

Plain baked potato

Pizza with vegetables, easy on the cheese

Pancakes

Bagels

Figure 10.7 Wise Choices in Fast-Food Restaurants

Food Intake Before, During, and After Exercise

In addition to an athlete's 24-hour intake, a plan must also be devised for consuming food at the appropriate times. Food and fluid intake prior to, during, and after exercise must be part of the athlete's overall plan. Each time period has important goals that should be met.

FOOD AND FLUID INTAKE PRIOR TO EXERCISE

"Prior to exercise" is not a well-defined term but in sports nutrition it usually refers to an approximate four-hour period before exercise begins. Pre-exercise, pretraining, and precompetition meals are also terms that are used. In the hour immediately preceding competition the emphasis is usually on fluid intake, which may also include some carbohydrates. For some athletes, pretraining and precompetition meals are similar because training and competition are similar. But in other cases they are remarkably different because a training session will last for many hours but a race will be over in seconds or minutes.

The goals of food and fluid intake prior to exercise are typically to 1) provide glucose, 2) delay fatigue during prolonged exercise, 3) prevent hypohydration and excessive dehydration, 4) minimize gastrointestinal distress, and 5) satisfy hunger. These goals are the same for both pretraining and precompetition meals; however, the precompetition meal must always consider the impact that the stress of the impending competition has on the gastrointestinal tract.

There are no hard and fast rules regarding food and fluid intake prior to exercise, although there are general guidelines, which are summarized in Figure 10.8. Each athlete must use trial and error to determine the best precompetition and pretraining foods and fluids. Consideration must be given to a variety of factors, including the amount of time prior to exercise, carbohydrate, protein, and fat content, consistency of the meal (i.e., solid, semisolid, or liquid), volume consumed, and food familiarity and preferences.

A meal, consisting of food and fluid, is usually consumed approximately one to four hours prior to exercise. This will help athletes satisfy their hunger, especially if this is the first meal after a night's sleep, and remain adequately hydrated. Determining how many hours prior to exercise a meal will be consumed will also determine the volume of food and fluid that can be comfortably consumed. The onset of exercise increases the blood flow to muscles and decreases the blood flow to the gastrointestinal tract. Thus, too large a volume of food or fluid consumed too close to exercise can result in gastrointestinal distress.

Carbohydrate: 1.0–4.5 g/kg 1–4 hours prior

Fluid: ~5–7 ml/kg at least four hours prior to exercise if adequately hydrated; additional ~3–5 ml/kg two hours prior if hypohydrated; sodium added to food or drink may be beneficial

Volume of food and fluid adjusted based on amount of time before exercise begins

Trial and error during training is encouraged

Figure 10.8 Guidelines for Food and Fluid Intake Prior to Exercise

Legend: g/kg = gram per kilogram body weight; ml/kg = milliliter per kilogram body weight

The timing of intake is easiest when the start time for training or competition is known in advance. For example, if a football game is scheduled to begin at 7:30 p.m., then the athlete will know the time of his pregame meal. If he knows that he will be eating at 3:30 p.m., then he knows the volume and kinds of foods and fluids that can be tolerated. In many sports, timing the pre-event meal is more difficult because the athlete may not know specifically when the competition will begin. Tennis provides a good example, as a tennis player competing in a tournament may know that he is the third match scheduled but he cannot predict how quickly the other two matches will be played or if the starting time may be altered due to weather delays.

Most of the studies of pre-exercise meals have been conducted with endurance athletes, often distance cyclists, under laboratory conditions. It is known that consuming carbohydrates (i.e., glucose) prior to exercise delays time to exhaustion and improves performance (Schabort et al., 1999; Sherman et al., 1989; Nuefer et al., 1987). The recommended amount of carbohydrates is 1.0 to 4.5 g/kg one to four hours prior to exercise. As a rule of thumb, athletes usually consume 1.0 g carbohydrate/kg as a multiple of the number of hours before exercising. In other words, athletes consume 1.0 g/kg one hour prior or 2.0 g/kg two hours prior. As the time before exercise increases, the amount of carbohydrates that can be tolerated increases. Large amounts of carbohydrates (e.g., 4 g/kg four hours prior to exercise) may be appropriate for some athletes but not for others. For example, an ultraendurance athlete who needs 10 to 19 g/kg of carbohydrates on the day of the event may need to consume 4 g/kg four hours prior because it is difficult to consume such a large amount of carbohydrates over the course of a day. In this case, a carbohydrate intake of 4g/kg is about 20 to 40 percent of total carbohydrate intake for the day. However, such an intake would be inappropriate for a shorter-distance

One 3 oz (3½ in) bagel

2 tsp light cream cheese

12 oz orange juice

8 oz carbohydrate beverage

Figure 10.9 Sample Precompetition Meal

Legend: oz = ounce; in = inch; tsp = teaspoon; kcal = kilocalorie; g = gram; kg = kilogram; lb = pound; g/kg = gram per kilogram bodyweight

This meal contains approximately 500 kcal, 100 g carbohydrate, 12 g protein, and 5 g fat. For a 50-kg (110-lb) athlete, the carbohydrate content of this meal is 2 g/kg. The bagel, cream cheese, and the orange juice would probably be consumed 2 hours prior and the sports beverage would be consumed slowly over the 2-hour period prior to competition.

runner (e.g., 10 K [6.2 miles]) because total daily carbohydrate is much lower (~6–8 g/kg) and 4 g/kg in one meal would be 50 to 67 percent of the day's carbohydrate intake. Pre-exercise carbohydrate content is also dependent on the athlete's tolerance.

In addition to carbohydrates, it is recommended that the pre-exercise meal generally contain a moderate amount of proteins, a small amount of fats, and some fluid. Fats slow gastric emptying (the amount of time it takes for the food to leave the stomach) and are digested more slowly than carbohydrates and proteins. However, fats do provide a greater degree of satiety (the feeling of fullness and satisfaction) and athletes often include some fats in the hours prior to exercise to keep them from feeling hungry. Figure 10.9 gives an example of a precompetition meal for a 50 kg (110 lb) athlete.

Fluid intake is typically a priority prior to exercise, so part of the pre-exercise meal will be fluid. One hour before training or competition, much of the athlete's intake will be fluid because it is often easier to tolerate fluid as the time to begin exercise draws closer. The amount will vary based on the body size of the athlete. The American College of Sports Medicine (ACSM) (Sawka et al., 2007) recommends that athletes who are adequately hydrated prior to exercise consume ~5–7 ml/kg body weight at least four hours prior to exercise. Those who are entering training or competition in a hypohydrated state may benefit from an additional ~3–5 ml/kg in the two hours prior to the onset of exercise. In practical terms, a euhydrated 50 kg (110 lb) female may need to consume 250–350 ml (~8–12 oz or 1–1½ cups) of fluid in the four hours before exercise. If hypohydrated, this athlete may benefit from the consumption of an additional 150–250 ml (5–12 oz) of fluid in the two hours prior to exercise. These rule of thumb amounts are good guidelines, but they must be adjusted based on individual tolerances and environmental conditions.

In many cases, water is sufficient but carbohydrate-containing beverages may also be consumed. Sodium added to foods and beverages in small amounts may also be beneficial because sodium helps to stimulate thirst, increase the body's drive to drink, and retain fluid.

Stress can affect the body positively (e.g., heightened awareness, motivation) or negatively (e.g., headaches, nervousness). Gastrointestinal upset is a common response to the stress of competition and athletes may experience nausea, vomiting, abdominal cramps, and/or diarrhea. Too great a volume of food or the presence of unfamiliar foods can trigger or worsen the situation. These problems may be avoided by using trial and error during training to determine the volume and types of food that are appropriate for the athlete to consume prior to competition. Common adjustments are to allow more time prior to the onset of exercise, reduce the volume normally consumed, or include more semisolid or liquid foods. If athletes will be consuming the precompetition meal at the site of competition, they should find out the kinds of foods that will be available or bring their own foods. Athletes should not try new foods as part of a precompetition meal without first consuming those foods during training to determine their expected gastrointestinal response.

Some athletes do not consume any food prior to exercise and wonder if this is appropriate. Research studies suggest that the lack of food prior to exercise decreases performance, so most athletes will likely benefit from pre-exercise foods or beverages (Maffucci and McMurray, 2000; Chryssanthopoulos and Williams, 1997). Low blood glucose is associated with feelings of hunger, an inability to concentrate, and poor endurance, so some food or beverage intake prior to training is usually recommended. Those performing high- to very-high-intensity, short-duration exercise would likely limit their intake to a small, primarily carbohydrate meal and allow sufficient time for gastric emptying.

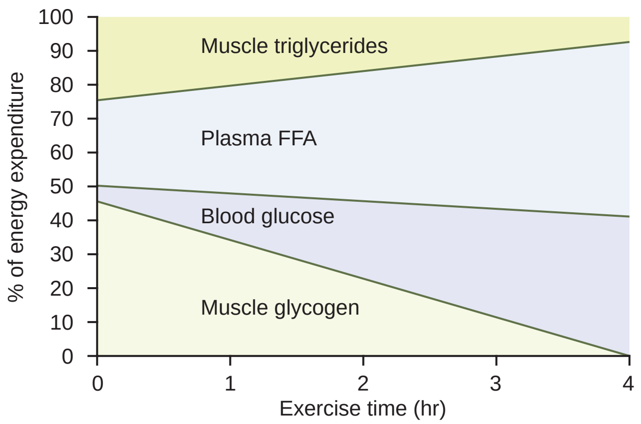
Early start times of competitive events may alter the athlete's usual eating pattern. For example, rowers in a 2,000-km (~1¼ mile) race with a 7:00 a.m. start time will be up at 4:00 a.m. and may not have any appetite because they are usually asleep at this time. Eating a banana at 6:00 a.m. and sipping a sports beverage would provide a small amount of glucose that would be quickly absorbed, but any more food or fluid than that may be too much before high-intensity, short-duration exercise. Marathon runners often put a sports drink and a carbohydrate snack next to their bedside and consume it in the early hours of the morning of competition when they get up in the night to use the bathroom. The need for trial and error, and some creativity, cannot be overemphasized. The wrong precompetition meal can be far more detrimental than the right pre-competition meal can be beneficial!

FOOD AND FLUID INTAKE DURING EXERCISE

The goals of food and fluid intake during exercise are typically to 1) provide glucose, 2) delay fatigue, 3) prevent or delay hypohydration and excessive dehydration, 4) prevent excessive changes in electrolyte balance such as hyponatremia (low blood sodium), and 5) minimize gastrointestinal distress. Intake of foods and fluids during exercise is vitally important for endurance and ultraendurance athletes (e.g., distance runners and cyclists, triathletes, adventure racers) and those that engage in intermittent, high-intensity exercise for more than one hour (e.g., soccer and basketball players). Athletes in other sports may consume food and/or fluids (e.g., golfers), but the demand for either is less than athletes engaged in higher-intensity sports. Obviously, some athletes cannot ingest any food or fluids during an event.

Prolonged exercise, especially in the heat, can result in hypohydration, which can impair performance, contribute to fatigue, and be a health risk. Hypoglycemia, or low blood glucose, also impairs performance and contributes to fatigue. The ability to prevent hypoglycemia and hypohydration and to delay fatigue is the basis for specific carbohydrate and fluid recommendations during exercise.

Marathon running is an excellent example of why distance runners consume carbohydrates during a race and during long training runs. Endogenous (within the body) carbohydrates are limited to muscle glycogen, liver glycogen, and blood glucose and together provide approximately 500 g or 2,000 kcal of carbohydrates. Carbohydrates are an important fuel source for a 26.2-mile run (as are fats and to a small degree proteins, but this discussion will only focus on carbohydrates). As shown in Figure 10.10, when the marathon begins, the majority of the carbohydrates are supplied by muscle glycogen. Blood glucose provides a small but steady supply of glucose to the muscles. As the marathon continues and muscle glycogen stores become depleted, a higher percentage of the carbohydrates used come from blood glucose as the muscles increase their uptake of glucose from the blood. In response to the increased uptake of blood glucose, the liver increases the breakdown of liver glycogen, which provides glucose to the blood and keeps blood glucose concentration stable. In other words, the glucose is being taken out of the blood by the muscle cells but is being replaced by glucose from the liver cells. As long as the liver can keep pace with muscle glucose uptake, the concentration of glucose in the blood will remain fairly stable and within the normal range. But it is hard for the liver to keep pace for two reasons: 1) the rate at which new glucose can be made by the liver (gluconeogenesis) is limited and



◀ hr = hour | FFA = free fatty acids

Figure 10.10 Use and Source of Fuel During a Marathon

2) the total amount of glycogen stored in the liver is small, approximately 100 g or 400 kcal. When the uptake of glucose by muscle exceeds the ability of the liver to provide glucose, blood glucose begins to drop and may eventually fall below the normal range (i.e., hypoglycemia develops).

The example above explains how the body adjusts when blood glucose starts to decline but how eventually blood glucose would drop. However, the athlete can prevent a fall in blood glucose by consuming carbohydrates during exercise. Consuming carbohydrates during a marathon or other prolonged endurance task is important because it prevents hypoglycemia, which results in light-headedness and lack of concentration, and will provide a source of carbohydrates for metabolism when endogenous sources are limited. Without carbohydrate intake during prolonged endurance exercise, muscle and liver glycogen stores can be nearly depleted (the body guards against their total depletion), which is a condition strongly associated with fatigue and reduced exercise performance. Nearly every marathon runner or triathlete has a sad story about "hitting the wall" or "bonking," terms that refer to an inability to complete a race due to glycogen depletion.

Research studies have shown that the consumption of carbohydrates during prolonged exercise improves performance and delays fatigue by preventing glycogen depletion and hypoglycemia. The recommended intake is 30 to 60 g of carbohydrates per hour (Coyle and Montain, 1992). The maximum absorption of carbohydrate from the gastrointestinal tract is estimated to be 1 g of glucose per minute or approximately 60 g/h (Guezennec, 1995). Glucose, glucose polymers (chains of glucose), sucrose (white table sugar), and maltodextrin (corn sweetener) are all absorbed at about the same rate, so the source of carbohydrates or their glycemic response is not thought to be a major factor. The exception is fructose, which is absorbed more slowly and must be converted by the liver to glucose. By itself, fructose ingestion is not an

Chris Hondros/Getty Images

Nearly every marathon runner has a story about "hitting the wall."

Mike Stobe/Getty Images

Athletes in intermittent, high intensity sports also benefit from carbohydrate-containing fluids during training or competition.

effective way to provide glucose to the blood during prolonged exercise. However, fructose may be one of several sugars included in sports beverages that are promoted for use during exercise. Those who experience gastrointestinal upset with fructose should check beverage labels carefully and choose a fructose-free product.

A small body of literature also suggests that carbohydrate consumption is beneficial for intermittent, high-intensity exercise greater than one hour (Winnick et al., 2005; Welsh et al., 2002; Nicholas et al., 1999 and 1995; Davis et al., 1997). Some of these studies were conducted with subjects that ran or cycled intermittently but not continuously while a few were conducted with soccer and basketball players. The results of these studies have been applied to "stop-and-go" sports such as soccer, basketball, ice hockey, field hockey, rugby, squash, and tennis in which large amounts of muscle glycogen may be depleted during training and competition. The same general recommendation made to prolonged endurance athletes—30 to 60 g of carbohydrate per hour—is made to athletes engaged in intermittent, high-intensity sports.

Fluid intake during training and competition (if intake is possible) is important to prevent excessive dehydration (i.e., $>$ 2 percent of body water loss), hypohydration, and heat illness and to delay fatigue. The amount and frequency of fluid that should be consumed is discussed in detail in Chapter 7. In the past, athletes were advised to consume 150 to 350 ml (~6–12 ounces) of fluid at 15 to 20 minute intervals, beginning at the onset of exercise (Convertino et al., 1996). The ACSM currently recommends that a customized plan be devised for each athlete and does not recommend discrete amounts or time intervals because such recommendations, inappropriately applied, could result in substantial over- or underconsumption of fluid and related medical problems (Sawka et al., 2007).

To prevent hyponatremia, endurance and ultra-endurance athletes should avoid excess fluid intake and replace sodium lost. For endurance athletes who sweat heavily and whose sweat contains a large amount of sodium (i.e., "salty sweaters"), consumption of 1 g of sodium per hour is recommended (Murray, 2006). Specially formulated products typically contain 0.5 to 0.7 g of sodium per liter of fluid. Such beverages may also be beneficial for endurance athletes who do not lose large amounts of sodium in sweat because sodium stimulates thirst and promotes water retention. Additionally, the slightly salty taste of such beverages may make the taste more desirable, resulting in greater consumption at a time when athletes often voluntarily reduce their fluid intake.

Much of the information about intake during exercise focuses on athletes in prolonged endurance sports because the risk for heat illness is high, hyponatremia can occur, and the need for fluid and carbohydrate is great. From a practical point of view, endurance athletes can "kill two birds with one stone" by drinking their source of carbohydrates. But the rate of gastrointestinal absorption must be considered. When exercise intensity is greater than 75 percent of $\dot{V}O_{2max}$, the rate of absorption of carbohydrate-containing fluids will be slowed and the risk for gastrointestinal upset is increased. Too great a concentration of carbohydrates can also slow gastric emptying, yet too small a concentration does not provide many carbohydrates. Most endurance athletes consume a sports beverage with 4 to 8 percent carbohydrates. At these concentrations, each liter (1,000 ml, or a little more than four 8-oz cups) contains 40 to 80 g of carbohydrates. These carbohydrate beverages are typically consumed every 15 to 20 minutes.

Carbohydrate-containing sports drinks are popular, but sufficient fluid and carbohydrates can be obtained in other ways. Solid and semisolid carbohydrate foods plus water can also provide carbohydrates and fluid and improve performance (Robergs et al., 1998; Lugo et al., 1993). For example, a marathon runner may prefer two packets of gel (~50 g carbohydrates) and water. Other

Carbohydrate: 30–60 g/h.

Fluid: Customized plan to prevent excessive dehydration and excessive changes in electrolyte balance based on sweat rate, sweat composition, duration of exercise, clothing and environmental conditions.

Sodium: 1 g/h if a "salty sweater" (i.e., a high sweat rate and high loss of sodium in sweat while exercising).

Trial and error during training is encouraged.

Figure 10.11 Guidelines for Food and Fluid Intake During Exercise

Legend: g/h = gram per hour

Layne Murdoch/NBAE via Getty Images

Athletes in sports such as basketball typically consume both water and carbohydrates, usually as sports beverages, when they are on the sidelines.

popular carbohydrate foods that may be eaten during endurance activities include bananas, energy bars, and Fig Newtons. While many athletes in prolonged training or competitions consume a sports beverage, they may also like the variety that food and water combinations provide. Trial and error is necessary to determine tolerance. Figure 10.11 summarizes the guidelines for food and fluid intake during exercise.

Carbohydrate and fluid intake during distance running has received a lot of attention because the need to replenish these nutrients is high, and distance runners tend to have more gastrointestinal problems than other distance athletes (e.g., cyclists), but many athletes need a plan for food and fluid intake during exercise. Athletes in sports such as basketball or soccer typically consume both water and carbohydrates, usually as sports beverages, when they are on the sidelines.

At halftime, they may have a carbohydrate snack (e.g., banana, orange, energy bar) and fluid. Athletes in sports such as (American) football usually concentrate on fluid intake rather than carbohydrate intake. A track athlete who is running a short race lasting only seconds or a few minutes does not need to be concerned about food or fluid intake during competition, but that same athlete who runs an individual race, is part of two relays, and performs the long jump will need to have some carbohydrates and fluid during the track meet. Each situation is different, and it is the intensity and duration of the exercise and the conditions under which athletes train and compete that will primarily dictate the need for food and fluid during training and competition.

The need for carbohydrates and fluid during exercise has dominated the scientific literature for many decades. More recently, researchers have begun to examine the need for protein intake during exercise. For example, Koopman et al. (2004) studied eight trained ultraendurance athletes who consumed a carbohydrate beverage or a carbohydrate/protein beverage during six hours of continuous exercise. Whole body protein balance was negative when only carbohydrates were consumed. When the beverage contained both carbohydrates and proteins, protein balance was either positive or less negative. The authors suggest that the inclusion of proteins in a carbohydrate beverage increases protein synthesis and decreases protein breakdown during prolonged, moderately intense (50 percent $\dot{V}O_{2max}$) exercise. More studies are needed to confirm this effect in ultraendurance athletes.

FOOD AND FLUID INTAKE AFTER EXERCISE

When exercise ends, the recovery period begins. For many athletes, recovery time is limited because they train or compete nearly every day. Some have multiple competitions on the same day. Food and beverage intake should begin immediately after exercise if possible. The goals of food and fluid intake after exercise are to 1) provide carbohydrates to resynthesize muscle glycogen, 2) provide proteins to aid in the repair of muscle, 3) rehydrate and reestablish euhydration, and 4) replace lost electrolytes.

Exercise depletes glycogen stores, which should be restored before the next training session. The rate and extent to which muscle glycogen is resynthesized depends on a number of factors, including the extent of depletion, the presence of insulin, the activity of enzymes such as glycogen synthase, the degree of muscle damage, and the amount and timing of carbohydrate intake.

The timing of carbohydrate intake after exercise is critical. Consuming carbohydrates immediately after exercise provides glucose at a time when cellular glucose sensitivity and permeability are optimal and the rate of glycogen restoration is high. Muscle glycogen is resynthesized at its highest rate immediately after exercise. A two-hour delay after exercise can reduce glycogen synthesis substantially (Ivy, 1998). Glycogen resynthesis is a slow process and may take more than 20 hours. If possible, athletes should consume carbohydrates immediately after exercise to take advantage of rapid glycogen resynthesis and consume adequate daily carbohydrates to optimize glycogen stores. It is recommended that glycogen-depleted athletes consume approximately 1.5 g of carbohydrates per kilogram of body weight in the first hour after exercise. Some of these carbohydrates should have a medium- to high-glycemic index (see Chapter 4). For example, a 176-lb (80-kg) athlete should consume approximately 120 g of carbohydrates within 60 minutes postexercise. One banana, 10 ounces of a high-carbohydrate sports drink, and one 2-oz bagel would provide this amount of carbohydrates, with the beverage and the bagel stimulating a higher glycemic response. An additional carbohydrate intake of 0.75 to 1.5 g/kg each hour over the next three hours is recommended for maximum glycogen resynthesis, but an athlete's intake may be limited by appetite and gastrointestinal distress. Many endurance athletes focus on a high-carbohydrate intake immediately after exercise and a high-carbohydrate meal within a couple of hours.

In addition to the timing and amount of carbohydrates, other factors influence recovery. Postexercise protein intake is beneficial to muscle protein anabolism. Studies have shown that the consumption of at least 6 g of indispensable amino acids immediately after resistance exercise results in a net increase in muscle protein balance (Ivy et al., 2002; Borsheim et al., 2002). Stated on a g/kg basis, ~0.1 g/kg of indispensable amino acids is recommended after exercise (Gibala and Howarth, 2006). This is a small amount of amino acids (e.g., 10 g for a 100-kg [220-lb] athlete) and could easily be met by consuming yogurt with fruit in the bottom, chocolate milk, or a turkey sandwich. These foods not only provide proteins but also carbohydrates.

The postexercise period is also critical for replenishing fluids, and in some cases, sodium and other electrolytes that may have been lost in large amounts. The amount of fluid that is necessary for replenishment is estimated by comparing pre- and postexercise weights. It is recommended that athletes drink approximately 1.5 L (~50 oz) of fluid per kg body weight lost, beginning as soon after exercise as is practical. In other words, a 2.2 lb loss of scale weight requires ~6 cups of fluid intake (Sawka et al., 2007; American College of Sports Medicine, 2000). Rehydration and obtaining a state of euhydration, especially after exercise in the heat, can take many hours, but should be initiated immediately after exercise.

Athletes who are "salty sweaters" must also replenish the sodium chloride lost. These athletes are typically advised to sprinkle table salt (i.e., sodium chloride) on their food or consume salty snacks (e.g., pretzels dipped in salt) after exercise. Sports beverages may contain some sodium, but the amount is usually too low for those who have lost considerable sodium in sweat. Figure 10.12 summarizes the guidelines for food and fluid intake immediately after exercise.

> Carbohydrate: 1.5 g/kg in the first hour after exercise, including some with a medium to high glycemic index; Additional intake of 0.75–1.5 g/kg per hour over the next 3 h.
>
> Protein: ~0.1 g/kg of indispensable amino acids (or at least ~6 g) after exercise.
>
> Fluid: ~1.5 L (~50 oz or ~6 cups) of fluid per kg body weight lost, beginning as soon after exercise as is practical.
>
> Sodium: Consume foods containing sodium. If large amounts of sodium have been lost, salt food or consume salty snacks.
>
> Other electrolytes: Consume a variety of food including fruits and vegetables.

Figure 10.12 Guidelines for Food and Fluid Intake After Exercise

Legend: g/kg = gram per kilogram body weight; h = hour; g = gram; oz = ounce

From a practical perspective it may be difficult for athletes to immediately implement postexercise recovery strategies. Training or competition may depress appetite, and fatigue may be so great that rest or sleep may be the desired postexercise activity. Some collegiate athletes need to attend class soon after practice or workouts. The athlete may not consider food and fluid intake the highest priority, but immediate postexercise intake is critical for optimal recovery.

> **What's the point?** Each athlete needs an individualized diet plan to meet daily nutrient requirements with special consideration for the foods and beverages that should be consumed before, during, and after exercise.

Nutrition Periodization

Periodization is a training concept that involves changing the intensity, volume, and specificity of training to achieve specific goals that will enhance performance.

> **Periodization:** Dividing a block of time into distinct periods. When applied to athletics, the creation of time periods with distinct training goals and/or a nutrition plan to support the training necessary to meet those goals.

This same periodization concept is used in sports nutrition to support training and optimize performance. Nutrition periodization is the development of a nutrition plan that parallels the demands of each training cycle (Seebohar, 2004). For example, as training intensity and volume increase or decrease, energy intake must similarly increase or decrease if body composition is to be maintained. When an endurance athlete tapers training prior to competition, carbohydrate intake is increased to help maximize muscle glycogen stores. If the athlete's goal is to increase muscle mass, then a sufficient energy (kcal) and protein intake is needed in addition to the resistance training. Weight loss is a particular challenge because too great of a reduction in caloric intake may undermine training and performance.

A nutrition periodization plan requires an understanding of each athlete's sport. Sports are often broadly categorized, for example, swimming, running, and cycling, but these sports vary tremendously based on the distance covered. Distance athletes in these sports (e.g., 25-K [15.5-mile] open-water swimmer) face vastly different physiological and nutritional demands when compared to sprinters (e.g., 50-meter swimmer). Not surprisingly, sports nutrition recommendations for distance and sprint athletes are very different. Additionally, most sports nutrition recommendations are made for well-trained athletes. Most recreational athletes who do train do so at a reduced level compared to their well-trained counterparts. The nutritional demands for many recreational athletes may not be any greater than for those in the general population that are lightly active. The intensity and duration of exercise are key factors when determining nutrition needs.

Table 10.3 groups sports together based on the physiological demands of training and competition. Such a categorization is useful to convey basic nutrition guidelines to coaches and athletes, especially those who are just beginning to learn about sports nutrition. For example, although soccer, basketball, and ice hockey are different sports, nutrition recommendations are similar. In general, recommended daily carbohydrate intake is 6–8 g/kg, increasing up to as high as 10 g/kg during heavy training and competition to replenish severely depleted glycogen stores. Protein recommendations are typically 1.4–1.7 g/kg with intakes at the higher end of the range recommended during training periods when the athlete's goal is an increase in muscle mass. These recommendations are more similar to those made to distance runners than they are to baseball players or golfers.

Although some sports may have similarities, it is also vital to understand the unique demands of each sport. Maintaining proper hydration is important for both soccer and ice hockey players, but soccer players have less access to fluids during competition than hockey players who are frequently substituted and can sip fluids when they are not on the ice. Hockey players, however, are fully clothed so they may sweat heavily but not evaporate the sweat, the primary mechanism for lowering body temperature. Each of these athletes needs an individualized fluid replenishment plan.

Although both are members of a track team, sprinters and throwers have different body composition goals.

Body composition goals vary between sports and among athletes within the same sport. For example, very-high-intensity, very-short duration track and field athletes benefit from high muscularity, but sprinters also benefit from a relatively low percentage of body fat while throwers (e.g., discus) benefit from having a percentage of body fat that is higher than most other athletes. Within a team sport, players may be distinguished by position and have different body composition goals as is the case of interior linemen and linebackers on a (American) football team. Each athlete needs an individualized training and nutrition plan and sports dietitians are trained to create such plans.

Nutrition periodization is comprehensive and requires a thorough understanding of the athlete's training, demands of competition, body composition goals, macronutrient needs, and dietary preferences. Spotlight on a Real Athlete, later in this chapter, describes the training and competition schedule and body composition goals of Annika, a female collegiate rower in an eight-person boat. The performance goal is to attain the fastest time in each 2,000-meter race as well as to try and break the 7-minute mark.

In summary, nutrition periodization is a relatively new term, but the concept of a nutrition plan to support training and improve performance is well established. It is imperative that those who work with a variety of athletes understand the training and competition demands, of each sport. Sports may be grouped into categories based on similar physiological demands, and general nutrition recommendations can be made. Sports dietitians can then guide individual athletes in the development of a personalized nutrition periodization plan.

Table 10.3 Summary of Training Demands, Body Composition Goals, and General Nutrition Guidelines for Various Sports

Category	Description	Predominant Eneregy System	Typical Sports	Body Composition	General Nutrition Guidelines (daily)
Very high intensity, very short duration	Maximal effort of less than 30 seconds	Creatine Phosphate Anaerobic Glycolysis	Track and field: Sprints (50–200 m); Jumps (hurdles, high jump, long jump, triple jump, pole vault); Throws (shot, javelin, discus, hammer); Swimming sprints (50 m); Cycling sprints (200 m); Weight lifting; Power lifting	High muscularity; low body fat except for throwers and power lifters	CHO: 5–8 g/kg Pro: 1.2–1.7 g/kg Fat: Remainder of kcal to meet energy needs Fluid: Losses may high if training in high temperature, high humidity environments and need to be replaced during and after training
High intensity, short duration (continuous)	Exercise lasting between 30 sec and 30 minutes	Anaerobic Glycolysis Oxidative Phosphorylation	Running (200–1,500 m and elite 10 km); Swimming (100–1,500 m); Short distance cycling (individual and team pursuit); Rowing (crew); Figure skating; Speed skating (500 m to 5,000 m); Downhill mountain biking	High power-to-weight ratio; relatively high muscularity and relatively low body fat	CHO: 5–8 g/kg Pro: 1.2–1.7 g/kg, reflecting need to maintain or increase muscle mass Fat: Remainder of kcal to meet energy needs Fluid: (See above)
High intensity, short duration (intermittent)	Each exercise bout lasts for seconds or minutes and is repeated with some rest periods	Anaerobic Glycolysis Oxidative Phosphorylation	Gymnastics; Wrestling; Boxing; Martial arts (various); Body building	High power-to-weight ratio; high muscularity and low body fat. Weight may have to be certified; Appearance is scored in body building and may influence the scoring in women's gymnastics	CHO: 5–8 g/kg, Pro: 1.2–1.7 g/kg, reflecting need to maintain or increase muscle mass Fat: Remainder of kcal to meet energy needs Fluid: (See above); Athlete may have restricted fluid in an effort to "make weight" and should replenish fluid as soon as possible after weight-in
Intermittent, high intensity ("Stop and go")	Exercise is a combination of sprints, moderate intensity exercise and low intensity activity or rest. The length of the event is typically one or more hours	Anaerobic Glycolysis Oxidative Phosphorylation	Team sports: Soccer; Basketball; ice and field hockey; Rugby; (American) Football; Lacrosse; Volleyball; Individual sports (may also involve 1 or 3 other players): Tennis; Handball; Racquetball; Squash	Varies according to sport, position, the amount of area that must be covered, the frequency that players are substituted, and the relative need for speed, strength, and power	CHO: 6–8 g/kg; 8–10 g/kg during heavy training and competition Pro: 1.4–1.7 g/kg, reflecting need to maintain or increase muscle mass Fat: Remainder of kcal to meet energy needs Fluid: Losses may be high and difficult to replace during training and competition Sodium: Losses may be high when exercise is greater than 2 hours and needs to be replaced during or after exercise

continued

Table 10.3 Summary of Training Demands, Body Composition Goals, and General Nutrition Guidelines for Various Sports (continued)

Category	Description	Predominant Eneregy System	Typical Sports	Body Composition	General Nutrition Guidelines (per day)
Endurance and ultraendurance	Continuous exercise lasting more than one hour; typically continuing for many hours	Oxidative Phosphorylation	Distance running (cross country, marathon); Distance swimming (25 km open water); Distance cycling (100 km or more); Cross country skiing. Ultra sports involve longer than usual endurance distances (triathlon, swimming the English Channel, multiday bike rides)	Excessive body fat is not desirable because it represents nonforce-producing weight that reduces exercise efficiency. A low percentage body fat that can only be attained or maintained with restriction of caloric intake is also not desirable.	Can vary widely depending on intensity and duration of exercise during training and competition CHO: 5–7 g/kg, when training is reduced, increasing up to 12–19 g/kg with heavy training or ultradistance competitions Pro: 1.2–2.0 g/kg Fat: 0.8–2.0 g/kg to meet energy needs Fluid: Losses typically high and difficult to replace during training and competition Sodium: Losses may be high and need to be replaced during or after exercise
Low intensity (intermittent)	Some maximal effort but majority of exercise is low intensity. Event lasts for several hours	Oxidative Phosphorylation	Golf; baseball	Body composition plays a lesser role in these sports than in many other sports	Follow general principles outlined in the Dietary Guidelines for Americans Fluid: Losses may be high in high temperature, high humidity envirmonments and need to be replaced during and after exercise

Legend: m = meter; g = gram; kg = kilogram; km = kilometer; CHO = carbohydrate; Pro = protein

Compiled from Chapters 21–26 of *Sports Nutrition: A Practice Manual for Professionals,* 4th ed., Dunford, M. (ed.). The American Dietetic Association, Chicago, IL.

Caffeine and Alcohol

The human body requires neither caffeine nor alcohol but both are consumed, so each is included in general dietary discussions. For those who choose to consume caffeine or alcohol, moderation is recommended.

CAFFEINE

Caffeine is the most widely consumed, self-administered **psychotropic** drug in the world. However, it is legally and socially acceptable, so it stands apart from other drugs. Caffeine is found in many beverages and a few foods and is considered part of a normal diet. The primary active ingredient in caffeine is methylxanthine. Caffeine is considered safe at low concentrations, although there are side effects, including addiction. Athletes use caffeine for a number of reasons, including performance enhancement, weight loss, and central nervous system stimulation. Caffeine can improve performance due to a heightened sense of awareness and a decreased perception of effort. At certain urinary concentrations caffeine is considered a banned substance by some sports-governing bodies, but such levels would not be reached with normal food and beverage consumption.

Caffeine Content of Foods and Beverages. Caffeine is found in foods, beverages, and medications as shown in Table 10.4. In the United States, when caffeine is added to a food or beverage it must appear in the list of ingredients, but the amount added is not required to appear on the label. The caffeine content of most beverages is listed on the manufacturer's website.

Table 10.4 Caffeine Content of Selected Foods, Beverages, and Medications

Product	Caffeine Content (mg)
Brewed coffee (8 oz)	80–135
Instant coffee (8 oz)	65–100
Expresso coffee (2 oz)	~100
Decaf coffee (8 oz)	5
Brewed tea, hot or iced (8 oz)	~50
Most soft drinks (12 oz)	35–45
Mountain Dew (12 oz)	55
Red Bull energy drink (8.3 oz)	80
Expresso Hammer Gel (36 g)	50
Milk chocolate (1.5 oz)	10
Dark chocolate (1.5 oz)	30
Coffee ice cream or yogurt (~1 cup)	45–60
Excedrin (2 caplets)	130
Vivarin, maximum strength NoDoz, or caffeine tablets (1 tablet)	200
Ripped Fuel Extreme	220
Stacker 3	250

www.cspinet.org/new/cafechart.htm, manufacturers' websites
Legend: oz = ounce; g = gram

Safety of Caffeine. Caffeine is considered safe for most adults although it has several known side effects. Blood pressure is increased both at rest and during exercise, heart rate is increased, gastrointestinal distress can occur, and insomnia may result. The side effects are more likely to occur in people who are caffeine naïve (i.e., do not routinely consume caffeine). For routine users, some tolerance to caffeine's effects develops. Developing tolerance means that the user must increase the dose to produce the desired effect. Caffeine is addictive and sudden withdrawal results in severe headaches, drowsiness, inability to concentrate, and feelings of discontent. Addiction has been documented with doses as low as 100 mg daily (Evans and Griffiths, 1999).

Caffeine is difficult to study because most people do not ingest pure caffeine; rather, they ingest it as a beverage that contains other compounds. Studies of caffeine consumed via coffee, tea, or soft drinks cannot be directly compared. Many study results are conflicting. For example, some studies have shown that caffeine users are not at risk for elevated blood pressure while other studies have shown an increase in blood pressure with caffeine use (Winkelmayer et al., 2005; Noordzij et al., 2005; James, 2004). A common guideline is that moderate doses of caffeine, defined as 200 to 300 mg daily, are considered to be safe. Caffeine consumption greater than 500 mg per day is associated with anxiety, irritability, insomnia, headaches, and gastrointestinal distress.

A daily caffeine intake of up to 300 mg does not seem to affect an athlete's hydration status. This amount of caffeine has about the same diuretic effect as water, which is mild. Excess losses of water or electrolytes are not expected with moderate daily doses of caffeine (Maughan and Griffin, 2005; Armstrong, 2002). However, some athletes do abuse caffeine. For example, wrestlers and bodybuilders may use caffeinated beverages in the final stages of "cutting" weight because it is a mild diuretic and a stimulant that masks fatigue. The use of caffeine in the already hypohydrated individual is a concern because it can exacerbate the degree of dehydration and contribute to life-threatening medical conditions.

Psychotropic: Capable of affecting the mind.

Effectiveness of Caffeine as a Performance Enhancer. In the late 1970s when some scientific evidence emerged that caffeine could enhance endurance performance, distance athletes began to consume caffeine to optimize performance (Costill, Dalsky, and Fink, 1978). The rationale for its use was that caffeine enhanced fatty acid utilization during endurance exercise, which theoretically could reduce muscle glycogen usage. In other words, caffeine was purported to have a glycogen-sparing effect, a distinct advantage in long-endurance events. Later research revealed that

SPOTLIGHT ON A REAL ATHLETE

Annika, a Collegiate Rower

The collegiate rowing (crew) season begins in late August or September. Fall is the preparation period (general training) and lasts until December. Team practices are generally 2½ hours, six mornings per week, alternating between land and water. Land practices consist of a warm-up period followed by a cardiovascular workout using Erg (rowing) machines and a cool-down period. Also included are one-eighth-mile uphill runs repeated 10 to 12 times and circuit training with weights at approximately 30 stations (e.g., low resistance, more repetitions for endurance). Practices on the water involve 1 hour of continuous rowing but at only 70 percent of the maximum stroke rate with a focus on technique. In addition to morning team practice, individual secondary workouts are held three times per week and include 1 hour of cardiovascular work and 30 minutes of weight lifting. During the secondary workouts, heavier weights are used but with fewer repetitions to build strength.

Beginning in January, practices are more frequently held on land and generally last 3 hours, five to six mornings per week. The focus is on rowing power and technique rather than on speed. Secondary workouts put more emphasis on weight lifting to build muscle mass and increase strength. The opening of the crew season is traditionally marked by “double days,” usually held during spring break. Double days consist of training from 5 to 9 a.m. and from 2 to 5:30 p.m.

Spring is racing season. On-water training takes place on four consecutive days (Monday through Thursday) and the focus is on sprints, the middle 1,000 meters of the race, and starting technique. The intensity of much of the training session is high, but of short duration. Secondary workouts are required three days per week, but the goal is to maintain the muscle mass gained in the preseason, not to build muscle mass.

Races are held nearly every weekend so practices are Monday through Thursday, and Friday is a rest or travel day. In meets with many teams, heats are run in the morning and the finals are about 5 hours later. Some meets may take place over two days. Although rowers train for hours on a near daily basis, the typical race is only 2,000 meters and takes women 8 minutes or less to complete. The race starts with an extremely high stroke rate (38 strokes per minute) and then settles into race pace (32 strokes per minute). The last 500 meters is a sprint and rowers try to increase the stroke rate from 32 to 38 strokes per minute.

Racing season lasts until May or early June and many rowers de-train as soon as the season is over. Rowers are typically physically and mentally fatigued after nearly nine months of continuous training and need an off-season. Most do not engage in exercise or training and many experience body composition changes including loss of muscle mass and small increases in body fat.

Figure 10.13 illustrates a nutrition plan that reflects a female collegiate rower’s one-year training schedule. Annika weighs 156 lb (71 kg) and has 15 percent body fat during the competitive season, which she considers optimal for performance. At the end of the active recovery period (off-season) her scale weight is 159 lb (72.3 kg) and she has gained 8.5 lb (~4 kg) of body fat and lost approximately 5.5 lb (2.5 kg) of muscle mass. This change in body weight and composition is a result of planned inactivity during the active recovery period and a failure to reduce caloric intake in proportion to the reduction in energy expenditure after the end of the competitive season.

Annika’s goals in the seven-month preparation period (preseason) include returning to her competitive body weight and composition, which means she must lose some body fat and gain some muscle mass. The sports dietitian that she consults with suggests that Annika work first to reduce body fat and try to protect the amount of muscle mass she has at the beginning of the season. They discuss Annika’s dietary intake in the off-season. Annika realizes that she continued to eat a lot of food even though she was not training and that she overate fatty foods, especially ice cream. The sports dietitian suggests that Annika consume about the same amount of food (37 kcal/kg) as she did in the summer and rely on the increased energy expenditure resulting from rigorous early season training for a slow weight loss. The sports dietitian also suggests that she alter the composition of her diet and increase the amount of carbohydrates to be able to resynthesize daily the muscle glycogen depleted through endurance training. Annika wants to follow a lower-fat, higher-protein diet, a dietary pattern that she had used in the past to successfully lose body fat.

Following this plan, Annika lost 6 lb (2.7 kg) of body fat by the end of October and weighed 153 lb (69.5 kg). She only wanted to lose a couple more pounds over the next two months, so the sports dietitian suggested that she increase her energy intake slightly (from 37 to 39 kcal/kg) to slow the weight loss. When Annika went home for winter break she weighed 150 lb (~68 kg).

Annika’s goals changed when she returned to campus in January. Her new goal was to increase 5 pounds of muscle mass. An assessment of her body composition revealed that she weighed 150 lb (~68 kg), of which approximately 126 lb (~57 kg) were fat-free mass (84 percent) and 24.5 lb (~11 kg) (16 percent) were body fat. Another meeting with the sports dietitian resulted in a while caffeine may enhance fatty acid mobilization during endurance exercise, fat oxidation is not significantly increased, nor is muscle glycogen spared. Currently, the consensus view is that caffeine may be an effective **ergogenic** aid, not because of enhanced fatty acid mobilization but because of its role as a central nervous system stimulant (Doherty and Smith, 2005; Graham, 2001; Graham and Spriet, 1995; Spriet, 1995).

It appears that caffeine improves endurance performance because of a heightened sense of awareness and

One-Year Training and Nutrition Plan for a Female Collegiate Rower												
	Preparation							Competition		Transition		
	General Training				Specific Training			Racing Season		Active Recovery ("off-season")		
	Emphasis on endurance/cardiovascular			Rest	Emphasis on strength/power, increased muscle mass			Weekly competitions		Rest		
	19.5 hrs training/wk			Rest	22.5 hrs training/wk*			12 hrs training/wk + 1–3 races/wk		No training		
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Weight	155 lb	153 lb	150 lb	150 lb	152 lb	154 lb	156 lb	156 lb	156 lb	155 lb	157 lb	159 lb
BF/FFM (%)	18/82	17/83	16/84	16/84	16/84	16/84	16/84	15/85	15/85	17/83	18.5/81.5	20/80
BF (lb)	28	26	24.5	24.5	24.5	24.5	25	23.5	23.5	26	28	32
FFM (lb)	127	127	126	126	128	130	131	132.5	132.5	129	128	127
Energy	37 kcal/kg (~2,600 kcal)		39 kcal/kg (~2,650 kcal)		44 kcal/kg (~3,080 kcal)			40 kcal/kg (~2,840 kcal)		35–37 kcal/kg** (~2,485 to 2,625 kcal)		
CHO (g/kg)	7		7		8			7		5		
Pro (g/kg)	1.2		1.4		1.6			1.5		0.8		
Fat (g/kg)	0.5		0.6		0.6			0.7		1.4		

Figure 10.13 Nutrition Periodization for a Female Collegiate Rower

Legend: wk = week; lb = pound; kcal = kilocalorie; kcal/kg = kilocalorie per kilogram body weight; g/kg = gram per kilogram body weight; BF = body fat; FFM = fat-free mass; CHO = carbohydrate; Pro = protein

*Double days (1 week prior to racing season).

**Athlete has not reduced caloric intake in proportion to reduced energy expenditure, is choosing to consume a higher fat diet, and is gaining body fat and losing fat-free mass.

different dietary plan for the second part of the preparation period. Since the hours of training per week are increased and Annika wants to gain muscle mass, the sports dietitian suggests that she increase her energy intake to 44 kcal/kg. Annika decides to increase her caloric intake by slightly increasing the carbohydrate and protein content of her diet rather than increasing her fat intake. Even though some of her teammates eat a lot of fatty foods during this high-energy-expenditure period, Annika prefers a lower-fat diet. By the end of the preparation period, a physically and mentally demanding three months, Annika had gained about 5 lb (~2.2 kg) of fat-free mass and weighed 156 lb (71 kg) (~16 percent body fat).

The beginning of racing season is marked by double days, one week of intense training twice a day. Annika knows from previous seasons that she will lose a couple of pounds of weight during this week because her energy expenditure is so high and she does not have much appetite after two-a-day workouts. By the time the competitive season begins, seven months after returning to training, Annika has met all her weight and body composition goals and is 156 lb (71 kg) and 15 percent body fat. Her in-season energy intake (40 kcal/kg) needs to be lower than the previous three months because of a lower training volume. However, Annika needs to consume sufficient carbohydrates so muscle glycogen is restored after each training session and competition. To prevent the gain of body fat during the next active recovery period (off-season), Annika will need to reduce energy intake to match her energy expenditure.

a decreased perception of effort. Individuals that are not habituated to regular caffeine use more readily experience these benefits. Some strength athletes also use caffeine for the purpose of activating muscle fibers. Caffeine may have an effect on recruitment of muscle for exercise by reducing the motor unit recruitment threshold and enhancing nerve conduction velocity. It may also have a direct effect on muscle by altering calcium release kinetics by the sarcoplasmic reticulum (Graham, 2001). Caffeine's effectiveness as a performance enhancer is a result of its stimulatory properties.

Effectiveness of Caffeine for Weight Loss. Although athletes may state that they use caffeine to lose body fat, studies have not shown that caffeine, by itself, has a substantial effect on fat or weight loss. However, caffeine does enhance the effect of ephedrine, a dietary supplement used for weight loss. Ephedrine and caffeine for weight loss are discussed in Chapter 11.

Caffeine as a Banned Substance. In the past, caffeine was banned by many sports-governing bodies including the International Olympic Committee (IOC). In 2004, the IOC moved caffeine from its Prohibit List to its Monitoring Programme. This move allows athletes to take cold remedies, which often contain caffeine, and drink caffeinated beverages without risk of disqualification. The National Collegiate Athletic Association (NCAA) lists caffeine under banned stimulants. Based on post-competition urine analysis, a urinary caffeine concentration exceeding 12 mcg/ml would be considered a positive test and subject the athlete to disqualification (NCAA Bylaw 31.2.3). However, such a concentration would be very difficult to reach via normal food and beverage intake (e.g., 6–8 cups of caffeinated coffee 2 to 3 hours prior), and the equivalent amount of caffeine-containing tablets would likely impair performance in other ways (e.g., shaking, rapid heartbeat).

ALCOHOL

In the context of this textbook, alcohol refers to the consumption of ethanol. Alcohol consumption is described as "drinking," and one drink is defined as ½ oz (~15 ml) of ethanol. Three to 4 oz (90 to 120 ml) of wine, a 10-oz (300-ml) wine cooler, a 12-oz (360-ml) beer, or 1½ oz (45 ml) of hard liquor (e.g., a "shot" of whiskey) each contain approximately ½ oz (15 ml) of ethanol. Moderate alcohol intake is defined as the consumption of up to one drink per day for women and up to two drinks per day for men. A widely accepted definition of binge drinking is four or more drinks by a female and five or more drinks by a male at one time. The NCAA only bans alcohol use by athletes in the sport of rifle (NCAA Bylaw 31.2.3 Banned Drugs); however, many colleges and universities have team rules that ban alcohol or limit its consumption by players who are of legal drinking age. Alcohol contains 7 kcal/g and one "drink" typically provides ~100 to 150 kcal (see Table 10.5).

Table 10.5 Caloric Content of Alcohol-Containing Beverages

Beverage	Serving Size (oz)	Energy (kcal)*
Beer, regular	12	150
Beer, stout	12	190
Light beer	12	100–125
White wine	4	80
Red wine	4	100
Dessert wine	4	190
Wine cooler	10	150
Whiskey, 80 proof	1.5	100
Champagne	4	85
Margarita (tequila, triple sec, lime juice)	3	170
Singapore sling (gin, lemon juice or sour mix, club soda, cherry brandy, grenadine)	8	230
Tequila sunrise (tequila, orange juice, grenadine)	5.5	190

Legend: oz = ounce; kcal = kilocalorie

*Energy content will vary depending on the brand or the prportion of ingredients in mixed drinks.

Alcohol Use by Athletes. Information about athletes' alcohol consumption is primarily derived from studies of collegiate athletes. A limited number of studies have found that college athletes consume more alcoholic drinks per week, binge drink, and engage in risky behaviors more often than nonathletes (Martens, Cox, and Beck, 2003; Miller et al., 2002). These patterns are more likely to occur in males. Athletes use alcohol as a coping mechanism and it provides them temporary stress relief and elevated mood. However, there are a number of negative consequences, including depression, physical injury, poor school performance, and legal problems associated with driving under the influence and other inappropriate behaviors. Some athletes are likely to use alcohol as a medication for underlying psychiatric conditions such as depression and anxiety. Self-medication for these conditions is not recommended and alcohol is an especially poor choice as a treatment because alcohol use both causes and extends depression.

Effect of Alcohol on Training or Performance. A limited number of studies have been conducted on the effects of alcohol on training and performance. Shirreffs and Maughan (2006) reviewed recently published evidence and described potential negative effects on glycogen metabolism, hydration, thermoregulation, and the ability to exercise after previous alcohol use. Alcohol's effects appear to be indirect and are subject to substantial individual variation.

Binge drinking after glycogen-depleting exercise may result in a low carbohydrate intake, which reduces the body's ability to resynthesize muscle glycogen. In the one study conducted (Burke et al., 2003), when the majority of dietary carbohydrates were replaced with 120 g of alcohol (~11 drinks in Australia) after prolonged cycling, glycogen synthesis was reduced by 50 percent at 8 hours and 16 percent at 24-hours when compared to the control group that did not replace dietary carbohydrates with alcohol. There was no statistical difference in glycogen storage of the control and treatment groups when 120 g of alcohol was taken in addition to, rather than as a substitute for, dietary carbohydrates. However, this amount of alcohol consumption increased the caloric content of the diet by 10.5 kcal/kg (e.g., ~800 kcal in a 75-kg person).

Alcohol may be counterproductive as a rehydration strategy because alcohol has a diuretic effect (see Chapter 7). Dilute solutions of alcohol (up to 2 percent alcohol) have a similar rehydration effect to alcohol-free beverages in that the fluid itself causes some diuresis. Concentrated alcohol solutions (4 percent or more) result in negative fluid balance. Shirreffs and Maughan (2006) estimate that 25 ml (~0.8 oz) of a 40 percent ethanol solution contains approximately 10 ml of alcohol and 15 ml of water. This solution induces a urinary output of about 100 ml, so the net loss of water is 85 ml or about 3 ounces of water. To place this information in perspective and to estimate the amount of fluid that may be lost due to diuresis, the percentage of alcohol contained in a beverage must be known. In the United States, the approximate alcohol percentage of beer is 4 to 4.5 percent, wine is 15 to 20 percent, and one "shot" of hard liquor is 30 to 50 percent. These are all concentrations of alcohol that are associated with negative fluid balance to varying degrees.

Alcohol intake prior to exercise performed in low environmental temperatures is not recommended because it can reduce core temperature. Binge drinking the day prior to performance is not recommended because it may impair next-day performance even though blood alcohol concentration is zero (i.e., "hangover" effect). Alcohol intake immediately prior to exercise is never recommended because it can impair judgment (Shirreffs and Maughan, 2006).

Negative and Positive Effects of Alcohol on Health. Alcohol can be both detrimental and beneficial to health, depending on the amount consumed as well as the pattern of consumption. Alcohol use can lead to addiction, aggressive behavior, poor judgment, automobile deaths, homicide, and suicide. Its moderate use is related to a number of chronic diseases and it may have a beneficial effect on three—cardiovascular disease, stroke, and diabetes. However, alcohol use has a detrimental effect on a large number of chronic diseases, including mouth, esophageal, liver, and breast cancers, depression, epilepsy, hypertension, hemorrhagic stroke, and cirrhosis of the liver (Reynolds et al., 2003; Rehm et al., 2003).

Moderate alcohol intake may be beneficial for reducing risk for cardiovascular disease, stroke, and diabetes because of its ability to increase high-density lipoproteins and its effects on blood clotting. Consumption of alcohol in quantities greater than moderate can cause stroke, cardiac arrhythmias, and elevated blood pressure (Reynolds et al., 2003; Rehm et al., 2003). The benefits of alcohol intake are clearly associated with *moderate* use.

Dietary Supplements

Proper diet is fundamental to good health and athletic performance. Athletes recognize its important roles but many find it difficult to consume a diet that supports training. Athletes spend millions of dollars on dietary supplements each year in the belief that their use will help them improve their athletic performance or make them healthier. While some dietary supplements may have this effect, others may have the opposite effect, resulting in impaired performance or health. Although rare, dietary supplements have actually contributed to or caused the deaths of some athletes. Athletes could also unintentionally consume a banned substance since the purity of dietary supplements can vary.

Consuming a diet that supports training and good health is a long-term investment. Like any other long-term project the benefits may not be evident on a day-to-day basis. Athletes looking for a "quick fix" will not likely find it through diet alone. One of the lures of dietary supplement use is the possibility of immediate results. Many supplements are advertised as the newest and fastest way to enhance performance, and the promise, hope, and hype are often hard to resist. Some dietary supplements are also ergogenic aids. An ergogenic aid is any substance or strategy that improves athletic performance, but the term is often used to describe substances or techniques that increase the production of energy or the ability to do work. Many ergogenic aids

Ergogenic: Ability to generate or improve work. Ergo = work, genic = formation or generation of.

are drugs or medical procedures (e.g., **blood doping**) but some, such as creatine, are dietary supplements.

Before consuming any dietary supplement or using any ergogenic aid, the athlete should answer four questions: Is it legal? Is it ethical? Is it safe? Is it effective? It is critical for athletes, parents, coaches, trainers, sports dietitians, exercise physiologists, physicians, and anyone else involved in sports medicine to learn about dietary supplements and ergogenic aids and how to address this ever-changing aspect of athletics. Many people do not realize that dietary supplements are loosely regulated in many countries including the United States

Information about the Dietary Supplement Health and Education Act (DSHEA) can be found in Chapter 1. In brief, the following points should be kept in mind anytime an athlete considers consuming a dietary supplement:

1. Regulation of dietary supplements in the United States is minimal. Federal law does not ensure the safety or effectiveness of any dietary supplement.
2. Dietary supplements may contain banned substances and could result in forfeiture, penalties, and banishment from the sport (see Appendix L for a list of drugs banned by the NCAA).
3. Most dietary supplements have not been studied in trained athletes and few have a large body of scientific literature regarding safety and effectiveness. A notable exception is creatine.
4. There are few dose-response studies of dietary supplements. Dose-response studies are important to determine ineffective doses, the most effective dose, and the dose at which toxicity symptoms begin to appear.
5. The manufacturer suggests the dose and amount to be taken daily that appear on the supplement label. These quantities may or may not reflect the dose and amount used in research studies.
6. Few dietary supplements have been shown to enhance performance and their effects on performance are relatively small.
7. Some dietary supplements have been shown to be detrimental to performance.
8. There is no substitute for disciplined training and proper diet.

THE PROFESSIONAL'S ROLE IN DISCUSSING SUPPLEMENTATION WITH ATHLETES

Practitioners will have little credibility with athletes if they simply dismiss the use of dietary supplements. Regardless of the practice setting, practitioners can play a very important role. Those with scientific training can explain the purported physiological mechanisms and effects and discuss how a supplement might benefit or harm the individual athlete. The complexity of the dietary supplement issue requires that recommendations be evidence based and individually considered. Some information is available on the label of the supplement (see Spotlight on Supplements: Understanding a Dietary Supplement Label), but the label does not include information about safety and effectiveness. Serious discussion needs to take place to determine if, and how much, of a supplement would be safe and effective for an athlete to use. Such decisions should not be made on a whim by the athlete and should not be taken lightly by the practitioner.

Healthcare professionals, such as physicians and dietitians, are trained to recommend use of a supplement on the basis of proven safety and effectiveness in humans. Most athletes are concerned about safety but are willing to *hope* that it will be effective. Some athletes are so focused on trying to improve performance that they are willing to sacrifice safety and long-term health. With such differences in philosophy it is easy to understand why there are disagreements and controversies about the use of dietary supplements (Schwenk and Costley, 2002).

It is the professional's role to provide as much unbiased information as possible to the athlete. This includes the established safety and effectiveness profile in humans, the yet-to-be established information extrapolated from animal studies, and the policies of the governing bodies of the athlete's sport. Pros and cons, risks, and benefits should be part of the discussion. It is unethical to suggest that the information is unbiased if the athlete's supplement purchase would mean monetary gain for the person giving the information. In other words, anyone selling a supplement is not an unbiased source of information. Athletes should be aware that individuals who sell dietary supplements might be involved in multilevel marketing (MLM). MLM is a form of direct sales that allows a person (distributor) to buy a product wholesale and resell it. Sales goals may be established and any unsold product is costly to the distributor, so there is pressure to sell a certain amount of product, typically to relatives, friends, and acquaintances. Distributors may also derive income from the sales of other distributors that they have recruited (Barrett, 2001). It bears repeating: anyone selling a supplement for monetary gain is not an unbiased source of information about that supplement's safety and effectiveness.

Ultimately, it is the athlete who must choose if, and how much, of a supplement to consume. This is important because the risk and the benefit should accrue to the same person. It is the athlete who must deal with disqualification and suspension if the dietary supplement, by accident or design, contains a banned substance. The professional's role is to provide athletes with information so wise decisions about dietary supplements can be made. If the professional has concerns about an athlete's

Blood doping: Intravenous (IV) infusion of the athlete's previously withdrawn blood for the purpose of increasing oxygen-carrying capacity.

Understanding a Dietary Supplement Label

The following information must appear on the label of a dietary supplement (see Figure 10.14). The format is similar to the Nutrition Facts label found on food but there are some differences.

Serving size: Similar to the Nutrition Facts label found on food, the serving size must be listed. The information in the Supplements Facts box is based on the serving size listed. Typically the serving size is one capsule or one tablet.

Amount: The quantity of each compound must be listed. Common measures include grams (g), milligrams (mg), and micrograms (mcg or μg). Some supplement labels use older measures, such as International Units (IU), which can be confusing. For example, the Dietary Reference Intake for Vitamin D is expressed in micrograms, but many vitamin D supplements use IU and a conversion is not required to be on the label. For botanicals and herbals, the label must indicate whether the compound is fresh or dried (e.g., powdered). If extracted, then the solvent used to extract the herbal ingredient must appear.

Percent Daily Value: Daily Value (DV) is the amount needed by a person consuming a 2,000- to 2,500-kcal diet. Nutrients that have an established Daily Value, such as many vitamins and minerals, are listed first. The supplement may contain more than 100 percent of the DV and can exceed the Tolerable Upper Intake Level (UL). Botanicals, herbs, and other compounds that do not have a Daily Value established are marked with an asterisk (*).

Ingredient list: The list of ingredients includes both active (e.g., vitamin E) and inactive (e.g., fillers and stabilizers) compounds. The terms in the Supplements Facts box and the ingredient list may have different names, even though the compounds are the same. For example, vitamin E may be listed on the label but the scientific name for vitamin E, alpha-tocopherol, may appear in the ingredients list.

All ingredients must be listed on the label, but they may not all appear in the ingredient list. If the ingredient appears on the display panel as a statement of identity, it need not be listed again in the ingredient list. The term *proprietary blend* is used frequently. The ingredients in a proprietary blend are listed, but the amounts of the substances are not. This term is used to prevent competitors from knowing the exact formulation of a company's product, but it also prohibits consumers from knowing the amount of each ingredient contained in the supplement.

Additional information: Directions for use must appear. This is the manufacturer's recommendation and there is no requirement that the amount recommended be shown to be effective. The directions for use may be greater than the serving size shown, in which case values listed would need to be adjusted. For example, if the serving size is one tablet and it contains 250 percent of the DV but it is suggested that two tablets be taken daily, then the supplement if taken as suggested would provide 500 percent of the DV.

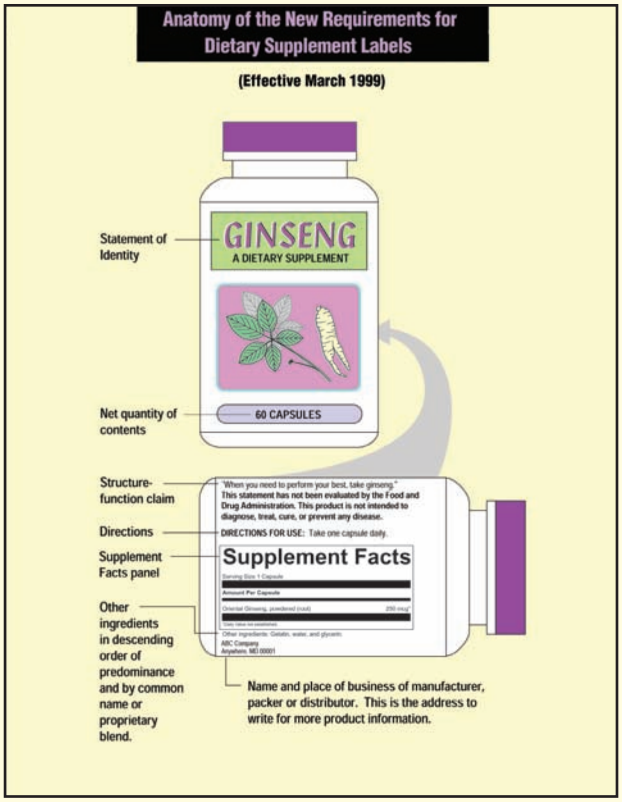


Figure 10.14 Supplement Facts Label

Principal Display Panel: The brand name and the number of tablets in the container must appear. The product must be identified but there are several ways that this can be done. For example, the terms *dietary supplement, vitamin supplement,* or *herbal supplement with vitamins* could all be used to describe the same product.

Health and Structure-function claims: Statements that describe the effect the product has on the structure or function of the body are allowed. Health claims may be made, but therapeutic claims may not be made. Therapeutic claims are those that involve the diagnosis, treatment, or prevention of disease. The statement, "Calcium builds strong bones" is allowable because it is a health claim. The statement, "Calcium restores lost bone" is not allowed because it is a therapeutic claim. Because the Food and Drug Administration does not evaluate structure or function claims, the following statement must appear: "This product is not intended to diagnose, treat, cure, or prevent any disease." Many structure-function claims are written in such a way as to be misleading.

health because of supplement use, it is appropriate to express them.

A dietary supplement is legally defined as a vitamin, mineral, herb, botanical, amino acid, metabolite, constituent, extract, or a combination of any of these ingredients (Food and Drug Administration, 1994). It may be helpful when discussing supplements with athletes to group supplements with similar characteristics together so that they may be compared. In this section, dietary supplements are grouped into five categories: 1) vitamins and minerals, 2) amino acid and protein supplements, 3) supplements related to energy metabolism, 4) supplements for the purpose of weight reduction, and 5) botanical and herbal supplements.

VITAMIN AND MINERAL SUPPLEMENTS

Vitamins and minerals are one of the most widely used supplements by athletes (Greenwood et al., 2000; Jonnalagadda et al., 2001). But how beneficial might they be for improving nutritional health or performance? The answer to that question depends on the athlete's current diet and is determined by comparing the athlete's intake with the Dietary Reference Intakes (DRI) for vitamins and minerals, as discussed in Chapters 8 and 9. This is a good starting point for a discussion of dietary supplements with athletes because the need for vitamin or mineral supplementation can be easily evaluated (see Spotlight on Supplements: Should I Take a Vitamin or Mineral Supplement?).

There is no evidence that athletes consuming a diet that is adequate in energy and nutrients need vitamin or mineral supplementation or that such supplementation will improve performance; therefore, there is no general

Tanya Constantinne/Blend Images/Getty Images

Evaluating the need for a multivitamin and mineral supplement involves estimating current intake, awareness of safe levels, and weighing the risks and benefits.

recommendation for athletes to take a daily vitamin or mineral supplement. However, there are some athletes that will need vitamin or mineral supplement. For example, an athlete whose caloric intake is consistently low, especially if it is due to an eating disorder, is a candidate for a multivitamin and mineral supplementation. A vegan athlete not consuming vitamin B_{12}-fortified foods may need to supplement with vitamin B_{12} because this vitamin is only found naturally in animal-derived foods or specially fortified products. An athlete with iron-deficiency anemia will probably be advised to take an iron supplement. Note that these are individual cases and the decision to supplement is based on the individual's dietary intake, medical condition, and an expected high benefit/low risk outcome. Supplementation in these cases is effective for the prevention and treatment

SPOTLIGHT ON SUPPLEMENTS

Should I Take a Vitamin or Mineral Supplement?

Before answering the question, "Should I take a vitamin or mineral supplement?" determine the answers to the questions listed below. Part of the decision-making process requires the gathering of information, and an important source of information is a dietary analysis of current intake.

1. Do I consume an adequate amount of energy (kcal)?
2. Do I consume an adequate amount of vitamins and minerals?
3. If intake is inadequate, could the missing vitamins or minerals be obtained easily from food?
4. Could a vitamin or mineral supplement be harmful to my health (discuss this with your physician)?

If a decision is made to supplement, more questions should be asked. These include:

1. How much of each vitamin or mineral is in the supplement? In other words, what is the dose?
2. When added to the amount consumed from food, does the total intake exceed the Tolerable Upper Intake Level (UL)?
3. When will I reevaluate my decision (e.g., at the time of my annual physical)?

of a specific vitamin or mineral deficiency. The only population-wide recommendation for multivitamin and mineral supplementation in athletes is for pregnant or lactating athletes. Pregnancy or lactation places increased nutritional demands on the body that are hard to meet from diet alone.

A quick look at the supplement aisle in any grocery store confirms that in addition to multivitamin/mineral supplements, each vitamin and mineral is also sold separately. Of particular interest to athletes are the antioxidant vitamins—C, E, and beta-carotene—and the minerals iron, calcium, zinc, and chromium. Each of these supplements is explained in detail in Chapters 8 or 9. The evaluation process is the same as for a multivitamin and mineral supplement and involves estimating current intake, awareness of uppermost levels that are safe, and weighing the risks and the benefits. Some athletes do lack sufficient antioxidant vitamins in their diets because of a low intake of fruits, vegetables, and plant fats.

AMINO ACID AND PROTEIN SUPPLEMENTS

The recommended protein intake for athletes and the use of protein supplements is fully described in Chapter 5. In general, athletes engaged in training need between 1.0 and 2.0 g protein/kg body weight/day. Protein supplements may contain whey, casein, and soy proteins, some of the same proteins that are found in milk, meat, fish, poultry, eggs, and soy. In the presence of resistance training and adequate kilocalories, proteins from either food or supplement sources are part of a plan to increase muscle size and strength. Protein supplements are not more or less effective than food proteins. Obtaining proteins from food is easy and reasonably affordable. Obtaining proteins from supplements is usually more expensive but may be more convenient because of portability and preparation issues (i.e., adding protein powder to water can be done quickly anywhere). While amino acids and protein supplements are under the dietary supplement umbrella, athletes would be wise to consider them in the context of their overall dietary protein intake (see Spotlight on Supplements: Should I Take a Protein Supplement?)

SUPPLEMENTS RELATED TO ENERGY METABOLISM

Dietary supplements containing vitamins, minerals, and amino acids (proteins) are similar in that these compounds are found in food and there are established guidelines for recommended intake. Since most athletes are not clinically deficient in these nutrients, it is not likely that these supplements will have a substantial impact on the performance of most athletes. Supplements that are related to energy metabolism, known as ergogenic aids, have the potential to positively affect performance. Ergogenic aids, which include more than just dietary supplements, are much different than supplemental vitamins, minerals, or proteins.

In his book *Lore of Running* (2002), Dr. Timothy Noakes estimates the extent to which various interventions enhance performance (Figure 10.15). Training is likely to have the greatest impact on performance. **Carbohydrate loading** prior to and carbohydrate intake during endurance exercise are estimated to improve

Carbohydrate loading: A diet and exercise protocol used to attain maximum glycogen stores prior to an important competition.

SPOTLIGHT ON SUPPLEMENTS

Should I Take a Protein Supplement?

Before answering the question, "Should I take a protein supplement?" determine the answers to the questions listed below. Part of the decision-making process requires the gathering of information and an important source of information is a dietary analysis of current intake.

1. Do I consume an adequate amount of energy (kcal)?
2. How much protein do I need to consume daily?
3. How much protein do I currently obtain from food?
4. If there is a discrepancy between intake and amount needed, could I obtain the additional proteins needed from food?
5. Could a protein supplement be harmful to my health?

If a decision is made to supplement, more questions should be asked. These include:

1. What is the protein content of the supplement?
2. Is one type of protein supplement preferred (e.g., whey, casein, soy)?
3. Does the protein supplement contain other nutrients or ingredients (e.g., vitamins, minerals, artificial sweeteners, lactose)?
4. When will I reevaluate my decision (e.g., at the end of the competitive season)?

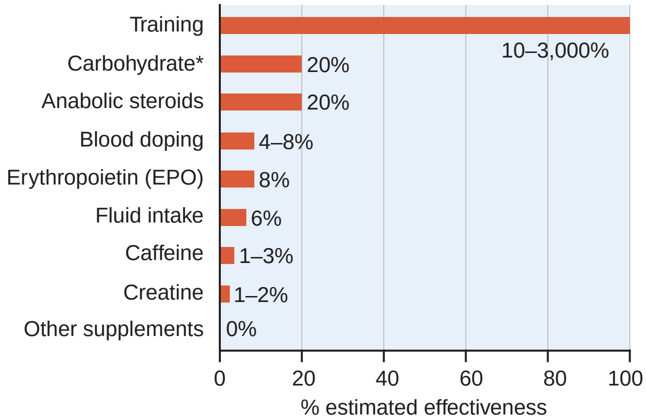


Figure 10.15 Estimated Performance Improvement of Various Interventions

*Carbohydrate loading or ingestion in endurance exercise > 3 hours.

Information adapted from Noakes, T.M. (2002). *Lore of Running,* 4th ed. Human Kinetics, Champaign, IL.

endurance performance by approximately 20 percent. Anabolic steroids are estimated to improve performance of some athletes by 20 percent due to increases in muscle size and strength. The use of blood doping (4 to 8 percent improvement) and **erythropoietin** (8 percent) also enhance endurance performance, but to a lesser degree than carbohydrate loading. Use of anabolic steroids, blood doping, and erythropoietin are illegal and unethical but their ability to impact performance is much greater than any of the dietary supplements used for the same purpose. Assuming that creatine and caffeine supplements are used appropriately, Noakes estimates the performance enhancement associated with these supplements to be low, 1 to 2 percent for creatine and 1 to 3 percent for caffeine. The effect of medium-chain triglycerides, branched-chain amino acids, and L-carnitine is estimated to be zero. Similarly, the

The Internet Café

Where Do I Find Reliable Information about Dietary Supplements?

There are numerous government-sponsored websites that have information on dietary supplements. The two "watch" sites listed below are both dedicated to helping consumers make informed decisions but neither is government-sponsored.

National Institutes of Health, Office of Dietary Supplements
http://ods.od.nih.gov/index.aspx

National Center for Complementary and Alternative Medicine, Dietary and Herbal Supplements
http://nccam.nih.gov/health/supplements.htm

MedlinePlus, Dietary Supplements
http://www.nlm.nih.gov/medlineplus/dietarysupplements.html

SupplementWatch.com
http://www.supplementwatch.com

QuackWatch (nonprofit)
http://quackwatch.org

SPOTLIGHT ON SUPPLEMENTS

ESPN—Every Supplement Produces News—How Professionals Can Keep Up

Dietary supplements do not need premarket approval; thus, once a supplement is developed and ready for sale the supplement company can launch an aggressive marketing campaign. Advertising can create a "buzz" about a dietary supplement that was previously unknown. Going to the manufacturer's website will yield some information about the active ingredients; however, in many cases they are listed as a "proprietary blend" and it is impossible for the professional to know and evaluate the compounds. In such cases, the athlete should be cautioned that the active ingredients in the supplement are not known and there is no way to judge safety and effectiveness. For those athletes who are subject to testing for banned substances, it is imperative that they understand that the supplement could contain an active ingredient that is a banned substance and will subject them to penalty.

If a new supplement lists the active ingredient(s), the professional can find information quickly through a variety of ways. The National Institutes of Health (NIH) provides information through its Office of Dietary Supplements and its National Center for Complementary and Alternative Medicine. MedlinePlus, a service of the NIH and the National Library of Medicine, has extensive information about dietary supplements including a section titled, "latest news." Some commercial sites also conduct scientific reviews and rate products. Website addresses for these resources are listed as part of The Internet Café: Where Do I Find Reliable Information about Dietary Supplements?

Professional journals frequently publish comprehensive reviews about active ingredients found in popular dietary supplements, but such articles take time to research and to write. These review articles are excellent ways to learn about the body of literature that exists. The rapidly changing dietary supplement marketplace requires that the professional be constantly reading new material to keep abreast of scientific research evaluating the safety and effectiveness of sports-related supplements.

Group A (Supported for use by Australian Institute of Sport athletes)
Antioxidants
Bicarbonate
Caffeine
Calcium
Creatine
Electrolyte replacement
Glucosamine
Glycerol
Iron
Liquid meal supplements
Multivitamin/mineral
Sick pack (vitamin C and zinc)
Sports bars
Sports drink
Sports gels

Figure 10.16 Australian Institute of Sport Supplement Group Classification

http://www.ais.org.au/nutrition/SupClassification.asp

Australian Institute of Sport (AIS) has grouped dietary supplements and sports foods into categories based on their safety and effectiveness (Figure 10.16). The performance-enhancing supplements supported for use by AIS athletes include creatine, caffeine, **glycerol,** and **bicarbonate loading.**

Athletes should be aware that most ergogenic dietary supplements, with the exception of those listed above, have not been shown in scientific studies to be effective in improving performance. However, scientific studies of performance-enhancing supplements are limited to determining the general effect on the study population. It is conceivable that some dietary supplements judged ineffective in scientific studies could have a positive (or negative) individual effect. Athletes who wish to experiment with dietary supplements advertised as ergogenic aids should be reminded to fully investigate all four critical aspects—legality, ethics, safety, and effectiveness.

SUPPLEMENTS RELATED TO WEIGHT REDUCTION

Weight reduction, particularly the reduction of body fat, is one of the most difficult goals for humans to achieve and sustain. Athletes typically do not need to lose large amounts of body fat but they may wish to "fine-tune" their body composition for both performance and appearance purposes. In many cases athletes are faced with the need for quick weight loss (e.g., returning to training camp above their optimal performance weight and percentage of body fat). There are many dietary supplements sold for the purpose of stimulating fat loss, but few have enough scientific data to draw conclusions about safety and effectiveness. Of those compounds that have been studied, the study population is usually obese, sedentary females. Data for safety and effectiveness of these supplements by athletes is usually nil or difficult to interpret.

Some of the dietary supplements sold for weight loss are botanical or herbal supplements (see following section). These supplements have active ingredients that are not found in food and their effects are more druglike than foodlike. However, dietary supplements

Erythropoietin: Hormone that stimulates the development of red blood cells in the bone marrow.

Glycerol: A sugar alcohol. Ingestion results in temporary fluid retention and reduction of urine production.

Bicarbonate loading: Consumption of sodium bicarbonate or sodium citrate prior to high-intensity exercise to neutralize the acid produced during high-intensity exercise.

KEEPING IT IN PERSPECTIVE

Where Supplements Fit into the Athlete's Training and Nutrition Plan

To achieve the highest level of success in sports, athletes must be genetically endowed and they must train optimally to meet their genetic potential. Training is fundamental to improving athletic performance and proper nutrition supports the demands of training. In particular, sufficient carbohydrate and fluid intake are essential for successful training and performance. In the postexercise recovery period, the intake of carbohydrates, fluid, electrolytes, and small amounts of proteins will help restore the body and ready it for future training or performance. Nutrition is fundamental to training, which is fundamental to successful performance.

A few dietary supplements (e.g., creatine, caffeine) can augment, but not replace, proper training and good nutrition. The effect of these supplements is comparatively small when considered alongside training and proper diet; however, small effects may be beneficial in some well-trained athletes. To improve performance, athletes would be wise to think "food first, supplements second" and to be an open-minded skeptic.

are regulated as foods, not drugs. A monumental difference between food and drug regulation is that foods are generally assumed to be safe until proven otherwise, while drugs may not be sold until the Food and Drug Administration grants approval based on scientific data of safety and effectiveness. Additionally, most dietary supplements for weight loss are intended for use by obese, sedentary individuals, so an athlete's use of these supplements is considered "off-label." Self-prescribed, off-label usage essentially places the athlete in an unsupervised experimental study of one. The two botanical weight-loss supplements that have the greatest safety concerns are ephedra, which is discussed in Chapter 11, and bitter orange (Dwyer, Allison, and Coates, 2005; Shekelle et al., 2003).

Most other dietary supplements sold to promote weight loss have been shown to have few or no adverse effects. However, studies of these supplements have also shown little to no benefit. Examples of apparently safe but generally ineffective weight-loss supplements include chromium picolinate (see Chapter 9), conjugated linoleic acid, chitosan (Chapter 6), garcinia cambogia, glucomannan, guar gum, beta-hydroxymethylbutyrate (Chapter 5), and yohimbe. Pyruvate and yerba mate are also considered ineffective but data are lacking to determine safety (Dwyer, Allison, and Coates, 2005).

Athletes need reliable information about the safety and effectiveness of dietary supplements for weight loss. Since the effectiveness of such supplements for athletes is suspect, it is important to discuss weight-loss goals with athletes and help them with a well-designed diet and exercise plan for weight loss within a realistic time frame. Often forgotten or ignored is a discussion of how diet might be changed in the off-season to prevent weight gain. These issues are discussed further in Chapter 11.

BOTANICAL AND HERBAL SUPPLEMENTS

Botanicals are compounds that have been extracted from foods and then concentrated. Herbs are plants with nonwoody stems, and herbals are the compounds, known as active ingredients, that are found in those plants. Herbals are often used as alternative medications. Botanicals and herbals have been used for thousands of years and some have excellent safety profiles. For some, safety is very dependent on dose. This means that athletes and other consumers must be diligent in determining which dose will be too little, too much, or just right if they choose to use these products.

Herbal is a loosely defined term and each individual may interpret the term differently. Many consumers use it in the context of a compound that is found naturally in a plant. These compounds are thought to have healing properties and are often used as alternative medicines. The same basic questions apply to any herbal dietary supplement: Is it legal, ethical, safe, and effective? If used as an alternative medicine, then two more questions must be answered: 1) Is it safer, equally safe, or not as safe as the medicine it is replacing? 2) Is it more effective, equally effective, or not as effective as the alternative?

Some of the most popular herbal supplements in the United States are echinacea, St. John's wort, ginkgo biloba, saw palmetto, ginseng, goldenseal, aloe, kava kava, and valerian. Many consumers take these supplements to prevent or treat disease. Herbals used as alternative medicines are beyond the scope of this book, but because herbals are classified as supplements and not medications, it is important for athletes to inform their physicians and pharmacists about the use of herbals, especially to discuss potential interactions with prescription medicines. Discussing herbal supplements with athletes is typically different from discussing vitamin, mineral, or protein supplements because many herbals are compounds that are not normally found in food or provided by the diet.

Botanicals are compounds that have been extracted from foods and then concentrated in pills. Three popular botanical supplements are garlic, soy, and phytochemicals, which are used for health-related but not performance-related purposes. These supplements are popular

THE EXPERTS IN. . .

Sports Nutrition

Sports nutrition is a relatively young field. Two well-known dietitians who have long been involved in sports nutrition are Ellen Coleman, M.A., M.P.H., R.D., CSSD, and Nancy Clark, M.S., R.D., CSSD. Both consult with athletes in training and have written several books on sports nutrition. Bob Seebohar, M.S., R.D., C.S.C.S, CSSD, developed the concept of nutrition periodization that forms the basis of his work with elite athletes, particularly those in endurance and ultraendurance sports. All three are also Board Certified Specialists in Sports Dietetics (CSSD). Dr. Louise Burke, Ph.D., APD, in her role as head of the Department of Sports Nutrition for the Australian Institute of Sport, has published numerous scientific and practice-oriented articles and books. These are among the leaders in the growing field of sports nutrition.

because research studies have shown that when people eat a diet containing substantial garlic, soy, or fruits and vegetables (good sources of phytochemicals) their risk for some chronic diseases is lower. An important point is that the original idea for concentrating these compounds came from studies of people's diets. For example, in Japan, a country where soy is an everyday food, breast cancer rates are low.

When studies show differences in eating patterns and disease risk, it is important to study any diet and disease associations. One of the first questions that must be asked is whether the food has a substantial effect on its own or whether it is part of a larger dietary pattern. For example, is the low incidence and prevalence of breast cancer in Japanese women due solely to their soy intake or is soy part of a healthy diet and lifestyle that also includes fish, vegetables, and daily exercise? Further study may also determine that there is not a diet/disease association. For example, Japanese women may have a genetic predisposition for low rates of breast cancer.

If a food is an independent factor in lowering disease risk, other questions must be answered. What is the active ingredient(s)? How does the active compound work? Can the active ingredient be extracted and concentrated? If concentrated in supplement form, will it be as beneficial as the original food? Could the benefit be greater because the supplement is a more concentrated source? Or will the benefit be less because something is missing in the supplement that is found in food and is a factor in effectiveness? Does a concentrated amount result in unintended effects? Clearly, many questions must be answered to determine the safety and effectiveness of botanical supplements. Questions about botanical supplements are probably best discussed with a physician, dietitian, or pharmacist.

What's the point? Dietary supplementation decisions are a part of the athlete's comprehensive nutrition plan, although the effectiveness of supplementation on training and performance is likely to be small. Minimal regulation of dietary supplements in the United States means that athletes must be careful in choosing dietary supplements.

Summary

The need for energy (i.e., caloric intake) forms the basis of dietary planning. Energy needs vary according to the training cycle and it may be necessary for athletes to moderately restrict energy intake at certain times to reduce body fat. Sufficient carbohydrate and protein intake is necessary to support training, recovery, and performance so these nutrients are considered first. The intake of the other energy-containing nutrients, fats, and alcohol, is determined after carbohydrate and protein needs are established. Eating nutrient-dense foods is the key to consuming an adequate amount of nutrients, particularly vitamins and minerals.

Translating nutrient recommendations into food choices is not easy, and dietary patterns based on food groups can help athletes to plan daily dietary intake. While a preformulated pattern based on a given caloric intake, such as those found on the MyPyramid website, can be helpful, such patterns are only guidelines and must be individualized for each athlete. In addition to the nutrient content of the **diet,** the athlete must consider the timing of intake.

The pre-exercise meal is typically relatively high in carbohydrates, moderate in proteins, relatively low in fats, and provides adequate fluid and energy. Food and fluid consumed during exercise can help delay fatigue and prevent hypohydration but needs to be in a volume and form that minimizes gastrointestinal distress. Postexercise food and fluid intake supports recovery, and recommendations are made for the amount and timing of carbohydrates, proteins, fluid, and sodium intake after exercise ends.

Each athlete will need a comprehensive nutrition plan to support training, achieve desirable body composition, and optimize performance. Known as **nutrition periodization,** this plan outlines nutritional needs over months, weeks, and days of training and competition. Without a well-thought-out plan, the athlete may fall short of the nutrition support needed to meet training and performance goals and to recover from exercise.

The use of dietary supplements is an ever-changing and ever-challenging aspect of sports nutrition. Four critical issues are legality, ethics, safety, and effectiveness. Dietary supplements in the United States are not well regulated, and safety and effectiveness are not assured. Some dietary supplements must be considered in the context of dietary intake since many of the ingredients found in supplements are also found in food. However, since the legal definition of dietary supplements is so broad, some supplements, in particular herbals, are not found in food and are more likely to be used as alternative medicines. Most dietary supplements sold to promote weight loss have been shown to have little or no benefit. Other than creatine and caffeine, most **ergogenic** dietary supplements have not been shown in scientific studies to improve performance. Training, proper carbohydrate and fluid intakes, and electrolyte replacement are fundamental to successful performance and no dietary supplement can match the safety and effectiveness of these practices. Education is key as athletes consider dietary supplement use in the broad context of their training, performance, and health goals.

Post-Test: Reassessing Knowledge of Diet Planning for Athletes

Now that you have more knowledge about diet planning, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. When planning dietary intake, athletes should first consider how much dietary fat would be needed.
2. The key to eating nutritiously without consuming excess kilocalories is to choose foods that have a high nutrient density.
3. There is no room in the athlete's diet for fast foods.
4. After exercise, athletes should wait about an hour before consuming food or fluids.
5. To achieve optimum performance, most athletes will need to use some dietary supplements.

Review Questions

1. Explain two ways to interpret the phrase, "I'm on a diet."
2. What is nutrition periodization? Give examples of how energy or nutrient needs might change across a one-year training cycle.
3. When planning a diet, why is the athlete's energy goal established first?
4. Explain why nutrient density is important. Give examples of foods that are nutrient dense and energy (kilocalorie) dense.
5. What are the advantages to using MyPyramid Food Intake Patterns or exchange lists? Disadvantages?
6. What are the goals of food and fluid intake prior to exercise? During exercise? After exercise? Give example of foods or beverages that would meet those goals.
7. Is caffeine safe and effective? Explain your answer.
8. Describe alcohol use by college males. What effects might alcohol consumption have on athletic performance? What are the negative and positive health effects of alcohol consumption?
9. What is a dietary supplement?
10. How are dietary supplements regulated?
11. What guidelines can be used to determine if nutrient intake is adequate or excessive?
12. Describe the information found on a dietary supplement label. How does the information differ from that found on a food label?
13. What kinds of information should the athlete consider before deciding whether to consume supplemental vitamins, minerals, or amino acids?
14. Are ergogenic dietary supplements effective? Explain your answer.
15. Are dietary supplements safe and effective for weight loss? Explain your answer.

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11 Weight and Body Composition

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Learning Objectives

1. Describe the various components that make up the body's composition.
2. Describe how body composition and body weight are measured, how these results should be interpreted, and how each relates to performance.
3. Explain error of measurement and compare and contrast the measurement error of each method used for estimating body composition.
4. Understand how the relative need for size (weight), strength, and speed in a particular sport is reflected in the body composition of elite athletes in those sports.
5. Calculate target body weight and minimum body weight.
6. Outline the basic principles associated with gaining lean body mass and losing body fat and the most appropriate times during the yearly training cycle to change body composition or weight.
7. Define weight cycling and explain the effects it may have on performance and health.
8. Discuss the legality, ethics, safety, and effectiveness of muscle-building supplements such as anabolic/androgenic steroids and prohormones and weight-loss supplements such as ephedrine and caffeine.

Pre-Test Assessing Current Knowledge of Body Composition and Body Weight

Read the following statements and decide if each is true or false.

1. Percent body fat and fat mass can be precisely measured in athletes with a number of different methods.
2. The most accurate method of measuring body fat for any athlete is underwater weighing.
3. In sports in which body weight must be moved or transported over a distance (e.g., distance running), it is a performance advantage to have the lowest weight possible.
4. To increase muscle mass, most athletes need a substantial increase in their usual protein intake.
5. For athletes who want to restrict energy intake to lose body fat, the recommended time to do so is at the beginning of the preseason or during the off-season.

Body composition and body weight are related to performance, appearance, and health. Body composition, particularly the relative amount of **muscle mass,** has the potential to positively impact exercise and performance. Weight and body composition may have a substantial impact on performance in certain sports, but may play a much lesser role in others. In some sports body weight must be certified before the athlete can participate in that day's competition and the focus, at least temporarily, is achieving a particular scale weight. Body composition and weight influence body image, and the desire to attain a particular body image or weight can be a powerful motivator. An excessive or rapid loss of body weight can produce harmful medical consequences in otherwise healthy individuals. Excess body fat, especially fat that accumulates deep in the abdominal cavity, may influence the onset or progression of chronic diseases and long-term health. Keeping all three areas in mind—performance, appearance, and health—helps athletes maintain the proper perspective when setting body weight and composition goals.

In many sports attaining a relatively high percentage of lean mass and a relatively low percentage of body fat is an appropriate goal that has the potential to improve performance. However, it is not possible to predict the percentage of body fat associated with optimal performance and "lowest" is not necessarily "optimal." Achieving the "most" muscle mass or the "lowest" percentage of body fat possible may not be desirable. For example, the excess weight from skeletal muscle can damage joints and ligaments. Like many other aspects of human physiology, the extremes can be dangerous and most athletes find that their desirable body composition does not lie at the extreme ends of the body composition continuum.

The percentage of body fat of elite athletes in a number of sports has been measured and the results are sometimes used as a guideline for lesser-trained athletes in those sports. Measurements of body fat are just *estimates,* however, and should be interpreted with caution. Individual characteristics such as genetic predisposition to fatness or leanness must be considered so that realistic goals can be set. Trying to obtain an unrealistic percentage of body fat that has been arbitrarily chosen (e.g., a male who wants to be 4 percent body fat) can be unproductive, ineffective, and dangerous.

In sports in which weight must be certified (e.g., wrestling) or judging of performance is subjective and influenced by appearance (e.g., figure skating), a low body weight may be beneficial. Some athletes naturally have a low body weight, but others find themselves using dangerous practices (e.g., voluntary starvation, dehydration) to produce the large or rapid weight loss needed to "make weight." In acrobatic sports, such as gymnastics, a high **power-to-weight ratio** is desirable (i.e., having a lot of muscle to produce force at a minimal body weight). The establishment of a safe minimum body weight is important and must take into account the athlete's current amount of muscle mass, frame size, genetic predisposition to leanness or fatness, and biologically comfortable weight range. Attaining too low of a body weight can come at a cost to both performance and health—reduction of muscle mass, loss of body water, loss of bone mineral density, and initiation of disordered eating behaviors.

Aside from performance-related reasons, appearance may motivate athletes to make body composition changes. Athletes who achieve a body composition that is held in high esteem by society (e.g., lean and muscular, thin and **prepubescent**) receive praise and positive reinforcement. For some, self-esteem is closely tied to body image, and thus, body weight or composition. For these individuals, changes in body composition, especially increases in body fat, may be a source of great concern and unwanted media attention.


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Body composition and weight are important in sports with weight classes (e.g., wrestling) or subjective judging that is influenced by appearance (e.g., figure skating, gymnastics).

To change body composition or weight the athlete must alter energy intake, energy output, or both. The athlete will need a well-thought-out exercise and diet plan that correlates with the demands of each training cycle. To increase muscle mass, an athlete must engage in strength training, consume a sufficient amount of energy (kcal), and be in positive nitrogen balance to support tissue growth. To decrease body fat, energy expenditure must be greater than energy intake. The active recovery (off-season) or the early preseason periods, when training volumes are lower than the precompetition period, are typically the best times for substantial losses of body fat. Many athletes want to simultaneously increase muscle mass and decrease body fat, and achieving both of these goals takes an individualized plan and some trial and error.

In the United States, anything related to the topic of weight loss receives automatic attention, in part, because overweight and obesity are epidemic. Most trained athletes do not need to lose large amounts of body fat. However, small increases or decreases in body fat have the potential to affect performance and appearance, so fat loss is also a hot topic among athletes. Some athletes can gain substantial amounts of body fat in the

Muscle mass: The total amount of skeletal muscle in the body. Expressed in pounds or kilograms.

Power-to-weight ratio: An expression of the ability to produce force in a short amount of time relative to body mass.

Prepubescent: Stage of development just before the onset of puberty.


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Mark Mainz/Getty Images

An athlete's body composition can be important for reasons other than performance.

off-season and want to reduce fat stores rapidly prior to the return to training camp. Athletes are not immune to advertisements or rumors that promise fast and easy fat loss.

For most people, reducing body fat is a relatively slow process, but the loss of body weight can be rapid when achieved primarily by water loss. Athletes who want to reduce body weight rapidly to "make weight" often use a combination of methods including diuretic use and excessive sweating in addition to fasting and increasing exercise. These techniques can result in mild to serious or fatal medical complications.

Measuring body weight and body composition can provide information that can help athletes attain their performance, appearance, and health goals. However, the usefulness of body weight and composition measures depends on their accuracy. Additionally, the results must be interpreted correctly so appropriate goals may be set and progress can be monitored. This chapter begins with a discussion of body composition and weight and some of the methods used to assess each as accurately as possible.

Understanding Weight and Body Composition

The term *body composition* refers to all of the components that make up the body. The human body is composed of an extraordinary variety of different types of cells and materials. Because they are so numerous, these components are often grouped into more general categories for their study and discussion. In the fields of exercise physiology and sports nutrition, body composition is often subdivided into the broad categories of **fat mass** and **fat-free mass.** Fat mass is all of the fat material in the body and fat-free mass is composed of all other tissues in the body that are not fat, the most prominent nonfat tissue being skeletal muscle. Athletes are also interested in the ratio of fat mass to total body mass, which may be expressed as **percent body fat.** The weight of the body is also a factor, particularly in sports with weight categories.

CONCEPTS OF BODY MASS, WEIGHT, AND COMPOSITION

Of primary importance are the specific components of body tissues—total **body mass** (weight), body fat (fat mass), muscle mass, bone mass and density, and fluids. The term *mass* is often used interchangeably with weight, but technically they are not the same. *Mass* is the term that describes the amount of matter or material that makes up an object, while weight is an expression of the force that is exerted by that object due to gravity. To illustrate the difference, consider the mass and weight of astronauts during a space mission. They have the same body mass in space as they do on Earth, but they "weigh" much less in space due to the greatly reduced force of gravity. Because the difference on Earth is minute, the terms *mass* and *weight* are used interchangeably in this text. Other terms commonly used are defined in Spotlight on Enrichment: Understanding Body Composition Terminology.

SPOTLIGHT ON ENRICHMENT

Understanding Body Composition Terminology

Body Mass: Total amount of matter or material of the body; commonly used interchangeably with weight. Expressed in pounds (lb) or kilograms (kg).

Fat Mass (FM): Total amount of fat in the body. Expressed in pounds or kilograms.

Percent Body Fat (% BF): The amount of fat relative to body mass. Expressed as a percentage of body weight.

Fat-Free Mass (FFM): The total amount of all tissues in the body exclusive of fat including muscle, bone, fluids, and organs. Expressed in pound or kilograms.

Essential Fat: The minimum amount of body fat necessary for proper physiological functioning; estimated to be approximately 3 percent of body weight for males and 12 percent for females.

Lean Body Mass (LBM): Total amount of all physiologically necessary tissue in the body; Fat-Free Mass and essential fat (FFM + essential fat). Often used incorrectly to mean the same as FFM. Often used generically when referring specifically to muscle mass (e.g., "strength training results in an increase in LBM"). Expressed in pounds or kilograms.

Muscle Mass: Total amount of skeletal muscle in the body. Expressed in pounds or kilograms.

Bone Mass or Bone Mineral Content (BMC): Total amount of bone in the body. Expressed in pounds or kilograms.

Bone Mineral Density (BMD): The amount of bone per unit area. Expressed in grams per cubic centimeter (g/cm^2).


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Males and females may store fat in different sites, either predominantly in the abdominal area or in the hips, thighs, or buttocks.

Both for athletes and for the general public, the most common distinction in body composition is body fat. Fat in the body is typically categorized as essential or storage fat. **Essential fat** is the minimum amount of body fat necessary for proper physiological functioning and is estimated to be approximately 3 percent of body weight for males and 12 percent of body weight for females. Of the 12 percent, approximately 9 percent is considered sex-specific fat, the fat necessary for proper hormonal and reproductive functions. When compared to male athletes in similar sports, females typically have a higher percentage of body fat than their male counterparts. For example, both male and female bodybuilders are extremely lean; however, the leanest elite female bodybuilders will have a greater percent of body fat than the leanest elite male bodybuilders simply because of the differences in gender.

Storage fat is composed of **subcutaneous fat** and **visceral fat.** Subcutaneous fat is located under the skin and is typically the largest amount of fat in the body. Visceral fat surrounds organs and is located well below the skin, for example, in the abdominal area. Males and females may store fat in different sites, displaying a gender-specific physiological preference for the pattern and location of fat storage. Male fat distribution is described as android and is characterized by fat storage predominantly in the abdominal area. Normal-weight females generally store fat in the hips, thighs, and buttocks, a pattern known as gynoid fat distribution. These typical fat distribution patterns have led to body shape being described as similar to a pear (gynoid) or an apple (android), and may have health implications (see Chapter 12).

However, gender alone cannot explain fat distribution patterns. Females do not always exhibit the typical gynoid pattern due to genetics, menopausal status, and obesity, which may result in a tendency to store excess fat in the abdominal area. Males also differ from one another due to differences in fat distribution within the abdominal region. In some males, excess fat is more readily stored in deep abdominal (i.e., visceral) fat than in subcutaneous abdominal fat. Visceral fat is more metabolically active than subcutaneous fat and is a factor in some chronic diseases as explained in Chapter 12.

Although athletes are interested in body fat, they are also concerned about fat-free mass or the tissues in the body that are not fat. Fat-free mass includes muscle, bone, fluids, and organs. In particular, athletes focus on muscle mass. As with body fat, estimating only muscle mass is difficult, so it is more common to estimate **lean body mass (LBM).** LBM refers to the total amount of all physiologically necessary tissue in

Fat Mass (FM): Total amount of fat in the body. Expressed in pounds or kilograms.

Fat-Free Mass (FFM): Total amount of all tissues in the body exclusive of fat; includes muscle, bone, fluids, organs, etc. Expressed as pound or kilograms.

Percent Body Fat (% BF): Amount of fat relative to body mass. Expressed as a percent of total body weight.

Body mass: Total amount of matter or material of the body; commonly used interchangeably with weight. Expressed in pounds or kilograms.

Essential fat: Minimum amount of body fat necessary for proper physiological functioning; estimated to be approximately 3 percent of body weight for males and 12 percent for females.

Subcutaneous fat: Fat that is stored in a layer under the skin.

Visceral fat: Fat that is stored around the internal organs.

Lean Body Mass (LBM): Total amount of all physiologically necessary tissue in the body; i.e., Fat-Free Mass and essential body fat. Expressed in pounds or kilograms.

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Charles Gullung/Photonica/Getty Images

Body shape is often categorized as ectomorphic, mesomorphic or endomorphic.

$$\textbf{BMI} = \frac{\text{Weight (kilograms)}}{\text{Height}^2 \text{ (meters)}}$$

◀ BMI = body mass index

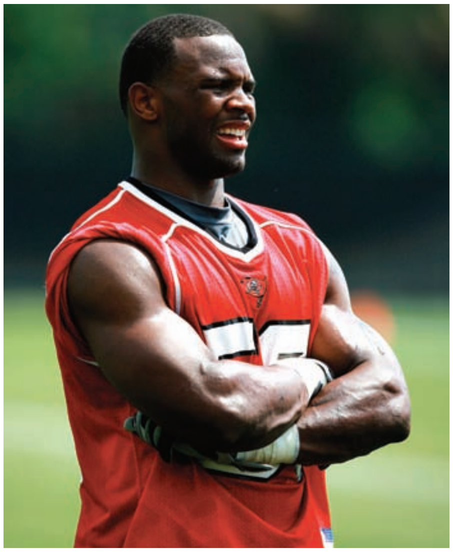
Figure 11.1 Body Mass Index (BMI) kg/m^2

the body and includes fat-free mass and essential body fat. In everyday language, the term *muscle mass* is interchanged with the term *lean body mass* (e.g., “strength training results in an increase in LBM”), but muscle is only one component of lean body mass. Body composition discussions usually focus on body fat and muscle mass and these two components will be the focus of this chapter. Bone density is discussed in Chapters 9 and 12 and fluids are covered in Chapter 7.

Body shape can also enter into body composition discussions. Individuals may be divided into one of three categories based on somatotype or body build: Endomorph, mesomorph, or ectomorph, based upon the work originally published by Sheldon in 1940. Endomorphs are characterized as being stocky with wide hips and a tendency to easily gain body fat, especially visceral fat. Ectomorphs are typically described as being slightly built with less developed muscle mass and fat stores. Many ectomorphs have difficulty gaining weight. Mesomorphs, especially males, can gain muscle mass relatively easily and typically do not have excessive amounts of body fat. Somatotypes may be useful when discussing genetic predisposition and body composition, especially with those who have set unrealistic goals and are struggling with body image problems.

Many people, including athletes, know their usual body weight. Body weight has been used in various ways, either alone or in relation to some other factor such as height. Body weight can be assessed relative to body height, a measurement known as Body Mass Index (BMI). The formula for calculating BMI is shown in Figure 11.1. Appendix N features a nomogram with precalculated BMI. BMI is a screening tool for the general population that helps individuals determine a “healthy weight” range and is not used with athletes. The BMI formula assumes that adult height is stable and that any increase in scale weight is a result of an increase in body fat. The use of BMI as a tool to screen for chronic disease risk in the general population is explained in Chapter 12.

It is inappropriate to use BMI with pregnant females (whose increase in weight is due to more muscle, blood, and fluid, as well as fat), people who have decreased in height due to osteoporosis, or trained athletes. Trained athletes typically have more skeletal muscle and less body fat than sedentary adults. To illustrate, a 6'3" (1.9 m) male athlete who weighs 240 lb (109 kg) would have a BMI of 30 and be classified as obese. As is clear from the photo on the next page, this athlete is not obese; rather, he is lean and his percentage of body fat is



Doug Benc/Getty Images

This athlete is lean and muscular but falls into the obese category by body mass index (BMI).

relatively low. BMI is not an appropriate disease risk screening tool for athletes.

While the use of weight for comparison to others or for tracking individual change over time might be useful, the major problem with the use of body weight is that it gives no information about body composition. Weight is also an imprecise measure of health. In most cases it is more important to know the absolute amount of certain tissues and their relative proportion to other tissues in the body than to focus on body weight.

Body fat is expressed as an absolute amount (fat mass in pounds or kilograms) or as a percentage of the total body mass (percent body fat). Normative values for percent body fat for adult men and women by decade are found in Appendix M.

The value in distinguishing body composition, particularly body fat, can be seen in an example of a sumo wrestler and a bodybuilder. These two athletes have the same body weight, yet dramatically different body composition. The sumo wrestler has a much larger percentage of body fat while the bodybuilder has much less body fat and more muscle tissue. Similarly, two females may both weight 110 lb (50 kg) and appear to be "thin" because they have a relatively low body weight. However, one may have a high percentage of body fat and a lack of muscle tissue compared to the other who has more developed skeletal muscle and a smaller amount of body fat.

Discussion and determination of body composition are complicated by the vast array of tissue types in the body. Various models have been proposed to simplify the estimation and analysis of body composition, and each accounts for the major constituents of the body in a different way (see Figure 11.2). The simplest is the two-compartment model, which accounts for fat mass (FM) as one compartment and fat-free mass (FFM) as a single compartment consisting of all tissues in the body except for fat. The major assumption with the two-compartment model is that all tissues in the FFM have the same density. This assumption obviously builds some error into the model, as it is well known that tissues as different as muscle and bone do not have a uniform density. In addition, the density of certain tissues, such as bone, may differ substantially between individuals or in the same individual over the life span. The two-compartment model is simple, but is based upon assumptions that reduce its accuracy.

To determine body composition with greater accuracy, three- and four-compartment models were created once the technology was developed to measure specific tissues (Figure 11.2). For example, dual-energy X-ray

Photo Japan/Alamy

Robert Cianflone/Getty Images

The sumo wrestler and the bodybuilder have similar body weight yet dramatically different body composition.

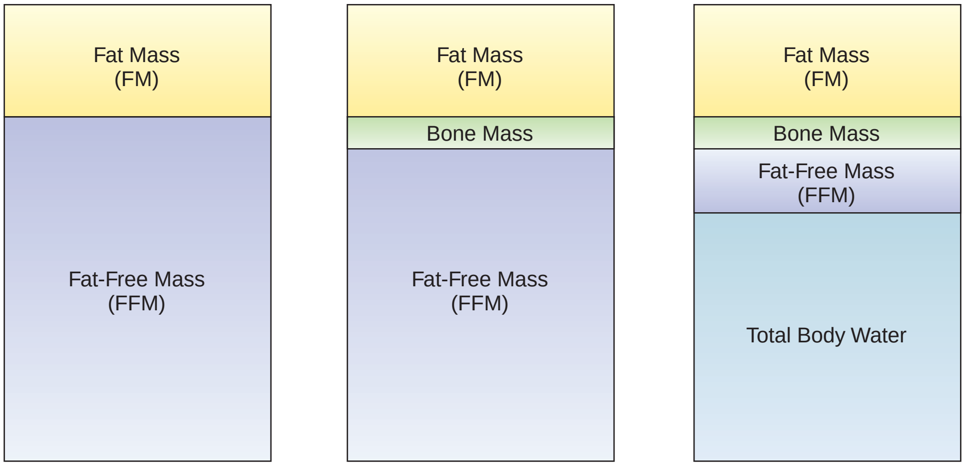


Figure 11.2 Two-, Three-, and Four-Compartment Models of Body Composition

absorptiometry (DEXA) technology allowed for the measurement of bone mineral density and bone mass and led to the development of the three-compartment model. Use of isotope dilution and bioelectrical impedance analysis (BIA) to determine total body water provided the information necessary for a four-compartment model, which provides better estimates of body composition by accounting for more types of tissues than the other models.

Measuring Weight and Body Composition

To understand weight and body composition, one must understand the techniques used to estimate them and the errors that result from any type of measurement. Weight or body composition measures are meaningless if accurate procedures are not used. A detailed discussion of the exact procedures involved with each method is beyond the scope of this text, and good reviews can be read in a number of fitness assessment resources (Whaley et al., 2006; Nieman, 2007). Even when the procedure is performed correctly, the results can be misinterpreted if the standard error of the estimate is not considered. The purpose of this section is to enable students in sports-related fields to acquire a practical, working knowledge of this potentially confusing subject with a strong understanding of the appropriate use and limitations of body composition assessment.

MEASURING BODY WEIGHT

A balance beam scale or a digital scale should be used to determine body weight (see Figure 11.3). To ensure accuracy, the scale should be calibrated monthly or quarterly and immediately after being moved. Scale weight should be taken as soon as the individual is awake, after emptying the bladder, and before any food or drink is consumed. On a balance beam scale, weight should be recorded to the nearest 0.5 lb or 0.2 kg (Modlesky, 2006). Home scales are convenient but most lack the accuracy of a balance beam scale. Repeated scale weights (e.g., daily, weekly) should be taken on the same scale under similar conditions (e.g., time of day).

Andy Doyle

Figure 11.3 Balance Beam Scale

METHODS FOR ESTIMATING BODY COMPOSITION

There are a variety of methods available to determine body composition, each with advantages and disadvantages (see Table 11.1). Some of the factors that must be considered with any method are the accuracy or precision of measurement, practicality, ease of use, time

Table 11.1 Comparison of Methods Used to Estimate Body Composition

Method	Accuracy	Practicality and Portability	Ease of Use	Time	Cost	Subject Comfort and Effort	Technician Training
Underwater (hydrostatic) weighing	SEE = ±2.7%	Practical in exercise physiology laboratories or large fitness centers; Not portable	Requires subject to submerge, exhale, and hold breath	~ 30 minutes because the procedure should be repeated 5 to 10 times	Initial purchase of equipment is expensive	Subject may be uncomfortable wearing a bathing suit, submerging in water, and exhaling air	Training is needed but is not difficult
Plethysmography	SEE = ±2.7–3.7%	Requires 8' × 8' space; Can be moved with proper equipment, but takes effort	Requires subject to sit quietly	~ 5 minutes	Initial purchase of equipment is expensive	Subject may be uncomfortable wearing a bathing suit and cap and sitting in an enclosed space	Minimal training needed
Skinfold measurements	SEE = ±3.5%	Practical in settings that have a private area; Very portable	Requires subject to be still; Measurement sites must be determined and marked	< 5 minutes	Initial purchase of equipment is relatively inexpensive	Subject may be uncomfortable partially disrobing; Some skinfolds are difficult to grasp	Training and consistency are critical; Technique improves with experience
Bioelectrical Impedance Analysis (BIA)	SEE = ±3.5%	Practical in most settings; Very portable	Easy to use	< 5 minutes	Initial purchase of equipment is moderately expensive	Procedure is simple but pre-measurement guidelines require substantial subject compliance	Minimal training needed
Near-infrared Interactance (NIR)	SEE = ±4–5%	Practical in most settings; Very portable	Easy to use	< 5 minutes	Initial purchase of equipment is moderately expensive	Simple procedure; Generally no problems	Minimal training needed
Dual-Energy X-ray Absorptiometry (DEXA)	SEE = ±1.8%; more research needed to verify SEE	Practical in imaging centers, physicians' offices, or research facilities; Not portable	Easy to use	~ 5 to 10 minutes	Initial purchase of equipment is very expensive	Simple procedure; Subject is exposed to a very small amount of radiation; Use prohibited during pregnancy	Training is needed; License to operate is required
Computed Tomography Scans (CT) and Magnetic Resonance Imaging (MRI)	Not yet established	Practical in imaging centers and research facilities; Not portable	Requires subject to be still throughout the entire procedure	~ 30 minutes	Initial purchase of equipment is very expensive	Procedure is relatively simple with some subject discomfort	Training is needed; License to operate is required

Legend: SEE = Standard Error of the Estimate required to obtain the measurement, cost, portability, comfort, effort required by the subject, and training required of the technician. Accuracy is the most important element, but some of the most accurate measurement technologies cannot be used outside a research setting. Methods with lesser accuracy are sometimes used for practical reasons. Some easy-to-use methods are practical but their accuracy is low and they may give athletes a false picture of their true body composition. In some cases the accuracy is so low the estimate is essentially meaningless.

The most important point to understand at the outset is that body composition, specifically body fat, cannot be directly measured except by chemical analysis of human cadavers. All other methods of determining body composition estimate or predict body composition using data from the direct chemical analysis of a relatively limited number of human cadavers. It is even difficult to accurately estimate body fat in cadavers. If one thinks about the different roles of fat (e.g., cell membranes, covering nerve cells, surrounding internal organs) and where it is distributed in the body (e.g., adipocytes, under the skin, muscle cells, blood), then one can gain an appreciation for the difficulty in accounting for all of the fat mass in the body.

Error of Measurement. Because the only true measurement of the amount of fat in the body is by chemical analysis of cadavers, all current approaches to determining body composition estimate or predict body fat from some other measurement. Therefore, all of these methods are indirect determinations and will have some built-in or **inherent** error. In addition, there is potential for technical error in the assessment method itself. It is extremely important to understand the potential for these errors and how they might affect body composition results and recommendations based on those results.

To illustrate measurement error, consider underwater weighing as a method of determining body composition, specifically percent body fat. This technique is used to determine the density of the body from which the percentage of body fat is predicted. The original studies from which these prediction equations were developed show there is a strong correlation between body density and percent body fat, but there is not 100 percent accuracy (Brozek et al., 1963; Siri, 1956). This type of error is expressed as the Standard Error of the Estimate (SEE) and represents the degree to which the measured factor is likely to vary above or below the result obtained.

The SEE for percent body fat determined from underwater weighing is approximately ± 2.7 percent (Lohman, 1992). This means that if percent body fat is determined as accurately as possible by the underwater weighing technique for a group of people, it is likely that the result obtained will be within a range that is 2.7 percent above or below the figure determined for two-thirds of the people measured. In other words, even if this technique is performed flawlessly, a person whose body fat result by underwater weighing is determined to be 15 percent may actually have body fat as high as 17.7 percent or as low as 12.3 percent. Out of a group of 100 people with a body fat estimate of 15 percent, 67 will actually have a percentage of body fat within the range of 12.3 to 17.7 percent. While this is a fairly large range, one also must be aware that the remaining one-third of the group, or 33 people, are likely to have their "real" body fat percentage be even further outside the ± 2.7 percent range.

Underwater weighing is one of the more "accurate" methods, so one can easily see where caution must be taken in interpreting body composition results. Those who work with athletes should be aware of the error associated with various body composition assessment methods and, in particular, should not assume false precision for these methods. For example, body fat percentages expressed to 2 or 3 decimals suggest a degree of measurement precision that is unrealistic (e.g., a printout of a body composition test that states "Your body fat is 15.35%"). Caution must also be used when interpreting small changes in body fat percentage. Changes in body composition of 1 or 2 percent, particularly over a short period of time (i.e., days to weeks), should be interpreted carefully because this amount of change is within the measurement error of the method.

All measurement methods have a certain amount of error that is inherent in the methodology. This error assumes the technique is administered with the highest degree of adherence to the appropriate procedures. There is additional error, however, in all of these methods that may be associated with how the body composition technique is performed, either by the subject or by the technician responsible for the measurement. Technical error that may be added to the error inherent in the method must be carefully considered, both in choosing an appropriate technique and in interpretation of the results. Simply stated, body composition that is assessed by any indirect method is not precise because of measurement error.

Athletes may wonder which method of measuring body composition is the most accurate. Underwater weighing was used to establish some of the early estimations of body fat from cadavers and has therefore long been considered the gold standard of body composition methods. It has also been used as the **criterion** for the establishment of other methods such as the skinfold technique. Underwater weighing is no longer considered the gold standard because there are now more sophisticated methods (e.g., magnetic resonance imaging and computed tomography) that are used as criterion methods, although there is still a lack of data from these newer methods to establish population norms (Modlesky, 2006). These methods are also not practical to use in most cases, so underwater weighing is often considered to be the most accurate method readily available to athletes.

$$\textbf{Body density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\textbf{Body density} = \frac{\text{Weight in air}}{\dfrac{\text{Weight in air - weight in water}}{\text{Density of water}} - \text{Residual volume}}$$

Figure 11.4 Hydrostatic (Underwater Weighing) Formulas

Body density is determined from the mass divided by the body's volume. Mass is measured as weight (weight in air). Volume is determined as the buoyant force in water; the difference between the body's weight in air and submerged in water. Other factors to account for in the equation are the density of the water and the residual volume (air that remains in the lungs).

DENSITOMETRY (UNDERWATER WEIGHING AND PLETHYSMOGRAPHY)

One approach to estimating body composition is by determining the overall density of the body. Fat tissue has a lower density (0.9 g/ml) than other tissues, so theoretically, the less dense a person's body is the more body fat is present. How is body density determined? Body density can be calculated as the ratio of body mass (weight) to body volume. Mass (weight) is easily measured on a scale, but what about volume? Archimedes' Principle is used by two techniques to determine body volume and density.

Hydrodensitometry or Underwater Weighing. Underwater weighing is a technique of estimating body composition that has been utilized for decades and may be the most accurate method available to many athletes for determining body fat. Mass can be determined easily by measuring the person's weight, and density can be calculated if the body's volume is known (Figure 11.4). Submersion in water can be used to determine volume, either by the amount of water that is displaced (e.g., water rising as one slips into the bath tub) or by determining the buoyant force acting on the submerged object. In the human body, two things are less dense than water and act to help the body float—air and fat. In underwater weighing, the air is accounted for by having the subject exhale as much air from the lungs as possible (down to **residual volume**) and by accounting for the residual volume in the prediction equation (Figure 11.4). A person that has more body fat will float more readily (i.e., have a greater buoyant force) and will therefore have a larger volume and a lower density. Conversely, a person of the same weight with less body fat and more muscle will tend to sink more easily (i.e., have less buoyant force), exhibiting a smaller body volume and higher density. Higher body density is associated with lower body fat.

The underwater weighing procedure requires the subject to exhale as much air as possible, submerge the body completely underwater, and remain motionless long enough for the technician to obtain an accurate reading of the underwater weight (see Figure 11.5). Many individuals have great difficulty with these procedures, particularly those not comfortable in the water. Therefore, substantial error can be introduced by the subject's inability to adhere to the procedures required by this method. While underwater weighing may be an accurate assessment of body composition for some, it may not be the most accurate method for all subjects. Another potential source of error is the determination of the amount of air in lungs of the subject. The greatest accuracy is obtained when lung volume is measured with one of several gas dilution techniques, but this type of apparatus may not be available or practical to use outside a

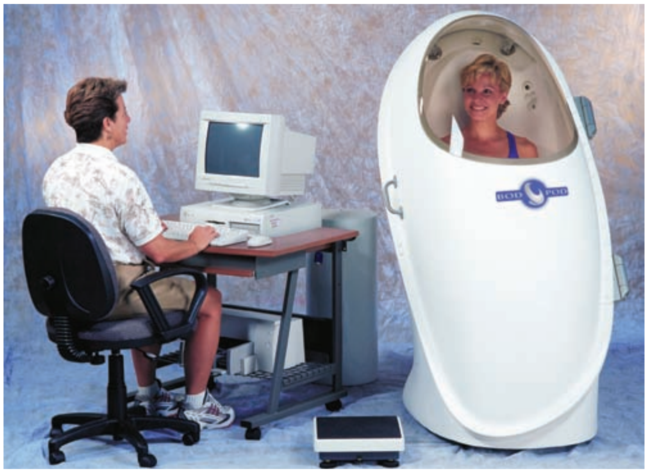
Figure 11.5 Hydrostatic Weighing Procedure

Subjects are seated in the water in a seat suspended from a scale. The subject must exhale as much air as possible (down to residual volume), submerge their body completely under water, and remain as motionless as possible until an accurate scale weight (underwater weight) can be determined. To ensure consistent results, 5 to 10 measurements are required.

Inherent: Unable to be considered separately.

Criterion: Accepted standard by which other decisions are judged.

Residual volume: The amount of air left in the lungs after a maximal, voluntary exhalation.



Life Measurement, Inc., www.bodpod.com

Figure 11.6 Air Plethysmography

Air displacement is used to determine body volume, body density, and body composition.

laboratory or research setting. More potential error is introduced when lung volume is estimated using prediction equations. Further error is introduced if the subject is unable to exhale all of the air down to residual volume; the extra air in the lungs makes the person more buoyant, and if unaccounted for, results in an error that overestimates body fat. In a study of trained athletes, a relatively small difference (~175 ml) in the amount of air in the lungs contributed to an average difference of over 1 percent in the final estimated body fat percentage (Morrow et al., 1986).

Other disadvantages of the underwater weighing method include the large, cumbersome, and not easily portable equipment needed. A water-filled tank large enough to accommodate a human body is not easily moved and is generally fixed in a laboratory or fitness-testing location. The gas dilution systems to measure lung residual volume are expensive, require technical expertise to operate, and need maintenance and sanitary cleaning of the breathing tubes. There are also issues related to the subjects and the facilities, such as the need for changing and clothes storage areas (e.g., locker facility) that are compatible with wet activities. Subjects must wear bathing suits (preferably with minimal material for greatest accuracy), which may be an issue of modesty or cultural sensitivity. Because of the need to repeat the procedure for greater accuracy, an underwater weighing session can be time consuming, easily taking 30 minutes or more, particularly for an inexperienced subject.

Plethysmography. Due to the problems associated with using underwater weighing to determine body volume and density, **plethysmography** (displacement of air to determine body volume) was developed. The subject sits in an air-tight enclosure (see Figure 11.6) while the amount of air displaced by the subject's body is sensed by a special diaphragm and pressure transducer. Once the body volume is determined, body density can be calculated and body fat estimated.

Studies show this method correlates well with body fat percentage determined from underwater weighing (McCrory et al., 1995) and has good test-retest reliability. The SEE is 2.2–3.7 percent (Fields et al., 2002). The major advantage of this system is the absence of water submersion, which can be a concern for subjects and a source of substantial error. It is also much less time consuming than underwater weighing. Studies suggest that this method can be used with approximately the same degree of accuracy as underwater weighing (McCrory et al., 1995). For greatest accuracy, subjects should wear tight-fitting clothing and a swim cap (to compress air pockets in the hair), which may lead to modesty concerns. The disadvantages include the high cost of the device, limited portability, the finite size of the seating area (i.e., larger athletes such as some basketball players or football linemen may not fit), and claustrophobic fears.

SKINFOLD MEASUREMENT

A certain proportion of fat in the body is stored subcutaneously (under the skin). Body composition that is estimated from skinfold thickness is based on the assumption that a measurement of the thickness of the subcutaneous fat layer is directly related to the total amount of fat in the body. A skinfold thickness may be determined by pinching a fold of skin and measuring with calipers (see Figure 11.7). Just one site may be used, but the sum of several different sites (two, three, and seven sites are frequently measured) is more accurate. Common sites used with men are chest, abdomen, and thigh while sites used with females are typically triceps, **suprailium,** and thigh. Most commonly used skinfold prediction equations have been derived using body density or body fat determined from underwater weighing, which means this method of estimation is twice removed from the original body density and fat measurements.

Generalized equations such as the commonly used three- and seven-site Jackson and Pollock equations (Jackson and Pollock, 1978; Jackson et al., 1980) were developed using diverse subjects (i.e., both genders and a wide age range) so that the equations would be suitable for use in a broad population of men and women. These equations have an SEE of approximately ±3.5 percent. To put this error in context, recall that two-thirds of the people being measured would have their "real" percent body fat fall within this range (e.g., 11.5 to 18.5 percent for an estimated body fat of 15 percent). Other specialized equations have been developed for use in very specific populations such as certain ethnic groups. Heyward and Stolarczyk (1996) provide an excellent guide for determining the most appropriate skinfold equation to

Steven Peters/Riser/Getty Images

Figure 11.7 Skinfold Measurement

The thickness of the fold of skin is determined with calipers on predetermined locations on the body. Equations incorporating the sum of each skinfold thickness measured are used to predict body density and percent body fat.

Tanita Corporation

Figure 11.8 Bioelectrical Impedance Analysis

A nonharmful electrical current is conducted through the body and the impedance to the flow of that current is measured and used in an equation to predict body composition.

use for specific populations, an important consideration when working with diverse populations.

Compared to other methods, the equipment required is relatively inexpensive (ranging from $10 to $500 for skinfold calipers) and is very portable. Little space is required but a relatively private area is needed because access to some skinfold sites requires partial disrobing. As with other methods, privacy or modesty may be an issue. Results are easily calculated, either by using electronic automatic calipers (e.g., Skyndex) or commercially available software. Programmable calculators and computer spreadsheets can easily be configured with the body density and body fat formulas needed to calculate body composition.

The skinfold technique can provide a reasonable degree of accuracy if performed correctly by a trained technician. Proper location of the skinfold sites is critical, as is the accurate pinching of the skinfold, the measurement of its thickness, and the choice of the most appropriate equation. Proper training of the technician is important, as is a substantial amount of experience in grasping the skinfolds with appropriate force (too much force can compress the skinfold and lead to an underestimate of the thickness and vice versa) and reading the skinfold caliper. This method may be difficult to employ with some subjects, as some skinfolds are very difficult to grasp and measure accurately, particularly the chest skinfold on many overfat males and the thigh skinfold on many females and males. In addition, individuals with very large amounts of subcutaneous fat may have skinfold thicknesses that exceed the measurement capacity of the skinfold calipers. The skill of the technician is a critical element because an unskilled technician introduces too much error and the resulting estimate cannot be used with confidence.

In addition to estimating percent body fat, skinfold measurement may provide valuable **anthropometric** information for tracking changes over time. For example, if an athlete's skinfold thicknesses decrease over the course of the off-season to the competitive season, one can be confident that body fat has decreased. Specific skinfold sites can be tracked in a longitudinal fashion for athletes in this way. An important issue is the accuracy of the measurements, which should be conducted by the same trained technician if possible.

BIOELECTRICAL IMPEDANCE ANALYSIS

The Bioelectrical Impedance Analysis (BIA) body composition methodology is based upon the rationale that body tissues can be distinguished based upon their relative ability to conduct electrical currents. Water and tissues containing a high proportion of water conduct electrical currents easily, while tissues that contain little water, such as fat, impede the flow of electrical currents. With this method, a nonharmful electrical current is conducted through the body and the impedance to the flow of that current is measured (see Figure 11.8). Body composition is not measured directly; rather, an algorithm, or prediction equation is used to predict body composition from a three-compartment model: fat mass, fat-free

Plethysmography: Measuring and recording changes in volume of the body or a body part.

Suprailium: An area of the body directly above the crest of the ilium, the hip bone.

Anthropometric: Body measurements such as height, weight, waist circumference, or skinfold thickness.

mass, and body water. These algorithms or equations are generally **proprietary** (private) to the company that has developed them so it is difficult to conduct independent scientific studies of the formulas.

Commercially available BIA units typically have one of three configurations, measuring impedance between arms and legs, between the legs, or between the arms. The first approach requires the subject to lie down and have electrodes placed on their ankles and wrists. The latter two devices require the subject to stand in bare feet on a scalelike platform or hold onto the device with metal contacts with bare hands. BIA devices range from very expensive, multi-frequency devices that measure whole body impedance and estimate total body water (both intracellular and extracellular) to inexpensive, low-frequency devices marketed for use in the home.

Accuracy of the body composition estimate is based largely upon the accuracy of determining the electrical impedance and the underlying assumptions used in the equations regarding water content of various tissues. Differences in water content and body density, which may vary due to age, gender, ethnicity, recent physical activity, and hydration status, must be considered. If all conditions are controlled appropriately and subject and technical error is minimized, the estimate obtained via BIA is comparable to that of skinfold assessments, an SEE of approximately ± 3.5 percent.

BIA has some distinct advantages as a method of estimating body composition. Other than removing shoes and socks, the method requires no special clothing or disrobing, reducing concerns of privacy and modesty. The devices are easily portable, can be used in a variety of settings, and generally require only a few minutes for the assessment to be completed. The devices are computerized and are programmed to calculate the results and generally have an option for printing out the results. In addition, there is not a large potential for subject or technician error as long as data entry is done correctly and fairly simple procedures are followed (e.g., correct electrode placement).

Major error or variation can occur, however, if the technician or subject does not adhere to premeasurement factors that may affect body water. Changes in hydration status and physical activity may affect bioelectrical impedance analysis, particularly if changes occur near the time of measurement. For that reason, preassessment guidelines should be given and adhered to by the subject and confirmed by the technician before any measurement takes place:

- Abstain from eating or drinking within 4 hours of the assessment
- Avoid moderate or vigorous physical activity within 12 hours of the assessment
- Abstain from alcohol consumption within 48 hours of the assessment
- Ingest no diuretic agents, including caffeine, prior to the assessment unless prescribed by a physician

Bioelectrical impedance can be a relatively quick and easy assessment method for estimating body composition, but careful attention must be paid to these preassessment directions to avoid introducing excessive error. This is especially true for athletes who would need to schedule the test around their training schedule. Additionally, any information provided by the subject (e.g., weight, physical activity) must be accurate, a potential problem for recreational and nonathletes who may underestimate body weight and overestimate physical activity. A major disadvantage of BIA is the cost of the device, which may be substantially greater than other methods with similar accuracy (e.g., skinfold calipers).

NEAR-INFRARED INTERACTANCE

Near-infrared interactance (NIR) is based upon the ability of different tissues to absorb or reflect light. A near-infrared light emitting and sensing wand is placed over a body part such as the belly or center of the biceps. A light beam is directed into the tissue, some of which is absorbed and some of which is reflected back and is measured by spectroscopy in the wand. Less dense tissue absorbs more near-infrared light and more dense tissues reflect more light back to the sensor. The differential absorption and reflection of the near-infrared light is used in prediction equations to estimate percent body fat. Similar to bioelectrical impedance, body composition is not measured directly.

NIR devices are portable, easy to operate, and are not exposed to substantial technician or subject error if the information provided by the subject about weight and physical activity is reliable. The procedures are not disruptive for the subject as only one site on the body is typically measured (e.g., the biceps of the dominant arm). Concerns are raised about the use of only one site for predicting percent body fat. Studies of the accuracy of body composition estimated by NIR shows an error of approximately $\pm 4 - 5$ percent (Hicks et al., 2000; McLean and Skinner, 1992), making this method less accurate by comparison to the methods discussed previously. Until greater accuracy is achieved, the estimates obtained by NIR may have too much potential error to be used with confidence.

DUAL-ENERGY X-RAY ABSORPTIOMETRY

Dual-Energy X-Ray Absorptiometry (DEXA) is a method that uses low-intensity, focused X-rays to scan the body for determination of bone mineral density and content. Originally developed for clinical use for measuring loss of bone density, the bone mineral information can

Figure 11.9 Dual-Energy X-ray Absorptiometry

Using low-intensity, focused X-rays, bone and soft tissue can be scanned and percent body fat estimated.

also be used as part of a three-compartment model for estimating body composition. The potential exists for this to be a precise method for body composition determination because it accounts for one of the tissue compartments that can vary substantially between people and within an individual over a lifetime.

In this procedure, the subject lies motionless on the scanning table for a few minutes while a full body scan is performed, yielding both skeletal and soft tissue images (see Figure 11.9). Based upon proprietary algorithms developed by each company, body composition is determined, with estimates of **bone mass,** fat mass, and fat-free mass provided. Some software programs use anatomical landmarks to digitally section the body into segments for analysis of regional body composition (e.g., trunk, arms, and legs).

Because of the expense of the equipment and the associated radiation safety requirements, DEXA is a method of body composition assessment that is not likely to be found outside specialized clinical facilities, research laboratories, or doctors' offices. The equipment also contains an X-ray generating device, and is therefore subject to state or local licensing and safety regulations. Technicians operating the DEXA equipment must be trained in the use of the equipment and in radiation safety. While the dosage of radiation a subject is exposed to for a whole body scan is very small, there is a potential for accumulated radiation exposure with repeated scans, and there are some conditions (e.g., pregnancy) that prohibit use. The devices do have size limits for subjects due to the available scanning area. Subjects that are very tall (over 6'4" [193 cm]) or that are severely obese may not be scanned accurately, as their body may not fit within the limits of the available scanning area.

Whole-body scans for body composition are relatively fast on newer DEXA equipment, generally taking only a few minutes. Other than adhering to the directions to eliminate metal objects from the body (e.g., jewelry) or clothing (e.g., belt buckle, underwire bra), the subject has little to do other than to remain motionless until the scan is completed. There is little opportunity for technician error other than positioning the subject correctly on the scanning table and entering the subject information correctly. The error has been reported to be approximately ±1.8 percent (Whaley et al., 2006), but additional research must be performed before DEXA can be considered the new gold standard method of body composition assessment (Kohrt, 1995).

COMPUTED TOMOGRAPHY SCANS (CT) AND MAGNETIC RESONANCE IMAGING (MRI)

Advanced clinical imaging techniques have also been used to assess body composition. Two such methods are computed tomography (CT) and magnetic resonance imaging (MRI). Similar to DEXA, these methods are generally only found in specialized clinical facilities or research laboratories and are not commonly used in assessment of body composition outside research studies. These devices are able to image tissues in the body in cross-sectional slices. The amount of tissue in each section is estimated and whole-body composition is estimated by summing the sequential section images. These technologies have not been used on a sufficient number or breadth of subjects to establish the SEE. The specialized nature of these technologies makes their widespread use in body composition assessment unlikely in the near future.

What's the point? All body composition measurement methods are indirect predictions of body fat. They all have some inherent error and the potential for technical error, which must be considered when selecting a measurement method and interpreting the results.

Interpretation of Body Composition and Weight

Once the appropriate body composition assessments have been completed and the results are known, the subject will likely ask, "What do these numbers mean?" The health, fitness, or nutrition professional may wonder, "What do I do with these results?" The initial

Proprietary: Privately owned and administered.

Bone mass: Total amount of bone in the body. Expressed in pounds or kilograms.

caution about body composition bears repeating here: Assessments of body composition are only estimates. Each method of assessment has a degree of error that must be taken into account when analyzing and interpreting the results, and this error may be compounded by technical, technician, or subject error. Suggesting to athletes that body composition assessment is overly precise or using the information to establish rigid goals is incorrect and inappropriate.

INTERPRETING BODY COMPOSITION RESULTS

Body composition results should be presented as a range that includes the error of measurement. As mentioned previously, if percent body fat is estimated to be 15 percent using the underwater weighing method, then this figure should be interpreted as the percentage of body fat that is likely to be within the range of 12.3 to 17.7 percent. The athlete should also be informed that there is a possibility the actual body composition may be higher or lower than this range. Percent body fat and lean body mass estimates can be used to determine an appropriate scale weight that reflects desired body composition (demonstrated later in this chapter). Excessive body fat likely has an impact on performance and health, and body composition assessment can help to establish and monitor progress toward a more desirable body composition. Measurement of body composition can also help athletes assess if their training program and dietary intake needs to be adjusted to meet body composition goals.

Knowledge and experience in assessment of body composition and good old-fashioned common sense need to be employed when evaluating these results and making recommendations. For example, if an athlete has a body composition assessment showing an increase in body fat of 0.5 percent over a three-month period of time, at the same time that training volume has increased, scale weight has decreased and clothes are looser-fitting, then the accuracy of that body composition assessment must be questioned and reevaluated.

INTERPRETING BODY WEIGHT

Weight is reported as a single number and is generally compared to previous weights. A change in body weight can reflect a change in muscle mass, body fat, hydration status, or a combination of these factors. Weight can fluctuate on a daily basis and is most useful to athletes as a way to track hydration status, especially for those who are training in hot, humid conditions and are losing large amounts of fluid each day as sweat. In this instance, daily weight may be an appropriate means of checking hydration status and ensuring adequate rehydration. Although athletes in some sports must be focused on body weight because of weight restrictions or classes, it is probably not appropriate for most athletes to be overly concerned about checking their weight on a daily basis. For purposes other than hydration status or "making weight," a reasonable approach might be for an athlete to check weight on a less frequent basis, such as once each week. Care should be taken to measure body weight using the same scale if possible and under the same conditions (e.g., same time of day, same timing in relation to exercise, food, and beverage consumption).

Visual monitoring, along with scale weight, can be used as a "check" on body composition, but this technique is highly subjective. As an example, consider a 24-year-old male athlete who usually weighs 185 lb (84 kg) when he is in a state of **euhydration.** Based on assessment of body composition at this weight, this athlete's percent body fat is estimated to be 8 to 10 percent. He knows that when he gains body fat the fat tends to be deposited in his abdominal area. At 185 lb (84 kg) and 8 to 10 percent body fat, this athlete understands what his body "looks" like and can visually monitor his body composition. If his weight increases to 190 lb (~86 kg) and the 5-lb (~2-kg) increase in weight reflects an increase in abdominal body fat, then he should be able to detect this increase in the mirror and by the fit of his clothes. The usefulness of visual monitoring depends on honest assessment. If this athlete held his breath and tightened his abdominal muscles while looking in the mirror, he could pretend that the 5-lb increase was not a result of increased body fat. Those with a distorted body image should not use frequent scale weights and visual monitoring because each can be misinterpreted and lead to practices that harm physical and mental health.

Body Composition and Weight Related to Performance

Changes in body composition and body weight may have the potential to improve performance; thus, some athletes want to define "optimal" ranges. Optimal weight or body composition cannot be predicted, and even among elite athletes in the same sport there are individual differences due to genetics, training, and nutrition. The lowest body weight or percent body fat is not always the best and, in some cases, may be detrimental to performance. This section reviews current knowledge of body composition, body weight, and performance.

RELATIONSHIP OF BODY COMPOSITION TO PERFORMANCE

Body composition and other body anthropometric characteristics (e.g., height) are physical characteristics that can have an impact on an athlete's performance, but these factors play a more important role in some

Paul Jasienski/Getty Images
John R. McCutchen/Union-Tribune via Getty Images
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Jeff Gross/Getty Images

Figure 11.10 Comparison of Body Composition of Different Athletes in the Same Sport

sports, and for different positions within certain sports, than others. For example, body composition may play a minor role in certain skill-oriented sports. Athletes that are successful in baseball or golf display a wide variety of body types and body composition that may be more similar to the general population (see Figure 11.10). Successful baseball players at the highest level may be fit and lean like Derek Jeter or may have a body composition more similar to the average, sedentary adult like David Wells. Golf is another example in which athletes with different body compositions have been successful (e.g., Tiger Woods, Phil Mickelson, John Daly).

There is an inverse relationship between body fatness and performance in some sports, particularly those in which body weight must be transported, as in distance running or other endurance sports. Excessive body fat comprises "dead weight" for the athlete—weight that must be carried but does not contribute in a positive way to the activity. Carrying excess weight makes the athlete less energy efficient so he or she must exert more effort to transport the weight. This doesn't mean that performance will always be improved if these athletes attain an absolute minimum weight, however. There is a point of diminishing returns, both for performance and for health that the athlete must consider. At some point the caloric restriction and training that is needed to further reduce body weight and fat may become counterproductive.

INTERRELATIONSHIP OF SIZE (WEIGHT)/STRENGTH/SPEED

The "optimal" body composition for an athlete must consider the mass, strength, speed, and power demands of the sport, or the position within the sport. At one extreme, the sumo wrestler represents an athlete that

Euhydration: "Good" hydration (eu = good); a normal or adequate amount of water for proper physiological function.

Gray Mortimore/Stone/Getty Images

In sports in which explosive power provides a competitive advantage, having a high power to weight ratio is important.

must possess a very large body mass. This large body mass is difficult to push out of the competitive ring due to inertia and lack of momentum. Strength and speed are important for these athletes, but a very large body mass is critically important—a strong and fast sumo wrestler will have little success if he is outweighed by several hundred pounds by his competitors. The other extreme may be represented by a ski jumper. A certain amount of strength is required for controlling the skis and for propelling the body into the air at the end of the ski jump, but low body weight is a great advantage for these athletes to stay in the air longer. Other athletes fall somewhere in between these extremes in terms of body mass, body fat, and muscle. In sports or positions in which explosive power is a requirement or provides a competitive advantage, having a large amount of muscle mass and a high power-to-weight ratio is important. Excess body fat may diminish this power-to-weight ratio and is therefore undesirable. Athletes such as male gymnasts, ice hockey players, short-distance runners (e.g., 100-m runners), speed skaters, and (American) football linebackers and running backs are often very muscular and lean and have a high power-to-weight ratio.

Although summaries (see Figure 11.11) or averages of body fatness for athletes across a variety of sports are available (Hoffman et al., 2006; Petersen et al., 2006; Ostojic, Mazic, and Dikic, 2006; Silvestre et al., 2006; Clark et al., 2003; Tuuri, Loftin, and Oescher, 2002; Noland et al., 2001; Deutz et al., 2000; Collins et al., 1999; Kreider et al., 1998; Wilmore, 1983;), individual athletes must be considered on a case-by-case basis. Additionally, athletes within a particular sport may have varying body composition characteristics. Interior linemen in (American) football typically have requirements for greater body mass, even if some of that mass is fat. Along with muscle, the additional body mass prevents them from being "pushed around" as easily. Players at other positions must run faster and farther (e.g., linebacker, wide receiver, running back) and excessive body fat may

• NCAA Division I football	
All positions	10.2–23.8
Defensive backs	7.0–14.4
Receivers	8.8–16.4
Quarterbacks	14.0–21.8
Linebackers	12.4–23.6
Defensive linemen	14.4–24.8
Offensive linemen	18.4–28.6
• Basketball*[a]	
All positions	6.9–16.1
Centers	8.8–20.0
Forwards	6.9–13.7
Guards	6.8–13.1
• Cycling	
Road*	6.9–10.1
• Ice hockey*	8.0–12.0
• Rugby*	9.1–19.6[b]
• Running (females)	
Middle distance*	7.9–16.5
Long distance*	11.9–18.3
• Soccer (females)	13.3–18.9
• Soccer	7.6–18.0[c]
• Swimming/diving (females)	
Middle distance or diving	16.8–29.8
Long distance	20.3–33.7[d]
• Wrestling	6.6–11.3[e]

Figure 11.11 Estimated Percent Body Fat Ranges for Collegiate or Professional Athletes in Selected Sports.

Legend: NCAA = National Collegiate Athletic Association

These values represent reported percent body fat ranges and not optimal ranges for collegiate or professional athletes, ages 18–29 years. Values are for males unless noted.

*Professional or elite athletes, not collegiate athletes.
[a]French and Serbian players only.
[b]Forward players have higher percent body fat than back players.
[c]Midfielders have higher percent body fat than backs or forwards.
[d]Masters swimmers, ages 21–73 years.
[e]NCAA Division I, II, III championship wrestlers.

Compiled from research studies measuring body composition by hydrostatic weighing, skinfolds, or DEXA. Hoffman et al., 2006; Montgomery, 2006; Petersen et al., 2006; Ostojic, Mazic, and Dikic, 2006; Sallet et al., 2005 and 2006; Silvestre et al., 2006; Clark et al., 2003; Tuuri, Loftin, and Oescher, 2002; Noland et al., 2001; Deutz et al., 2000; Collins et al., 1999; Kreider et al., 1998.

impair their performance. Body fat among a group of football players may therefore range from approximately 7 to 28 percent.

In addition to performance and appearance, athletes may also want to change their weight or body composition for health-related reasons. Weight, as a sole measure, is not an accurate predictor of health. However, there is an association between body weight, chronic disease risk, and mortality (Hu et al., 2004; Lee, Blair, and Jackson, 1999). This association is very much influenced by cardiovascular fitness. It is important for individuals to assess if their current weight and percent body fat are within a healthy range. In addition to the amount of body fat, the distribution of body fat is a disease risk factor. All of these issues are discussed in Chapter 12, Diet and Exercise for Lifelong Fitness and Health.

Changing Body Composition to Enhance Performance

Many athletes want to change their body composition. Highly trained athletes are typically lean but may want to gain muscle mass to increase strength or lose a small amount of body fat to improve their power-to-weight ratio or their appearance. Lesser-trained athletes often wish to increase muscle mass and lose body fat, sometimes in substantial amounts. Some recreational athletes want to lose moderate to substantial amounts of body fat. This loss of body fat may positively affect performance, but in many cases the desire to lose body fat is related more to appearance and the desire for better health. A minority of athletes need to gain body weight and need to increase body fat in addition to increasing muscle mass. Regardless of the athlete's priorities, the same questions are frequently asked: 1) How much should I weigh? 2) What percentage of body fat should I have? 3) How do I increase muscle mass? 4) How do I lose or gain body fat? and 5) How do I increase muscle mass and lose body fat at the same time? This section explains how a target weight based on body composition is determined and briefly outlines the changes in exercise and training that are needed to achieve muscle mass or body fat goals.

DETERMINING A TARGET BODY WEIGHT BASED ON DESIRED BODY COMPOSITION

After body composition has been estimated as accurately as possible, athletes can use that information to establish their "optimal" body composition goals. Athletes should be cautioned to choose realistic lean body

SPOTLIGHT ON ENRICHMENT

Athletes and Appearance—Meeting Body Composition Expectations

Athletes in subjectively scored sports must consider their body's appearance because it may influence their scores. The most obvious case is that of bodybuilders because the appearance of the body is a fundamental element of the sport. Sports such as women's gymnastics and figure skating have "cultural" standards for appearance that relate to body composition.

Many athletes' bodies are judged by the large audiences reached through the visual media.

Weight and body shape dissatisfaction and body image disturbances are prevalent in these and other appearance-dependent sports. Psychological issues related to body image should not be overlooked in subjectively scored sports, as they may lead to disordered eating, which is discussed in depth in Chapter 13 (Ziegler et al., 2005 and 1998; Jonnalagadda, Ziegler, and Nelson, 2004).

While most athletes' bodies are not scored, they are judged by the large audiences reached through the visual media. Fashionable, tight-fitting clothing is part of the sports scene. Television coverage of sports is so extensive that many athletes are celebrities and the general population often expects celebrities to be thin, and in the case of athletes, muscular with a low percentage of body fat. Youth sports, such as high school football and the Little League World Series, are now shown on local or national TV. It is not surprising that some athletes at all levels of competition feel pressure to attain a body composition that is held in high esteem by society. Appearance is one reason that athletes, even high school athletes, consume supplements and drugs, some of which are obtained illicitly. In fact, an athletic appearance is so powerful that high school nonathletes use anabolic steroids to attain the higher muscularity and lower body fat that is typical of trained athletes (Calfee and Fadale, 2006). Anabolic steroid use by trained and recreational athletes for appearance purposes appears to be increasing (Copeland, Peters, and Dillon, 2000).

$$\text{Target Body Weight} = \frac{\text{Current FFM}}{1 - \text{Desired \% BF}}$$

The formula assumes euhydration and a constant fat-free mass.

Figure 11.12 Target Body Weight Formula

Legend: FFM = fat-free mass; BF = body fat

mass and body fat goals that consider their genetic predisposition to leanness and fatness. Once body composition goals are chosen, the weight that reflects those goals can be estimated. This weight is referred to as a target body weight or body weight goal. The target body weight is only an estimate, and rigid adherence to attaining a given scale weight or body composition is never recommended. However, a target body weight can be a helpful guideline, and a formula for calculating such a weight is shown in Figure 11.12. The formula assumes euhydration (Rankin, 2002).

For example, a baseball player currently weighs 190 lb (~86 kg) and is approximately 16 percent body fat (body fat range ~13–19 percent). His current fat-free mass is 84 percent of his weight, or ~160 lb (~72.5 kg), and he has approximately 30 lb (~13.5 kg) of body fat. His goal is ~10 percent body fat (i.e., 90 percent fat-free mass), a figure that is consistent with his genetic predisposition to fatness and his sport (long-ball hitter and outfielder). As shown in Figure 11.13, if all weight is lost as fat, his target body weight to reflect a body composition of 10 percent body fat is ~178 lb (~81 kg).

The target weight formula considers the athlete's current amount of fat-free mass. What if the athlete wishes to gain muscle mass and lose body fat? A target weight can still be determined, but the desired increase in muscle mass must be added to the current fat-free mass. Continuing with the previous example, the 190-lb (~86-kg) baseball player wishes to gain 5 lb (~2.2 kg) of muscle mass (from 160 to 165 lb [72.7 to 75 kg]) and reduce body fat to ~8 percent for performance and appearance reasons. If he achieved these goals his target weight would be ~179 lb (~81 kg) (see Figure 11.14). It should be noted that *choosing* desirable amounts and proportions of fat-free mass and body fat is not difficult, but *achieving* such levels may be. Above all, body composition and weight goals must be realistic and achievable via diet and training programs that do not put the athlete's health at risk.

Current weight = 190 lb

Current % BF = 16 % (obtained via underwater weighing)

Current % FFM 84 % or 0.84 (calculated from % BF)

Current FFM = 190 lb × 0.84 = 160 lb

Desired % body fat = 10 % or 0.10

$$\text{Target Body Weight} = \frac{160\text{ lb}}{1 - 0.10} = \frac{160\text{ lb}}{0.90} = 178\text{ lb}$$

Figure 11.13 Calculation of a Target Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

In this example, the athlete wants to lose body weight as fat.

$$\text{Target Body Weight} = \frac{\text{Current FFM} + \text{Desired FFM increase}}{1 - \text{Desired \% BF}}$$

$$\text{Target Body Weight} = \frac{160\text{ lb} + 5\text{ lb}}{1 - 0.08} = \frac{165\text{ lb}}{0.92} = {\sim}179\text{ lb}$$

Figure 11.14 Calculation of a Target Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

In this example, the athlete wants to change both lean body mass and fat mass. (see text for details)

INCREASING MUSCLE MASS

When the appropriate stimulus is applied to skeletal muscle and the necessary hormonal and nutritional environment is present, muscle mass can increase. First, an overload stimulus must be applied consistently over time—the muscle must be stimulated to produce force at a greater frequency, intensity, and/or duration than is accustomed. Athletes generally accomplish this through one of many strength-training approaches. The increase in muscle mass is referred to as **hypertrophy,** and is a result of individual muscle fibers being stimulated to increase in size by synthesizing more contractile protein.

Role of Exercise. For the sedentary adult or the athlete that is not accustomed to strength training, virtually any strength-training protocol will result in increases in strength and some initial increase in muscle mass. Once athletes are accustomed to basic strength training, further increases in muscle mass can be achieved through periodized strength training. The hypertrophy phase of periodized strength training is designed to maximize the potential for increasing muscle mass and is characterized by an emphasis on increasing the total volume of strength training. Increasing strength-training volume is accomplished by structuring a large number of sets and repetitions of a variety of strength-training exercises. The intensity or load (amount of weight lifted) is kept in the moderate range so that the prescribed number of sets and repetitions can be completed.

The amount of increase in muscle mass in response to strength training is difficult to accurately predict and is dependent upon a number of factors such as genetics, body type, hormonal status, and nutritional status. Those individuals with ectomorphic body types may not have the genetic disposition to add large amounts of muscle mass compared to those with more mesomorphic body types. Testosterone and growth hormone are the primary hormones responsible for stimulating an anabolic, or tissue-building, state in the body, particularly for muscle and connective tissue. There are large **interindividual** differences in circulating testosterone concentrations, certainly between males and females, but even among males.

Role of Nutrition. Proper nutrition is necessary to support the increase in muscle size that is associated with resistance-training programs described above. While many nutrients are important for muscle growth, two areas receive the majority of attention—energy (kcal) and protein. Synthesis of muscle tissue requires positive energy balance (i.e., caloric intake is greater than caloric expenditure). The athlete must also be in positive nitrogen balance (NB) and positive muscle protein balance (MPB). Positive nitrogen balance occurs when total nitrogen (protein) intake is greater than nitrogen lost via the urine and feces. In other words, the athlete must be consuming a sufficient amount of dietary protein. Positive muscle protein balance occurs when muscle protein synthesis is greater than muscle protein breakdown. To achieve positive energy, nitrogen, and muscle protein balance, an adequate energy intake is just as important as an adequate protein intake (Gropper, Smith, and Groff, 2005; Phillips, Hartman, and Wilkinson, 2005; Phillips, 2004; Tipton and Wolfe, 2001).

Athletes who wish to increase muscle mass should determine their baseline energy intake, which is the approximate amount of kilocalories needed daily to maintain current body weight and composition. Daily energy intake is greatly influenced by the amount of energy expended through physical activity. As discussed in Chapter 2, daily energy requirement for females and males is estimated to be approximately 35 and 38 kcal/kg, respectively, when daily activity is equivalent to walking two miles. When energy expenditure is higher due to moderate to heavy exercise on most days, baseline energy requirement may be as high as approximately 44 kcal/kg for females and 50 kcal/kg for males.

It is estimated that an additional 5 kcal above baseline energy need is required to support the growth of 1 gram of tissue (Institute of Medicine, 2002). One pound of tissue weighs 454 g; thus, a rule of thumb estimate is that approximately 2,300 kcal are needed to support the growth of 1 pound of muscle ($454 \text{ g} \times 5 \text{ kcal/g} = 2{,}270$ kcal). Assuming that a male can gain 1 pound of muscle tissue per week (less for a typical female), it is estimated that, at a minimum, an additional 330 kcal per day need to be added to the baseline energy intake to support 1 pound of muscle growth a week. However, there is little research in this area, so the general recommendation is higher than the estimated minimum value. At present, to promote the growth of muscle tissue it is generally recommended that males increase daily caloric intake by 400 to 500 kcal (females to a lesser extent).

Some additional dietary protein is also needed to support the growth of muscle tissue. Approximately 22 percent of muscle is protein, so it is estimated that increasing muscle tissue by 1 pound would require the incorporation of approximately 100 g of protein ($454 \text{ g} \times 0.22 = 100 \text{ g}$). If calculated on a daily basis, approximately 14 g of additional protein would be needed daily ($100 \text{ g} \div 7 \text{ days} = 14 \text{ g}$), which in itself would provide ~56 kcal. These figures are by no means exact, but they do give athletes some guidelines for the additional energy and protein needed to support an increase in muscle tissue. The additional amount of protein needed is probably less than most athletes would estimate, however.

The following example illustrates the application of these guidelines. Sal is a 25-year-old male who was active in intramural sports while in college. Since graduation he has not participated in any kind of formal recreational activity but he walks about a mile each way to the subway station to commute to work. He has maintained his current weight of 161 lb (~73 kg) for the past year. Recently, he joined a gym and fitness center, which he plans to go to immediately after work. His goal is to lift weights and gain approximately 5 pounds (~2.2 kg) of muscle mass. Figure 11.15 shows Sal's current energy and protein intakes and his estimated energy and protein needs to increase 5 pounds of muscle mass.

Sal's case is typical of many athletes who find that their current protein intake already exceeds the amount needed for muscle growth. Sal needs to concentrate on increasing his caloric intake, including additional carbohydrate calories that will be needed for the resynthesis of muscle glycogen reduced by the resistance

Hypertrophy: An increase in size due to enlargement, not an increase in number; in relation to muscle refers to an increase in the size of a muscle due to an increase in the size of individual muscle cells rather than an increase in the total number of muscle cells.

Interindividual: A comparison or observation made between people.

Determine baseline intake:
Current energy need to maintain body composition: 2,774 kcal (73 kg × 38 kcal/kg)
Current daily protein need: 58 g (73 kg × 0.8 g/kg)

Recommended changes to increase 5 lb lean mass (assumes resistance exercise):
Daily energy intake:
3,174 kcal (2,774 kcal + ~400 kcal)
Daily protein intake: ~72 g (58 g + ~14 g)

Current dietary intake:
Energy: ~2,800 kcal
Macronutrient distribution: Carbohydrate: 420 g (60% of total caloric intake), protein: 84 g (12%), fat: 78 g (25%), alcohol: 12 g (3%)

Figure 11.15 Baseline and Projected Energy and Protein Needs of a Recreational Athlete to Increase Muscle Mass

Legend: kcal = kilocalorie; kg = kilogram; kcal/kg = kilocalorie per kilogram body weight; g = gram; g/kg = gram per kilogram body weight; lb = pound

exercise. Since Sal will be going to the gym after work, he could eat a substantial snack while commuting to the gym. A 6-inch turkey deli sandwich and 8 ounces of orange juice would provide approximately 390 kcal, 72 g of carbohydrate, 19 g of protein, and 4.5 g of fat. Note that some of the additional calories are in the form of proteins but that the majority is provided by carbohydrates. This kind of snack daily, in addition to his usual intake, provides the additional nutrients he needs to support muscle growth.

DECREASING BODY FAT

The general principles for the loss of body fat are the same for athletes and nonathletes: an increase in energy expenditure (activity or exercise), a decrease in food (energy) consumption, or a combination of both. There are thousands of weight-loss diets, but the common denominator is a decrease in caloric intake that results in fat loss over time. For the obese, sedentary individual the restriction of total energy intake and the length of the energy restriction seem to be more important than the carbohydrate, protein, and fat content (i.e., macronutrient composition) of the diet. Higher-protein, low-energy diets may be beneficial for athletes because they may help to protect against the loss of lean body mass, but carbohydrate intake must be sufficient to support the resynthesis of muscle glycogen depleted by training (Layman et al., 2005).

Role of Exercise. Exercise plays an important role in weight loss and change in body composition. The strategy for long-term weight loss and reduction of body fat is to achieve a moderate caloric deficit, or to expend more calories than are consumed. As discussed below, this can be achieved solely through reductions in food and beverage consumption, but this is generally not the recommended approach. Particularly if the caloric deficit is large, weight loss can be substantial, but a relatively large proportion of the weight lost is from the fat-free component of the body. In other words, lean body mass is lost, which is not desirable, particularly for the athlete.

Exercise can be used to increase caloric expenditure, which contributes to the caloric deficit necessary for weight and fat loss. In addition, the stimulus of exercise helps maintain fat-free mass while body weight and body fat decline. Manipulations of frequency, intensity, and duration of exercise, particularly aerobic-type exercise, can substantially increase caloric expenditure. In the face of a moderate caloric deficit, an athlete who is performing aerobic exercise will generally maintain fat-free mass or may only experience small declines. An athlete who incorporates strength training into his or her training program while experiencing a mild caloric deficit may experience increases in muscle mass and therefore fat-free mass, while losing a small amount body fat at the same time. This example illustrates the concern of relying too much on scale weight rather than body composition when the goal is to lose body fat. If muscle mass is slowly increasing at the same time that body fat is slowly decreasing, the scale weight the athlete takes each morning may not be changing perceptibly. The athlete may be discouraged by this lack of change in scale weight and misinterpret it to mean that no progress is being made when, in fact, desirable changes in body composition are occurring.

Role of Nutrition. To lose body fat, energy expenditure must be greater than energy intake. It is recommended that activity or exercise be increased and food intake decreased. However, athletes must consider the impact that increased exercise or decreased food intake will have on their ability to train and perform. Too much exercise can result in injury, and low energy, carbohydrate, and protein intakes can result in inadequate muscle glycogen resynthesis and loss of lean body mass. For many trained athletes, the extent to which they can increase exercise and decrease food consumption is limited and these limitations result in a slow loss of body fat.

Recall from Chapter 4 that an athlete's daily carbohydrate intake should not be less than 5 g/kg body weight to ensure adequate muscle glycogen resynthesis. Athletes who restrict energy intake should increase protein intake to at least 1.4 g/kg body weight to protect against large losses of lean body mass (see Chapter 5). Meeting these two nutrient recommendations requires an energy intake of approximately 26 kcal/kg (6.5 g × 4 kcal/g). The diet should not be too low in fat for many reasons, including the difficulty involved with complying with a very-low-fat diet. Considering minimum carbohydrate, protein, and fat guidelines, it is generally recommended that athletes who wish to lose body fat not restrict energy intake to less than 30 kcal/kg daily. To meet vitamin and mineral requirements, these diets need to contain many nutrient-dense foods. Some athletes, such as bodybuilders preparing for a contest, may employ more drastic reductions in energy intake but such diets are short term. Diets containing less than 30 kcal/kg daily typically do not meet daily vitamin and mineral requirements and tend to be extremely low in fat.

Athletes who restrict energy to lose body fat look for ways to do so while preserving muscle mass. Unfortunately, scientific study in this area using athletes as subjects is sparse. There are some studies in obese men to suggest that the loss of skeletal muscle could be **attenuated** when an energy-restricted diet is combined with resistance exercise. Although these studies were not conducted in athletes, athletes are often advised to include resistance exercise along with a higher protein (but still energy-restricted) diet in the hope that muscle mass can be preserved. Much more research is needed regarding the best ways to protect against the loss of muscle mass in both athletes and nonathletes, but this seems to be prudent advice (Stiegler and Cunliffe, 2006).

SIMULTANEOUSLY INCREASING MUSCLE MASS AND DECREASING BODY FAT

Many athletes want to simultaneously increase muscle mass and decrease body fat. In other words, they want to remain the same weight but they want to "replace" 5–10 lb (~2.2–4.5 kg) of fat with 5–10 lb of muscle. Although this sounds as if it would be easy for the body to accomplish, anabolism (synthesis) and catabolism (breakdown) are biologically opposite processes and it is difficult to estimate an appropriate daily caloric intake to achieve both simultaneously. A prudent recommendation is to focus on one goal at a time. For many athletes, there is a greater benefit to increasing muscle mass than to decreasing body fat. Weight may eventually be the same but it will probably fluctuate as muscle mass is increased and then body fat is decreased.

SEASONAL TIME COURSE OF BODY COMPOSITION CHANGES

The magnitude of the desired fat loss or lean body mass gain is a factor in deciding the best time in the training cycle to make body composition changes. Small losses of body fat and weight may be a consequence of the athlete's return to preseason training from the relatively sedentary active recovery (off-season) period. If the athlete continues to consume approximately the same amount of energy (kcal), then the increase in energy expenditure from a return to training will result in a loss of body fat. Similarly, an athlete who experiences a small loss of muscle mass in the off-season will see a gain in lean body mass with a properly designed preseason resistance exercise and nutrition program. Athletes can maintain a relatively stable body composition and weight by adjusting their energy intake to meet the energy expenditure requirements of each training cycle.

Larger decreases in body fat require a moderate reduction in food intake along with an increase in energy expenditure, because training alone would not likely create a large enough energy deficit to lose a substantial amount of fat in the preseason training period. Severe reduction in food intake (e.g., fasting, very-low-caloric diet) is not recommended because it interferes with the athlete's ability to train. A moderate reduction in food intake will result in a slow weight loss; therefore, losing considerable amounts of body fat means that weight-loss strategies must be initiated well before the competitive season. In fact, the athlete who wishes to lose relatively large amounts of body fat should begin the process after the competitive season ends (i.e., the active recovery period) and, if necessary, continue the weight-loss plan through the early part of the preseason. Trying to lose large amounts of body fat during the later part of the preseason when training volume is high or during the precompetition and competition periods can be detrimental to training and performance, because energy intake must be reduced at a time when energy and carbohydrate needs are high.

The active recovery period (off-season) is characterized by a reduction in exercise compared to the competitive season. It is also time away from the rigors of training. Some athletes may wish for time away from the rigors of following a diet that supports training, such as high daily carbohydrate consumption, timing of food intake, and monitoring of energy intake. The off-season can be an important break from disciplined eating although it is not a time for reckless abandon of all dietary restraint. However, the loss of a large amount of body fat takes time and some of that time will likely be during the off-season when a moderate restriction of energy intake is feasible and will not interfere with training. The suggestion to lose some weight in the active recovery period may come as a surprise to many athletes and may be difficult for some who prefer to have few dietary restrictions during the off season. Some of these athletes believe that large and rapid fat loss will be possible early in the preseason and do not use the active recovery period to lose body fat (or prevent a gain of body fat). Many are disappointed that preseason losses are not larger and that fat is not lost as rapidly as they had hoped and some engage in **"crash diets"**

Attenuate: Reduce the size or strength of.

Crash diet: Severe restriction of food intake in an attempt to lose large amounts of body fat rapidly.

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Body composition as well as athleticism is important for cheerleading.

$$\text{Minimum body weight} = \frac{\text{Current FFM}}{1 - \text{Minimum \% BF}}$$

Figure 11.16 Minimum Body Weight Formula

Legend: FFM = fat-free mass; BF = body fat

that produce large and rapid weight loss but are detrimental to training, hydration status, and health.

Large increases in muscle mass also take time. Male strength athletes in their 20s, such as (American) football players or bodybuilders, may increase lean body mass by 20 percent in the first year of a regular, heavy-resistance training program supported by a diet with adequate energy, carbohydrate, and protein intakes (Lemon, 1994). A 190-lb (~86-kg) football player might add up to 30 to 35 lb (~13.5 to 16 kg) of lean body mass in the first year of a dedicated training program for collegiate football. However, after the first year, gains in lean body mass are much smaller and increases of 1 to 3 percent are more likely in subsequent years. In other words, untrained athletes can experience large initial gains but trained athletes are likely to experience small gains. The 190-lb (~86-kg) collegiate freshman football player who is 220 lb (100 kg) at the beginning of his sophomore year could reasonably expect to gain 2 to 6 lb (~1 to 3 kg) of lean body mass, and not an additional 30 to 35 lb (~13.5 to 16 kg). Women cannot expect to gain as much muscle mass as men and it is estimated that women will experience approximately 50 to 75 percent of the gains seen in men (Stone, 1994).

LIGHTWEIGHT SPORTS: PUSHING THE BIOLOGICAL ENVELOPE

Some sports have designated weight categories because differences in body size make it impossible for all athletes to fairly compete among one another. Examples include wrestling, boxing, martial arts, and lightweight rowing. In sports in which weight must be moved, such as distance running, gymnastics, high jumping, or ski jumping, participants with a low body weight (but sufficient muscularity) generally have a performance advantage over those with a higher body weight due to larger amounts of body fat. Women's gymnastics, rhythmic gymnastics, and figure skating have a subjectively scored element and a low body weight may influence artistry scores. Cheerleading and ballet dancing, which require athleticism, are not scored, but being chosen for participation may depend on body composition.

All of these athletic events could attract athletes who are naturally light in weight and who could easily maintain a biologically comfortable low body weight. *Biologically comfortable weight* and *naturally lightweight* are terms used to describe individuals who do not need to engage in chronic energy restriction or acute fluid loss to maintain a low body weight. Indeed, these individuals are found in all of these sports from the recreational to the elite level. However, studies of wrestlers, rowers, boxers, and jockeys have reported that the majority of athletes are competing in a weight class that is below their natural weight (Kazemi, Shearer, and Choung, 2005; Hall and Lane, 2001; Filaire et al., 2001). One group of researchers found that the majority of lightweight rowers surveyed were not naturally lightweight and that 76.5 percent of the males and 84 percent of the females studied reduced their body weights in the four weeks before a major lightweight rowing competition (Slater et al., 2005).

As described previously, a target weight based on desirable body composition can be determined. For athletes competing in low-body-weight sports, it is critical that a *minimum* body weight also be calculated. A minimum body weight calculation takes into account the lowest percentage of body fat that an athlete could likely achieve without putting health at risk. A minimum weight formula is shown in Figure 11.16. The Spotlight on a Real Athlete: Sondra, a Superlightweight Kickboxer, illustrates how this calculation could be used to provide the athlete with important information.

Minimum body weight formulas are now used in wrestling to determine the appropriate weight category for competition. The National Federation of State High School Associations instituted rule changes beginning with the 2006–07 season that included: 1) a body fat assessment no lower than 7 percent in males and 12 percent in females, 2) a monitored weight-loss program that does not exceed 1.5 percent loss of body weight per week (seven days), and 3) a specific gravity of urine not to exceed 1.025 (a measure of hydration status). Many high schools are depending on certified athletic trainers to administer and monitor the program (National Federation of State High School Associations).

Weight Cycling in Athletes. Weight cycling is defined as repeated bouts of weight loss and weight gain. Weight cycling is common in sports where there are weight classes and an athlete's weight must be certified before competition (e.g., wrestling, lightweight rowing, boxing, judo, and tae kwon do). In these sports weight cycling is an established part of the sports' culture. The following section will focus on sports in which athletes frequently want to "make weight."

Athletes whose weight must be certified for competition often believe that weight cycling is necessary. Hall and Lane (2001) studied 16 amateur boxers and found that each had four weight goals during the year. These weights included 1) natural weight, 2) training weight, 3) competitive weight, and 4) championship weight. Figure 11.18 illustrates the average weights for these 16 boxers and shows the progression of weight loss from the preseason (natural weight) through the competitive season—74.7 kg (~164 lb) → 71.87 kg (~158 lb) → 69.93 kg (~154 lb) → 67.87 kg (~149 lb). On average the difference between natural and championship weight was approximately 5 percent of body weight. All the subjects in this study believed that weight loss was necessary and that the loss of weight would improve their performance. They also believed that food and fluid intake after the certification of

SPOTLIGHT ON A REAL ATHLETE

Sondra, a Superlightweight Kickboxer

Sondra, a 28-year-old superlightweight kickboxer, weighs 136 lb (61.8 kg) and is already lean, having an estimated 14 percent body fat. She would like to compete in the lightweight category, which has a maximum weight limit of 132 lb (60 kg). Sondra's dilemma is that she is not competitive with the other superlightweight kickboxers, so she is considering competing in a lower weight category although she has not weighed 132 lb (60 kg) or less since high school. Sondra is sure that she could lose 4 pounds if she put her mind to it; after all, discipline is one of the characteristics of the martial arts. She meets with a sports dietitian who is sympathetic to her goal to be a lightweight kickboxer, but indicates that it is important to consider all the effects weight loss can have on an already lean athlete's performance and health. To Sondra's surprise the detrimental effects are far reaching and include hormonal, bone mineral density, lean body mass, and mental changes. The sports dietitian calculates a minimum weight and explains its meaning (see Figure 11.17).

The minimum weight formula uses current weight and minimum percentage of body fat. At 136 lb (61.8 kg) and an estimated 14 percent body fat, Sondra has approximately 117 lb (~53 kg) of fat-free mass. Assuming that she could lose weight only as body fat and achieve 12 percent body fat, both of which would be a challenge, Sondra's weight would only be 133 lb (~60.5 kg). She would need to chronically undereat or voluntarily dehydrate before weigh-in to be certified as a lightweight. The sports dietitian points out that chronic low energy intake would put her at risk for losing some of her lean body mass and possibly developing disordered eating, amenorrhea, and low bone mass (see Chapter 13).

Sondra realizes that she is setting a goal weight that would be difficult to attain and maintain, yet she finds it hard to let go of the belief that getting to 132 lb (60 kg) is just a matter of having enough discipline. The dietitian encourages her to articulate her goals and reflect on what is needed to achieve them. Sondra's three main goals are to perform her best, be physically fit, and have fun. Good performance requires disciplined training, which Sondra enjoys because it is a challenge, but she knows that she does not have the skill to compete at the highest levels of competition. She also realizes that she loves to eat and her high level of training gives her the ability to eat a lot of food and easily maintain her natural weight and a fit and muscular body. She knows that some of the women who compete in the lower weight categories struggle to "make weight" and she has observed that these women often looked wan, tired, and sad.

The minimum weight formula may help an athlete like Sondra to realize in which body compartments the "weight" would need to be lost and if weight loss would likely mean loss of lean body mass or body water. Considering all of the factors, not just if she has the discipline to reach a certain scale weight, Sondra decides to remain a superlightweight kickboxer. The minimum weight formula helped her to understand that 132 lb (60 kg) was not the right weight goal for her.

$$\text{Minimum body weight} = \frac{\text{Current FFM}}{1 - \text{Minimum \% BF}}$$

$$\text{Minimum body weight} = \frac{117\text{ lb}}{1 - 0.12} = \frac{117\text{ lb}}{0.88} = 133\text{ lb}$$

Figure 11.17 Calculation of a Minimum Body Weight

Legend: lb = pound; FFM = fat-free mass; BF = body fat

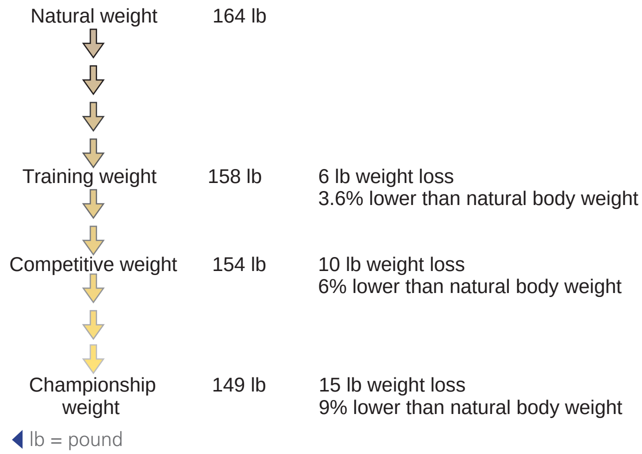

Figure 11.18 Progression of Weight Loss in Amateur Boxers

weight restored the nutrients and strength lost as a result of making weight. Weight cycling, both gradually over the season and rapidly during a given week in the season, is also documented in wrestling, judo, and tae kwon do and parallels boxing in many respects.

Weight is typically lost by increasing exercise, reducing food intake, and restricting fluid intake. Reducing natural weight to a training weight may be relatively easy since the energy expended during training is substantially greater than the energy expended during the off-season. Food intake is often reduced at the same time that exercise is increased, so weight loss is an expected outcome. However, reducing training weight to precompetition and competition weights, which may be considerably below natural weight, typically require more extreme interventions.

During the precompetition and competition phases, athletes often find that it is harder to reach the desired weight or to attain that weight each week. In studies of boxing and tae kwon do participants, researchers report that nearly all subjects restricted their food intake to a greater degree during the competition phases than during the training phase. One to two days prior to weigh-in, many engaged in partial or full fasting (restricting food intake only or both food and fluid intake, respectively). Fluid intake was frequently restricted at least 24-hours prior to weigh-in. On the day of the weigh-in, exercise (e.g., skipping rope, running) was used to further reduce weight and rapid water-loss methods (e.g., exercising in the heat or with sweat-inducing plastic suits, use of diuretics) were employed if goal weight was not likely to be obtained by any other means (Hall and Lane, 2001; Kazemi, Shearer, and Choung, 2005).

In 1994, Scott, Horswill, and Dick reported the results of a study of collegiate wrestlers competing in the 1992 season-ending National Collegiate Athletic Association (NCAA) tournament. At the time of the study there were approximately 20 hours between weigh-in and competition. The average weight gain after weigh-in was 3.73 kg (~8 lb). The wrestlers gained an average of 4.9 percent of body weight after weigh-in, with the wrestlers in the lower weight categories gaining the most weight. These results confirmed anecdotal reports of widespread use of weight cycling among elite collegiate wrestlers.

In the United States, rule changes were made in both NCAA and high school wrestling following the deaths of three collegiate wrestlers in 1997. Perhaps the most important NCAA rule change was moving the weigh-in to approximately two hours prior to competition. In 1999, the second year of the rule change, NCAA tournament wrestlers gained approximately 0.66 kg (~1.5 lb) after weigh-in (Scott et al., 2000). However, international-style wrestling (i.e., freestyle and Greco-Roman) has not made the time-of-weigh-in rule change and in 2004 Alderman et al. found that rapid weight loss and gain was still widely practiced. Their sample of 2,600 international-style wrestlers found that the average weight gain after weigh-in was 3.4 kg (~7.5 lb) or 4.8 percent of body weight. The more successful wrestlers, who were also older, gained significantly more weight after weight certification than the younger, less successful wrestlers.

Although it is not easy to study, there is some research documenting the effects of weight cycling, particularly rapid weight loss and gain, on performance, mental state, and health. Most studies have found that physical performance was not impaired, at least for measures of short-term, high-intensity exercise. Smith et al. (2001) found no significant differences in the performance of eight amateur boxers in a crossover study when they restricted food and fluid intake compared to when they did not. Fogelholm et al. (1993) found no decline in measures of sprinting, jump height, or anaerobic performance in wrestling or judo, with a 5 percent or less loss of body weight achieved either gradually (over three weeks) or rapidly (2.4 days). In the study of the 16 amateur boxers (Hall and Lane, 2001), the subjects were asked to set a goal for the number of repetitions they wanted to perform on a circuit-training protocol that simulated a boxing match. There was no significant difference between the number of repetitions achieved at the training weight and the championship weight, a difference of about 5 percent of body weight. However, the boxers *expected* that they would be able to perform approximately 15 more repetitions at their championship weight; none did. In other words, these boxers believed that losing ~5 percent of their weight would improve performance but it did not.

There has been speculation that weight cycling results in a decrease in resting metabolic rate (RMR). This is one theory behind the observation that athletes have a more difficult time making weight week after week, especially near the end of the season. However, most research in athletes does not demonstrate that weight cycling results in a measurable reduction in RMR in the short term (week by week in season) or the long term (over two or three seasons). Most of these studies were conducted in the 1990s and there are no recent studies of athletes and the effect of weight cycling on RMR (McCargar et al., 1993; McCargar and Crawford, 1992; Horswill, 1993; Schmidt, Corrigan, and Melby, 1993; Melby, Schmidt, and Corrigan, 1990).

Mental state, however, seems to change with weight cycling. Higher scores on measures of anger, tension, and fatigue and lower vigor scores are reported in amateur boxers and judoka (judo athletes). These changes are likely due to low energy intake (i.e., semi-starvation), low carbohydrate intake, and hypohydration (Hall and Lane, 2001; Filaire et al., 2001).

The biggest area of concern is the health of the athlete who needs to "cut" weight, a term used to indicate extreme diet and exercise measures to produce rapid weight loss. Alderman et al. (2004) found that more than 40 percent of wrestlers who engaged in rapid weight loss experienced headache, dizziness, or nausea at least once during the season. Other side effects, such as nosebleeds, disorientation, or a racing heart rate, also occurred in some wrestlers but with less frequency. The medical consequences associated with hyperthermia (elevated body temperature) and hypohydration as a result of rapid weight-loss techniques are well known. These conditions, some of which may be fatal, are discussed in Chapter 7.

A 2006 study of former Finnish athletes raises the possibility that weight cycling by athletes may predispose them to obesity later in life. Approximately 1,800 male elite athletes completed questionnaires in 1985, 1995, and 2001. The 370 weight cyclers, former boxers, weight lifters, and wrestlers had an average weight gain of 5.2 BMI units (~26 lb or 12 kg) compared to 3.3 BMI units (16.5 lb or 7.5 kg) in nonweight-cycling former athletes (Saarni et al., 2006).

What's the point? Weight and body composition measurements can be useful information for athletes, but these measures must be accurately obtained and interpreted and applied correctly.

WEIGHT GAIN IN UNDERWEIGHT ATHLETES

Some athletes are underweight and want to increase both muscle mass and body fat. This population has not been well studied. It is generally recommended that energy intake be increased by 500 kcal daily (Rankin, 2002). The additional energy should come from nutritious foods such as fiber-containing carbohydrates, proteins, and heart-healthy fats. Fat is the most energy-dense nutrient, however, simply adding large amounts of additional fats to the diet may be counterproductive. In some underweight people, a high-fat meal or snack is so **satiating** that food is not consumed again for many hours and results in a net decrease in the total energy (kcal) intake for the day. More information on dietary strategies for underweight athletes can be found in Chapter 10.

Supplements Used to Change Body Composition

Changing body composition through diet and exercise demands daily attention and discipline, and is typically a slow process. Therefore, it is not surprising that athletes look to supplementation of substances that promise to build muscle and reduce body fat easily and quickly. Some of these supplements may contain substances that are banned by sports-governing bodies. Before taking *any* supplement athletes should ask four critical questions: 1) Is it **legal**? 2) Is it **ethical**? 3) Is it **safe**? and 4) Is it **effective**?

MUSCLE-BUILDING SUPPLEMENTS

Perhaps no group of supplements holds more promise in the eyes of athletes than those involved in muscle protein synthesis. Increased muscle size and strength are important performance factors in many sports. As discussed previously, the building of muscle tissue through training and diet is a slow process that requires hard work and discipline. Substances that have received tremendous attention include testosterone and testosterone precursors.

Anabolic Steroids. Testosterone is a hormone that influences muscle protein synthesis. The use of anabolic steroids, scheduled drugs that are nearly identical to testosterone, is known to increase muscle mass and, in some individuals, muscle strength (American College of Sports Medicine, 1984). The self-prescribed use of anabolic steroids is illegal, prohibited by sports-governing bodies for ethical and safety reasons, and associated with some substantial medical risks, especially for females because of their irreversibility.

Satiate: To satisfy hunger.

Legal: Allowed under the law.

Ethical: Consistent with agreed principles of correct moral conduct.

Safe: Unlikely to cause harm, injury, or damage.

Effective: Causing a result, especially one that is intended or desired.

Those who work in sports-related fields might encounter athletes who use or are considering using anabolic steroids to increase muscle mass. A National Institute on Drug Abuse (NIDA) study reports that 2.6 percent of high school seniors have used anabolic steroids at least once. The prevalence in adults in not known but is estimated to be in the hundreds of thousands of adults (NIDA, 2005).

Athletes should be aware of the many legal, ethical, and safety issues involved. The impact on health may be mild to severe and, in rare cases, may result in death. Blood pressure and low-density lipoprotein concentration may increase while high-density lipoprotein concentration may decrease, which are risk factors for cardiovascular disease (see Chapter 12). Aggression, depression, and other psychological effects have been reported. Use by males may result in reduction in testicle size, accelerated baldness, and the development of breast tissue. Use by females may result in changes in menstruation and reproductive organs, baldness, lowering of the voice, and growth of facial hair. Adolescents, because they are typically still in a growth state, risk premature skeletal maturation before reaching their genetic potential for height. The National Institute on Drug Abuse and most sports-governing bodies have anabolic steroid information available for athletes.

Prohormones. Because athletes can be permanently banned from their sport for testing positive for anabolic steroids, many look for dietary supplements that would provide similar benefits. Among the most popular are the prohormones, compounds that are precursors to testosterone. Many prohormones, such as androstenedione, are banned by sports-governing bodies.

As shown in Figure 11.19, many compounds are involved in the synthesis of testosterone. Cholesterol is the precursor to testosterone and related compounds. Action by various enzymes results in the conversion of

SPOTLIGHT ON A REAL ATHLETE

One Wrestler's True Story

"I was a senior in high school, 18-years-old, and trying to lose weight for wrestling. I was 5'8" tall and started out weighing 145 pounds. Within about three weeks I had lost 17 pounds to make the 128 pound weight class. I was on a strict diet of 1,100 calories per day. Two days before I had to make weight, I would stop eating. The day before weigh-ins, I would not drink anything. I was always trying to burn off "extra" pounds by jumping rope or jogging. Whenever I worked out, I always wore two pairs of sweats in order to lose water weight. I jogged 12 miles one day to make weight for a match that evening. I would fast, and dehydrate myself by sweating and spitting in a cup in order to make weight. I never took laxatives, diuretics, or vomited to make weight. After weigh-ins, I ate as much as I wanted to without eating so much as to hinder my performance. On weekend tournaments I also ate between matches and afterwards. On Sunday, I started cutting back on my caloric intake and by Monday I was back down to 1,100 calories. I was usually at least 10 pounds overweight on Monday, also. I weighed myself around four times per day. It was such a physical and emotional strain on me to make weight I could only make the 128-pound class about once every two weeks. The other times I only had to make the 134-pound weight class. The trainer did a skinfold measurement to check my body composition and came up with a figure of below 3 percent body fat. I was probably in the best cardiovascular shape in my life due to my constant cardiovascular workouts. However, I did lose strength and muscle mass. I looked much thinner than I did before, and my cheeks and eyes were sunken in and I had dark circles under my eyes. I had trouble falling asleep at night. I constantly felt cold. I never seemed to generate enough body heat to keep warm. I was the only one wearing a jacket in my classes, and I had to sit on my hands to keep them warm. When I saw my friends with food or a soft drink, I would cuss at them. Fortunately, I was able to maintain a 4.0 grade point average. I became obsessed with food because I was so hungry and I couldn't eat. To compensate for that, I used to go to the grocery store a couple of times per week and walk up and down every aisle and make a mental list of all the foods I was going to eat when the season was over. I also used to do a lot of cooking and baking, but not eat any of it. By the end of the season, it had taken its toll on me. I secretly hoped that I would be eliminated and not qualify for the next tournament, so my season would be over and I could eat as much as I wanted to. I always tried my best to win, and I never tried to lose on purpose, but I think that it subconsciously affected my performance. Why would anyone do this to himself? My coaches told me they needed me to compete at that weight class. They told me I was the best wrestler at that weight class and it would make the team stronger if I competed there. One of my coaches told me how he did the same thing in high school and that if he could do it, I could do it, and I believed him. What they, and I, didn't realize was that I probably would have wrestled better, and been more of an asset to the team, if I had wrestled at a higher weight. If I had known then what I now know about the relationship between nutrition and athletic performance, I would have wrestled at the 140-pound weight class instead."

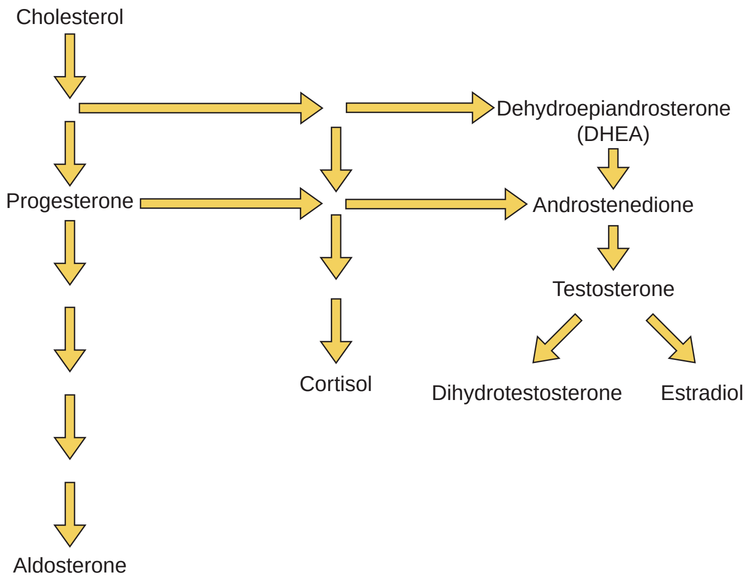

Figure 11.19 Testosterone Synthesis

The biochemical pathway of testosterone synthesis.

cholesterol to progesterone to androstenedione and to testosterone. Using a different biochemical pathway, cholesterol can also be converted to testosterone via dehydroepiandrosterone. Androstenedione and testosterone are precursors to estrogens such as estrone and estradiol.

Androstenedione, androstenediol, and, to a lesser extent, DHEA are often referred to as *prohormones*. They are precursors to testosterone and have similar, but not exact, chemical structures. Athletes hope that these prohormones will elevate testosterone concentration and consequently increase muscle protein synthesis. Studies of all of these compounds have yet to confirm this hope. Although some studies showed a short-term rise in testosterone concentration with supplementation, this short-term rise has no effect on muscle size, strength, or power (Broeder et al., 2000). In fact, androstenedione supplementation preferentially increases estradiol (via estrone), not testosterone, which can result in the development of breast tissue in males (Wolfe, 2000).

Androstenedione supplements became extremely popular when baseball star Mark McGwire admitted to taking “andro” during his home run record-setting season in 1998. His taking this supplement may have influenced many younger and less accomplished players to do so (Brown, Basil, and Bocarnea, 2003). The purity and safety of androstenedione supplements has been questioned. Suspicions have been raised about whether some androstenedione supplements may have been “spiked” with anabolic steroids.

In March 2004, the Food and Drug Administration (FDA) released a **white paper** that listed more than 25 potential androgenic and estrogenic effects associated with androstenedione use (FDA, 2004). This review of the scientific literature prompted the FDA to crack down on dietary supplements containing androstenedione. The FDA considers these supplements to be adulterated (impure), and therefore illegal to market. Androstenedione is a banned substance by most sports-governing bodies, which consider its use unethical and unsafe.

Dehydroepiandrosterone (DHEA) is also a precursor to testosterone and estrogen, but it is considered a weak androgen (steroid). It has a more general effect on tissues than anabolic steroids or androstenedione. DHEA diminishes substantially after early adulthood, probably due to a decrease in the number of cells that produce it (Hornsby, 1997). Thus, supplements are often advertised as being “a fountain of youth.” There is no scientific evidence that DHEA has an anabolic effect or can enhance athletic performance (Corrigan, 2002). However, interest in DHEA supplements increased after androstenedione supplements were no longer legally available in the United States.

DHEA was a prescription drug in the United States prior to the passage of the Dietary Supplement Health and Education Act in 1994. DHEA is now available over the counter and in dietary supplements. In other countries, such as Australia and New Zealand, it remains a controlled substance due to the potential for abuse. Because the long-term safety is currently unknown and effectiveness related to athletic performance is unproven, DHEA supplements for athletes are not recommended (Corrigan, 2002).

White paper: Official, well-researched government report.

WEIGHT-LOSS SUPPLEMENTS

Most people find it difficult to lose body fat and to maintain the loss. Any dietary supplement that may increase the amount lost or accelerate the rate of weight loss will be popular. Because dietary supplement manufacturers do not have to prove either safety or efficacy before a supplement is sold, there is an endless stream of weight-loss supplements on the market. Perhaps the most controversial weight-loss supplements are those that contain ephedrine (e.g., ephedra), which may be used alone, but is usually found in combination with caffeine.

Ephedra, Ephedrine Alkaloids, and Ephedrine. *Ephedra, ephedrine alkaloids,* and *ephedrine* are different terms and should not be used interchangeably. *Ephedra* is a botanical term and refers to a genus of plants. Some species of ephedra contain ephedrine alkaloids in the stems and branches. One of the ephedrine alkaloids is ephedrine. In common usage, dietary supplements that contain any of the ephedrine alkaloids are referred to as *ephedra*.

In traditional Chinese medicine, ma huang is extracted from a species within the plant genus *Ephedra*. This species, *Ephedra sinica* Stapf, contains six different ephedrine alkaloids. Of the six, the primary active ingredient is ephedrine. Ephedrine can also be synthesized in the laboratory. Traditionally, the Chinese have used ma huang to treat asthma and nasal congestion. In the United States, ephedrine is added to over-the-counter medications for the same purposes. But ephedrine and related compounds have been marketed as dietary supplements for two other purposes: weight loss and increased energy. Both are common goals for athletes. Are ephedrine and related compounds safe and effective for these purposes?

Safety of Ephedrine-Containing Compounds. The safety of ephedrine-containing dietary supplements has always been controversial and reviewing its history helps to underscore some important issues about safety, purity, and supplement regulation in the United States. After the passage of the Dietary Supplement Health and Education Act in 1994, the sale of dietary supplements containing ephedrine began to increase. The FDA expressed concern, in part, because of the number of adverse event reports (AER) they received. Consumers can report adverse events to a hotline and by 1997 half of the AER received involved ephedrine. The adverse events reported included known side effects such as headache, increased heart rate, increased blood pressure, and insomnia. The AER also included deaths to otherwise healthy middle-aged and young adults.

Adverse event reports are anecdotal evidence because they are personal accounts of an event. These reports were hard to interpret because many lacked information about the dose consumed. Some consumers may have used these supplements despite the manufacturer's warnings. Most warn against use by pregnant or lactating women, and those with a history of heart disease, diabetes, or high blood pressure.

A scientific review of 16,000 adverse event reports found that 21 were serious events: two deaths, nine strokes, four heart attacks, one seizure, and five psychiatric problems. In these cases ephedrine was believed to be the sole contributor, *but* there was not enough scientific evidence to establish a cause-and-effect relationship. In addition to the 21 serious events, ephedrine contained in dietary supplements was implicated as a contributing (but not sole) factor in 10 other cases with serious side effects (Shekelle et al., 2003).

Further complicating the issue of safety was that experts do not agree on the dosage that is considered safe. The FDA proposed that not more than 8 milligrams (mg) of ephedrine alkaloids be used in a 6-hour period *and* not more than 24 mg in a 24-hour period. Use should not exceed seven days (FDA, 2000). Another group of experts suggested that a single dose should not exceed 30 mg of ephedrine alkaloids and that up to 90 mg in a 24-hour period is safe. They suggest usage should not exceed six months (CANTOX report, 2000).

Another safety issue was quality control. In 2000, Gurley, Gardner, and Hubbard published a study of the ephedrine alkaloid content of 20 dietary supplements. The content of 10 of the products varied by more than 20 percent when compared to the amount listed on the label. The worst example was a product that contained more than 150 percent of the amount listed on the label. One product had no active ingredient, and particularly troublesome, five contained norpseudoephedrine, a controlled substance (drug). This study clearly illustrates why athletes must be concerned about the purity of dietary supplements.

Athletes should particularly be aware of the risk associated with using ephedrine-containing dietary supplements prior to strenuous workouts in the heat. In 2001, the National Football League (NFL) banned the dietary supplement ephedra after the death of an interior lineman during training camp. Although toxicological tests were not conducted on autopsy, an ephedrine-containing dietary supplement was found in the player's locker. In 2003, the safety of ephedrine-containing dietary supplements was again in the news with the death of a major league pitching prospect at spring training. In this case, the coroner implicated ephedrine as the cause of death. Contributing circumstances appear to include a history of borderline hypertension and liver abnormalities, exercising in hot and humid conditions, and restricting food and fluid intake in the previous 24-hours in an effort to lose weight.

The 2003 spring training death brought the issue of ephedrine in dietary supplements back to the forefront. In December 2003, the FDA issued an alert that advised consumers to stop buying and using dietary supplements containing ephedrine. In April 2004, the FDA banned the sale of ephedrine-containing dietary supplements. Although the alert was issued in December, the ban could not go into effect until the following April because there must be a 60-day period between the official notification of the ban and its enactment.

The ban is controversial. Under the Dietary Supplement Health and Education Act, the FDA can stop the sale of a dietary supplement if there is a demonstrated "significant or unreasonable risk of illness or injury." The legal issue boils down to this question: Do the serious events reported to date, including deaths in which ephedrine was the sole contributor but in which cause and effect cannot be established, constitute an unreasonable risk of illness or injury?

Proponents of the ban point to documented deaths. They also question whether there are any health benefits and suggest that the risk/benefit ratio meets the "unreasonable risk" portion of the criterion. Opponents of the ban counter that the risk is very small. In 1999, approximately 3 million people purchased ephedrine-containing dietary supplements and consumed an estimated 3 billion "servings." The risk of a serious adverse event is estimated to be less than 1 in 1,000 and a cause-and-effect relationship has not been established. The debate is often passionate, political, and polar (FDA, 2003).

In April 2005, a federal judge struck down a portion of the ban. In that decision, the judge ruled that the FDA did not establish that an unreasonable risk of illness or injury was associated with low-dose (10 mg or less) ephedrine-containing supplements. The federal ban remains in place for doses greater than 10 mg. Some states (e.g., California, Illinois, New York) have banned the sale of all ephedrine-containing dietary supplements and these state laws are not affected by the federal court's decision.

Most ephedrine-containing supplements also contain caffeine, a member of a group of stimulants known as the methylxanthines. Since caffeine sometimes carries a negative connotation with consumers, the source of methylxanthine may be herbal, either guarana or kola nuts. Methylxanthine enhances the effectiveness of ephedrine as a weight-loss agent. Look carefully at the label shown in Figure 11.20. A dietary supplement may contain both ephedrine and caffeine but those words will not appear if, for example, the source of those ingredients is ma huang and guarana.

SUPPLEMENT FACTS	
Serving size: 1 tablet	
Servings per container: 60	
Amount per serving	% Daily Value
Vitamin B_{12} 50 mcg	833%
Megatherm™ proprietary blend 350 mg	**
Ma huang	**
Guarana seed	**
Yerba mate	**
Green tea leaf	**

** Daily value not established

Ingredients: Megatherm™ proprietary blend, pyridoxine HCL, sorbitol, guar gum.
Storage: Keep in a cool dry place, tightly closed.
Suggested Use: As a dietary supplement, take one tablet daily.

Keep out of reach of children
Expiration date: Dec 2012

Figure 11.20 Label of an Ephedrine-Containing Supplement. This dietary supplement contains both caffeine and ephedrine, but these terms do not appear on the label.

Effectiveness of Ephedrine for Weight Loss. Studies have shown that the use of ephedrine and caffeine by obese people can produce a short-term weight loss of 8 to 9 lb (~3.5 to 4 kg). Studies to date have not been conducted for longer than six months, so it is unknown what the long-term effect might be or the effect of discontinuing the ephedrine and caffeine. It is also not known if an ephedrine-induced short-term weight loss has any long-term health benefit (Shekelle et al., 2003). Most athletes are not obese, so it is not known if, or how much, weight would be lost by athletes with ephedrine use.

Some athletes claim that ephedrine- and caffeine-containing dietary supplements give them "more energy." This is likely due to the stimulant effect of

THE EXPERTS IN…

Weight and Body Composition

Over the course of a long professional career, Jack Wilmore, Ph.D., helped athletes and sports-related professionals to correctly interpret information obtained from measuring body composition. As technology changed the measurement methods, Linda Houtkooper, Ph.D., R.D., emerged as an expert in some of the more sophisticated body composition techniques, such as DEXA scans. These and other experts have authored numerous scientific articles about accurately measuring body composition.

One of the more difficult areas of study has been the best ways for athletes to increase muscle mass and decrease body fat. Janet Walberg Rankin, Ph.D., has conducted research on weight control and body composition, particularly in resistance-trained athletes.

The Internet Café

Where Do I Find Reliable Information about Body Composition and Body Weight?

There are hundreds of noncommercial websites and hundreds of thousands of commercial websites with information about body composition and body weight. The prevention section of the Dietary Guidelines for Americans website includes a calculator for body mass index as well as information about a healthy weight. Shape Up America!, founded by former Surgeon General C. Everett Koop, is dedicated to raising awareness of obesity as a health-related issue as well as reducing the incidence and prevalence of childhood obesity. These are just two examples of websites with comprehensive information about body weight and composition.

Dietary Guidelines for Americans, 2005
http://www.healthierus.gov/prevention.html

Shape Up America!
http://shapeup.org

these compounds, which can mask fatigue. Some brands may be "spiked" with norpseudoephedrine, a stimulatory drug. Caffeine, ephedrine, and other stimulants are addictive and individuals will experience symptoms upon withdrawal, including headache, fatigue, drowsiness, depressed mood, irritability, and inability to concentrate (Juliano and Griffiths, 2004). These characteristics are undesirable and may interfere with training, making it difficult or uncomfortable for athletes to stop using stimulatory dietary supplements.

Effectiveness of Ephedrine on Performance. A small number of studies have been conducted on the use of nonherbal ephedrine and caffeine preparations in healthy males as a performance enhancer. Research in this area has been limited due to the ethical issues related to administering potentially harmful substances to human subjects. Ephedrine and caffeine administered together has been reported to increase performance by delaying time to exhaustion by up to 30 percent (Schekelle et al., 2003). Athletes also report a decrease in perceived exertion (Magkos and Kavouras, 2004). These results are not surprising given the stimulatory properties of these substances. Studies have not shown that ephedrine and caffeine, alone or in combination, are effective in increasing muscle strength, muscle size, or anaerobic capacity.

Other Weight-Loss Supplements. A quick search of the Internet reveals an astounding number of dietary supplements available for purchase for the purpose of weight (fat) loss. Many of these supplements are described as "fat burners," a loosely defined term that is used to describe compounds that help individuals to lose body fat, typically by increasing metabolism or enhancing fat breakdown. Many of the compounds are described as *natural*, which generally means that the active ingredient comes from an herbal rather than a synthetic source.

Ephedrine and ephedrine alternatives (with added caffeine) are examples of fat burners and have already been discussed. Other supplements promoted for fat loss include yerba mate, yohimbe, and hydroxycitric acid (*Garcinia cambogia*). Pittler and Ernst (2004) conducted a systematic review of 12 dietary supplements for weight loss and concluded that none could be recommended because scientific evidence was lacking for safety or effectiveness.

Summary

The body is composed of various tissues, including fat, muscle, bone, organs, and fluids. The relative percentage of these components, particularly body fat, may

KEEPING IT IN PERSPECTIVE

Body Composition, Body Weight, Performance, Appearance, and Health

Athletes are typically very interested in measuring their body composition. While weight and body composition are factors in athletic performance, the impact of either will vary depending on the sport. A lean, muscular athletic body usually has high social value, and many athletes wish to alter their weight and body composition for both performance and appearance reasons. Most athletes are not obese, so body weight is often not a chronic disease-related issue, but how rapidly and dramatically athletes lose weight may negatively impact their health.

Perspective can be lost when a certain body composition or weight is the ultimate goal instead of a means for potential improvements in performance or health. Trying to attain an ever-lower weight can result in declining or poor performance and does not make sense. Becoming too focused on a number can lead athletes to engage in risky behaviors, such as severe hypohydration, and lose sight of the bigger picture, which is optimal performance. It is easy to forget that body composition measurement is not precise and that reaching a certain percent of body fat may be at odds with performance and health goals.

affect performance, appearance, and health. There are a number of ways to measure body composition, but all have inherent measurement error and are considered only estimates of actual body composition. The subject or technician can introduce additional error. Therefore, body composition results should be interpreted carefully.

Body composition results can be used to determine an appropriate scale weight, establish percent fat and **lean body mass** goals, and assess the impact of training and nutrition strategies. Changing body composition may improve performance, but attaining an inappropriate body composition or weight can be detrimental to performance and health. Athletes in sports in which weight must be certified can calculate a realistic, attainable, and sustainable minimum weight.

Athletes may wish to change body composition and can do so with an exercise and diet plan that promotes maintenance or gains in lean body mass and/or loss of body fat. These goals are typically accomplished over time and should be a planned part of the athlete's training schedule. The timetable for achieving these goals may be slower than the athlete would like or imagines. Muscle building and "fat burning" supplements may be tempting to those desiring rapid results, but some of these supplements are not legal, ethical, safe, and/or effective. Athletes should consider performance, appearance, and health when setting weight and body composition goals.

Post-Test: Reassessing Knowledge of Body Composition and Body Weight

Now that you have more knowledge about body composition and body weight, look again at the statements that were listed at the beginning of the chapter. The answers can be found in Appendix O.

1. Percent body fat and fat mass can be precisely measured in athletes with a number of different methods.
2. The most accurate method of measuring body fat for any athlete is underwater weighing.
3. In sports in which body weight must be moved or transported over a distance (e.g., distance running), it is a performance advantage to have the lowest weight possible.
4. To increase muscle mass, most athletes need a substantial increase in their usual protein intake.
5. For athletes who want to restrict energy intake to lose body fat, the recommended time to do so is at the beginning of the preseason or during the off-season.

Review Questions

1. What is essential fat and how does it differ from storage fat?
2. Are lean body mass and muscle mass the same or different? Explain.
3. Compare and contrast the body build of endomorphs, mesomorphs, and ectomorphs. How might this information be used to help athletes set realistic body composition goals?
4. Why is body mass index (BMI) inappropriate to use with athletes?
5. Explain why percent body fat results should be given as a range rather than as a single number.
6. Describe various ways that error may be introduced into the measurement of body composition.
7. Compare and contrast the various body composition methods considering accuracy, cost, availability, portability, and ease of use. Which may be useful in a research setting? A high school? A university? A health and fitness club?
8. In what ways may body composition estimates be useful to athletes and those who work with athletes?
9. Body weight does not give information about body composition, so why is the measurement of body weight useful?
10. Describe a situation in which calculating a minimum body weight might be beneficial.
11. Name the two dietary factors that are critical to increasing muscle mass. Explain why each is important.
12. What effect does weight cycling have on performance? On mental health? On physical health?
13. Name some of the side effects of anabolic steroids and androstenedione.
14. Develop a point/counterpoint discussion for a ban on all ephedrine-containing dietary supplements.

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12 Diet and Exercise for Lifelong Fitness and Health

SteveNiedorf Photography/Stone/Getty Images

Learning Objectives

1. Discuss the relationship between nutrition and physical activity and lifelong fitness and health.
2. Identify reasons why energy expenditure may decline and weight may be gained as individuals age.
3. Compare and contrast general diet and exercise recommendations published by various organizations.
4. Outline the nutrition and exercise strategies associated with promoting health and delaying the onset of chronic diseases.
5. Briefly explain each chronic disease (cardiovascular disease, hypertension, obesity, type 2 diabetes, metabolic syndrome, lifestyle-related cancers, and osteoporosis) and how diet and exercise influence each.
6. Compare and contrast several popular weight-loss plans.
7. Explain the relationship among body weight, fat distribution, and the risk for chronic diseases in men and women.
8. Explain the philosophy of the nondiet or Health at Every Size (HAES) approach.
9. Discuss the process of behavior change.

Pre-Test — Assessing Current Knowledge of Health, Fitness, and Chronic Diseases

Read the following statements and decide if each is true or false.

1. There are many contradictions among diet and exercise recommendations that are issued by health promotion organizations.
2. Elite endurance athletes do not develop hypertension but lesser-trained athletes do.
3. Type 2 diabetes is caused by eating too much sugar.
4. A sedentary lifestyle is associated with a higher risk for heart disease, certain types of cancer, and diabetes.
5. Being physically active helps to reduce disease risk even if a person is obese.

"Everyone is an athlete. The only difference is that some of us are in training, and some are not." George Sheehan, physician, writer, and running philosopher, eloquently expressed the notion that the human body is made to be active and that people have different reasons and motivations for being physically active, exercising, or participating in sport (Sheehan, 1980). The majority of this textbook has approached sports nutrition from the perspective of highly trained athletes who are trying to achieve maximum performance and success in their sports. However, athletes with this single-minded goal not only make up a very small percentage of the population, they usually pursue their performance goals for a short amount of time relative to their lifespan. Few athletes remain highly competitive in their sports over a large portion of their lifetime.

Gary M. Prior/ALLSPORT

Rower Sir Steve Redgrave displays the gold medals that he won at five consecutive Olympic Games, however, few athletes remain highly competitive in their sports over a large portion of their lifetime.

Many adults who exercise fall into the category of recreational athletes. Some are former competitive athletes who continue to have a lifelong dedication to perform at the highest level they can achieve and who remain competitive within their age group in masters events. For other former athletes, participation rather than competition may be the motivation, particularly as they get older or have less leisure time to devote to training. Some recreational athletes are not former competitive athletes; they take up a sport as an adult and set a personal performance goal, such as running a marathon or scoring less than 100 in a round of golf. Recreational athletes may train or practice their sport, but the intensity and duration of training can vary tremendously. In addition to the benefits of participating and competing in sports, recreational athletes also benefit from increased fitness that contributes to good health and the possible prevention of chronic diseases.

While some adults are not recreational athletes, they do engage in routine physical activity. Physical activity is defined as bodily movement that results in an increase in energy expenditure above resting levels. The motivation to engage in physical activity varies, but typically the reasons

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For many athletes participation rather than competition may be the motivation, particularly as they get older or have less leisure time to devote to training.

Physically active people have many of the same goals as recreational athletes, such as improved fitness, good health, and disease prevention, but they are not performing or competing against others.

include improving health, "staying in shape," maintaining or losing weight, and enhancing appearance. Physically active people have many of the same goals as recreational athletes, such as improved fitness, good health, and disease prevention, but they are not performing or competing against others.

There is a relationship between exercise and nutrition for physically active people and recreational athletes, but because training is less than that of highly trained athletes some of the nutritional demands (e.g., caloric intake) are less. Physically active people typically need little modification of the principles of a healthy diet to support their physical activity. Similarly, the intensity and duration of training for most recreational athletes are not enough to require substantial modifications to a basic healthy diet. One exception may be the recreational endurance athlete whose intensity and duration of training (e.g., preparation for a marathon) necessitates the implementation of some of the sports nutrition principles discussed throughout this text and reviewed in Chapter 10.

Because "everyone is an athlete," it is important that all people be physically active on a daily or near daily basis. Exercise is one cornerstone of a healthy lifestyle; diet is another. There is a strong relationship between nutrition, physical activity, and long-term health, and a number of public health organizations have issued nutrition and physical activity guidelines. Many students reading this textbook will eventually work with clients who are trying to apply these recommendations. In many cases, these clients or patients will have a history of being sedentary and consuming a poor diet. Working with a sedentary, **overweight,** or **obese** adult who consumes the typical American diet is a tremendous challenge because the need to change is high but the motivation to change is often low or hard to sustain. Changes are especially difficult because the environment and culture in the United States and other industrialized countries promote physical inactivity and overconsumption of energy (kcal), sugar, fat, and salt.

The purpose of this chapter is to understand the basic diet and exercise principles related to lifelong fitness and health. A fundamental dietary principle—adequate nutrients within caloric need—applies to everyone. Daily exercise is a powerful influence on the amount of kilocalories needed and the amount of daily exercise performed often changes as people age. To illustrate some of these changes, this chapter includes several scenarios of adults at various stages of life. Each has different goals, demands, and motivations and therefore different needs. All can benefit from the application of scientifically sound nutrition and exercise information. These scenarios are also used to highlight a variety of chronic diseases and the influence that diet and exercise have on prevention and treatment.

The Lifelong Athlete

The term *athlete* often brings to mind the highly trained collegiate or professional player. However, individuals participate in sports competitively or recreationally long after their best performing years, and ideally people engage in exercise or remain physically active throughout their lives. An obvious factor that changes over an athlete's life is the level of performance, but lifestyle, personal and professional obligations, and health also change. All these factors must be considered when working with lifelong athletes.

POSTCOMPETITIVE ATHLETES

Most collegiate athletes do not become professional athletes. For example, the National Collegiate Athletic Association (NCAA) estimates that only 2 percent of

Overweight: Medical definition is a body mass index of 25–29.9.

Obese: Medical definition is a body mass index greater than 30.

NCAA football players will play professionally. Probability figures for men and women's basketball and men's soccer are even lower (http://www.ncaa.org/about/fact_sheet). Some postcollegiate athletes find that they wish to continue to train, albeit at a lower level, and eventually may become **masters athletes.** Others find that exercise becomes a lower priority and they are essentially "former" athletes. In either case, the reduction in training necessitates adjustments to the diet, particularly caloric intake. Weight gain is associated with chronic disease risk even in former elite athletes.

Pihl and Jurimae (2001) surveyed 150 former elite male athletes to study the relationship between changes in body weight and **heart disease** risk. Weight gain greater than 22 lb (10 kg) was associated with an increase in percentage of body fat and abdominal fat. These men were at a greater risk for elevated blood pressure, **low-density lipoprotein** cholesterol (LDL-C), and **triglycerides.** One of the biggest challenges for former competitive athletes, especially those in high-energy-output sports, is to prevent weight (fat) gain and the diseases associated with excessive body fat after they stop training and competing (Rosenbloom and Skinner, 2006).

However, weight gain is not inevitable in former athletes. A study of more than 4,600 male and female former collegiate rowers found that the former rowers had a significantly lower prevalence of obesity than the general population. This lower prevalence persisted over the life cycle, although the prevalence of obesity did increase with age. Interestingly, only 5 percent of female and 8 percent of male former rowers were still rowing. The likely explanation for the lower prevalence of obesity is that the former rowers continued to be physically active and were able to adjust their food intake to match their level of activity (O'Kane et al., 2002).

Masters athletes: A separate division created by a sports-governing body for athletes older than a certain age. Minimum age varies according to the sport. Also referred to as veteran athletes.

Heart disease: Diseases of the heart and its vessels. A more specific term than cardiovascular disease.

Low-density lipoprotein: A fat transporter containing a moderate proportion of protein, a low proportion of triglyceride, and a high proportion of cholesterol. Also known as "bad cholesterol."

Triglyceride: A type of fat containing one molecule of glycerol and three molecules of fatty acids.

Cardiovascular disease: A broad term that refers to all diseases of the cardiovascular system (e.g., heart, arteries, veins).

Hypertension: Blood pressure chronically elevated above normal resting levels.

DECLINING PHYSICAL ACTIVITY ASSOCIATED WITH AGE

In the United States, there is a steady decline in physical activity with aging (Behavioral Risk Factor Surveillance System, 2003). A large percentage of the population fails to obtain the recommended amount of physical activity. As individuals age, the total amount of physical activity decreases, and activity that is performed is typically of lower intensity and duration than in the past. Although there is some inevitable decline with aging, a large portion of the decline in physical functioning, such as aerobic capacity, strength, flexibility, decreased muscle and bone mass, or increased body fat, is due to a decrease in amount and intensity of physical activity.

NUTRTION AND EXERCISE GUIDELINES

The Dietary Guidelines for Americans are published every five years, most recently in 2005 (see Chapter 1). These diet and exercise recommendations promote health and reduce the risk for chronic diseases. The Dietary Guidelines emphasize consuming an adequate amount of nutrients within caloric needs and limiting the intake of saturated and *trans* fats, cholesterol, added sugar, salt, and alcohol. Regular physical activity is encouraged. Regardless of the level of energy expenditure daily, the Dietary Guidelines can be used as a basic pattern. Specific information about diet planning using the Dietary Guidelines is found in Chapter 10.

In addition to the Dietary Guidelines, other organizations also publish nutrition and exercise recommendations, often with a focus on a specific chronic disease, such as **cardiovascular disease** or cancer. Table 12.1 compares various nutrition guidelines. These guidelines are fundamentally the same, although the recommendations do vary. Still, when taken as a whole, the recommendations for reducing chronic disease risk are remarkably consistent.

Consumers may wonder why nutrition guidelines differ. One reason is that each chronic disease is different. For example, fatty acids directly affect the vessels of the heart, but fat does not directly affect blood pressure. Thus, guidelines for preventing heart disease include recommendations for fat intake, but guidelines for preventing **hypertension** (elevated blood pressure) do not. There are also different interpretations of the scientific literature. For example, some researchers promote a Mediterranean diet for heart disease prevention. The biggest differences between the Mediterranean and American Heart Association (AHA) diets are the types and amounts of fats consumed. Both diets are low in saturated and *trans* fats. The Mediterranean diet plan, which emphasizes the consumption of fish, nuts, and olive oil, is higher in

Table 12.1 Comparison of Various Nutrition Guidelines

	Dietary Guidelines for Americans, 2005	Mediterranean Diet	American Heart Association	American Cancer Society
Energy	Balance calories from foods and beverages with calories expended	Healthy weight and daily exercise encouraged	Match intake of total energy (kilocalories) to overall energy need	Balance caloric intake with physical activity
Carbohydrate intake	Choose fiber-rich fruits, vegetables, and whole grains often	Whole grains, vegetables, fruits, beans, legumes, and nuts daily. Sweets a few times per week	5 or more servings of a variety of fruits and vegetables, 6 or more servings of a variety of grain products, including whole grains	Eat 5 or more servings of a variety of vegetables and fruits each day; Choose whole grains in preference to processed (refined) grains
Protein intake	Emphasis on lean or lower fat protein sources	Beans, legumes, nuts, cheese, and yogurt daily; fish, poultry, and eggs a few times a week; red meat in very small amounts a few times per month	Include fat-free and low-fat milk products, fish, legumes (beans), skinless poultry, and lean meats	Limit consumption of processed and red meat
Fat intake	20 to 35% of calories, $<10\%$ from saturated fat, <300 mg cholesterol, keep *trans* fat low	25 to 35% of calories primarily from olive oil. If watching weight limit oil consumption; ~7 to 8% from saturated fat	Limit intake of foods with high content of cholesterol-raising fatty acids (e.g., saturated and *trans* fatty acids); Limit the intake of foods high in cholesterol; Substitute grains and unsaturated fatty acids from fish, vegetables, legumes, and nuts	Consume a healthy diet, with an emphasis on plant sources
Alcohol intake	If consumed, consume in moderation	Moderate consumption of wine with meals; purple grape juice may be substituted	Limit alcohol intake to no more than 2 drinks per day (for men) and 1 drink per day (for women)	If you drink alcoholic beverages, limit consumption; Drink no more than one drink per day for women or two per day for men
Sodium intake	$<$ 2,300 mg of sodium (~ 1 tsp salt)		Limit salt (sodium chloride) intake	
Weight	Maintain weight in a healthy range	Maintain a healthy weight	Maintain a healthy body weight	Avoid excessive weight gain throughout the life cycle; Achieve and maintain a healthy weight if currently overweight
Exercise	Engage in regular physical activity and reduce sedentary activities	Daily exercise including walking, physical work, and sports	Achieve a level of physical activity that matches (for weight maintenance) or exceeds (for weight loss) energy intake	Adults: at least 30 minutes of intentional, moderate-to-vigorous physical activity, 5 or more days of the week; 40–60 minutes of intentional physical activity preferable. Children/adolescents: at least 60 minutes per day, 5 days per week

omega-3 fatty acids and monounsaturated fatty acids than the AHA diet. The Mediterranean diet also puts less emphasis on the total amount of fat consumed (Curtis and O'Keefe, 2002; Kris-Etherton et al., 2001; Robertson and Smaha, 2001). Both diets reflect substantial changes from the diet currently consumed by most Americans, and the adoption of either diet plan would likely be beneficial.

Similarly, various physical activity and exercise recommendations have been made by health-related organizations, potentially leading to confusion on the part of the public (and with some professionals). There is consistency among these guidelines in that they *all* recommend regular, consistent lifelong physical activity. Differences and potential confusion arise due to the details of these guidelines, particularly the intensity and duration of activity or exercise. The key to understanding the differences is to consider the intent, target audience, and scientific basis underlying each recommendation.

As detailed in the 1996 Surgeon General's Report on Physical Activity and Health, there is a large body of scientific evidence supporting the positive relationship between physical activity and good health (U.S. Department of Health and Human Services, 1996). Large, **epidemiological** studies such as Blair et al. (1989) determined that there is a strong **inverse relationship** between physical activity and premature mortality, particularly from chronic diseases such as cardiovascular disease and cancer. In other words, people that lead physically active lives are much less likely to develop chronic diseases and die at an earlier age.

Based upon this epidemiological evidence, the Centers for Disease Control and Prevention and the American College of Sport Medicine (Pate et al., 1995) published physical activity recommendations suggesting that everyone should be physically active on most days of the week, accumulating at least 30 minutes of moderate-intensity activity. These recommendations are considered a *minimal* threshold of activity and are associated with health benefits (e.g., a reduction in risk of premature mortality).

In 2005, the Dietary Guidelines for Americans expanded on the minimal physical activity recommendation, increasing the suggested duration of physical activity to 60 or 90 minutes per day for specific situations. While 30 minutes of physical activity each day may be associated with better health and a reduction in premature mortality, this amount of activity may not be sufficient to meet more immediate health needs. For example, 30 minutes of accumulated activity on most days of the week may not result in enough caloric expenditure to prevent gradual weight gain, which may lead to obesity. Therefore, up to 60 minutes of activity daily may be necessary to maintain a healthy weight and to prevent obesity. Overweight or obese individuals that lose weight may require even more physical activity to sustain their newly acquired lower weight. Therefore, the recommendation for these individuals is up to 90 minutes of activity per day to prevent regaining weight.

The American College of Sports Medicine (ACSM) also published exercise recommendations in its Position Stand on The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Adults (1998). Recommendations address specific components of physical fitness, such as cardiorespiratory (aerobic) fitness, muscular strength and endurance, and flexibility. A range of exercise frequency, intensity, and duration is recommended as shown in Figure 12.1. For cardiorespiratory or aerobic exercise, the ACSM recommends a duration of 20 to 60 continuous minutes at moderate to vigorous Intensity, 3 to 5 days per week. Strength training is recommended 2 to 3 times per week with specific recommendations as to the number of exercises, sets, and repetitions. Stretching or flexibility exercises are recommended at least 2 to 3 times each week. Again, note that regular lifelong exercise is at the core of all exercise guidelines, but there are specific recommendations for each component of physical fitness.

The Internet Café

Where Do I Find Reliable Information about Diet, Exercise, and Health?

Many government and nonprofit health-related organizations maintain websites with extensive information about how diet and exercise promote good health and reduce the risk for chronic diseases. The following websites are among some of the best known and contain public domain documents, which can be downloaded without cost and used as educational materials.

Dietary Guidelines for Americans 2005. This website contains all documents related to the Dietary Guidelines, including recommendations for specific populations and consumer-oriented materials. **http://www.healthierus.gov/dietaryguidelines**

Dietary Guidelines for Healthy American Adults, American Heart Association (AHA). The AHA's scientific position paper containing dietary guidelines and information about exercise and fitness can be found at **http://www.americanheart.org/**

The American Cancer Society (ACS) Recommendations for Nutrition and Physical Activity for Cancer Prevention.

Recommendations by the ACS can be accessed at **http://www.cancer.org/**

What's the point? For good health, it is important to be physically active and consume a healthful diet throughout life.

Cardiorespiratory Fitness

1. **Frequency of training:** 3–5 days per week (d/wk).
2. **Intensity of training:** 55/65–90% of maximum heart rate (HR_{max}), or 40/50–85% of maximum oxygen uptake reserve ($\dot{V}O_2R$) or HR_{max} reserve (HRR). The lower intensity values, i.e., 40–49% of $\dot{V}O_2R$ or HRR and 55–64% of HR_{max}, are most applicable to individuals who are quite unfit.
3. **Duration of training:** 20–60 min of continuous or intermittent (minimum of 10-min bouts accumulated throughout the day) aerobic activity. Duration is dependent on the intensity of the activity; thus, lower-intensity activity should be conducted over a longer period of time (30 min or more), and, conversely, individuals training at higher levels of intensity should train at least 20 min or longer. Because of the importance of "total fitness" and that it is more readily attained with exercise sessions of longer duration and because of the potential hazards and adherence problems associated with high-intensity activity, moderate-intensity activity of longer duration is recommended for adults not training for athletic competition.
4. **Mode of activity:** Any activity that uses large muscle groups, which can be maintained continuously, and is rhythmical and aerobic in nature, e.g., walking-hiking, running-jogging, cycling-bicycling, cross country skiing, aerobic dance/group exercise, rope skipping, rowing, stair climbing, swimming, skating, and various endurance game activities or some combination thereof.

Muscular Strength and Endurance, Body Composition, and Flexibility

1. **Resistance training:** Resistance training should be an integral part of an adult fitness program and of a sufficient intensity to enhance strength, muscular endurance, and maintain fat-free mass (FFM). Resistance training should be progressive in nature, individualized, and provide a stimulus to all the major muscle groups. One set of 8–10 exercises that condition the major muscle groups 2–3 d/wk is recommended. Multiple-set regimens may provide greater benefits if time allows. Most persons should complete 8–12 repetitions of each exercise; however, for older and more frail persons (approximately 50–60 yr of age and above), 10–15 repetitions may be more appropriate.
2. **Flexibility training:** Flexibility exercises should be incorporated into the overall fitness program sufficient to develop and maintain range of motion (ROM). These exercises should stretch the major muscle groups and be performed a minimum of 2–3 d/wk. Stretching should include appropriate static and/or dynamic techniques.

Figure 12.1 American College of Sports Medicine Exercise Recommendations

Legend: min = minute; yr = year

American College of Sports Medicine (1998). Position Stand on The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Adults. *Medicine and Science in Sports and Exercise,* 30(6), 975–991.

The Impact of Chronic Diseases

Chronic disease is defined as a disease lasting three months or more that can be treated, but not cured. Some examples of chronic diseases include cardiovascular disease, most cancers, diabetes, and **osteoporosis.** Obesity is also considered a chronic disease by most health-related organizations because the number of formerly obese individuals who maintain their weight loss over their lifetimes is low. Of the 2.4 million people in the United States who die each year, approximately 70 percent die from chronic diseases (National Center for Health Statistics, 2006). Of the nongenetic factors that contribute to death in the United States, poor diet and lack of exercise are major contributing factors (~16.6 percent of all deaths), second only to the 18.1 percent of deaths caused by tobacco (Mokdad et al., 2004). These figures are based on data from the year 2000, and poor diet and lack of exercise are expected to become the leading modifiable causes of death. In the case of cancer, poor diet and obesity contribute to approximately 30 percent of all cancer deaths, similar to the number of cancer deaths caused by tobacco use (Weir et al., 2003; Harvard Report on Cancer Prevention, 1996). Figures 12.2 and 12.3 further illustrate the contributions of diet and exercise compared to other factors.

Epidemiological: The study of health-related events in a population.

Inverse relationship: Given two variables, when one increases the other decreases, and vice versa.

Osteoporosis: Disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture.

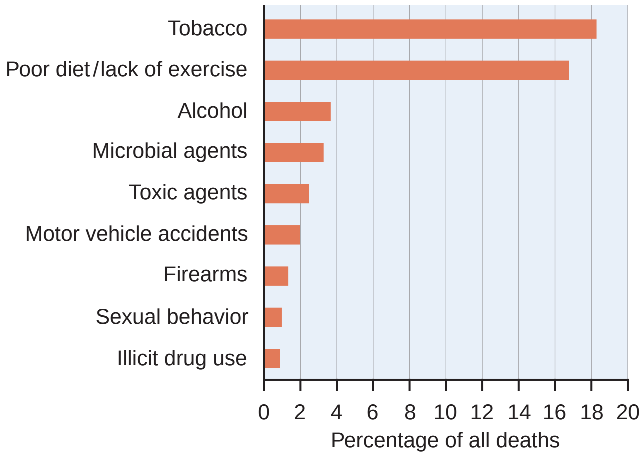


Figure 12.2 Contribution of Poor Diet and Lack of Exercise to Actual Causes of Death

Poor diet and lack of exercise are expected to overtake tobacco as the leading causative factor of death in the United States.

Mokdad, A.H., Marks, J.S., Stroup, D.F. & Gerberding, J.L. (2004). Actual causes of death in the United States, 2000. *Journal of the American Medical Association*, 291(10), 1238–1245. Erratum in: *JAMA*, 2005, Jan 19; 293(3), 293–294, 298.

Chronic diseases can begin in infancy, childhood, adolescence, or young adulthood. Thus, diet and activity are factors that influence disease early in life. These influences may not be evident in young people, so preventative strategies, even if seen as important, do not appear urgent. Chronic diseases develop, progress, and worsen with age. It may take years or decades before the disease has progressed to the point where symptoms become apparent; therefore, many chronic diseases are not noticed or diagnosed until individuals are in their fourth, fifth, or sixth decade of life. In adulthood, healthy eating and physical activity may delay the onset, slow the progression, and postpone some of the complications associated with a chronic disease. Any delays will likely preserve quality of life for a longer period of time and may eventually mean fewer or lower doses of medications. Consuming a healthy diet, engaging in physical activity, refraining from smoking, and minimizing exposure to environmental hazards (such as asbestos) pay the biggest dividends when they have been lifelong habits, but adoption of any of these habits at any age will likely have a positive influence on the course of chronic diseases (Garry, 2001).

HYPERTENSION

Hypertension is known as a silent killer because of the lack of recognizable symptoms. In most cases the cause is unknown. Genetic predisposition is very powerful, and blood pressure may also be affected by dietary sodium intake. In general, as sodium intake increases blood pressure increases, although not all people with a high sodium intake will be hypertensive. Some individuals are sodium sensitive and a high dietary sodium intake has a direct effect on raising their blood pressure. In these individuals, a reduction in sodium intake results in a decrease in elevated blood pressure (Institute of Medicine, 2004).

Studies have shown that endurance training helps reduce, but does not eliminate, the risk for hypertension. Even a small percentage of former elite endurance athletes will develop high blood pressure. Hernelahti et al. (1998) compared Finnish male endurance masters athletes to a control group. At the beginning of the study in 1984 both groups of men ages 35 to 59 were free of heart disease. When surveyed again in 1995, 27.8 percent of the control group used an antihypertensive medication compared to only 8.7 percent of

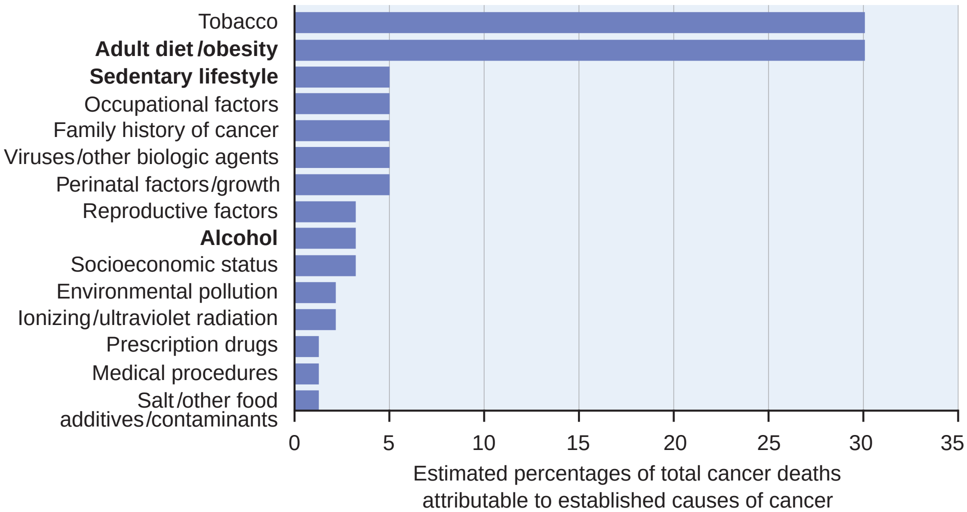


Figure 12.3 Factors Contributing to Cancer Deaths

Harvard Report on Cancer Prevention, Cancer Causes and Control, 1996.

the master athletes, but this group of highly active runners was not free of hypertension. In a subsequent study, the same researchers found that endurance training in young adult elite athletes reduced the risk for hypertension when the men were middle-aged or older. Continuing to be physically active throughout adulthood also reduced, but did not eliminate, the risk of ever becoming hypertensive (Hernelahti et al., 2002). Maintaining a healthy weight, consuming a healthy diet, and exercising routinely reduces the risk of hypertension for the majority of adults, but may not be sufficient for those that are hypertensive because of a genetic predisposition, sodium sensitivity, or other nonlifestyle-related factors. Some athletes may require the use of antihypertensive medications to keep their blood pressure within a healthy range. These individuals should work closely with a physician familiar with exercise to find a medication that appropriately controls their hypertension, but does not have an adverse effect on their exercise capability.

While some former, well-trained athletes become hypertensive, the majority of people in the United States with high blood pressure are sedentary and they would benefit from engaging in routine physical activity. Exercise, particularly endurance (aerobic) exercise, can result in a modest decrease in resting blood pressure both in the hours after the exercise bout and on a chronic basis. Many people with hypertension are also overweight or obese, and blood pressure may be lowered as a result of weight loss. Dietary changes other than restricting sodium (e.g., increasing intake of potassium-containing fruits and vegetables) can also reduce resting blood pressure. Prevention and treatment strategies are listed in the Spotlight on Chronic Diseases: Hypertension.

OVERWEIGHT AND OBESITY

According to the Centers for Disease Control and Prevention (CDC), 65 percent of all adults are overweight, so it may seem that weight gain is an inevitable consequence of aging. It is not. Weight gain in adults may be quite slow, often referred to as "creeping obesity." The average annual weight gain for adults is approximately 1¾ pounds (0.8 kg) per year; thus, over 20 years ~35 pounds (~16 kg) of weight would be gained (Winett et al., 2005). This is a population-wide estimate, so some people gain substantially more or less. However, weight gain can "creep up" on adults because less than two pounds per year is a relatively slow increase in body fat and represents a relatively small imbalance between energy intake and expenditure each day.

A key for many adults is to recognize the potential for slow weight gain and to change behavior to prevent it. For example, cookies are often available in the workplace. Each crème-filled sandwich cookie (e.g., Oreo) contains about 50 kcal. If eating two small cookies daily contributes to excessive caloric intake, then not snacking on cookies would be a small but meaningful behavior change. Similarly, climbing one or two flights

SPOTLIGHT ON CHRONIC DISEASES

Hypertension

Alternate term: High blood pressure.

Definition: Resting systolic blood pressure > 140 and/or resting diastolic blood pressure > 90 mm Hg (measured on more than one occasion); Prehypertension: 120–139 mm Hg (systolic), 80–89 mmHg (diastolic).

Prevalence: One of every three adults in the-United States (~65 million). More prevalent in African Americans and in older adults.

Symptoms: No distinct symptoms; known as a silent killer.

Cause: Unknown in 90 percent of all cases.

Prevention: 1) Maintain or achieve a healthy body weight 2) Follow the Dietary Guidelines or DASH diet (see appendix B) 3) Meet minimum activity or exercise recommendations.

Treatment: Dietary modifications, exercise, and/or medications can help control blood pressure.

Diet: 1) If overweight, reduction of body fat. A 10-pound (4.5-kg) weight loss is effective regardless of degree of overweight 2) Reduction of sodium intake. This strategy may be effective if the individual is sodium sensitive 3) Consumption of the DASH (Dietary Approaches to Stop Hypertension) diet. This diet emphasizes fruits, vegetables, whole grains, low- or nonfat dairy foods, lean meats, fish and poultry, nuts, beans, and oils. Potassium is plentiful and sodium is limited.

Exercise: 1) Moderate intensity exercise on most, preferably all, days of the week for at least 30 minutes (either continuously or accumulated) 2) Endurance (aerobic) exercise is the preferred type of exercise, although strength training may be supplemented in consultation with a physician.

National Heart, Lung and Blood Institute. http:www.nhlbi.nih.gov.

of stairs instead of riding the elevator in an office building several times a day also represents a relatively small change in energy (kcal) expenditure. However, when accumulated over time, this habitual activity can have a substantial long-term impact on weight management.

A relatively new area of research is the study of food consumption patterns that are associated with less weight gain over time. A four-year study conducted in Germany found that a diet that contained low-fat, high-fiber, high-carbohydrate foods such as fruit and whole-grain breads and cereals helped nonobese subjects maintain their body weight and prevent weight gain (Schulz et al., 2005). A similar study conducted in the United States found that a diet high in whole grains, fruits, vegetables, and low-fat dairy products resulted in smaller gains in body mass index. Also

SPOTLIGHT ON A REAL ATHLETE

Lucas, 23-Year-Old, Former Collegiate Cross Country Runner

Lucas, the collegiate cross country runner who runs 75 to 80 miles (125 to 135 km) per week has served as an example throughout this textbook. Based on a one-day dietary analysis (see Figures 12.4 and 12.5), Lucas' intake is estimated to be 3,333 kcal (~ 53 kcal/kg), 532 g carbohydrate (~ 8.5 g/kg), 124 g protein (~ 2 g/kg), and 94 g of fat (~ 1.5 g/kg). From a performance perspective, Lucas' energy, carbohydrate, protein, and fat intakes are considered appropriate (see Chapters 4, 5, and 6). But how does his diet fare when analyzed against dietary risk factors for chronic diseases? Figure 12.5 evaluates Lucas' diet for kilocalories and macronutrients as well as saturated, mono- and polyunsaturated fats, cholesterol, fiber, sugar, vitamin, and mineral intakes.

It often comes as a surprise to athletes like Lucas that the diet that provides sufficient kilocalories, carbohydrates, and proteins to support training and performance can fall short when evaluated for chronic disease risk. In Lucas' case, his diet is appropriate in many ways, but there are some red flags—saturated fat intake is higher than recommended, sodium intake is very high (~ 6,500 mg) considering that he does not lose much salt in sweat, and the intake of some vitamins and minerals (e.g., folate, niacin, magnesium) is low. Even if he were to continue to run 80 miles (135 km) per week, his pattern of eating could use some modification to help him reduce the risk for chronic diseases.

Heather Elder Represents/Jupiter Images

Lucas, a former collegiate cross country runner.

As is typical of many former collegiate athletes, Lucas will be reducing his weekly exercise from 80 miles to ~30 miles (135 km to 50 km) per week after he graduates from college. He intends to compete in 10-km (6.2-mile) races once a month, but the intensity and duration of his training will be substantially reduced. To prevent gaining weight as body fat, he will need to reduce his caloric intake, but it is also important that Lucas modify his diet in other ways. When Lucas has a preemployment physical, he is surprised to learn that he has hypertension, even though high blood pressure runs in his family. Lucas' physician recommended that he increase his fruit and vegetable intake and reduce his sodium intake.

MyPyramid.gov
STEPS TO A HEALTHIER YOU

	Goal*	Actual	% Goal
Grains	10 oz. eq.	11.8 oz. eq.	118%
Vegetables	4 cup eq.	1.2 cup eq.	30%
Fruits	2.5 cup eq.	1.7 cup eq.	68%
Milk	3 cup eq.	5.4 cup eq.	180%
Meats & Beans	7 oz. eq.	8.8 oz. eq.	126%
Discretionary	648	1152	178%

oz = ounce
eq = equivalent

*Your results are based on a 3,200 calorie pattern, the maximum caloric intake used by My Pyramid.

Figure 12.4 Analysis of Lucas' 24-Hour Dietary Intake associated with less weight gain was a dietary pattern that was low in red and processed meats, fast food, and soft drinks. These dietary patterns are similar to the DASH diet that has been shown to reduce blood pressure (Newby et al., 2004 and 2003). These studies are particularly important because they provide information about prevention of weight gain in nonobese populations.

There is a strong inverse relationship between level of physical activity and fitness and obesity; that is, the lower the level of activity and the lower the level of cardiovascular fitness the greater the risk of developing obesity. A number of studies have shown that increases in exercise time or volume and increases in aerobic fitness are associated with decreases in weight gain over time, independent of changes in diet. One such study

Nutrient	DRI	Intake	0% 50% 100%
Energy			
Kilocalories	3365 kcal	3332.8 kcal	99%
Carbohydrate	379–547 g	532.15 g	
Fat, total	75–131 g	93.86 g	
Protein	84–294 g	124.09 g	
Fat			
Saturated fat	<10%	36.63 g	
Monounsaturated fat	no rec	19.45 g	
Polyunsaturated fat	no rec	11.65 g	
Cholesterol	300 mg	195.79 mg	65%
Essental fatty acids (efa)			
Omega-6 linoleic	17 g	1.9 g	11%
Omega-3 linolenic	1.6 g	0.47 g	30%
Carbs			
Dietary fiber, total	38 g	37.4 g	98%
Sugar, total	no rec	310.37 g	
Vitamins			
Thiamin	1.2 mg	1.41 mg	118%
Riboflavin	1.3 mg	2.45 mg	188%
Niacin	16 mg	11.57 mg	72%
Vitamin B6	1.3 mg	1.09 mg	84%
Vitamin B12	2.4μg	4.82μg	201%
Folate (DFE)	400μg	229.4 μg	57%
Vitamin C	90 mg	237.29 mg	264%
Vitamin D (μg)	5 μg	4.05 μg	81%
Vitamin A (RAE)	900.41 μg	2134.31 μg	237%
Alpha-tocopherol (Vit E)	15 mg	19.63 mg	131%
Minerals			
Calcium	1000 mg	2165.1 mg	217%
Iron	8 mg	21.42 mg	268%
Magnesium	400 mg	291.13 mg	73%
Potassium	4700 mg	2468.13 mg	53%
Zinc	11 mg	12.04 mg	109%
Sodium	1500 mg	6512.82 mg	434%

kcal = kilocalorie
g = gram
rec = recommendation
mg = milligram

μg = microgram
DFE = dietary folate equivalents
RAE = retinol activity equivalents
Vit = vitamin
DRI = dietary reference intakes

Figure 12.5 Analysis of Lucas' Diet for Risk of Chronic Diseases showed that for cardiovascular fitness measured by the amount of time one could sustain on a maximal effort treadmill test, every minute of increased exercise time was associated with a measurable decrease in the risk of gaining weight, which in this study was an average of 22 pounds over a 7½-year period (DiPietro et al., 1998). Higher activity levels leading to higher aerobic fitness substantially reduces the risk of creeping obesity. The need to reduce energy expenditure after collegiate competition is a challenge for many collegiate athletes, both male and female, especially those who competed in high-energy-output sports (Rosenbloom and Skinner, 2006).

The prevalence of overweight and obesity in the United States is the highest of all the developed countries (National Center for Health Statistics, 2006). Each year, approximately 1 percent of the adult population moves from the overweight category (Body Mass Index [BMI] between 25 and 29.9) into the obese category (BMI > 30). In the United States, the environment promotes weight gain and obesity. Food is abundant, ever present in work and social situations, and relatively inexpensive. Portion sizes are large. Consumption of liquid calories in the form of soft drinks and other sweetened beverages is at an all-time high (Bray and Champagne, 2005). Jobs in service and information-based industries are generally sedentary and require people to sit at a desk or computer for large portions of the workday. The built environment has also largely engineered physical activity out of modern lifestyles: commuting by car, drive-thru services (e.g., restaurants, banks, dry cleaners, pharmacies), valet parking, elevators/escalators/people movers, riding lawnmowers, and leaf blowers. Electronic entertainment—24-hour, 200-channel television, video games, and personal computers—requires little physical activity. The prevalence of these factors has given rise to the term “toxic environment” to describe the current eating

SPOTLIGHT ON A REAL ATHLETE

Susan, 26-Year-Old, Former Collegiate Basketball Player, No Longer Playing Competitively

While some former collegiate athletes continue to train and compete, many do not. Consider the case of Susan, who finished her collegiate eligibility and is no longer playing basketball competitively. Still in her twenties, she is working full time in her first career job. While in college she played basketball several hours a day and was required to participate in a strength and conditioning program that included distance running, high-intensity conditioning (e.g., on-court sprints, intervals), strength training, and plyometric drills (e.g., speed, agility, quickness). Now that she has graduated, practices and workouts are not required and athletic program support, such as training table twice a day, is not available. Susan fixes meals sporadically and snacks a lot. Her goal is to “stay in shape,” but now she must do this on her own. She joined a health club and runs on a treadmill three to four days per week and, if available, plays pickup (half-court) basketball games afterwards for ~30 minutes. Never a fan of strength training, she now only lifts weights sporadically—one to two times per week, if at all.

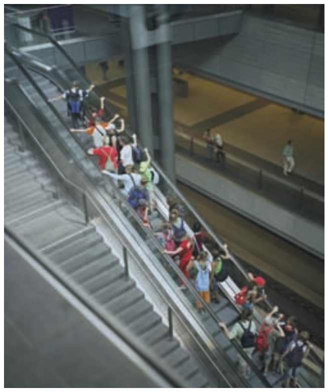

Brad Wilson/Stone/Getty Images

Susan, a former collegiate basketball player.

Susan is typical of many former collegiate athletes who find that the frequency, intensity, and duration of exercise are much less than in the past. Her training and basketball practices were required and so the discipline to exercise was “built in.” Susan’s new job gives structure to her schedule but not in the same way as the college environment. Physical activity is not part of the job and does not dictate her schedule. In fact, she must find time to exercise during her “free time” away from work. She must also find the discipline to exercise, something that was automatically present at basketball practices. In college she was a participant in a high-energy-output sport; now she is in a low-energy-output job. Not only did the exercise environment change, the eating environment changed. Susan works in an office and people constantly bring food to her desk and to the break room. She is responsible for buying and preparing her own food and vending machines are the most convenient lunch option. She is experiencing a very different food environment than her college training table that featured sit-down meals and healthy prepackaged takeout lunches.

Food Image Source/Getty Images

Jamie Rector/Getty Images



Reza Estakhrian/The Image Bank/Getty Images

Modern lifestyle promotes weight gain and obesity through abundant food and lack of physical activity.

and activity environment in the United States (Brownell, 2004). Food intake and physical activity are emphasized in the prevention of obesity because these factors are strongly influenced by behavior and humans can change their behavior.

While the environment plays a large role, overweight and obesity are multifactorial. Nonlifestyle factors include genetic predisposition and hormones. Some people have a greater tendency than others to gain body fat, but genetics is not the sole factor in the development of obesity. Adipose tissue was once thought of simply as a fat storage site, but it is now known that adipose tissue is part of the **endocrine** system. Adipocytes secrete hormones such as **leptin** (increases satiety) and stomach cells secrete **ghrelin** (increases appetite), compounds that have important regulatory capacities.

Women often wonder if pregnancy promotes obesity. For the majority of women, pregnancy is not associated with an increased risk for developing obesity. One and one-half years after delivery, the average women will only be 1.1 pound (~ 0.5 kg) more than her prepregnancy weight. However, 15–20 percent of women will gain a substantial amount of weight as body fat and are at risk for obesity (Johnson et al., 2006).

Overweight and obesity put individuals at risk for hypertension, **dyslipidemia** (i.e., elevated triglycerides or total cholesterol), type 2 diabetes, heart disease, stroke, gallbladder disease, **osteoarthritis, sleep apnea,** and some cancers. The presence of any of these diseases may be a motivator for behavior change and weight loss. For reasons of both health and appearance, many overweight and obese adults are seeking a diet plan that will help them to lose weight.

Popular Weight-Loss Diets. Although many weight-loss plans are available, this section will be limited to a description and discussion of four diets that have been consistently popular for many years and have been compared in scientific studies: Atkins (1972, 1999), Zone (Sears, 1995, 1997), Ornish (1993), and Weight Watchers (1966). Some of the characteristics of these diets are compared to each other in Table 12.2. The one consistent feature is that the diets do not require "calorie counting;" however, the caloric intake of each diet is designed to be less than usual intake. A reduced energy intake is a critical element of any weight-loss diet.

Atkins Diet. The Atkins diet is a carbohydrate-controlled diet consisting of four phases: induction, ongoing weight loss (OWL), premaintenance, and lifetime maintenance. The induction period is 14 days in length and carbohydrate intake is limited to 20 g/d. Twenty grams per day is an extremely low carbohydrate intake and a typical induction phase diet would include the elimination of all carbohydrate-containing foods except salad greens and similar vegetables (e.g., zucchini). Strict limits on carbohydrate intake result in a diet consisting of protein- and fat-containing foods such as meat, fish, poultry, and eggs. There is no stated restriction on caloric intake (i.e., calories are not counted), but following the induction phase plan typically results in a lower energy intake than previously consumed.

Endocrine: Relating to glands that secrete hormones.

Leptin: A hormone produced in adipose tissue that suppresses appetite; considered counter regulatory to ghrelin.

Ghrelin: A protein-based hormone secreted by the cells of the stomach and associated with appetite stimulation; counter regulatory to leptin.

Dyslipidemia: Abnormal concentration of blood lipids (e.g., cholesterol, lipoproteins, triglycerides).

Osteoarthritis: Degenerative joint disease characterized by pain and stiffness. Because it is so prevalent, it is often referred to simply as arthritis, although there are numerous types of arthritis.

Sleep apnea: Brief periods during sleep when breathing stops.

Table 12.2 Comparison of Weight-Loss Plans

	Atkins	Zone	Weight Watchers	Ornish
Carbohydrate	Very low (20 g/d during the induction stage) to low (60 g/d)	Low (40% of total energy intake)	Moderate	High
Fiber	Low	Moderate	Moderate to high	High
Protein	Moderate to high, protein foods may also be high in fat	High (30% of total energy intake), protein foods are low in fat	Moderate, protein foods are low in fat	Moderate, most from plant sources
Fat	Moderate to high	Moderate (30% of total energy intake), emphasis on monounsaturated fats	Low	Very low (less than 10% of total energy intake)
Total calories	Not counted but likely to be less than usual intake	Not counted but typically 1,000–1,600 daily	Not counted but each "point" is ~50–60 kcal and the number of points per day is limited	Not counted but likely to be less than usual intake
Mechanism for reducing caloric intake since calories are not counted	Appetite suppression due to ketosis	Number of carbohydrate, protein, and fat blocks are limited	Point totals for foods consider caloric, fat, and fiber content; number of points per day is limited	High fiber and very low fat intakes
Miscellaneous	Degree of insulin resistance considered	Glucose and insulin responses to carbohydrate foods considered, monounsaturated fats emphasized for hormone production	Known for its support network	Goal is to prevent and reverse heart disease but the diet also promotes weight loss

Legend: g/d = grams per day; kcal = kilocalorie

The **hypocaloric,** very low carbohydrate intake results in **ketosis,** a metabolic adaptation to starvation (see Chapter 6 for a detailed explanation). When carbohydrate is severely restricted, ketone bodies are produced as a result of the incomplete breakdown of fat. Brain and nervous tissues typically depend on carbohydrate for fuel but in its absence begin to use ketone bodies. Ketosis that results from starvation is referred to as benign dietary ketosis to distinguish it from the ketosis associated with uncontrolled diabetes and pregnancy, which can lead to a dangerous medical condition known as **ketoacidosis.** Benign dietary ketosis results in the preferential use of stored body fat and appetite suppression, two goals of the Atkins diet. In those without diabetes, ketosis rarely leads to ketoacidosis.

After the two-week induction phase, the carbohydrate content of the diet may be increased, depending on the amount of weight lost and the degree of **metabolic resistance.** Metabolic resistance is not a recognized medical term; rather, it is a term coined by Dr. Atkins to indicate the inability to lose weight or to continue to lose weight when consuming a diet containing less than 1,000 kcal or 25 g of carbohydrate daily.

After the two-week induction phase, if a relatively small amount of weight was lost (e.g., 8 pounds in a male who has 50 pounds to lose), then metabolic resistance is considered high and carbohydrate continues to be restricted in amounts similar to the induction phase. If a relatively large amount of weight was lost (e.g., 16 pounds in a male who has 50 pounds to lose), then carbohydrate intake may be increased to as high as 60 g/d. Maintenance-phase carbohydrate intake for those with high metabolic resistance remains low, approximately 25 to 40 g/d; however, those with low metabolic resistance may increase carbohydrate intake to 60 to 90 g/d during the maintenance phase. Even with increased carbohydrate intake, the Atkins diet remains relatively low in carbohydrate when compared to other diet plans.

Zone Diet. The Zone diet emphasizes the amount and type of carbohydrates, low-fat protein foods, and monounsaturated fats. This diet is also referred to as the 40-30-30 diet because of the contribution of each macronutrient to total energy intake (i.e., 40 percent carbohydrate and 30% each protein and fat). Such a macronutrient distribution results in the diet being relatively low in carbohydrates and high in proteins.

The amount of kilocalories in the diet are not restricted directly (i.e., caloric intake is not counted); rather, a certain number of carbohydrate, protein, and fat "blocks" are recommended. The diet usually ranges from 1,000 to 1,600 kcal daily. The Zone diet emphasizes the **glycemic effect** of carbohydrate foods, with an emphasis on consuming those that do not produce a rapid rise in insulin. The diet also emphasizes monounsaturated fats because of their influence on the production of **eicosanoids,** compounds made from unsaturated fatty acid that have hormone-like activity (e.g., **prostaglandin**).

The first step in planning the Zone diet is a determination of the daily amount of protein needed. Daily protein intake is divided into blocks, each consisting of about 7 g. Carbohydrate blocks contain approximately 9 g of carbohydrate with an emphasis on low-glycemic fruits, vegetables, and grains. One goal of the diet is to keep a 1:1 ratio of protein to carbohydrate blocks. Each fat block contains approximately 1.5 g of fat, predominantly as monounsaturated fats such as nuts, olive oil, and avocadoes. Three meals and two snacks are recommended daily with an almost equal number of protein, carbohydrate, and fat blocks at each meal or snack.

Ornish Diet. The Ornish diet is a plant-based diet that emphasizes high-fiber carbohydrate foods. This diet is very low in fat, approximately 10 percent of total energy intake, and moderate in protein, mostly from plant sources. Caloric intake is not counted; rather, individuals are instructed to "eat when hungry, stop when full," but energy intake is likely limited due to the low-fat, high-fiber content of the diet. Foods are generally divided into one of three groups: consume in large quantities, consume in moderation, and avoid. Beans, legumes, whole grains, fruits, and vegetables are emphasized. Nonfat dairy products and nonfat or low-fat commercially prepared meals are to be consumed in moderation. Foods to be avoided include all kinds of meat, poultry, fish, low-fat and regular dairy products, oils, sugars, alcohol, nuts, seeds, olives, and avocadoes.

Weight Watchers. The Weight Watchers program has evolved since its inception in 1966 and currently involves a point system known as FlexPoints®. All foods are assigned points based on fat, fiber, and caloric content. A point target is determined based on current weight. Points can also be earned by exercising, and these points can be used to add more food to the diet plan or to accelerate the rate of weight loss. The Weight Watchers diet reduces caloric intake indirectly through the point system, rather then by a direct counting of calories. The diet is low in fat and high in fiber. The hallmark of the Weight Watchers program has been its support system, either in person or online. The program also focuses on teaching participants sensible eating habits.

Comparing the Effectiveness of Various Weight-Loss Diets. The diet plans described above have been used by millions of people and which plan is "best" has long been debated by both scientists and the lay public. In 2005, Dansinger et al. reported the results of a study that compared weight loss in obese subjects (average BMI of 35) who followed one of the four diet plans previously described, providing a scientific basis for answering the question, "Which weight-loss diet is the best?" In those who completed the study, weight loss after one year was about 3 percent of body weight (~5–7 lb [~2–3 kg]) regardless of the diet plan. The more restricted plans, Atkins and Ornish, were harder for participants to adhere to (i.e., higher drop-out rate). A similar study conducted in the United Kingdom found that the four weight-loss diets studied (Atkins, Weight Watchers, Slim-Fast, Rosemary Conley [similar to Weight Watchers]) were equally effective in producing weight (fat) loss over six months. The average fat loss was ~10 lb (4.4 kg). During the first four weeks, those on the Atkins diet lost weight at a faster rate, but by the end of the six months there was no significant difference in the total amount of weight lost (Truby et al., 2006).

All the plans studied were low in kilocalories (energy), although kilocalories were not directly counted in any of the plans. It is the macronutrient composition that varied in these weight-loss plans. For the obese, sedentary individual, the restriction of energy and the length of the energy restriction seem to be more important that the carbohydrate, protein, and fat content of the diet for short-term (i.e., less than one year) weight loss. Due to individual variations in response it is not appropriate to recommend "one" weight-loss diet plan to the entire population (Volek, Vanheest, and Forsythe, 2005).

Hypocaloric: A low amount of dietary kilocalories compared to what is needed to maintain body weight.

Ketosis: General definition is the production of ketone bodies (a normal metabolic pathway). Medical definition is an abnormal increase in blood ketone concentration.

Ketoacidosis: Medical condition in which the pH of the blood is more acidic than the body tissues.

Metabolic resistance: A term coined by Dr. Atkins to indicate the inability to lose weight or to continue to lose weight when consuming a diet containing less than 1,000 kcal or 25 g of carbohydrate daily.

Glycemic effect: The effect that carbohydrate foods have on blood glucose and insulin secretion.

Eicosanoid: A class of compounds manufactured from polyunsaturated fatty acids that are involved in cellular activity, including mediating inflammation.

Prostaglandin: A compound made from arachidonic acid (an omega-6 fatty acid) that has hormone-like (regulatory) activity.

Table 12.3 Advantages and Disadvantages of Restricted Fat or Carbohydrate Weight-Loss Plans

	Advantages	Disadvantages
Restricted fat diets	• Eliminates nutrient with the greatest caloric density • Fat is easy to overconsume (low fiber, pleasing taste, widely available) • Some scientific evidence of weight loss success • Self-reports of weight loss success (National Weight Control Registry) • Reduces total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C)	• Low fat/high carbohydrate diets may increase triglyceride concentrations and decrease high-density lipoprotein cholesterol (HDL-C), especially in the absence of significant weight loss and exercise
Restricted carbohydrate diets	• Focuses on high fat and protein foods—favorite foods of some people • Reduces appetite (due to ketosis) • Some studies show greater weight loss than with low-fat diets • High protein intake helps to preserve lean body mass • Elicits a low insulin response that may allow for better mobilization of stored fat • Reduces triglyceride, TC, and elevated insulin concentrations • Increases HDL-C	• No long-term data (> 1 year) on safety or effectiveness • Risk for gout, kidney stones, and osteoporosis may be increased

Volek, J.S., Vanheest, J.L. & Forsythe, C.E. (2005). Diet and exercise for weight loss: a review of current issues. *Sport Medicine*, 35(1), 1–9.

However, the debate does not stop with the knowledge that all the hypocaloric diets were equally effective in producing a relatively small short-term weight loss. There may be advantages to consuming either a low-fat or low-carbohydrate diet as shown in Table 12.3. For example, self-reported dietary strategies of those individuals who have maintained at least a 30-lb (13.6-kg) weight loss for at least five years suggest that a diet low in fat (~ 24 percent of total energy intake) is an important element in weight maintenance. This low-fat diet is part of a lifestyle that includes an expenditure of energy via exercise of approximately 2,800 kcal per week (Klem et al., 1997).

On the other hand, low-carbohydrate diets have been shown to decrease appetite (due to circulating ketone bodies) and decrease **visceral fat,** which is stored in the abdominal area. The reduced visceral fat, an important health-related issue, may be due to reduced circulating insulin that results with a low carbohydrate intake. An individual's response to the macronutrient composition of the diet may vary, again underscoring the importance of recognizing that one weight-loss diet plan is not appropriate for the entire population (Volek, Vanheest, and Forsythe, 2005).

The majority of scientific studies suggest that altering the energy balance equation with a combination of dietary restriction and exercise is the most effective means of achieving long-term weight loss. Energy balance can be altered by exercise alone, although weight loss may not be of the same magnitude as occurs with diet alone or the combination of diet and exercise. One explanation may be that the individual compensates for the additional energy expenditure from the exercise by increasing caloric (food) intake. When a compensatory increase in caloric intake is avoided, exercise can result in substantial weight loss.

The amount of exercise necessary for achieving and maintaining weight loss (i.e., up to 60 to 90 minutes on most days) is substantially greater than the minimum amount of physical activity that is recommended for good health (i.e., accumulating 30 minutes of moderate-intensity activity on most days). If the primary goal is weight loss rather than large improvements in cardiovascular fitness, duration of exercise appears to be more important than intensity, provided the exercise is of at least moderate intensity. For example, approximately the same number of kilocalories would be expended running 4 miles at a 7½-minute-per-mile pace and walking the same distance at a 15-minute-per-mile pace (4 mph), but walking would take twice the time. The exercise intensity and rate of caloric expenditure is obviously higher when running and will contribute to greater increases in cardiovascular fitness levels as well as to caloric expenditure. Many people may find this intensity of exercise difficult to sustain and uncomfortable, and may desire to pursue activities of lower intensity, such as walking. A comparable level of caloric expenditure can be achieved, but the duration of the activity must be extended, in this case to 60 minutes. Approximately 200 to 300 minutes of exercise each week (30–40 minutes per day) or > 2,000 kcal of energy expended per week is necessary for weight loss and maintenance of weight loss. This amount of exercise may appear to be daunting to the sedentary individual not accustomed to physical activity, but it is achievable with gradual progression over time to these targets.

Prevention of weight gain is critical because overweight and obesity are difficult to treat. Consider the experience of those who are registered in the National Weight Control Registry. This registry consists of approximately 3,000 people, most of whom are Caucasian (97 percent), female (80 percent), and married (67 percent). On average, the registrants have lost 66 lb (30 kg) and have maintained this weight loss for an average of 5½ years. The average maximum BMI attained was 35 and most lowered their maximum lifetime BMI by 10 BMI units (e.g., BMI was reduced from 35 to 25). Average daily caloric intake is 1,381 kcal with approximately 24 percent of total energy provided by fat. Women expend approximately 2,545 kcal weekly through exercise, while men expend about 3,923 kcal/wk; exercise expenditure is equivalent to about one hour of moderately intense exercise daily. Interestingly, 90 percent reported previous failed attempts at weight loss and attribute their current success to a greater commitment, stricter dieting, and more emphasis on exercise (Wing and Hill, 2001). These data should be interpreted carefully, as they are self reported and obtained from a self-selected (nonrandom) sample. However, it is quite clear how difficult it is once weight has been gained to lose that weight and maintain the weight loss.

To summarize, for fat (weight) loss to occur energy expenditure must be greater than energy intake. This can be accomplished by reducing food intake and/or increasing exercise. Although many weight-loss diet plans do not "count calories," they are designed to restrict caloric intake. A weight-loss plan that severely restricts the types of foods that may be eaten, be it carbohydrate or fat, is more difficult to follow over the long term. These plans may lead to successful short-term weight loss, but high drop-out rates and weight gain after one year suggest that they more often promote a temporary loss of body fat.

What's the point? Losing excess body fat and maintaining the weight loss are difficult for most people. Although many weight-loss diets are available, no single weight-loss plan has been shown to be the *most* effective.

DIABETES

Diabetes is a metabolic disease characterized by a high blood glucose concentration and is typically divided into two types. Type 1 diabetes, also referred to as insulin dependent diabetes mellitus (IDDM), is an autoimmune disease that destroys the beta cells of the pancreas, which results in an inability to manufacture

Visceral fat: Fat stored around major organs.

SPOTLIGHT ON CHRONIC DISEASES

Overweight and Obesity

Definition: In adults: Overweight—BMI between 25 and 29.9; Obesity—BMI 30 or greater.

Prevalence: Overweight—65 percent of adults and 17 percent of children; Obesity—30 percent of adults; Prevalence in United States is highest of all developed countries.

Symptoms: Change in body weight and appearance; change in breathing pattern during sleep; fatigue or lack of stamina.

Cause: Energy imbalance, in large part due to excessive food intake and/or lack of physical activity.

Prevention: 1) Matching caloric intake with caloric expenditure 2) Eating predominantly because of physiological hunger 3) Age- and activity-appropriate portion sizes 4) A diet emphasizing fruits, vegetables, whole grains, low- or nonfat dairy foods, and lean meats, fish, and poultry, similar to the DASH (Dietary Approaches to Stop Hypertension) diet 5) Minimum of 150 minutes of moderate-intensity exercise each week.

Treatment: Treatment must be individualized.

Diet: 1) Reduce food intake 2) Reduce portion sizes 3) Follow a hypocaloric diet that includes nutrient-dense foods.

Exercise: 1) Moderate-intensity physical activity or cardiovascular exercise 2) ≥200–300 minutes per week or ≥2,000 kcal per week of energy expenditure 3) Strength training as a supplement to cardiovascular exercise 2 to 3 times per week focusing on increased volume rather than increased intensity (i.e., increased sets and repetitions rather than increased resistance or weight).

Centers for Disease Control and Prevention. http://www.cdc.gov/nccdphp/dnpa/obesity/

insulin. Type 1 diabetes makes up less than 10 percent of all the cases of diabetes in the United States. Far more prevalent is type 2 diabetes, also known as noninsulin dependent diabetes mellitus (NIDDM), which accounts for more than 90 percent of all U.S. diabetes cases and affects at least 15 million people. In some cases, individuals produce too little insulin, but in most people with type 2 diabetes the insulin produced is ineffective because cells, particularly muscle, fat, and liver cells, are insensitive to its action (i.e., **insulin resistance**). Approximately 85 percent of people with type 2 diabetes are obese and have insulin resistance, but nonobese individuals can also manifest type 2 diabetes (American Diabetes Association, 2004). Diabetes that is associated with overweight or obesity is sometimes referred to as **diabesity.**

Approximately 40 million people in the United States are considered prediabetic and are at risk for developing diabetes as a result of obesity, sedentary lifestyle, and consumption of an unhealthy diet. A diet that provides adequate but not excessive caloric intake and the consumption of whole grains, fruits, vegetables, and low-fat protein foods has been shown to reduce risk for developing diabetes (van Dam et al., 2002; Hu et al., 2001).

Type 2 diabetes was previously referred to as adult-onset diabetes because it was uncommon in children or adolescents. However, the number of nonadults diagnosed with type 2 diabetes is dramatically increasing and that term is no longer appropriate (Pinhas-Hamiel et al., 1996). The increase in child and adolescent type 2 diabetes reflects the increase in child and adolescent obesity and is most common in those who are also sedentary and have a family history of diabetes.

Type 2 diabetes is characterized by **hyperglycemia** (i.e., elevated blood glucose concentration) that is a

SPOTLIGHT ON A REAL ATHLETE

Vijay, 38-Year-Old Occasional Triathlete

As former collegiate athletes age, they may find it difficult to continue to exercise and eat a healthy diet. Vijay is in his late thirties and has been active to some degree all his life. He ran track in high school and college and continued with distance running throughout his twenties. After graduating from college he transitioned from a highly trained competitive athlete to a well-trained recreational athlete. Now married with three young children, he finds that he only has time to occasionally compete in age-group division triathlons. Vijay has limited time for the intense workouts needed to be highly competitive, so his main goal is to train enough to complete the occasional triathlon in a “reasonable” time. Each week he tries to complete two workouts each of distance running, cycling, and swimming (i.e., six endurance workouts per week). He has discovered that finding time each week to train is difficult, not only because of a busy family life, but also due to the demands of his job, which requires frequent travel. Although Vijay enjoys exercise, it is not always easy when he is on the road because hotel fitness facilities are limited. He also faces the challenges of consuming an appropriate diet while eating out a lot. Business is often conducted over meals, which tend to be high in kilocalories, fat, sugar, salt, and alcohol. Vijay is not obese but he has slowly gained weight since graduating from college and many of his family members are obese. He is prone to rapid abdominal weight gain and he can easily gain 2 to 3 pounds (~ 1 kg) on a business trip as a result of excessive food and alcohol intake.

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Vijay, an occasional triathlete.

Vijay acknowledges that his diet needs to improve, but changing dietary intake has not been a priority for him, in part, because he is not obese. He has always consumed sports drinks during exercise but recently he began to drink them throughout the day because of excessive thirst. Excessive urination brought him into the doctor’s office, where he was diagnosed with type 2 diabetes. Vijay, who is not obese and engages in some exercise every week, is an example of the minority of adults diagnosed with type 2 diabetes. The majority of adults diagnosed with type 2 diabetes are obese and sedentary.

result of insulin resistance, a defect in insulin secretion or insulin deficiency over time. Under normal conditions, the increase in blood glucose that occurs after a meal stimulates the secretion of insulin, which then mediates the uptake of glucose into cells via glucose transporters located on the surface of the cell membranes. Insulin resistance occurs when the same level of insulin fails to stimulate the same degree of glucose uptake, and blood glucose concentration remains higher than would be expected. If blood glucose remains elevated, the pancreas may be able to secrete more insulin and eventually enough insulin may be present to result in adequate glucose uptake. In some people with type 2 diabetes, insulin production is actually greater than normal, but the cells are resistant to insulin's blood glucose lowering effect. Over time the insulin resistance may become more severe and even higher than normal insulin secretion is not enough to reduce blood glucose concentration to a normal level. Hyperglycemia and **hyperinsulinemia** (elevated blood insulin) result. In other people with type 2 diabetes, the pancreas produces insulin in quantities less than normal, which results in hyperglycemia. Over time, people with type 2 diabetes may experience a steady decline in insulin production, which makes it difficult to maintain a normal blood glucose concentration and may eventually result in the need for insulin injections.

Obesity worsens insulin resistance. An obese person with diabetes needs more insulin than a nonobese person with diabetes to maintain a normal blood glucose concentration. Obesity appears to drive a vicious cycle in which an increase in body fat results in cells becoming more insulin resistant and insulin resistance results in increasing obesity. Obesity results in an elevated blood insulin concentration (hyperinsulinemia) and hyperinsulinemia favors fat storage and inhibits fat breakdown (Girod and Brotman, 2003).

Type 2 diabetes is also characterized by abnormal lipid (fat) metabolism. Since the cells lack glucose for fuel, fat in the blood is increased to provide cells an alternative fuel source. This results in an increase in the deposition of fatty acids into the cells of the muscle, liver, and pancreas, which makes the muscle and liver cells even more insulin resistant and the beta cells of the pancreas more dysfunctional. This abnormal lipid metabolism is related to an increase in abdominal obesity, which readily releases fatty acids into the blood (Raz et al., 2005).

Insulin resistance: A condition in which the hormone insulin fails to stimulate tissues to take up the same amount of glucose.

Diabesity: Diabetes associated with overweight or obesity.

Hyperglycemia: Blood glucose concentration that is higher than the normal range.

Hyperinsulinemia: Blood insulin concentration that is higher than the normal range.

SPOTLIGHT ON CHRONIC DISEASES

Type 2 Diabetes

Alternate term: Noninsulin dependent diabetes mellitus (NIDDM); formerly adult-onset diabetes.

Definition: A metabolic disease characterized by insulin resistance.

Prevalence: In the United States: 90 percent or more of the diagnosed cases of diabetes (at least 15 million); Approximately 6 million are undiagnosed and ~40 million have prediabetes.

Symptoms: Impaired fasting glucose, polyuria (excessive urine), polydipsia (excessive thirst), polyphagia (excessive hunger or food intake).

Cause: Insulin resistance (85 percent of cases).

Prevention: 1) Maintain a healthy weight 2) Meet minimum physical activity recommendations 3) Consume a healthy diet that emphasizes whole grains, fruits, vegetables, and low-fat protein foods.

Treatment: Achieve and maintain control of blood glucose; prevent or delay onset or progression of complications.

Diet: 1) Hypocaloric diet, if weight loss is needed 2) Consumption of a healthy diet such as that promoted by the Dietary Guidelines; moderate consumption of sugar and alcohol 3) Adjust amount and timing of food intake to maintain glycemic control 4) Other dietary changes may be needed based on presence of complications (e.g., heart disease, kidney disease, hypertension).

Exercise: 1) Low- to moderate-intensity physical activity 2) Cardiovascular, strength training, and flexibility exercises 3) Consistent frequency; not more than 72 hours between exercise bouts 4) Minimum of 10–15 minutes; accumulate at least 30 minutes each day; progress to intensity and duration consistent with weight-loss recommendations.

American Diabetes Association. http://www.diabetes.org/home.jsp

Exercise helps to break the vicious cycle because it has an insulin-like effect. Exercise stimulates the movement of glucose transporters to the surface of the cell membrane where they can increase glucose uptake into the skeletal muscle cells, a large storage site for glucose. Exercise results in a lower fasting blood glucose concentration and improved insulin sensitivity (i.e., less insulin resistance). This effect lasts no more than approximately 72 hours after the exercise so regular physical activity is needed.

One misconception is that eating too much sugar will *cause* diabetes. Sugar and other carbohydrate foods are broken down to glucose, and blood glucose concentration does rise temporarily after their ingestion. The body then secretes insulin, which mediates the uptake of glucose into the cells, resulting in a return to a normal blood glucose concentration. Taking in too much sugar does not cause a problem under normal conditions. However, an individual's dietary intake may increase the risk for diabetes if it leads to weight gain, which leads to insulin resistance. Sugar intake may be a factor in weight gain if it represents excess caloric intake.

Although 15 million people have been diagnosed with type 2 diabetes, it is estimated that 6 million people are undiagnosed, a particular problem because the effects of type 2 diabetes can be numerous and severe, especially if untreated. Associated medical conditions include atherosclerotic cardiovascular disease and cerebrovascular disease (e.g., hardening of the arteries that can cause heart problems and stroke), hypertension, peripheral vascular disease (e.g., narrowing of the vessels in the legs, arms, kidneys), nephropathy (kidney disease), retinopathy (eye disease leading to blindness), neuropathy (degeneration of nerve function), and susceptibility to infections and slow wound healing.

Physical activity and diet play major roles in the treatment of type 2 diabetes. Together, diet and exercise can help individuals lose weight, maintain blood glucose control, and delay or slow the progression of the medical conditions associated with diabetes. One key to diabetes treatment is changes in lifestyle, although diet and exercise strategies are often underutilized in favor of oral antidiabetic medications.

HEART DISEASE

Cardiovascular disease is responsible for approximately 685,000 deaths in the United States each year (Hoyert, Kung, and Smith, 2005). Various terms are used—cardiovascular disease, heart disease, coronary heart

SPOTLIGHT ON A REAL ATHLETE

Freddie, 48-Year-Old, Former Star High School Athlete, Physically Active Until His Mid-Twenties, Sedentary For 20 Years

Freddie is 48-years-old and in six months will attend his 30th high school reunion. A star athlete in football and wrestling in high school, Freddie did not compete after graduation but tried to remain physically active. In the last 20 years there has been a gradual and consistent decline in both the amount and intensity of physical activity, partly because of the chronic effects of recurring knee injuries. Twenty-five years ago he ran every day to stay in shape, but now he only walks occasionally. Over the years he has lived up to his nickname, "Fast Food Freddie." As a result he has gained 50 pounds since high school, much of it "in the gut."

Freddie is typical of many Americans—years of physical inactivity leading to poor cardiovascular fitness and a diet excessive in energy (kcal), fat, sugar, and sodium and low in fiber. At a recent health fair Freddie had his blood pressure taken and discovered that it was elevated. He also filled out a questionnaire for heart disease risk. Since he hadn't been to a physician recently, he was unable to complete the section on blood lipids, but he did note that he has several risk factors—hypertension, excess body fat, physical inactivity, excess alcohol intake, and family history for heart disease. This prompted Freddie to make an appointment with his physician for a physical.

Reza Estakhrian/Taxi/Getty Images

Freddie, former high school athlete.

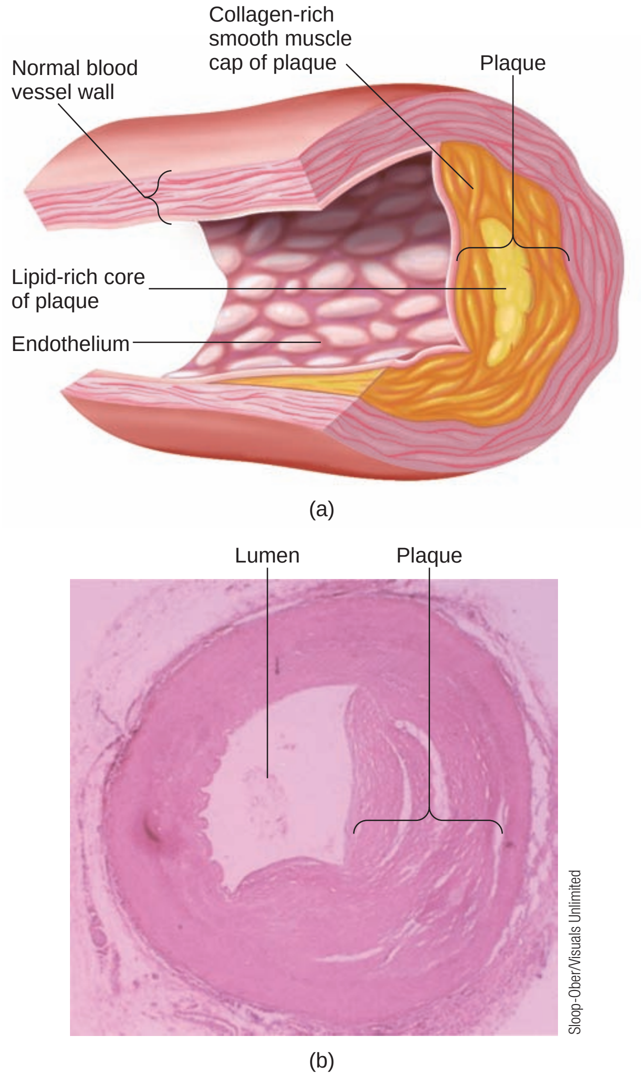

Figure 12.6 Plaque and the Development of Atherosclerosis

Plaque forms in the walls of large blood vessels and can contribute to the narrowing and hardening of the vessels of the heart.

disease, **coronary artery disease** (see glossary)—but the focus of this section is **atherosclerosis** (hardening and narrowing of arteries). **Atherosclerotic heart disease** is a life-threatening disease when it occurs in the coronary arteries.

The atherosclerotic process begins in childhood and adolescence with the development of fatty streaks on the interior walls of arteries. Fatty streaks, which are initially soft, enlarge and harden and become **plaques,** which eventually protrude into the **lumen** of the artery and may obstruct blood flow (see Figure 12.6). Plaques are found between the middle and inner layers of the coronary arteries and cause them to harden and narrow. By age 30 most people have fairly well-developed plaques (Madamanchi, Vendrov, and Runge, 2005).

Major Risk Factors:

Age (for men, $\geq$45 years; for women, $\geq$55 years)

Cigarette smoking

Family history of early heart disease

For men, a first-degree relative (father or brother) $<$55 years

For women a first-degree relative (mother or sister) $<$65 years

High-density lipoprotein cholesterol (HDL-C) $<$40 mg/dl

Hypertension ($\geq$140/90 mm Hg)

Diabetes

Figure 12.7 Major Risk Factors for Heart Disease

Legend: mg/dl = milligrams per deciliter; mm Hg = millimeter mercury

Plaques seem to form when low-density lipoproteins (LDL), which are carriers of cholesterol, are oxidized. Oxidation damages blood vessels and the immune system responds with **platelet** and other immune cell migration to the site of injury to engulf the oxidized LDL. The platelets adhere to the vessel to repair the damage. The immune cells (known as foam cells) become filled with cholesterol and eventually harden and become plaque. Over time scar tissue begins to form, debris accumulates because the surface of the vessel wall is irregular, and the lumen (space available for blood flow) narrows (Madamanchi, Vendrov, and Runge, 2005).

The major risk factors for heart disease are shown in Figure 12.7 and include age, cigarette smoking, family history of early heart disease, low concentration of **high-density lipoprotein** cholesterol (HDL-C), hypertension, and diabetes. A high concentration of HDL-C

Coronary artery disease: Reduction of blood flow to the coronary arteries typically caused by atherosclerosis. Also known as coronary heart disease.

Atherosclerosis: Hardening of the arteries.

Atherosclerotic heart disease: Atherosclerosis that occurs in coronary arteries, restricting blood flow to the heart.

Plaque: When referring to cardiovascular disease, fatty streaks in vessels that have hardened.

Lumen: Space inside a structure such as the blood vessels or the intestine.

Platelet: A cell found in the blood that assists with blood clotting.

High-density lipoprotein: A fat transporter containing a high proportion of protein and a low proportion of triglyceride and cholesterol. Also known as "good cholesterol."

Table 12.4 Blood Lipid Laboratory Tests

Laboratory Test	Interpretation of Laboratory Results	Comments
Total cholesterol (TC)	• Desirable (low risk for heart disease): < 200 mg/dl (< 5.17 mmol/L) • Moderate risk: 200–240 mg/dl (5.17–6.18 mmol/L) • High risk: > 240 mg/dl (> 6.21 mmol/L)	• Cholesterol testing is a screening tool • Adults with values in the desirable range and few risks factors for heart disease are tested once every five years • Testing is more frequent if values are moderate or high, if several other risk factors are present, and to determine effectiveness of any interventions • Exercise by itself does not confer protection from elevated levels so athletes should be screened as part of a routine physical exam
Low density lipoprotein cholesterol (LDL-C)	• < 160 mg/dl (4.14 mmol/L) when no or one risk factor is present • < 130 mg/dl (3.36 mmol/L) if two or more risk factors are present • < 100 mg/dl (2.6 mmol/L) if heart disease or diabetes has been diagnosed • < 70 mg/dl (1.81 mmol/L) for those with known arterial narrowing or heart surgery	• Best predictor of heart disease risk • Typically calculated, not measured directly • Calculated values are most accurate after a 12-hour food and water fast • Direct measure (not calculated) is preferred when triglycerides are known to be elevated
High density lipoprotein cholesterol (HDL-C)	• Optimal: > 60 mg/dl (1.56 mmol/L) • Desirable: ≥ 40 mg/dl (1.04 mmol/L) • Increased risk: < 40 mg/dl (< 1.04 mmol/L)	• Does not require fasting
Triglycerides	• Desirable: < 150 mg/dl (< 1.69 mmol/L) • Slightly elevated risk: 150–199 mg/dl (1.69–2.25 mmol/L) • High risk: 200–499 mg/dl (2.26–5.63 mmol/L) • Very high risk: > 499 mg/dl (> 5.63 mmol/L)	• 12-hour food and water fast is necessary

Legend: mg/dl = milligrams per deciliter; mmol/L = millimoles per liter

Lab Tests Online http: //labtestonline.org.

(i.e., > 60 mg/dl) is protective and is powerful enough to "offset" one of the major risk factors (Moyad, 2004). A 50-year-old male who smokes, whose father died at age 50 from a heart attack, and who has low HDL-C, high blood pressure, and diabetes has six risk factors. A 70-year-old nonsmoking female with no family history of heart disease but diabetes and hypertension has three risk factors. A 50-year-old nonsmoking male with no family history of heart disease and normal blood pressure and blood lipids (e.g., LDL-C, HDL-C) has one risk factor—age.

Contributing risk factors include elevated total blood cholesterol concentration, excess body fat (i.e., overweight or obese), physical inactivity, excess alcohol intake, and unhealthful responses to stress. Three of the six major risk factors and all the contributing risk factors are modifiable to some degree. Diet and exercise, along with smoking cessation, are the cornerstones of cardiovascular disease prevention. Those over the age of 20 may assess their risk for heart disease at http://www.nhlbi.nih.gov/guidelines/cholesterol.

Laboratory tests are used to assess heart disease risk and the most common ones are shown in Table 12.4. A basic screening tool is the measurement of blood cholesterol, but the relative concentrations of the lipoproteins that transport cholesterol are of greater value than the total amount of cholesterol for predicting risk. Low-density lipoproteins have an affinity for depositing excess cholesterol in the artery walls, which contributes to atherosclerosis. An elevated LDL-C concentration is undesirable because it is associated with an increased risk for cardiovascular disease. This has led to the designation of LDL-C as "bad" cholesterol, an attempt to impress on the general population the undesirable effects of elevated LDL-C.

The amount of LDL-C in the blood and the amount of antioxidants available to protect the LDL-C from oxidation are important factors in the initiation and progression of atherosclerosis. An appropriate LDL-C concentration is determined based on the presence of major risk factors as shown in Table 12.4 (Grundy et al., 2004). For example, for an individual with no or one risk factor an LDL-C of 160 mg/dl or less would be appropriate, but the target LDL-C would be 130 mg/dl or less if two or more risk factors were present. Cholesterol is also carried by high-density lipoproteins (HDL-C). These carriers have an affinity for removing excess cholesterol from the artery walls if it has not yet been calcified and

Christina Micek

These foods are typically high in saturated fats.

Christina Micek

These foods often contain saturated and *trans* fats.

transporting the cholesterol to the liver for degradation. This has given rise to the term "good" cholesterol. As previously mentioned, the most desirable HDL-C concentration is greater than 60 mg/dl because such values are associated with a low risk for heart disease. Consumers may have difficulty remembering the various laboratory values so the message is often simplified: low levels of HDL and high levels of cholesterol, LDL, and triglycerides are undesirable.

There is strong evidence that diets high in saturated and *trans* fatty acids increase LDL-C by influencing the liver cells to manufacture more low-density lipoproteins. As the LDL-C concentration in the blood increases the risk for cardiovascular disease increases. Alternatively, for every 1 percent reduction in LDL-C concentration there is a 1 percent reduction in heart disease risk (Grundy et al., 2004). Foods in which saturated fatty acids predominate include beef and pork fat, butter, whole milk, and coconut and palm oils. *Trans* fatty acids occur with hydrogenation, the addition of hydrogen atoms to an unsaturated fatty acid, and are found in processed foods. *Trans* fats act like saturated fats in the body even though they originally were unsaturated fats. On average, U.S. adults consume 11 to 12 percent of total energy intake as saturated fatty acids and 2.6 percent as *trans* fat. The Institute of Medicine (2002) recommends that less than 10 percent of total calories be saturated fat and that *trans* fat intake be as low as possible. Many manufacturers are removing *trans* fats from foods and restaurants are cooking with oils that are free of *trans* fats because of the negative health consequences. There are no known health benefits associated with *trans* fats.

In some people, excess dietary cholesterol raises blood cholesterol concentration and reducing dietary cholesterol intake lowers elevated blood cholesterol. However, in other people with a high blood cholesterol concentration, decreasing dietary cholesterol does not result in decreased total blood cholesterol. These individuals, because of their genetic makeup, compensate for lower dietary cholesterol intakes with increased synthesis of cholesterol by the liver. Therefore, some people are sensitive to the amount of cholesterol in their diet and should make appropriate dietary adjustments, while others are affected more by the amount of saturated fat rather than the actual amount of cholesterol in their diets (Gropper, Smith, and Groff, 2005). Foods high in cholesterol and saturated fats are listed in Table 12.5.

A high-fat intake, by itself, is not a risk factor for cardiovascular disease, but a common recommendation is to decrease dietary fat, especially from animal sources. Reducing total fat intake, especially when animal fat intake is high, typically reduces the intake of saturated fats and cholesterol. Consuming foods that contain monounsaturated, polyunsaturated, and omega-3 fatty acids are encouraged because they reduce the risk for cardiovascular disease. Olive oil, flaxseed oil, nuts and seeds, wheat germ, fatty cold-water fish (e.g., salmon, trout, tuna), and leafy green vegetables all contain heart-healthy fats. The type of fat consumed is more important than the amount of fat consumed, although the amount is still a consideration because it affects total caloric intake. More information about dietary fat can be found in Chapter 6.

Most Americans are overweight or obese and reducing dietary fat is one way to reduce total energy intake. **Hypercaloric** diets, whether they are high-fat/low-carbohydrate diets or low-fat/high-carbohydrate diets,

Hypercaloric: An excessive amount of dietary kilocalories compared to what is needed to maintain body weight.

Table 12.5 Foods Containing Cholesterol and Saturated Fat

Food	Cholesterol* (mg)	Saturated Fat** (g)
2 scrambled eggs made with milk and butter	429	4.5
Liver (3 oz)	~300–400	1
Squid (3 oz)	220	1.6
1 egg (found in the yolk)	210	1.5
1 slice (75 g) pound cake made with butter	166	9
1 slice pecan pie	160	5
1 cup eggnog	150	11
Shellfish such as shrimp or abalone (3 oz)	~150	1.4
One extra crispy fried chicken breast (Kentucky Fried Chicken)	135	8
Double cheeseburger (Burger King)	100	15
Eel (3 oz)	107	2
Lamb (3 oz)	~80–100	4–8
Beef or pork (3 oz)	~60–80	5.5–8.5
Chicken (3 oz) (not breaded or fried)	~60–80	1.5–2
3 pancakes made with eggs and milk	80	2
Vanilla milk shake, small (Carl's Jr)	50	7
Hot dog or sausage (1 item)	~45	2.5–6
Most fish, baked or steamed (3 oz)	~30–40	<0.25
Most cheese (1 oz)	~25–30	~5
2 slices of a 14-in cheese pizza	32	7
Butter (1 T)	32	6
½ cup cooked egg noodles	26	0.25
1 cup whole milk	24	4.5
1 cup 2% milk	20	3
Lard (1 T)	14	5
Large fries (McDonald's)	0	4.5
Potato chips (1 oz or about 20 chips)	0	3
Luna tropical crisp energy bar or Balance original chocolate bar	0	3.5

Legend: mg = milligram; g = gram; oz = ounce; T = tablespoon

*It is recommended that no more than 300 mg of cholesterol be consumed daily.

**It is recommended that no more than 10% of total calories be provided by saturated fat. For example, on a 2,000 kcal diet, no more than ~22 g of saturated fat are recommended.

lead to excess body fat and increased cardiovascular disease risk. Typical American diets are also high in sodium and sugar. A high sodium intake may increase blood pressure in some people, and hypertension is a major risk factor for cardiovascular disease. High sugar intake by itself is not a risk factor but may contribute to a hypercaloric diet. Frequent fast-food consumption may be related to weight gain. Research shows that when

Consuming foods that contain monounsaturated, polyunsaturated, and omega-3 fatty acids are encouraged because they may reduce the risk for cardiovascular disease.

adults eat fast food, caloric intake is high and vitamin and mineral intake is low (Bowman and Vinyard, 2004).

The intake of alcohol may be either beneficial or detrimental, depending on the amount consumed. A moderate daily alcohol intake is associated with reduced risk for cardiovascular disease. Moderate intake is defined as one drink per day for women and up to two drinks daily for men. One drink contains ½ ounce (~15 ml) of ethanol, the amount typically found in 12 ounces (360 ml) of beer, 3 to 4 ounces (90 to 120 ml) of wine, or 1½ ounces (45 ml) of hard liquor (e.g., a "shot" of whiskey). The intake of more than three drinks daily (i.e., more than 1½ ounces [~20 g] of ethanol) is associated with increased blood pressure, cardiomyopathy (enlarged and weakened heart), and increased triglycerides.

Exercise and physical activity play an important role in the management of blood lipids. Exercise can exert an independent effect, but this effect is small, approximately 10 percent. In other words, an individual with an elevated total cholesterol concentration of 250 mg/dl might expect the effect of exercise alone to reduce cholesterol by approximately 25 mg/dl to 225 mg/dl. Similarly, a person with an HDL-C of 40 mg/dl may see a modest increase to approximately 44 mg/dl. Exercise and physical activity are integral to maintaining normal blood lipid concentrations, but exercise alone may not result in the magnitude of change necessary to meet blood lipid goals when blood lipids concentrations are abnormal. The most beneficial effect of exercise for blood lipid management appears to be its role in weight loss and maintenance. There is an added beneficial effect on elevated blood lipid concentrations when exercise results in weight loss.

SPOTLIGHT ON CHRONIC DISEASES

Heart Disease (Atherosclerosis)

Alternate term: Atherosclerotic Heart Disease, Coronary Artery Disease, Coronary Heart Disease. Heart disease refers to diseases of the heart and its vessels. It is sometimes used interchangeably with the term cardiovascular disease.

Definition: Atherosclerosis refers to the hardening and narrowing of the arteries.

Prevalence: Approximately 23.5 million adults in the United States (11 percent of the adult population), resulting in nearly 700,000 deaths annually.

Symptoms: Typically no symptoms until an artery is substantially narrowed or blocked, which can lead to chest pain, heart attack, arrhythmias, or stroke.

Cause: Buildup of plaque at the site of damage or injury to an artery.

Prevention: 1) Maintain or achieve a healthy weight 2) Consumption of a diet that emphasizes fruits, vegetables, whole grains, low- or nonfat dairy foods, lean meats, fish, and poultry, nuts, beans, and oils. 3) Maintain or progress to a minimum of 150 minutes of moderate-intensity exercise each week.

Treatment: Treatment must be individualized.

Diet: 1) Hypocaloric diet, if weight loss is needed 2) Modifications typically include a reduction in total fat, saturated fat, *trans* fat, and cholesterol, but an individual treatment plan is needed 3) A low-sodium diet may be recommended if hypertension is present.

Exercise: 1) Moderate-intensity physical activity or cardiovascular exercise 2) ≥200–300 minutes per week or ≥2,000 kcal per week of energy expenditure 3) Strength training as a supplement to cardiovascular exercise 2 to 3 times per week focusing on increased volume rather than increased intensity (i.e., increased sets and repetitions rather than increased resistance or weight).

Krauss et al., 2000; National Heart, Lung, and Blood Institute, http://www. www.nhlbi.nih.gov/; National Heart Association, http://www.americanheart.org; Centers for Disease Control and Prevention, http://www.cdc.gov.

Cardiovascular disease is multifactorial and each factor can have more or less of an influence on a given individual because of that person's genetic profile. It is easy to focus on the extremes: the inactive male who eats poorly and has a single, fatal heart attack at age 40 and the physically inactive smoker with no dietary restraint who celebrates his 80th birthday. But the majority of people fall in between these extremes. The average American is at risk for dying from or being disabled by cardiovascular disease because the diet consumed promotes heart disease in many different ways. This poor diet is generally accompanied by inactivity. Together, diet and exercise influence seven of the 10 known risk factors and four of the six major risk factors.

METABOLIC SYNDROME

Metabolic syndrome (also known as insulin resistance syndrome and syndrome X) is characterized by a clustering of metabolic disorders and risk factors: obesity, hypertension, dyslipidemia, glucose intolerance, and insulin resistance (see Table 12.6). Those with metabolic syndrome have a significantly greater risk of developing atherosclerotic cardiovascular disease and type 2 diabetes.

Table 12.6 Diagnostic Criteria for Metabolic Syndrome

Measure	Criteria*
Waist circumference	≥ 102 cm (≥ 40 in) in men ≥ 88 cm (≥ 35 in) in women
Triglycerides	≥ 150 mg/dl (1.7 mmol/L) **or** drug treatment for elevated triglycerides
High-density lipoprotein cholesterol (HDL-C)	< 40 mg/dl (0.9 mmol/L) in men < 50 mg/dl (1.1 mmol/L) in women **or** drug treatment for reduced HDL-C
Blood pressure	≥ 130 mm Hg systolic blood pressure **or** ≥ 85 mm Hg diastolic blood pressure **or** drug treatment for hypertension
Fasting glucose	≥ 100 mg/dl **or** drug treatment for elevated glucose

Legend: cm = centimeter; in = inch; mg/dl = milligrams per deciliter; mmol/L = millimoles per liter; mm Hg = millimeter mercury

*Any 3 of the 5 criteria constitute a diagnosis of metabolic syndrome.

Grundy, S.M., Cleeman, J.I., Daniels, S.R., et al. (2005). Diagnosis and management of the metabolic syndrome. An American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation*, 112(17), 2735–2752.

The major factors underlying the development of the metabolic syndrome are obesity and insulin resistance, two conditions previously discussed (Grundy, 2006). Of particular importance is abdominal or upper body obesity. Upper body obesity consists of both visceral and subcutaneous abdominal fat stores. Visceral fat, which refers to fat stored deep within the abdominal cavity surrounding the organs, is characterized by mesenteric and omental fat cells. These adipocytes have more beta-receptors than other types of fat cells, so the lipid stored in visceral fat cells is easily mobilized from the cells into the blood, which flows directly into the liver via the portal circulation. This blood contains a high concentration of free fatty acids, which inhibit the breakdown of insulin and increase the liver's synthesis of glucose and triglycerides.

SPOTLIGHT ON A REAL ATHLETE

Freddie, 48-Year-Old, Former Star High School Athlete, Physically Active Until His Mid-Twenties, Sedentary For 20 Years (Continued)

After finding out at the health fair that his blood pressure was elevated, Freddie made an appointment to see a physician. A physical exam confirmed his hypertension, obesity, and excess abdominal fat. A blood test revealed that he had elevated blood cholesterol, LDL-cholesterol, and triglycerides, and a low concentration of HDL-cholesterol. His fasting blood glucose was also elevated. These finding were not a surprise because Freddie knew that he had gained a lot of weight and had become increasingly sedentary. He expected the doctor would tell him that he had heart disease, like his oldest sister. What surprised him was the diagnosis of metabolic syndrome, a disease that Freddie was unfamiliar with.

Freddie realizes that he needs diet and exercise intervention and hopes that it is not too late. His physician assures him that it is not and that the initial therapeutic approach will be through lifestyle modification. Freddie needs to increase the amount of daily physical activity and include regular aerobic exercise along with some strength training. He needs to reduce weight (fat) by increasing exercise and decreasing food intake. He also needs to limit his intake of saturated fats, cholesterol, and salt (sodium). His physician tries to impress upon him the importance of lifestyle changes, but he is realistic when he indicates to Freddie that many aspects of his life will be affected, including what he does with his leisure time, the amount of TV he watches, and how often he eats out.

Subcutaneous fat is less metabolically active than visceral fat. In the abdominal area, subcutaneous fat is found just below the skin and does not surround the organs. Subcutaneous fat is also found below the waist (e.g., hips, thighs). In adult males, 20 percent of total storage fat is visceral fat; in adult females visceral fat is approximately 6 percent of total fat. Visceral fat increases in both males and females as they age. Genetics are a powerful influence on body fat distribution, and as much as half of the influence on visceral fat distribution may be due to a single gene. It is visceral fat that is most related to an increased risk for chronic diseases.

Abdominal obesity is associated with insulin resistance and an elevated waist circumference is one of the diagnostic criteria for metabolic syndrome (see Table 12.6). Other factors associated with metabolic syndrome are elevated fasting blood glucose, dyslipidemia (abnormal blood lipids including elevated triglyceride and LDL-C concentrations and low HDL-C concentration), hypertension, a pro-inflammatory state, sleep apnea (cessation of breathing during sleep), and physical inactivity. Those diagnosed with metabolic syndrome have a three-fold risk for developing atherosclerotic cardiovascular disease and a five-fold risk for developing type 2 diabetes compared to those without metabolic syndrome (Grundy et al., 2005).

Obesity, particularly abdominal obesity, is a major risk factor for metabolic syndrome and, as previously discussed, is usually a result of inactivity and excess caloric intake. However, physical fitness and exercise have a direct and independent effect on metabolic syndrome risk. A large epidemiological study (Katzmarzyk et al., 2005) confirmed that the risk for metabolic syndrome, as well as all-cause and cardiovascular disease mortality, increased as BMI category increased from normal to overweight to obese. However, when the level of cardiovascular fitness of the subjects was considered, the risk of premature mortality decreased regardless of body weight category or the presence of metabolic syndrome. The authors concluded that the amount of physical activity necessary to maintain the observed level of physical fitness provided some health protection and reduced the risk normally associated with obesity and the metabolic syndrome. In other words, being physically active is important regardless of weight.

Other studies report similar findings. Ekelund et al. (2005) found a strong **association** with level of energy expenditure through physical activity and risk

Metabolic syndrome: A disease characterized by a clustering of metabolic disorders and risk factors: obesity, hypertension, dyslipidemia, glucose intolerance, and insulin resistance.

Association: When referring to statistics or scientific studies, the existence of a relationship between two variables. Does not mean that it is a cause-and-effect relationship.

SPOTLIGHT ON CHRONIC DISEASES

Metabolic Syndrome

Alternate term: Insulin Resistance Syndrome, Prediabetes, Syndrome X.

Definition: A clustering of risk factors that often accompany obesity and are associated with increased risk for atherosclerotic heart disease and type 2 diabetes.

Prevalence: Nearly 25 percent of U.S. adult population; Age-dependent—incidence rises to >40 percent in those >60 years; prevalence higher in some ethnic groups such as African Americans and Mexican Americans.

Symptoms: Abdominal obesity, hypertension, dysplipidemia, impaired fasting glucose, sleep apnea.

Cause: Obesity, insulin resistance.

Prevention: 1) Maintain or achieve a healthy weight 2) Physical activity (meet at least minimal recommendations for activity and then progress) 3) Consume a healthy diet such as that outlined in the Dietary Guidelines.

Treatment: Weight loss, physical activity, dietary modifications, medication. Treatment must be individualized.

Diet: 1) Hypocaloric diet 2) Dietary modifications typically include a reduction in total fats, saturated fats, *trans* fats, and cholesterol to improve abnormal lipid concentrations, but an individual treatment plan is needed 3) Consumption of the DASH (Dietary Approaches to Stop Hypertension) or similar type of diet. This diet emphasizes fruits, vegetables, whole grains, low- or nonfat dairy foods, lean meats, fish, and poultry, nuts, beans, and oils. Potassium is plentiful and sodium is limited.

Exercise: 1) Accumulate at least 30 minutes of moderate-intensity physical activity on most days of the week 2) Progress to 60 to 90 minutes of moderately intense exercise on most days to lose weight and maintain weight loss.

National Heart, Lung, and Blood Institute. http://www.nhlbi.nih.gov/; National Heart Association, http://www.americanheart.org.

of developing metabolic syndrome, independent of the fitness level. Finley et al. (2006) found that cardiorespiratory fitness was inversely associated with metabolic syndrome regardless of dietary intake. These studies illustrate the importance of regular physical activity and exercise in the prevention of metabolic syndrome. Note that these and other studies show that risk can be reduced through regular physical activity, even if the activity does not result in reducing or eliminating the obesity. People should be encouraged to become and remain physically active, even if tangible results of their activity such as weight or fat loss are not readily apparent. A healthy diet is also important, but special emphasis should be put on becoming physically active.

The primary therapeutic approach for those with metabolic syndrome is lifestyle modification. The specific components of this lifestyle modification are: 1) increased physical activity, 2) weight reduction, 3) consumption of a diet that reduces risk for heart disease, and 4) smoking cessation. As discussed previously, the interaction of diet modification and physical activity/exercise is an important approach to achieve and maintain a healthy weight. Weight loss, appropriate dietary modifications, and exercise also work independently and interactively on other risk factors such as hypertension and dyslipidemia. In addition to lifestyle changes, those with metabolic syndrome may need pharmacological intervention such as antihypertensive, lipid-lowering, and antihyperglycemic medications.

OSTEOPOROSIS

The National Osteoporosis Foundation (2005) estimates that approximately 44 million women and men have low bone mineral density (BMD) and are at risk for developing osteoporosis. Osteoporotic bones are fragile and more prone to fractures, particularly in the spine (vertebrae), wrist, and hip. A hip fracture in an elderly adult is typically a life-changing event that may result in the inability to live independently, a living situation that older people highly value. The key is prevention, and preventative exercise and diet strategies should be instituted early in life.

Physical activity and exercise have a positive impact on bone health while inactivity has a negative effect on bone mineral density. Bones are often thought of as inert structures, but bones are active tissues with minerals being constantly added and removed. Because there is an apparently inevitable decline in bone mineral density with aging, there are two important strategies for developing and maintaining bone health throughout life. The first is to develop an optimal bone density by the third decade of life, the point at which a person achieves maximal bone density. The second strategy is to slow the loss of bone so that low bone density, which is associated with increased risk of fracture, is delayed as long as possible.

Physical activity and exercise, particularly weight-bearing activities, such as running, jumping, and gymnastics, are associated with increased bone mineral

SPOTLIGHT ON A REAL ATHLETE

Lena, 67-Year-Old, Formerly Lightly Active, Now Has Physical Limitations

Lena is a 67-year-old widow who lives independently in the home she and her husband built 40 years ago. As a teenager and young adult she was not expected to exercise, but she was lightly active for many years because she liked to garden. She has more time available for physical activity now that she is retired, but she must do so within her physical limitations. In the last year she has begun to experience some physical decline, such as decreased strength, and difficulties in balance when walking and rising from a sitting position. Although her body weight is not changing, she is losing lean body mass and gaining some body fat. She loves playing with her grandchildren but finds that she gets out of breath easily. She has recently been diagnosed with osteoporosis. Her biggest fear, and her biggest motivation for making lifestyle changes, is that she will fall and break a hip, be placed in a long-term care facility, and will never be able to return to her home. Lena's challenge is to find ways to be physically active without leaving her home or yard.

Ariel Skelley/The Image Bank/Getty Images

Lena, formerly active, now has physical limitations.

Physical activity and exercise are associated with increased bone mineral density in children, adolescents, and young adults.

density in children, adolescents, and young adults. The impact stress that is inherent in these activities stimulates a greater deposition of mineral in the bone, making bones stronger and more resistant to fracture. It is not surprising that activity of greater intensity that involves greater impact stress results in greater bone mineral adaptation. Moderate-intensity strength training in children, adolescents, and young adults has a positive impact on bone mineral density; however, these groups need proper guidance so appropriate strength-training guidelines are followed. The positive bone changes made in childhood and adolescence persist into adulthood, when it is important to maximize bone density. A detailed description of the bone remodeling process is found in Chapter 9.

For middle-aged and older adults, the primary strategy is to maintain bone mineral density by reducing the age-related decline in BMD as much as possible. Regular exercise and physical activity play a major role in this effort. It is not clear if older adults can increase their bone mineral density through exercise, but it is apparent they can slow the rate of decline. Again, weight-bearing exercise and strength training are the most effective activities for maintaining bone health in adults. While higher-intensity activities that impose greater impact stress generally result in more beneficial effects, older adults may not be motivated to or feel safe participating in high-stress activities that require jumping or running. They may also be limited in these activities by previous injuries or the presence of other exercise-intensity-limiting factors such as atherosclerotic heart disease. These groups also need guidance regarding proper strength-training techniques.

In addition to exercise, diet plays an important role in attaining maximum bone density. Although many nutrients are associated with bone health, calcium and vitamin D receive the greatest attention because of their fundamental roles. As discussed in Chapter 9, adequate calcium intake is critical during childhood, adolescence, and young adulthood because the majority of the bone's mineral content is achieved before age 20 and peak bone mass is reached by approximately age 35.

Nutrient intake after age 35 is still important but, similar to exercise, the focus turns first toward preventing and then slowing the loss of bone mineral. One of the best strategies is to consume the recommended amounts of calcium and vitamin D daily; unfortunately, deficiencies of these nutrients are prevalent in U.S. adults. Maintenance of bone mineral becomes increasingly difficult with the onset of menopause because of the loss of estrogen's positive effects on bone mineralization and turnover.

Calcium supplementation is frequently recommended for middle-aged and older females but its effects are limited, especially in the years immediately following the onset of menopause. The results of prospective, double-blind placebo-controlled studies show calcium supplements are not as powerful as originally hoped for slowing the loss of bone mineral and reducing risk for fracture. In the first five years after the onset of menopause, the rate of bone resorption is so high that calcium supplementation cannot completely offset it. Calcium supplements appear to be more effective in the second and third postmenopausal decades by reducing bone loss (which has now slowed), increasing bone density, and lowering fracture rate (Morgan, 2001). It is naïve to believe that the impact of low calcium intake over decades can be reversed after the onset of menopause with the consumption of calcium supplements.

Avenell et al. (2005) reviewed results of randomized trials to determine the effect of vitamin D supplements on the prevention of fractures. By itself vitamin D supplementation does not prevent fractures, but when taken with calcium supplements, the risk for hip and nonvertebral fractures was slightly reduced in **noninstitutionalized** adults. The only subgroup that appeared to have significantly fewer fractures with vitamin D and calcium supplements were the institutionalized elderly. Because supplementation appears to be limited in its effects, the need for prevention of low bone mineral density cannot be overstated.

Assessing Bone Mineral Density. Epidemiological studies have established that low bone density increases fracture risk and that bone density is the best predictor of fracture risk in postmenopausal women (Lufkin, Wong, and Deal, 2001). Since 1994, a diagnostic criteria has been available to assess bone density in Caucasian women. African Americans and men have

Noninstitutionalized: Not living in an institution such as a nursing home or mental health hospital.

Normal	BMD score > -1
Osteopenia	BMD score ≤ -1 but > -2.5
Osteoporosis	BMD score ≤ -2.5

BMD = Bone mineral density
Scores are z-scores

Figure 12.8 Bone Mineral Density Assessment Criteria
Kenny & Prestwood (2000).

approximately 20 percent greater bone density than white women (Zizic, 2004). Bone mineral density scores are established for normal, **osteopenia** (low bone mass), and osteoporosis (low bone mass with structural deterioration) as shown in Figure 12.8. A score of 0 means that bone density is equal to the peak bone mass expected in healthy premenopausal Caucasian women in their twenties. A score between 0 and > -1 is considered normal bone density. A score of –1 is one standard deviation below the norm and is associated with a doubling of the relative risk for fracture. Low bone density (osteopenia) is defined as a BMD score ≤ -1 but > -2.5. A BMD score ≤ -2.5 is the criterion for osteoporosis (Kenny & Prestwood, 2000). These scores are z-scores, meaning they are compared with the bone mass of age-matched peers. Scores can also be given as t-scores, which means that the individual's bone mass is compared to a healthy 30-year-old. Research studies often report z-scores, whereas an individual having bone mineral density measured in a clinical setting (e.g., physician's office or imaging center) will likely receive a t-score. The use of z- and t-scores causes some confusion among consumers because the category criteria are slightly different, so it is important to consult with one's physician about how the score should be interpreted.

For those who have been diagnosed with osteoporosis, doctors often recommended that they focus initially on performing low-intensity, weight-bearing exercise such as walking. Walking is beneficial for cardiovascular fitness and is an exercise that older adults can perform comfortably. Incorporating strength-training exercises two to three times per week could also be appropriate, although supervision is needed to assist with balance and prevent falls. Strength training provides significant stress on bones that is beneficial, and has the added benefit of increasing muscular strength, which aids in balance, locomotion, and the performance of daily tasks. While these activities would be beneficial, it is unknown if exercise can reduce the decline in bone mineral density that occurs in women as a result of menopause. Similarly, it may be prudent to consume calcium and vitamin D supplements, but the effect may be limited.

LIFESTYLE-RELATED CANCERS

One-third of all cancer deaths in the United States are associated with poor diet, inactivity, and overweight or obesity. This is approximately the same proportion of deaths associated with tobacco use. Lifestyle plays an important role in reducing the risk for cancer, and the American Cancer Society has published diet and

SPOTLIGHT ON CHRONIC DISEASES

Osteoporosis

Alternate term: Bone-thinning disease.

Definition: Bone mineral density more than 2.5 standard deviations below the young adult mean value, with or without fractures.

Prevalence: 10 million adults (90 percent women); ~34 million adults have low bone mass. Figures for both osteoporosis and low bone mass are expected to rise each year as the U.S. population ages.

Symptoms: Bone fracture, particularly vertebral and hip.

Cause: Loss of bone mineral exceeds replacement.

Prevention: 1) Weight-bearing exercise on a near daily basis 2) Adequate calcium and vitamin D intake.

Treatment: In addition to diet and exercise, medications may be prescribed.

Diet: 1) Maintain or increase calcium and vitamin D intake to recommended amounts 2) Supplemental calcium and vitamin D may be prescribed.

Exercise: 1) Exercise duration of 30 to 60 minutes on a near daily basis 2) Weight-bearing endurance (aerobic) exercise 3 to 5 times per week 3) Strength-training exercise 2 to 3 times per week.

National Osteoporosis Foundation. hppt://www.nof.org.

activity guidelines (Kushi et al., 2006). The four major recommendations are: 1) Maintain a healthy weight throughout life; 2) Adopt a physically active lifestyle; 3) Consume a healthy diet, with an emphasis on plant sources; and 4) If you drink alcoholic beverages, limit consumption.

These recommendations were adopted by the ACS based on the body of scientific literature for cancer prevention; however, these recommendations are similar to those made for other chronic diseases. Specific to cancer, overweight and obesity are associated with approximately 15 to 20 percent of all cancer deaths. Physical activity affects cancer risk, in part, because it helps people maintain a healthy weight, but being physically active also has other positive effects on cancer risk reduction. Studies show that plant foods, such as fruits, vegetables, and whole grains, help reduce cancer risk. The emphasis is on plant foods because of the nutrients they contain, but there are also data to suggest that red meat (e.g., beef, pork, and lamb) and processed meat (e.g., cold cuts, hot dogs, bacon) are associated with an increase in colon, rectal, and prostate cancers. A healthy diet can also help individuals to maintain a healthy weight. Excessive alcohol intake is associated with cancers of the mouth and liver, and the same recommendations regarding amount are made for preventing heart disease, as discussed earlier.

The American Cancer Society recommendations underscore a point made earlier in the chapter: Diet and exercise recommendations are remarkably consistent. There is a large body of literature that supports such recommendations, but the majority of people do not follow them and the prevalence of chronic diseases continues to increase in most cases. The challenge is to help children and adolescents establish healthy diet and exercise habits and to help adults change unhealthy lifestyle behaviors.

The Internet Café

Where Do I Find Reliable Information about Chronic Diseases?

The Centers for Disease Control and Health Prevention (CDC) devotes a section of its extensive website to chronic disease prevention **(http://www.cdc.gov/nccdphp/overview.htm).** Information on overweight and obesity can be found at **http://www.cdc.gov/nccdphp/dnpa/obesity/.** Other government and nonprofit organizations with prevention and treatment information about specific chronic diseases are listed below.

American Diabetes Association **(www.diabetes.org)**

American Cancer Society **(www.cancer.org)**

American Heart Association **(www.americanheart.org)**

National Heart, Lung, and Blood Institute **(www.nhlbi.nih.gov/)**

National Osteoporosis Foundation **(www.nof.org)**

What's the point? Regular physical activity and a healthful diet across the lifespan are fundamental to preventing and delaying chronic diseases.

Osteopenia: Low bone mineral density. A risk factor for osteoporosis.

SPOTLIGHT ON CHRONIC DISEASES

Lifestyle-Related Cancers

Definition: A class of diseases characterized by uncontrolled cell division.

Prevalence: In the United States ~ 14 million adults (6.6 percent of the adult population) have now or previously been diagnosed with cancer.

Symptoms: Symptoms vary depending on the site of the cancer.

Cause: There is no single cause for all types of cancer. Factors include genetics, environmental toxins, sun exposure, tobacco use, and lifestyle habits such as poor diet and physical inactivity.

Prevention: 1) Attain or maintain a healthy weight 2) Adults should engage in at least 30 minutes of moderate-to-vigorous physical activity on five or more days of the week. Forty-five to 60 minutes of physical activity are preferable. 3) Children and adolescents should engage in at least 60 minutes per day of moderate-to-vigorous physical activity at least five days per week. 4) Consume a healthy diet, with an emphasis on plant foods 5) Limit alcoholic beverage consumption.

Treatment: Treatment depends on the cancer site.

American Cancer Society Guidelines on Nutrition and Physical Activity for Cancer Prevention (2006) and the Centers for Disease Control and Prevention, http://www.cdc.gov/nchs/fastats/cancer.htm.

ASSESSING CHRONIC DISEASE RISK

Body mass index is the most widely use screening tool for evaluating the risk of disease based on weight. As discussed in Chapter 11, BMI is inappropriate to use with athletes, pregnant women, and adults over the age of 65. However, for the majority of young and middle-aged adults, BMI is a useful screening tool, particularly for Caucasians. When BMI is used alone, it is not as predictive as when used with waist circumference, a measure of abdominal body fat. These are widely available and easily performed screening methods and can be used at health fairs and gyms as well as in medical settings.

BMI is determined by using height and weight, which may be measured or self reported. Using a nomograph (see Appendix N) or an online BMI calculator (http://www.cdc.gov/nccdphp/dnpa/bmi/), BMI can be quickly derived. Criteria for underweight, healthy weight, overweight, obese, and severely obese are shown in Figure 12.9.

Many studies have reported an association between body weight, chronic disease risk, and mortality (Hu et al., 2004; Lee, Blair, and Jackson, 1999). This association is very much influenced by cardiovascular fitness. Recall from Chapter 1 that association suggests that a relationship exists, but does not mean there is a cause-and-effect relationship. In fact, no BMI category, even the healthy weight category, is free of disease.

Tables 12.7 and 12.8 show the prevalence of disease in men and women based on BMI. Notice that 27 percent of men and women in the healthy weight category (i.e., BMI 18.5–24.9) have high blood cholesterol and 23 percent have high blood pressure. Increasing weight has a greater impact on the prevalence of hypertension than any of the other chronic diseases. Women with a BMI >40 (6 percent of adult females) have a greater risk for chronic diseases than any other BMI category, so individuals should be concerned when a very large amount of weight is gained. However, some severely obese individuals do not manifest any of the "typical" obesity-related diseases. Must et al. (1999) report that 30 percent of severely obese Mexican-American women have blood pressure, blood glucose, and blood lipids within normal ranges. Just as the prevalence of disease in the healthy weight category is not zero, neither is the prevalence of disease in the severely obese 100 percent.

Distribution of body fat may be one reason that obese and severely obese people do not exhibit some of the common obesity-related chronic diseases. Abdominal obesity, also referred to as upper body or central obesity, confers a different risk than lower body (gynoid) obesity. Hypertension, type 2 diabetes, insulin resistance, and dyslipidemias are related to the amount of visceral fat (i.e., abdominal obesity) as previously discussed.

Underweight	Less than 18.5
Healthy weight	18.5–24.9
Overweight	25–29.9
Obese	Greater than 30 (Severe obesity may be defined as greater than 40)

Figure 12.9 Body Mass Index (BMI) Criteria

The unit of measure for BMI is kg/m^2 but it is most often reported without a unit of measure.

THE EXPERTS IN. . .

Nutrition and Exercise in Chronic Diseases

Many leaders in the study of chronic diseases are physicians who also hold doctoral degrees in public health. Scott Grundy, M.D., Ph.D., holds the Distinguished Chair in Human Nutrition at the University of Texas Southwestern Medical Center and has published hundreds of articles about heart disease and diet. Walter Willett, M.D., Dr. P.H., is the Fredrick John Stare Professor of Epidemiology and Nutrition at the Harvard School of Public Health. His research group is responsible for groundbreaking work in the area of dietary factors that may cause or prevent chronic diseases such as cardiovascular disease and cancer.

James Hill, Ph.D., is Director of the Center for Human Nutrition in Denver, Colorado. He has published hundreds of research articles about the roles of diet and exercise in body weight regulation. A focus of his research is the effects of a high-fat diet and inactivity on obesity. Steven Blair, P.E.D., is the former president and chief executive officer of The Cooper Institute in Dallas, Texas. He has conducted extensive research regarding the roles of exercise, physical fitness, and body composition on chronic diseases. Jeff Volek, Ph.D., R.D., is a leading authority on the composition of the diet to improve weight loss, cardiovascular disease, and diabetes. His research includes the study of dietary intake, exercise, and dietary supplements to change body composition. Health professionals use such research findings as the basis for making recommendations to their patients and clients.

Table 12.7 Prevalence of Disease in Men Based on BMI

	<18.5	18.5–24.9	25–29.9	30–34.9	35–39.9	>40
Type 2 diabetes	5%	2%	5%	10%	12%	11%
Gallbladder disease	7%	2%	3%	5%	6%	10%
Heart disease	12%	9%	10%	16%	10%	14%
High blood cholesterol	7%	27%	36%	39%	34%	36%
High blood pressure	23%	23%	34%	49%	65%	65%
Osteoarthritis	<1%	3%	5%	5%	5%	10%

The unit of measure for BMI is kg/m^2 but it is most often reported without a unit of measure.

Must, A., Spadano, J., Coakley, E.H., et al. (1999). The disease burden associated with overweight and obesity. *JAMA*, 282(16), 1523–1529.

Table 12.8 Prevalence of Disease in Women Based on BMI

	<18.5	18.5–24.9	25–29.9	30–34.9	35–39.9	>40
Type 2 diabetes	5%	2%	7%	7%	13%	20%
Gallbladder disease	6%	6%	12%	16%	19%	23%
Heart disease	12%	7%	11%	13%	12%	19%
High blood cholesterol	13%	27%	46%	40%	41%	36%
High blood pressure	20%	23%	39%	48%	55%	63%
Osteoarthritis	8%	5%	9%	10%	10%	17%

The unit of measure for BMI is kg/m^2 but it is most often reported without a unit of measure.

Must, A., Spadano, J., Coakley, E.H., et al. (1999). The disease burden associated with overweight and obesity. *JAMA*, 282(16), 1523–1529.

Screening for fat distribution can range from the most precise methods—CT (computer tomography) and MRI (magnetic resonance imaging) scans—to the more widely used method of measuring waist circumference to the easy but imprecise visual classification based on body shape. CT and MRI measurements are used in research settings. For medical and health screening purposes, waist circumference measurements may be made, but this method should be used only in people with a BMI <35. A waist circumference >40 inches (102 cm) in men and >35 inches (88 cm) in women is associated with greater visceral fat storage and greater disease risk. However, waist circumference measures both visceral and subcutaneous abdominal fat, which makes this screening method less precise than scans. Measuring the height of the abdomen when the person is lying down, a method known as **sagittal** trunk diameter, is also a reasonably good method of estimating visceral fat, but its use in medical or health club settings is limited.

Visual screening of body shape, which can be self-administered, is an imprecise measure that separates those with central obesity ("apple-shaped") from those with gynoid obesity ("pear-shaped"). Adult men are typically apple-shaped while adult women are typically pear-shaped. After menopause, women often change shape because of the accumulation of visceral fat, which does increase their risk for some chronic diseases.

The use of BMI and waist circumference together is a reasonably good screening tool that can be administered easily. Those identified as being at risk because of their weight and fat distribution should be referred to a physician for further evaluation.

THE IMPACT OF FITNESS AND FATNESS ON HEALTH

The rapidly rising prevalence of overweight and obesity, as well as the increase in diseases such as type 2 diabetes and metabolic syndrome, has resulted in intense media coverage of body weight. A statistic that appeared for

Sagittal: Related to the median (middle) plane of the body or a body part.

many years in medical journals and in the lay press was that 300,000 deaths in the United States each year could be attributed to obesity. This statistic was derived from a study published by Allison et al. in 1999 using data from 1991. A 2005 study using data from the year 2000 suggests that the number of obesity-related deaths is much lower than estimated in the past—approximately 112,000 per year (Flegal et al., 2005).

Glen Gaesser, Ph.D., an exercise physiologist, disputed the 300,000 figure in his book, *Big Fat Lies* (2002). He suggested that the Allison et al. study was flawed because it controlled for age, gender, and smoking, but did not control for physical activity, level of fitness, dietary intake, history of weight cycling, the present or past use of harmful weight-loss methods, or access to health care. Gaesser emphasized that he agreed that a sedentary lifestyle, low aerobic fitness, and an unhealthy diet contribute to premature mortality. His complaint was that scientists call this condition obesity. With such a high prevalence of overweight and obesity in the United States and such a low prevalence of permanent weight loss, many people wonder if they can be fit if they are fat.

It is clear that there is an interaction between physical activity, physical fitness, obesity, and health. The presence of obesity has multiple negative effects on long-term health, but being physically active may **attenuate** some of these effects. From a health perspective, maintaining a healthy weight is clearly preferable, but if one is overweight or obese, health benefits can be obtained by being physically active, even before weight loss occurs. This should not be interpreted to mean that the effect of obesity is neutralized as long as physical activity is maintained, but it illustrates the importance of physical activity in reducing health risk relatively quickly. In other words, people can be positively reinforced by the knowledge that they are experiencing the health benefits of physical activity long before weight loss might occur.

HEALTH AT EVERY SIZE MOVEMENT

Losing body fat is not easy, and maintaining a lower body weight if once overweight or obese is difficult to sustain. Some health professionals have begun to question the benefits of traditional weight-loss diets, noting that the prevalence of obesity is increasing despite overwhelming emphasis on losing excess body fat by the media and health professionals. Concern has also been raised about the psychological impact of stressing weight loss in an environment that promotes overeating and inactivity. Many of those who do successfully lose weight appear to maintain it by continuing to restrict kilocalories (e.g., the $<1{,}400$ kcal daily reported by the National Weight Control Registry), but the psychological effects of long-term energy restriction is a concern. Some of those who develop disordered eating and eating disorders have a history of dietary restriction and have followed numerous weight-loss plans. For all these reasons the nondiet approach or the Health at Every Size (HAES) movement was born (Miller, 2005).

The term *nondiet* was coined in response to the frequent use of the word *diet* to mean a weight-loss diet. The nondiet or Health at Every Size approach emphasizes a healthy diet, normalization of eating habits (including therapy for deep-seated emotional issues that affect food intake), and moderate physical activity. The focus is on a positive body image regardless of size and supports the concept that people can be both fat and fit. Weight loss may be a *consequence* of changing dietary intake to reflect healthy eating recommendations and increasing physical activity, but loss of weight is not an *expectation*. Rather, success is defined as improved metabolic fitness (e.g., lowered blood pressure or blood lipids), eating behaviors (e.g., less restraint or disordered eating), and well-being (e.g., less depression, increased self-esteem). Research in this area is in its infancy but there is some evidence that health is improved with this approach independent of any loss of weight (Miller, 2005; Bacon et al., 2002).

Although there is still disagreement about the extent of the direct effect of obesity on mortality, nearly everyone agrees that a sedentary lifestyle, low aerobic fitness, and poor diet contribute to both premature death and disease. This chapter began with an emphasis on being physically active on a daily or near daily basis because "everyone is an athlete." Exercise and a healthy diet were repeated themes in the discussions of prevention and treatment of various chronic diseases. This chapter ends with information about making behavior change.

BEHAVIOR CHANGE

By all accounts behavior change is needed in both developed and developing countries to prevent and treat lifestyle-related chronic diseases. The increasing incidence and prevalence of obesity, especially in children and adolescents, type 2 diabetes, and metabolic syndrome are strong indicators that substantial changes are needed in diet and activity patterns. The critical issue is *how* people successfully make behavioral change.

Numerous models have been proposed to help individuals and health and fitness professionals understand the process of change. Just as no one weight-loss diet is universally effective, no one model for behavioral change is universally effective. All the models consider the four major questions that surround behavior change: 1) What is the motivation to change? 2) What resources are needed? 3) What is the decision-making process? and 4) How are decisions translated into repeated behaviors? (Baranowski et al., 2003).

Discussion of behavior change typically begins with knowledge. Knowledge is prerequisite to change and there is much for people to learn about diet and activity. For example, an individual must know what to eat (e.g., foods, nutrients) and how much to eat (e.g., estimated daily caloric intake). Similarly, knowledge about physical activity is needed, such as appropriate intensity and duration of exercise and the prevention of injury.

The Knowledge-Attitude-Behavior (KAB) model suggests that knowledge is the driving force behind behavior change. The accumulation of knowledge changes attitudes, which then result in a change in behavior. A rational decision-making process is employed. Although there may be a small subset of people for whom knowledge alone is the resource and a change in attitude is the motivator, most people do not successfully make behavior change based on knowledge alone. Thus, diet or exercise programs that only offer subject matter information typically have little success.

The Health Belief Model (HBM) suggests that a change in behavior is based on the perceived susceptibility and severity of illness, benefits to health, physical response, action cues, and **self-efficacy** (i.e., confidence that one's thoughts and behaviors can be changed). The primary motivation is the risk of contracting a disease, especially a serious disease. This motivation is referred to as the readiness to act. Cues, such as having a family member diagnosed with a disease, abnormal laboratory tests, or feeling fatigued, are readiness-to-act motivators. An important element is the individual's belief and confidence that behavior change can be successful.

Unfortunately, the Health Belief Model has had limited success. Adolescents and young adults have a sense of immortality, so they do not see themselves susceptible to chronic diseases. Even cues that suggest susceptibility, such as illness in a parent or media information about increasing rates of obesity, are not internalized and they choose to believe that these conditions "won't happen to me." Many chronic diseases have no symptoms (e.g., hypertension, osteoporosis), so there are no negative physical responses until the disease has manifested itself. Even adults who are motivated to change because of a diagnosed medical condition (e.g., obesity, diabetes, metabolic syndrome) may not have confidence that they can change their behavior. If they believe they will fail, they may not be motivated to try (Baranowski et al., 2003).

The Social Cognitive Theory (SCT) is frequently used in exercise and nutrition education programs. Three important issues are the individual's ability to perform the behavior (skill), the confidence to perform the behavior, and expected outcomes. Important environmental issues include modeling of behavior and availability. For example, to lift weights the equipment must be available and the person must have the skill and confidence to perform this activity. Having an exercise specialist demonstrate and teach proper weight-lifting technique and reinforce the participant's behavior may increase skill and confidence and the likelihood of maintaining the activity as part of one's lifestyle.

The primary motivator is the expected outcome. In the example above, the expected outcome may be an increase in muscle size or strength. One potential problem is that unrealistic goals may be set. For example, it would be unrealistic to expect that a weight-lifting program alone would result in large losses of body fat

Attenuate: To reduce the size or strength of.

Self-efficacy: The belief by an individual that he or she can effect change.

KEEPING IT IN PERSPECTIVE

Everyone Is an Athlete

Humans need to be physically active for good health. Modern society, however, does not require that people be active and it often encourages inactivity at work and at leisure. Industrialized societies also have an abundant food supply, and overconsumption is not only possible, but often encouraged. Exercise is a powerful influence on the amount of kilocalories needed daily to maintain body weight, so it is no surprise that sedentary people living in a society in which so much calorie-dense food is available would have a high prevalence of overweight and obesity. Such is the case and the culture of the United States and other developed countries.

Engaging in a healthy lifestyle, which includes near daily physical activity and a healthy diet that matches caloric intake to caloric expenditure, is "counter-culture." During early adulthood lack of exercise and poor dietary intake may not appear to have substantial consequences since most chronic diseases are not symptomatic during this time period. But chronic diseases may be developing and future health may be at risk. An active lifestyle and healthy diet are among the best investments that can be made in the human body and a long-term perspective on health should never be lost even by an elite athlete at the peak of his or her career.

in an obese individual. Another potential problem is the confidence to try a new behavior because substantial skill may be needed to make an exercise or dietary change. Barriers may also exist, for example, lack of exercise facilities, unsafe neighborhoods for walking, or unavailability of fresh fruits and vegetables. Knowledge, problem-solving ability, and decision-making skills are all part of this complicated process of behavior change. There are reports in the scientific literature of successful diet and exercise programs that have used the SCT model (Baranowski et al., 2003).

A widely used model for changing health-related behaviors is the Transtheoretical Model, frequently referred to as the Stages of Change Model (Prochaska and DiClemente, 1984). The stages of change include precomtemplation (no intention to change in the near future), contemplation (intention to change but at a later time), preparation (intention to change soon, such as within the next month), action (change is occurring), and maintenance (change is maintained for at least six months). Although the stages of change are frequently highlighted, they are only one aspect of the model that also includes decisional balance (e.g., pros and cons), self-efficacy, and the process of change (i.e., how people change).

Identifying the stage of change helps diet and exercise counselors to provide appropriate educational materials and support. For example, it is unlikely than an athlete in the precomtemplation stage would benefit from specific nutrition strategies, but information about how a dietary plan might enhance performance could be beneficial. Specific nutrition strategies would likely benefit an athlete in the preparation or action stages. Individuals in these stages often need close contact and support, since decisional balance and self-efficacy are important parts of making behavior change. When resources are limited, practitioners often focus on clients or patients who are in the preparation and action stages (Greene et al., 1999).

There are many other behavior change models, and it is worth repeating that no single model is the "correct" approach to promoting behavior change. Each model may be successful under certain circumstances and with a subgroup of people for whom the model is a good match. Understanding why people are sedentary and why people eat what they do will help in the planning of more effective intervention programs. Research in these areas is still in its infancy.

Summary

"Everyone is an athlete" and all humans should be physically active throughout their lives. Weight gain is common as people age, even among former athletes, but it is not an inevitable consequence of aging. Matching energy intake with energy expenditure can prevent weight gain. Regular, consistent lifelong exercise or activity is recommended, and specific guidelines are published for cardiorespiratory fitness, prevention of weight gain, and maintenance of weight loss.

Many organizations have issued dietary guidelines, which are also consistent in recommending maintenance of a healthy weight and the consumption of a diet rich in whole grains, fruits, vegetables, lean protein foods, and heart-healthy fats. Such a diet promotes health and may reduce the risk for chronic diseases such as **heart disease,** type 2 diabetes, and diet-related cancers.

Overweight and **obesity** are highly prevalent in the United States and exacerbate some chronic diseases, especially conditions associated with insulin resistance. There are many popular weight-loss plans, which feature hypocaloric diets with various macronutrient combinations, but no one plan has been shown to be the most effective. A sedentary lifestyle and poor diet are major contributors to many of the chronic diseases that plague modern societies—**hypertension,** heart disease, type 2 diabetes, **metabolic syndrome, osteoporosis,** and lifestyle-related cancers. While there is much knowledge about the roles diet and exercise play in both the prevention and treatment of these diseases, most people do not change their behaviors based on knowledge alone. Thus, an understanding of what motivates people to change their behavior and sustain the changes is needed.

Post-Test — Reassessing Knowledge of Health, Fitness, and Chronic Diseases

Now that you have more knowledge about health, fitness, and chronic diseases, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. There are many contradictions among diet and exercise recommendations that are issued by health promotion organizations.
2. Elite endurance athletes do not develop hypertension but lesser-trained athletes do.
3. Type 2 diabetes is caused by eating too much sugar.
4. A sedentary lifestyle is associated with a higher risk for heart disease, certain types of cancer, and diabetes.
5. Being physically active helps to reduce disease risk even if a person is obese.

Review Questions

1. What did Dr. Sheehan mean when he wrote, “everyone is an athlete?”
2. What happens to physical activity level as people age? Is this trend true of former athletes as well?
3. Is weight gain inevitable with aging? What advice would you give to collegiate athletes upon graduation about preventing weight gain?
4. Summarize the major points of the Dietary Guidelines for Americans.
5. Are diet and exercise recommendations published by various public health organizations generally similar or dissimilar? Explain.
6. What amount of activity is recommended as a minimum? For preventing weight gain? For maintaining weight loss? For cardiovascular fitness?
7. How do poor diet and lack of physical activity contribute to chronic disease risk?
8. Which chronic diseases are associated with being overweight or obese?
9. How would you respond to the question, “Which weight-loss diet is the best?”
10. Explain insulin resistance and why exercise is so important for those with this condition.
11. Explain what is meant by “good” cholesterol and “bad” cholesterol.
12. Describe the differences between visceral and subcutaneous fat and how fat distribution affects disease risk.
13. How do diet and exercise help prevent osteoporosis?
14. Will taking calcium and/or vitamin D supplements after menopause increase bone mass? Prevent or delay osteoporosis?
15. Describe the relationship between physical activity, diet, and the prevention of lifestyle-related cancers.
16. Why is body mass index (BMI) used as a screening tool for determining disease risk?
17. Are those in the BMI “healthy weight” category free from chronic diseases? Does the prevalence for the various chronic diseases increase as BMI increases? Explain.
18. Can a person be fit and fat? Explain.
19. Is knowledge alone enough for most people to make behavior change? Why aren’t people motivated by the belief that proper diet and exercise will help reduce the risk for chronic diseases?

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13 Disordered Eating and Exercise Patterns in Athletes

Steve Niedorf Photography/Stone/Getty Images

Learning Objectives

1. Describe the concepts of normal eating, disordered eating, and eating disorders.
2. Explain why eating disorders are classified as psychiatric diseases.
3. State the diagnostic criteria for anorexia nervosa, bulimia nervosa, and eating disorders not otherwise specified.
4. Outline the characteristics of anorexia athletica and compare and contrast it with other eating disorders.
5. State the prevalence of disordered eating and eating disorders in the male and female athletic and general populations and discuss its impact on physical and mental health and performance.
6. Differentiate between athletes with eating disorders and those who are training intensely but do not have a disordered eating pattern.
7. Discuss the appropriate responses by teammates, coaches, athletic trainers, and others if disordered eating or an eating disorder is suspected.
8. Explain the Female Athlete Triad and how each component affects health and performance.
9. Describe exercise dependence and explain how it differs from overtraining.

Pre-Test Assessing Current Knowledge of Disordered Eating and Exercise Dependence

Read the following statements and decide if each is true or false.

1. Disordered eating and eating disorders only affect female athletes.
2. Anorexia athletica means that an athlete has a classic case of anorexia nervosa.
3. Disordered eating and eating disorders are more likely to be seen among elite female athletes in sports such as distance running and gymnastics.
4. Coaches cause athletes to develop eating disorders.
5. A good diagnostic criterion for exercise dependence is the volume of exercise training (i.e., frequency and duration of exercise).

Karen had been running ever since she could remember, but it was not until her first year in high school when she joined the cross country team that she realized that she was in love with running. She loved everything about it—the digital training watch that she got for her 13th birthday, the wind in her long hair, the quiet time she had to herself away from her family's problems, and the feeling of accomplishment when she finished a race. She made a name for herself the first year and she realized that she could be the best runner at her school if she applied herself.

By her junior year she was featured in her hometown newspaper as someone to watch. She adopted a semi-vegetarian diet and altered her running stride to make it more efficient. She came in second in the regional meet and earned the right to go to the state championships. There she had a strong start but faltered down the stretch and she was disappointed for herself and her family. Her coach told her that if she trained just a little harder that she could be a contender in her senior year. Her parents were excited about the prospects of her earning a college athletic scholarship; without some financial help they had little hope of sending Karen away to college.

After the state meet Karen immediately began to train and to pay more attention to her diet. She noticed that the winners at the state meet had brought coolers with their own food and drinks. She became a vegetarian in earnest and began to eat differently than her friends and family, which meant that she often prepared her own food and ate alone. Eating alone turned out to be advantageous as she could avoid the family mealtime discussions that always left her feeling as if she was not good enough in her parent's eyes. Her best friend in middle school told her that she was no longer the happy-go-lucky girl she once was. Karen took that as a compliment—she was maturing and focusing on the future—college, running, and, maybe, the Olympics. She had dreams and they involved taking her beyond the little town in which she grew up.

She was diligent about her training and diet and her senior year was all that she had hoped. She smashed school records, erased regional marks, blew by the competition, and won the state meet by a record margin. Sought after by many colleges, Karen traveled out of state on recruiting visits. She received offers of athletic scholarships from several schools who were impressed with her perfect high school grades and high scores on her college entrance exams. Karen chose to attend a top-notch school on the other side of the country even though her parents had reservations about her being so far away and were concerned about how they would pay for the costs not covered by the scholarship.

Her freshman year of college was an eye-opener. Her college coach was much more demanding than her high school coach and everything about her seemed to be under scrutiny. She had made only a few friends, acquaintances really, and she missed her family, although her coach was like having family close. Much of the dorm food was not vegetarian and she found herself with few choices and even fewer foods that she enjoyed eating. One of her goals was to have the highest GPA on the team, but attaining perfect grades in college was much harder than in high school. When she was not training, she was studying. Karen was surprised to find out that the athletic scholarship she thought was guaranteed had to be renewed each year based upon her running and academic performances, something that really upset her parents. Although her coach never said it directly, he intimated that she would perform better if she were leaner. A couple of her teammates, whom she noticed were thin, wondered aloud if she had what it took to make it as a college runner at an NCAA Division I school. That was all the motivation that she needed to develop a stricter training program, and, for the first time in her life, a diet to lose weight and become thinner.

As she stepped up her training and restricted her diet, her performance began to improve. Karen rededicated herself to running and was almost robotic in her approach. She had convinced her parents to let her move into a single room in the dorm and not buy the meal plan. They reasoned that her diet would be healthier and that she would be happier if she prepared her own food in the small kitchen at the end of the hall. Karen found that she loved creating meal plans and looking through vegetarian cookbooks.

She made tremendous improvements by the end of her sophomore year and her coach said that she was poised to have a breakout junior year. Unfortunately, she developed a painful stress fracture in her lower leg early in the preseason of her third year. Karen struggled for many months not only because she was unable to train but also because she needed the intense physical activity to keep her weight low. Her coach was not paying much attention to her now that she was sidelined with an injury and she was already worried that her full athletic scholarship might be reduced for her senior year. Karen gained 10 pounds in two months while recovering from her injury, which scared her, so she began to restrict her diet to a few healthy foods—salads, bagels, fruits, and water—and weigh herself daily. She even cut her long hair in an effort to feel lighter.

By the beginning of the season she had received clearance to restart her training, but her injury had substantially set her training back and she was concerned that she was entering racing season without the necessary preseason training. Karen now relished her training runs and began to run on designated rest days, although she knew if her coach was aware of this that he would never have allowed it. If she had been honest with herself, she would have realized that she did not so much love running anymore, as she *needed* running. Her coach had mentioned that he was worried about her apparent lack of eating and she took his comment as a good sign since he obviously was paying attention to her again. Karen assured him that she was eating more now that she was training. She made sure that she was not lying by increasing the size of her salads. Secretly, she was a bit worried because her menstrual periods, which had been light but regular since high school, were now almost nonexistent—just two periods in the last year. She had not dated anyone since coming to college so she was not worried about being pregnant. But she did have an immediate health concern—recurrent upper respiratory tract infections that had plagued her for months.

Her junior season started with an excellent showing at a big meet and her coach repeated his prediction that this would be her breakout year. Her next effort was hampered by a cold and her coach seemed sympathetic to her frequent infections, although he did ask her specifically about her training and diet. Two more meets featured mediocre performances and she was not chosen to travel to an out-of-state invitation-only event. She resolved to work harder, training more than usual and eating a little less than she had been for the past few months. At the next meet she fainted at the start line and her coach said they needed to talk. She believed that she just had a bad day; he believed that she had anorexia athletica.

This case study will be used throughout this chapter to illustrate the development of and some of the problems associated with disordered eating and exercise patterns in athletes.

Overview of Eating and Exercise Patterns

"NORMAL" EATING

Eating is not solely physiological. While it is necessary to eat to obtain the nutrients needed for the body to properly function, eating also has a strong psychological component. There is no agreed-upon definition of normal eating, but the following definition is often used:

> Normal eating is being able to eat when you are hungry and continue eating until you are satisfied. It is being able to choose food you like and eat it and truly get enough of it—not just stop eating because you think you should. Normal eating is being able to use some moderate constraint in your food selection to get the right food, but not so restrictive that you miss out on pleasurable foods… Normal eating takes up some of your time and attention, but it keeps its place as only one important area of your life. In short, normal eating is flexible. (Satter, 1987).

For individuals with access to an adequate amount of food, normal eating represents the middle area on the eating continuum shown in Figure 13.1. When considered over a period of time, such as a week, month, or year, food may be either under- or overconsumed and on any given day the energy (kcal) or nutrient content may be higher or lower than recommended guidelines. Normal eating consists of consuming foods that are nutrient rich as well as eating some foods that might have a low nutrient content. The diet is moderate, balanced, and varied and is flexible, especially in response to social situations. Normal eating involves moderate constraint, not reckless abandon or overly-strict **discipline.**

Discipline: Moderate self-control or restraint.

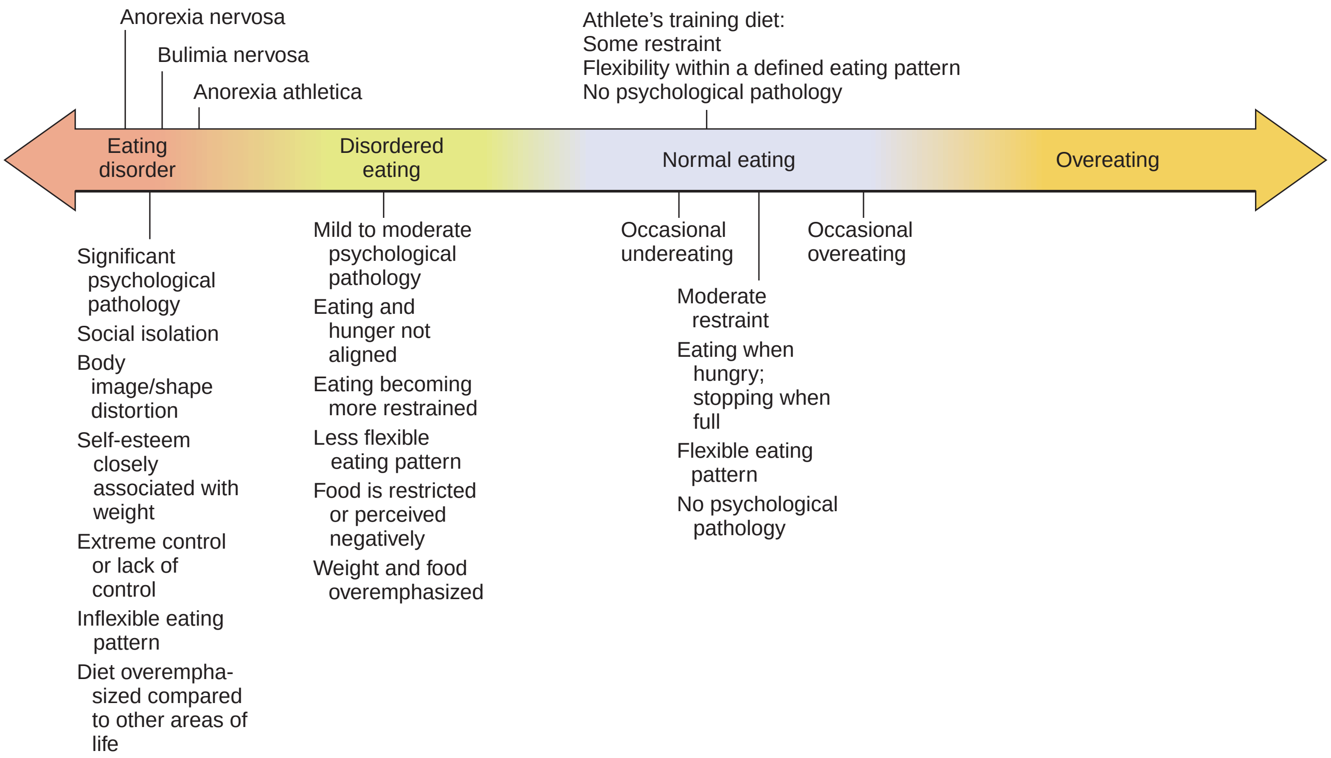

Figure 13.1 Eating Continuum

Eating disorders, disordered eating, normal eating, and overeating are areas along a continuum but these points are not well-defined.

Normal eating in athletes is particularly hard to define because some athletes must follow fairly strict eating guidelines to support their training and performance goals. A distance runner must be concerned about excessive caloric intake because weight gain as body fat could negatively affect training and performance. Rigorous training, especially during the latter part of the preseason, and the demands of competition require a well thought out diet plan. For example, the distance runner must be diligent about consuming the proper amount of carbohydrates daily or risk not restoring the muscle glycogen used during training and competition. The moderate restraint and dietary flexibility that is part of normal eating necessarily becomes a bit more restrained and less flexible during periods of intense training and competition, but it should not become overly restricted or inflexible. Normal eating among highly trained athletes is characterized by discipline, not by **obsession** (see Figure 13.1).

DISORDERED EATING

Disordered eating (DE) represents a deviation from normal eating, but the individual does not meet the diagnostic criteria for an **eating disorder (ED)**—anorexia nervosa, bulimia nervosa, or eating disorders not otherwise specified. Disordered eating is not well defined or easily recognized and encompasses a large area on the eating continuum (see Figure 13.1). The deviation from normal may be occasional and minor or it may progress and become more frequent and **pathological.** The difficulty lies in identifying the overall context of normal eating and then determining the degree to which behaviors deviate from normal, tracking the progression, and identifying the level of severity. Individuals may be described as having a subclinical eating disorder if they demonstrate a number of disordered eating behaviors (see examples below) and exhibit associated psychological issues (Beals, 2006). Single disordered eating behaviors are not as severe as a subclinical eating disorder, which is not as severe as a clinical eating disorder, but any of the three conditions is cause for concern and intervention.

One sign of disordered eating may be the inability to "eat when hungry and stop when full." In some cases, individuals will feel hungry but will refuse to eat at all or will wait until a predesignated time. When they do allow themselves to eat, the amount may be restricted. In other cases, the individual will be full but will continue to eat for nonphysiological reasons (e.g., anxiousness, loneliness, boredom). Body weight is not a good predictor of these behaviors; these examples include individuals who are underweight, normal weight, or overweight. Food intake may be strictly prescribed and this lack of eating flexibility is another characteristic of DE. One type of food (e.g., sweets) or nutrient (e.g., fat) may also be severely restricted and dietary intake can begin to conform to a rigid pattern. Food intake is often viewed from the perspective of restriction (e.g., "don't consume too many calories, don't eat any fat") rather than from the perspective of inclusion (e.g., "I need to eat an adequate amount of calories, including some fat"). Food and weight become overemphasized and take up a considerable amount of time and thought, to the exclusion of other important activities. Individuals with DE may exhibit any one or more of these behaviors, but, in short, disordered eating is inflexible.

Disordered eating in athletes is particularly hard to define because training and performance require attention and diligence to an eating plan, especially as athletes move to the more elite levels in their sports. The athlete's "normal" pattern may be one of mild restraint. For example, a gymnast who eats "normally" may watch what she eats so that she consumes an adequate but not excessive amount of kilocalories to maintain her already lean physique and low body weight. She is thoughtful about what she consumes because she wants to make sure that her intake of carbohydrates and proteins is sufficient and this necessarily means a lower-fat diet than the general population. However, she sees food for what it is—the fuel to help her train and perform—and she is not exhibiting signs of disordered eating. Contrast this to the gymnast who tallies the amount of fats and kilocalories consumed daily and classifies food as "good" and "bad." This gymnast monitors her diet so closely that she will not allow herself to consume dessert on *any* occasion. She eats when she feels hungry but if it is not a designated mealtime she will only consume carrots to satisfy her hunger. This gymnast is exhibiting some disordered eating behaviors and her disordered eating could become more severe. For example, in addition to the behaviors already described, she might become fearful of eating fats and refuse to eat more than 20 grams daily. If she exceeded this self-imposed limit, she might "punish" herself by doing 200 sit-ups and **fasting** for the rest of the day. She might begin to weigh herself daily and let the scale weight determine her eating pattern. These are examples of pathological behaviors associated with a subclinical eating disorder, but she would not meet the diagnostic criteria for an eating disorder.

EATING DISORDERS

Eating disorders represent a substantial deviation from normal eating (see Figure 13.1) and are **psychiatric** conditions that involve body image issues. The three clinical eating disorders recognized by the American Psychiatric Association (APA) are anorexia nervosa, bulimia nervosa, and eating disorders not otherwise specified (EDNOS) and each has established criteria (DSM-IV, 1994). Although anorexia nervosa and bulimia nervosa are both characterized as eating disorders, they are more dissimilar than similar. Those with EDNOS do not meet the specific criteria established for either anorexia or bulimia but a variety of significant problems are present, as will be illustrated later in this chapter. Although this chapter focuses on eating and exercise behaviors, one should not forget that eating disorders are psychiatric diseases and their development is a result of psychological disturbances often related to issues of control.

Anorexia Nervosa. **Anorexia nervosa** is characterized by a refusal to maintain a minimum body weight. There is an intense fear of gaining weight and an intense desire to be thin. Also present is an extremely distorted body image—those with anorexia nervosa see themselves as fat in their mind's eye even when they are **emaciated.** Two subtypes exist. The first is referred to as *Restricting type* and these individuals self-impose starvation and engage in excessive exercise. A second subtype is termed *Binge-Eating/Purging type*. These individuals employ starvation and excessive exercising techniques but may also overeat at times and then use self-induced vomiting, **diuretics,** or **laxatives** to compensate for the increased energy intake associated with the bingeing behavior.

The **prevalence** of anorexia nervosa in late adolescence and early adult females is estimated to be 0.5 to 1.0 percent of that population. It is most prevalent in females (more than 90 percent of all cases). Males do manifest anorexia nervosa, although the prevalence is unknown. The typical age range for females exhibiting anorexia nervosa is early adolescence (~ age 13) through early adulthood (mid-twenties) and critical ages appear to be age 14 (often the start of high school) and age 18 (start of College, living away from family). The **incidence** appears to be on the increase, but this trend is hard to document (DSM-IV, 1994).

Obsession: Idea or feeling that completely occupies the mind, sometimes associated with psychiatric disorders.

Disordered eating (DE): A deviation from normal eating.

Eating disorder (ED): Substantial deviation from normal eating, which meets established diagnostic criteria.

Pathological, pathology: A condition that deviates from that which is considered normal.

Fasting: Abstaining from food or drink.

Psychiatric: Relating to the medical specialty concerned with the diagnosis and treatment of mental or behavioral disorders.

Anorexia nervosa: A life-threatening eating disorder characterized by a refusal to maintain a minimum body weight.

Emaciated: Extremely thin; may be a result of self-starvation.

Diuretic: Causing an increased output of urine.

Laxative: A substance that promotes bowel movements.

Prevalence: The number of cases of a condition that exists in the population at a given point in time.

Incidence: The number of new cases of an illness or condition.

Anorexia nervosa is characterized by a refusal to maintain a minimum body weight.

Those with anorexia nervosa meet the following criteria, shown here as listed in the *Diagnostic and Statistical Manual of Mental Disorders,* 4th edition (DSM-IV, 1994):

A. Refusal to maintain body weight at or above a minimally normal weight for age and height (e.g., weight loss leading to maintenance of body weight less than 85% of that expected; or failure to make expected weight gain during period of growth, leading to body weight less than 85% of that expected).

B. Intense fear of gaining weight or becoming fat, even though underweight.

C. Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or denial of the seriousness of the current low body weight.

D. In postmenarcheal females, **amenorrhea,** i.e., the absence of at least three consecutive menstrual cycles (A woman is considered to have amenorrhea if her periods occur only following hormone, e.g., estrogen, administration.)

Specify type

Restricting type: during the current episode of Anorexia Nervosa, the person has not regularly engaged in binge-eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or **enemas**).

Binge-eating/Purging type: during the current episode of Anorexia Nervosa, the person has regularly engaged in binge-eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas).

While the four criteria are easily listed, diagnosing anorexia nervosa takes skill and clinical judgment. For example, there is not a single "normal weight" for any given age and height, so it must be determined for each Individual. Individuals of the same height have different normal weights because of differing bone structure and body composition. In addition, weight history (e.g., weight stability, lowest and highest weight attained) should be considered. Once a normal weight is established (e.g., 115 pounds [~ 52 kg]), then 85 percent of that weight can be calculated (e.g., 98 pounds [~ 44.5 kg]).

The fear the individual has about weight gain may actually increase as weight loss continues. It may seem counterintuitive that a female whose normal weight is 115 pounds (~52 kg) is fearful of weight gain when she is at 95 pounds (43 kg) and even more fearful when she weighs 90 pounds (41 kg). Recall that anorexia nervosa is a psychiatric disorder and that body image is distorted. It is common for someone with anorexia nervosa to look in the mirror and believe that she is fat or believe that one part of the body is fat (e.g., thighs or buttocks). In those with anorexia nervosa, self-esteem is dependent on body weight and body shape. Weight loss or maintenance of a body weight below one's minimum weight is seen by the individual as extreme self-discipline and is thought of as a desirable characteristic. Weight gain is seen as a lack of self-discipline and a lack of self-control and both are considered undesirable characteristics.

In most cases, weight loss is achieved primarily by voluntary starvation; excessive exercise may be a secondary method used. The self-starvation often begins with the elimination of foods high in kilocalories and becomes more restricted until the diet may contain only a few low-calorie-containing foods (e.g., vegetables). The term *anorexia* means loss of appetite and in this respect the disease is misnamed. Those with anorexia nervosa rarely lose their appetite; rather, they do not allow themselves to respond to it. They also rarely complain about their weight loss. Ironically, they are so self-controlled that they lose control. Control and self-esteem are psychological issues that will need to be addressed as part of therapy (DSM-IV, 1994).

Bulimia Nervosa. Bulimia nervosa is characterized by recurring binge eating coupled with inappropriate ways of preventing weight gain following the eating binge. Two subtypes exist. The first, known as the purging type, includes self-induced vomiting or the use of laxatives, diuretics, or enemas. The second, nonpurging type, involves fasting or excessive exercise. Those who purge attempt to keep the food from being absorbed (self-induced vomiting, use of laxatives) or prevent scale weight from increasing (use of diuretics or enemas). The nonpurgers compensate for the increased caloric intake by subsequent fasting or excessive exercise. Those with bulimia may use a number of methods, but purging by self-induced vomiting is the most common.

The prevalence of bulimia nervosa in the general population is difficult to estimate, in part because many people do not seek treatment so it goes undetected. It is

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most prevalent in females (~ 90 percent of those diagnosed with bulimia) but is not absent in males. The prevalence of bulimia in late adolescence and early adult females is estimated to be 1 to 3 percent of that population, which is greater than the prevalence of anorexia nervosa. The age range (adolescence to middle adulthood) is also larger than anorexia nervosa and some people struggle with bulimia for many years. Those with bulimia nervosa meet the following criteria:

A. Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
   1. eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than most people would eat during a similar period of time and under similar circumstances
   2. a sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating)
B. Recurrent inappropriate compensatory behavior in order to prevent weight gain, such as self-induced vomiting; misuse of laxatives, diuretics, enemas, or other medications; fasting; or excessive exercise.
C. The binge eating and inappropriate compensatory behaviors both occur, on average, at least twice a week for 3 months.
D. Self-evaluation is unduly influenced by body shape and weight.
E. The disturbance does not occur exclusively during episodes of Anorexia Nervosa.

Specify type

Purging type: during the current episode of Bulimia Nervosa, the person has regularly engaged in self-induced vomiting or the misuse of laxatives, diuretics, or enemas.

Nonpurging type: during the current episode of Bulimia Nervosa, the person has used other inappropriate compensatory behaviors, such as fasting or excessive exercise, but has not regularly engaged in self-induced vomiting or the misuse of laxatives, diuretics, or enemas (DSM-IV, 1994).

Diagnosing bulimia also takes considerable skill and clinical judgment because the physical signs may not be obvious, and most bulimics eat in secret because they are ashamed of their eating and compensatory behaviors. Additionally, individuals with bulimia are often within the normal weight range. Restricting caloric intake (i.e., "dieting") is frequently a binge-eating trigger. In other words, food intake will be severely restricted for a period of time in an effort to lose weight and during or after this self-imposed restriction binge eating will begin. A circular pattern can develop that involves food restriction for several days or weeks followed by a binge followed by food restriction. This pattern can continue for months or years.

A binge is described as eating a large amount of food in a short period of time, but there is no quantitative definition so the amount is relative to the individual's usual pattern of eating. During a binge, the food is usually consumed rapidly, thus an often-used guideline is that the food is consumed in 2 hours or less.

Those with the purging subtype typically self-induce vomiting. Initially a finger is used to invoke vomiting, but most bulimics can become adept at willing themselves to vomit. Laxatives are used by approximately one-third of purgers. Other methods that are sometimes mentioned—use of ipecac (a medicine used to induce vomiting, often in cases of accidental poisoning) and enemas—are actually rarely used. Use of the finger to induce vomiting causes calluses to form on the back of the finger(s) over time due to the finger(s) rubbing

Amenorrhea: Menstruation is absent or suppressed.

Enema: Insertion of a liquid via the rectum to induce a bowel movement.

Bulimia nervosa: An eating disorder characterized by bingeing and purging cycles.

against the teeth. Frequent exposure to vomitus, which is acidic, removes enamel from the teeth and leaves them more prone to cavities and dental decay. These are some of the more obvious physical signs to those who are trained to recognize them.

Binge eating is a source of distress for the individual. Vomiting may relieve the physical discomfort associated with extreme overeating but not the emotional discomfort. Those with bulimia lose control over the eating situation (they literally cannot stop the binge) and this is followed by depression related to loss of control. Self-esteem is closely tied to both body shape and weight, and those with bulimia nervosa are overly critical of their bodies. Self-esteem and control are psychological issues that will need to be addressed as part of therapy.

Eating Disorders Not Otherwise Specified. A third diagnostic category is **eating disorders not otherwise specified.** This diagnosis is the most common in outpatient settings where approximately 60 percent of all eating disorders diagnosed are EDNOS. Surprising, this prevalent form of an eating disorder does not have defined criteria and is not well studied. The EDNOS diagnosis is often a result of a "default" categorization—pathological behaviors are clearly present but the specific diagnostic criteria for either anorexia nervosa or bulimia nervosa are not met. EDNOS is sometimes described as a "mixed eating disorder" (Fairburn and Bohn, 2005). Examples of EDNOS listed in the DSM-IV (1994) include:

1. For females, all of the criteria for Anorexia Nervosa are met except that the individual has regular menses.
2. All of the criteria for Anorexia Nervosa except that, despite significant weight loss, the individual's current weight is in the normal range.
3. All of the criteria for Bulimia Nervosa are met except that the binge eating and inappropriate compensatory mechanisms occur at a frequency of less than twice a week or for a duration of less than 3 months.
4. The regular use of inappropriate compensatory behaviors by an individual of normal body weight after eating small amounts of food (e.g., self-induced vomiting after the consumption of two cookies).
5. Repeatedly chewing and spitting out, but not swallowing, large amounts of food.
6. Binge eating disorder: recurrent episodes of binge eating in the absence of the regular use of inappropriate compensatory behaviors characteristic of Bulimia Nervosa (see Spotlight on Enrichment: Binge Eating Disorder).

Pictures of emaciated females suffering from anorexia nervosa and newspaper articles that highlight individuals who eat a gallon of ice cream in a single sitting before self-inducing vomiting may lead to stereotyping of these eating disorders. As is evident by the EDNOS examples and prevalence, characterizing eating disorders is not simple and the early diagnosis of any eating disorder is difficult. Consider two females who are 5'8" and weigh 125 pounds (56.8 kg). This weight falls at the lower end of the normal weight for height range, and each woman would be described as thin. For the first woman, this is her biologically comfortable weight and she can maintain that weight with a normal pattern of eating and physical activity. She also has a realistic body image and is not overly concerned if her weight varies between 125 and 130 pounds (56.8 and 59 kg). This woman does not exhibit any characteristics associated with an eating disorder. In contrast, the second woman can only maintain her 125-pound (56.8-kg) weight with daily food restriction and excessive exercise. In fact, weight maintenance is not the goal because she is always thinking about losing five pounds. She is dissatisfied with her weight and considers herself not thin enough. She is fearful that her current weight will "balloon" to 130 pounds (59 kg), so if she exceeds 125 pounds (56.8 kg) when she steps on the scale, she fasts for the rest of the day and goes to the gym for an additional aerobic session. Her favorite food is a chocolate candy bar, but she panics if she eats more than her self-imposed limit of one-half of a candy bar and compensates by self-inducing vomiting. This woman does not meet the criteria for anorexia nervosa and does not appear emaciated, but she does have an eating disorder (not otherwise specified) that needs treatment.

ANOREXIA ATHLETICA

Anorexia athletica is a condition found in athletes that overly restrict caloric intake, engage in excessive exercise, or do both for the purpose of attaining or maintaining a low body weight as a way to improve performance. This eating disorder subcategory is not included in the *Diagnostic and Statistical Manual of Mental Disorders* (1994) but is used by some sport dietitians because it better describes the characteristics exhibited by athletes with eating disorders. Just as "normal" eating in athletes is a bit different from that of the general population, anorexia athletica is a bit different from anorexia nervosa or an EDNOS seen in the general population. The characteristics of anorexia athletica are as follows:

- Reduced body mass (weight) and loss of fat mass is performance related and not related to appearance or body shape. (It should be noted that concerns about body shape could arise as the individual compares body weight, shape, or composition to the sport's most successful athletes.)

- The loss of body mass results in a lean physique.
- **Weight cycling** (repeated weight gain and loss) is usually present although maintenance of a low body weight may be seen all year (preseason, competitive season, "off-season").
- Restriction of food intake and/or excessive exercise is voluntary or at the suggestion of a coach or trainer.
- The abnormal eating occurs while the athlete is competing but stops at the end of the athlete's career (Sudi et al., 2004).

Few studies have been conducted using the criteria for anorexia athletica, therefore, the prevalence is difficult to determine. A 1993 study of 522 Norwegian elite female athletes found that 43 (8.2 percent) met the criteria for anorexia athletica while seven (1.3 percent) had anorexia nervosa and 42 (8 percent) had bulimia nervosa (Sundgot-Borgen, 1993; Sudi et al., 2004). Beals and Manore (2002) found that the prevalence of clinical eating disorders in female collegiate athletes was low (2.3 percent and 3.3 percent of the sample were diagnosed with bulimia and anorexia, respectively), but that as many as one-third was at risk for an eating disorder. While prevalence figures help shed light on each eating disorder, the critical points are that all these eating patterns are deviations from normal, are harmful to the athletes who manifest them, and can be prevented or detected early (Beals and Manore, 2000).

Eating disorders not otherwise specified (EDNOS): A "mixed eating disorder" in which pathological behaviors are present but the diagnostic criteria are not met for either anorexia nervosa or bulimia nervosa.

Anorexia athletica: Overly restrictive caloric intake and/or excessive exercise in an athlete to attain or maintain a low body weight as a way to improve performance.

Weight cycling: Repeated weight loss and weight gain.

SPOTLIGHT ON ENRICHMENT

Binge Eating Disorder

Binge eating, one characteristic of bulimia nervosa, is described as eating a large amount of food in a short period of time. The binge is associated with a loss of control, which is distressing to the individual. In those with bulimia nervosa, compensatory behaviors (e.g., vomiting, laxatives, fasting, excessive exercise) are employed to offset the binge and limit its effect on body weight. In binge eating disorder (BED), no compensatory behaviors are used and the individual typically becomes or remains obese.

Binge eating disorder is considered an eating disorder not otherwise specified. However, there are specific diagnostic criteria included in the appendix of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV) for research purposes. These criteria need to be better studied and fine-tuned, but many researchers believe that there is a subset of obese individuals who suffer from BED and need psychological, nutritional, and medical treatment on the same scale as those suffering from anorexia nervosa or bulimia nervosa (Tanofsky-Kraff and Yanovski, 2004). The following criteria have been established to date:

A. Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
   1. Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than most people would eat during a similar period of time and under similar circumstances
   2. A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating)

B. The binge-eating episodes are associated with three (or more) of the following:
   1. Eating much more rapidly than normal
   2. Eating until feeling uncomfortably full
   3. Eating large amounts of food when not feeling physically hungry
   4. Eating alone because of being embarrassed by how much one is eating
   5. Feeling disgusted with oneself, depressed, or very guilty after overeating

C. Marked distress regarding binge eating is present.

D. The binge eating occurs, on average, at least twice a week for 6 months.

E. The binge eating is not associated with regular use of inappropriate compensatory behaviors (e.g., purging, fasting, excessive exercise) and does not occur exclusively during the course of anorexia nervosa or bulimia nervosa.

Binge eating disorder is not bulimia nervosa minus the compensatory behaviors. A comparison of the criteria indicates that individuals with BED eat rapidly until they are uncomfortably full, often when they are not hungry, and then feel disgusted, depressed, or guilty. The time period used for diagnosis also varies, with binge eating disorder occurring over a six-month period. More research is needed to identify those with BED and determine the most successful interventions.

What's the point? "Normal" eating is flexible. Disordered eating and eating disorders are deviations from normal and are often characterized by obsession or inflexibility.

Voluntary Excessive Exercise and Exercise Dependence. As with eating, exercise exists on a continuum, from a complete lack of activity to an amount of exercise that would be considered excessive. Also similar to eating, there are differences in amount that may be subtle and make it difficult to determine if the exercise is contributing positively to the athlete's performance or has become a detracting influence. The *intent* of the exercise is an important factor.

Individuals with disordered eating, eating disorders, or anorexia athletica may use exercise to increase their energy expenditure to lose weight or offset increased caloric consumption from bingeing. While physical activity and exercise are generally considered to be beneficial to health and well-being, an overdependence on exercise has the potential to become a harmful obsession (Bamber et al., 2000). Because of the commitment many athletes have to their training to improve performance, it is very difficult to distinguish the amount of exercise that is appropriate from that which may reflect a psychological disturbance.

In the past, researchers attempted to define "overexercise" or "excessive exercise," using absolute measures of the amount of exercise training, such as frequency and duration (Anshel, 1992). The major problem with this approach is the inability to set a definitive amount of exercise that accurately distinguishes what is appropriate or excessive for all athletes. For example, 75–80 miles (~ 125–135 km) of running a week by a college-aged female to control her weight would seem to be excessive, but this training volume might be appropriate for a collegiate cross country runner preparing for the competitive season.

There can also be a fine line between the frequency, intensity, and duration of exercise that improves performance and that which results in a decline in performance. The latter is known as overtraining and demonstrates the difficulty of identifying the appropriate amount of exercise and recovery to achieve optimal fitness and reach a peak level of performance. As discussed earlier in this chapter in relation to eating behaviors, there are subtle differences in the intent of the exercising behavior and the athlete's psychological state. These differences help to distinguish committed exercise training from overtraining from **exercise dependence.**

SPOTLIGHT ON ENRICHMENT

Do Wrestlers Have Eating Disorders?

Wrestlers meet the criteria for anorexia athletica. However, wrestlers generally do not meet the criteria for anorexia nervosa or bulimia nervosa. The few studies that have been conducted with wrestlers indicate that the majority do not possess the psychological pathology that accompanies eating disorders and contributes to their severity. Wrestlers do not base their self-esteem on their body weight. Most wrestlers only engage in abnormal eating behaviors during wrestling season. Their in-season eating pattern is described as **non-normative** (a deviation from normal), but they generally fall within the normal range when administered tests that measure thoughts, feelings, or attitudes that are associated with anorexia nervosa. Thus, restricting food and fluid are potentially dangerous to a wrestler's physical health, but this eating pattern is transient and does not likely have long-term effects on mental health (Dale and Landers, 1999; Enns, Drewnowski, and Grinker, 1987). Some wrestlers do score above the cutoff on tests used to identify at-risk eating behaviors, and there is concern that the binge eating that is part of many wrestlers' weight cycling patterns may lead to an eating disorder after their careers end and weight loss is not so easily achieved after overeating. Weight cycling, and the effect that it may have on performance and health, is discussed in Chapter 11.

Wrestlers may eat abnormally during the wrestling season, but generally do not meet the criteria for anorexia nervosa or bulimia nervosa.

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Some researchers have proposed the concept of primary and secondary exercise dependence (Veale, 1987). The proposed idea of primary exercise dependence involves a preoccupation with exercise—an "addiction" to exercise alone—that is independent of other potential mental disorders and is not used for other reasons such as controlling weight. A lack of supporting scientific research and more recent studies has called into question the prevalence of primary exercise dependence (Bamber et al., 2000, 2003).

In a study of female exercisers, Bamber et al. (2000) found that exercise dependence was not present in women who did not also demonstrate an eating disorder or disordered eating. Exercise dependence was defined as an unhealthy preoccupation with exercising, which had the potential to become a damaging obsession. Behaviors associated with exercise dependence include exercising when medically **contraindicated,** psychological distress when withdrawing from exercise, and a consuming obsession with exercise that transcends considerations of work and social life.

In a subsequent study, Bamber et al. (2003) identified four dimensions of exercise dependence: impaired functioning, withdrawal, presence of an eating disorder, and other associated features. The proposed criteria for exercise dependence are shown in Table 13.1. The distinguishing features that appear to separate exercise dependence from committed training or overtraining are impaired functioning (e.g., psychological, social and occupational, physical, and/or behavioral), withdrawal symptoms, and presence of an eating disorder.

Disordered Eating and Eating Disorders in Athletes

PREVALENCE

The prevalence of disordered eating and eating disorders in athletes is very difficult to determine. Beals (2006) notes that only four studies have used a large enough sample size and valid survey instruments to be

Exercise dependence: An unhealthy preoccupation with exercising.

Non-normative: A pattern of behavior that deviates from what is considered to be normal.

Contraindicated: Inadvisable because of a likely adverse reaction.

Ian Waldie/Getty Images

Sports that require or reward low body weight, low percent body fat, or thin appearance have a higher prevalence of disordered eating and eating disorders.

considered scientifically sound. In these studies the prevalence ranged from a low of 1.3 percent (anorexia nervosa in female athletes) to as high as 20 percent (any clinical eating disorder in female athletes). In addition to prevalence figures, some other conclusions can be drawn from these four studies. First, similar to the general population, female athletes are more likely than male athletes to exhibit both disordered eating and eating disorders. Second, the prevalence of disordered eating (i.e., subclinical eating disorders) is higher than the prevalence of clinical eating disorders. Third, the sports that have a higher prevalence are those that require or reward a low body weight, a low percentage of body fat, or a thin appearance.

Sundgot-Borgen et al. (1999) reported the results of their study that included the entire population of Norwegian elite male and female athletes. Scientists can usually study only a sample of the population, so this study offered additional insight because of its unique design. Using the DSM-IV criteria, the authors found that 20 percent of elite female athletes and 8 percent of elite male athletes met the diagnostic criteria for anorexia nervosa, bulimia nervosa, or eating disorders not otherwise specified. Clearly, elite female athletes are at greater risk than elite males, but eating disorders in elite male athletes should not be overlooked. Of the elite female athletes who developed ED, 60 percent indicated that dieting was an important factor in its development while 28 percent indicated injury was a factor. Of the elite males with ED, only 13 percent indicated that dieting was an important factor while injury (25 percent) and overtraining (21 percent) were mentioned more frequently.

Athletes in many sports are considered at risk for disordered eating and eating disorders (see Figure 13.2). Aesthetic sports, where appearance is part of the scoring, can lead to an overemphasis on a thin appearance.

- Ballet dancing (women)
- Bodybuilding
- Boxing
- Cheerleading (women)
- Diving (women)
- Figure skating (women)
- Gymnastics (women)
- Horseracing (jockeys)
- Lightweight rowing
- Martial arts (e.g., Judo, Karate, Kickboxing, Tae kwon do)
- Rhythmic gymnastics
- Running (middle or long distance)
- Swimming
- Ski jumping
- Synchronized swimming
- Wrestling

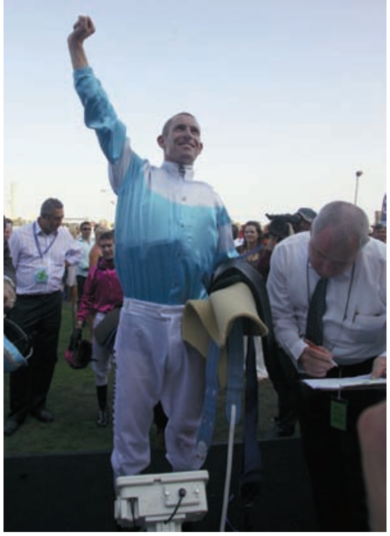
Figure 13.2 Sports Considered Higher Risk for the Development of Disordered Eating.

© John Terence Turner/Alamy

Ballerinas may be at increased risk for disordered eating because the body's appearance is an integral part of the art of ballet.

Examples of such sports include women's gymnastics, figure skating, diving, ballet, and cheerleading. Their male counterparts are expected to be lean and muscular but not necessarily thin, so there are a higher percentage of at-risk females than males in these sports. Due to the acrobatic nature of some sports such as gymnastics, a high power-to-weight ratio is important and may influence some athletes to attempt to achieve a minimal level of body fatness while maintaining muscle mass.

A low body weight can also be seen to be advantageous in sports in which weight must be moved, such


Bradley Kanaris/Getty Images

Athletes in sports with weight restrictions are at risk for developing eating disorders.


AP Photo/Mark Humphrey

Athletes that compete in sports with revealing clothing may feel internal or external pressures to meet body image expectations.

as distance running. Both females and males in this sport may struggle with disordered eating as they try to attain and maintain a low body weight. Very low body weights are also advantageous for jockeys and ski jumpers, and some of these athletes develop disordered eating. Athletes in sports with weight categories (e.g., wrestling, boxing, martial arts, lightweight rowing) are at risk for eating disorders, especially if competition weight is well below a normal, biologically comfortable weight. Sports with revealing clothing (e.g., swimming, diving) or in which body appearance is the sport (e.g., bodybuilding) put athletes of both genders at risk. While these are some obvious examples of sports that create conditions that may pressure athletes to engage in pathological eating behaviors, any athlete may be at risk because low body weight is not the only driving factor. Recall that those diagnosed with bulimia nervosa often are normal weight individuals.

Little is known about disordered eating and eating disorders in male athletes. It has been suggested that males more often develop pathological eating behaviors (i.e., disordered eating) rather than eating disorders and that males with disordered eating have more depression and substance use than males with "normal" eating patterns. Body image disorders appear to be more prevalent in males in Western countries than in non-Western countries. There is more media emphasis on male body image than in the past but it is unknown what, if any, effect increased media attention may have (Baum, 2006). An emerging area of interest,

SPOTLIGHT ON ENRICHMENT

The Adonis Complex

The Adonis Complex: The Secret Crisis of Male Body Obsession (Pope, Phillips, and Olivardia, 2000) is a consumer-oriented book written by three university professors (two M.D.s and one Ph.D.) outlining the psychological problems associated with striving for excess muscularity. These problems include obsessive-compulsive behavior, chronic depression, eating disorders, and/or substance abuse (e.g., anabolic steroids).

The parallel medical term is muscle dysmorphia, a pathological preoccupation with gaining muscle mass. The few studies that have been conducted, primarily in males who lift weights, suggest that muscle dysmorphia is an obsessive-compulsive disorder, but there are elements of inaccurate body image, body dissatisfaction, and eating attitudes that are similar to those found in diagnosable eating disorders. Those with muscle dysmorphia have highly developed skeletal musculature but they believe their muscles are too small. They are dissatisfied with their appearance, weight, and amount of muscle mass and are at risk for using anabolic steroids to change body composition (Choi, Pope, and Olivardia, 2002; Olivardia, Pope, and Hudson, 2000).

Body dissatisfaction in men is increasing, but the incidence and prevalence of muscle dysmorphia is not known (Choi, Pope, and Olivardia, 2002). Muscle dysmorphia is an example of body dysmorphic disorder (preoccupation with defective appearance), the latter of which is listed in the diagnostic manual for the American Psychiatric Association.

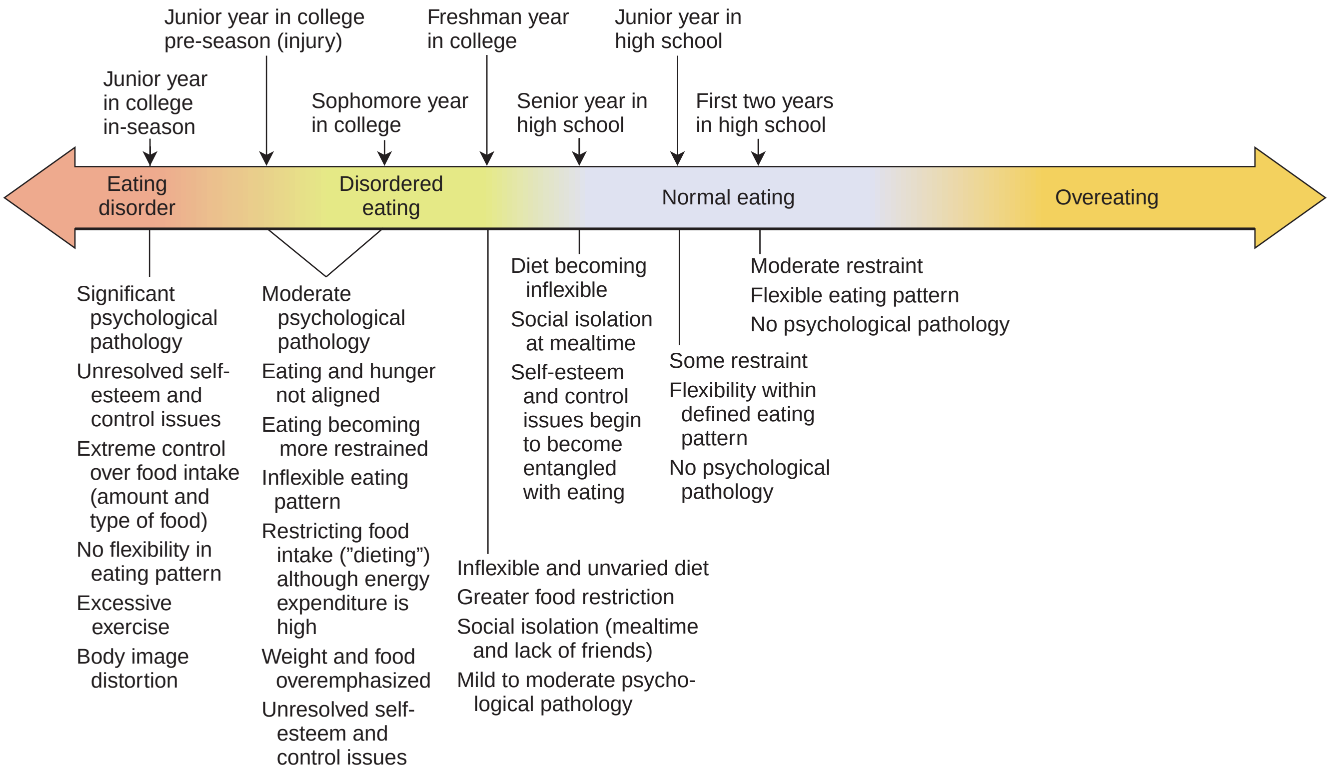


Figure 13.3 An Eating Continuum Example: Karen, the Cross Country Runner

Karen's behaviors placed on the eating continuum.

muscle dysmorphia, is explained in Spotlight on Enrichment: The **Adonis** Complex.

THE DEVELOPMENT OF DISORDERED EATING AND EATING DISORDERS IN ATHLETES

This chapter began with a vignette about Karen, a collegiate cross country runner. As is hinted at in the scenario, there were some unresolved family, control, and self-esteem issues. Karen also exhibited some personality traits, such as perfectionism, excessively high achievement goals, and obsessiveness, which are associated with eating disorders. Participating in a sport, wanting to excel, fierce competitiveness, or being injured do not cause an eating disorder. These may be factors that influence its development, but an eating disorder is, at the core, a psychiatric disease.

Karen was a naturally talented runner who had a "normal" eating pattern when she entered high school. As she became more dedicated to improving her running, she adopted a semi-vegetarian diet in her junior year of high school to support her training and performance goals. If she consumed sufficient kilocalories and nutrients and maintained some dietary flexibility, then her diet would be considered "normal" for a well-trained athlete. She enjoyed the recognition she got from her parents for being in the newspaper. In her senior year she followed a more strict vegetarian diet, preparing her own food and eating alone. She started to become socially isolated at mealtime, and her diet was becoming more inflexible. During therapy, Karen identified her senior year as the point in time when she began to move away from "normal" on the eating continuum (see Figure 13.3) because she had found a way to "control" her parent's comments and her feelings of low self-esteem that accompanied dinner-time conversation. At the same time her successful cross country season was showering her with attention, something she realized later that she desperately needed.

At 18 she left home to attend college and compete at the NCAA Division I level. Although she was a talented high school runner, this is always a vulnerable time for an athlete who goes from being "a big fish in a little pond" to "a little fish in a big pond." For Karen, it became a time of distress because she felt that she had little control over her life. Some of her teammates (who were also her competitors) made disparaging comments, and these comments affected her self-esteem. Eating in the dorm contributed to her diet becoming less flexible and

Muscle dysmorphia: Pathological preoccupation with gaining muscle mass.

Adonis: Greek mythological character described as an extremely handsome young man.

more monotonous. That she no longer enjoyed eating was also a factor because pleasurable eating is a part of "normal" eating. The stated reasons for moving into a single room and fixing her own food was the potential for more nutritious eating, but the unstated reason was that she felt more in "control" when she ate alone, something she had first discovered in high school. Changes in her eating situation led her away from a normal eating pattern by creating more isolation at mealtime that supported greater food restriction.

Karen had made few friends and missed her family, so her coach became her surrogate family. She sought his attention in the same way that she sought her parent's attention in high school—by being a successful runner. When Karen perceived that the coach thought that she needed to be leaner, she had a new goal to accomplish. Her body weight became closely tied to her self-esteem.

An important issue for Karen was her decision to start a weight-loss diet. Recall that dieting can be a factor that triggers the development of an eating disorder, especially in elite female athletes. She restricted her caloric intake (at the same time that she increased her energy expenditure), but she did not establish a weight-loss goal, so she had no way of knowing if, and when, she met that goal. She was also using her weight as a way of vying for her coach's attention.

Karen's injury further contributed to her disordered eating for both physical and psychological reasons. Her goal was to keep her weight "low," but the injury prevented energy expenditure through exercise. A goal of losing weight or maintaining an already low body weight when injured is often not realistic. Trying to attain an unrealistic goal moved Karen further along the disordered eating continuum. The injury also changed the amount of attention that she received from her coach, the person in her life whose opinion she cared about the most.

When her injury was resolved, she continued to consume a restricted diet and voluntarily engaged in excessive exercise. Increasing the serving size of a low calorie food such as salad was not an appropriate dietary response to a substantial increase in training volume. When she did not get an invitation to an important meet, her response was to train more and eat less. At this point, Karen exhibited all the signs of anorexia athletica and had unresolved psychological issues related to control, self-esteem, and personal relationships.

DISTINGUISHING BETWEEN "NORMAL" AND DYSFUNCTIONAL BEHAVIORS IN ATHLETES

Excellent athletic performance, especially at the elite level, requires rigorous training. A nutritious diet supports training and can improve performance, and some athletes must follow fairly strict eating protocols to support their training, body composition, and performance goals. Both training and eating can become regimented, a factor that may contribute to disordered eating. A fine line separates rigorous training and eating regimes that enhance performance and support health from disordered eating and exercise dependence that hurt performance and undermine health. Crossing this imaginary line may be accidental or intentional. Since early intervention is critical for treatment and recovery and the athlete may be unaware or in denial that problems exist, it is important for coaches, athletic and personal trainers, and others who work closely with athletes to be able to distinguish that which is "normal."

Table 13.2 compares the features that may help to distinguish "normal" and disordered eating and exercise patterns in athletes. Athletes in both groups share many features: a high level of physical training, an eating plan to support the demands of training, and a desire to change body composition. But there are marked differences between the two groups in actions and perspective. Returning to the example of Karen, she exhibited almost all the features of disordered eating and exercise patterns shown in Table 13.2.

In addition to behavioral signs, there may be physical signs of disordered eating and eating disorders. Some of these signs may not be noticeable until the disordered eating is prolonged or severe. Frequent gastrointestinal (GI) problems may be present early (some athletes may use GI distress to control weight), but by themselves are too general to predict disordered eating. As food intake is restricted and nutritional status declines, the athlete may exhibit weight loss, chronic fatigue, iron-deficiency anemia, irregular or absent menstruation, and slow recovery from illness or injury. Those with anorexia nervosa may be exceptionally intolerant to cold temperatures (due to low percent body fat) or grow fine hair on the body (known as lanugo) in an effort to regulate body temperature. Bulimics may have callused fingers, teeth with little enamel, or esophageal erosion from self-inducing vomiting (Beals, 2006).

DISORDERED EATING AND EATING DISORDERS IN ATHLETES: WHEN AND HOW TO INTERVENE

Early intervention is critical in the treatment of disordered eating and eating disorders. If left alone, athletes typically do not resolve these issues themselves. In some cases, the athletes do not realize that they have fallen into a disordered eating pattern; in other cases, the athletes staunchly deny that an eating problem exists. If a coach, athletic trainer, or teammate suspects that any degree of disordered eating exists, the question is not when, but how, to intervene.

Beals (2006) notes that if disordered eating is suspected, the appropriate course of action is to approach the athlete and refer to a trained professional for further

Table 13.2 Distinguishing "Normal" and Abnormal Eating and Exercise Patterns

	Features of athletes with "normal" eating and exercise patterns	Features of athletes who may have disordered eating and exercise patterns
Performance	Performance is improved or a high level of performance is maintained	Performance declines
Training	Purposeful training; no overtraining	Excessive exercise or activity; self-imposed overtraining or exercise dependence; anxious if not able to train; continues to train with injury against medical advice
Energy intake	Caloric intake is monitored; athlete is disciplined but not obsessive about the amount of food consumed	Caloric intake is controlled; athlete is disciplined and obsessive; amount of calories consumed is recorded or mentally counted; consumption of caloric intake over self-imposed limit causes anxiety
Perspective on food intake	Food is needed to fuel training; eating is enjoyed and viewed positively	Food needs to be restricted; eating is not enjoyable and viewed negatively
Dietary intake	Consumption of "healthy foods" and adequate kilocalories; no concern about occasionally eating low nutrient dense foods	Consumption of "healthy foods" but inadequate kilocalories; Concern about or refusal to occasionally eat low nutrient dense foods
Dietary flexibility	Routinely follows a well-planned diet but is flexible as needed	Ritualistic and inflexible pattern of eating
Body image	Accurate and positive body image	Inaccurate and negative body image
Body composition	Realistic weight and body composition goals that improve or maintain performance; goals are attainable without compromising health	Unrealistic weight and body composition goals that do not improve or maintain performance; goals are not attainable without compromising health
Muscle mass	Increased or maintenance of muscle mass with resistance training	Decreased or inability to increase muscle mass with resistance training

evaluation. If confirmed, the placement of the athlete into a treatment program is crucial. Approaching anyone with an eating disorder is an extremely sensitive issue and must be done in a professional and confidential manner. In some universities a referral protocol has been established, and, if so, it should be followed exactly. If no protocol exists, a good starting point is to refer the athlete to the team physician.

The primary goal of treatment is to help the athlete resolve both the psychological and physical issues present. Early intervention is critical to meeting that goal, because those with less severe or less prolonged problems have a better chance of successful treatment. If appropriate, a second goal is for the athlete to return to the sport. Athletes who refuse treatment or do not satisfactorily complete treatment should not be allowed to train or compete because their mental and physical health will be compromised (International Olympic Committee [IOC], 2005).

Treatment involves three components—psychological, nutritional, and medical. Each needs to be treated by an expert, so treatment involves a team approach Including a psychologist, registered dietitian, and physician. Psychological counseling is necessary because psychological disturbances are at the core of the eating disorders. A description of the intensive psychological therapy needed is beyond the scope of this chapter, but it is fundamental to treating any eating disorder. Nutritional counseling is necessary, even though many who have eating disorders know a great deal about the caloric and nutrient content of food. Nutrition counseling helps them to view food in a normal context, one in which eating is both flexible and enjoyable. Medical guidance is needed to resolve physical problems resulting from the eating disorders and to coordinate medical care over the course of treatment, which may be months or years in length, depending on the severity of the eating disorder.

What's the point? Disordered eating and eating disorders are a threat to an athlete's physical and mental health and any signs or symptoms should not be ignored. Early identification, intervention, and treatment are critical.

Female Athlete Triad

The Female Athlete Triad (see Figure 13.4) is a term used to describe three interrelated conditions: disordered eating (resulting in low energy availability), amenorrhea (a sign of hormonal disruption), and **osteoporosis** (evidence of low bone mineral density). The three may be present together and have developed in sequence—low energy availability due to low energy intake and high energy expenditure leads to amenorrhea that leads to osteoporosis—although each of these conditions can occur independently of the others. Each of the three factors develops along a continuum. Both the International Olympic Committee Medical Commission (2005) and the American College of Sports Medicine (1997, currently under review) have issued position papers on the Female Athlete Triad. Preventing and treating the Female Athlete Triad is a high priority because of the substantial short- and long-term medical problems that can occur.

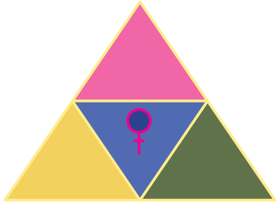
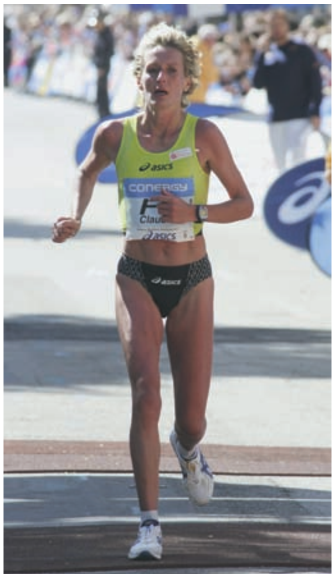


Figure 13.4 The IOC symbol for the Female Athlete Triad



Alexander Hassenstein/Bongarts/Getty Images

In sports in which low body weight may be associated with better performance, athletes may undereat, resulting in a chronic energy deficit.

LOW ENERGY AVAILABILITY

Low energy availability results when the female athlete is in negative energy balance. Negative energy balance is the result of energy expenditure exceeding energy intake. Athletes in sports in which low body weights are required (e.g., lightweight rowing, lower weight categories in the martial arts) or desired (e.g., gymnastics, ballet dancing, distance running) may intentionally undereat in an effort to attain or maintain that low body weight. Coupled with the high energy expenditure required for training in these sports, an ongoing **energy deficit** is likely. This deficit may last months or years. In adolescent athletes, physical growth also requires energy, and growth may contribute further to the energy deficit.

Low energy availability may or may not be associated with disordered eating. For example, a female distance runner with a low body weight may try to slightly underconsume energy (kcal) intake daily when compared to energy expenditure to prevent a gain in body fat. She could have a well-planned, nutritious, and disciplined training diet that is not an obsession and not disordered eating. Since she is intentionally in an energy deficit, she is at risk for developing amenorrhea and osteoporosis, but she does not have the same psychological risk as a similar athlete with disordered eating or an eating disorder. Those female athletes who exhibit disordered eating patterns are at greater risk both physiologically and psychologically. It bears repeating that food restriction or "dieting" in a low body weight elite female athlete is often a trigger that can lead to disordered eating, which can progress to an eating disorder.

Persistent and severe energy deficits force the body to adapt and begin to suppress physiological functions that are associated with normal growth and development. The Female Athlete Triad singles out one altered physiological function that is a result of low energy availability—amenorrhea (IOC, 2005).

AMENORRHEA

Amenorrhea is defined as the absence or suppression of menstruation. In the United States, primary amenorrhea describes a female who has gone through puberty but by age 15 has not yet menstruated. In secondary amenorrhea, the female began menstruating but menstruation has been absent for three or more months. There are a variety of medical conditions that may have an effect on normal menstruation patterns. In the context of the Female Athlete Triad, the amenorrhea is a result of low energy availability and is not due to some other medical condition or contraceptive technique that may result in absent menstruation.

Osteoporosis: Disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture.

Energy deficit: Result of consuming less energy (kcal) than expended.

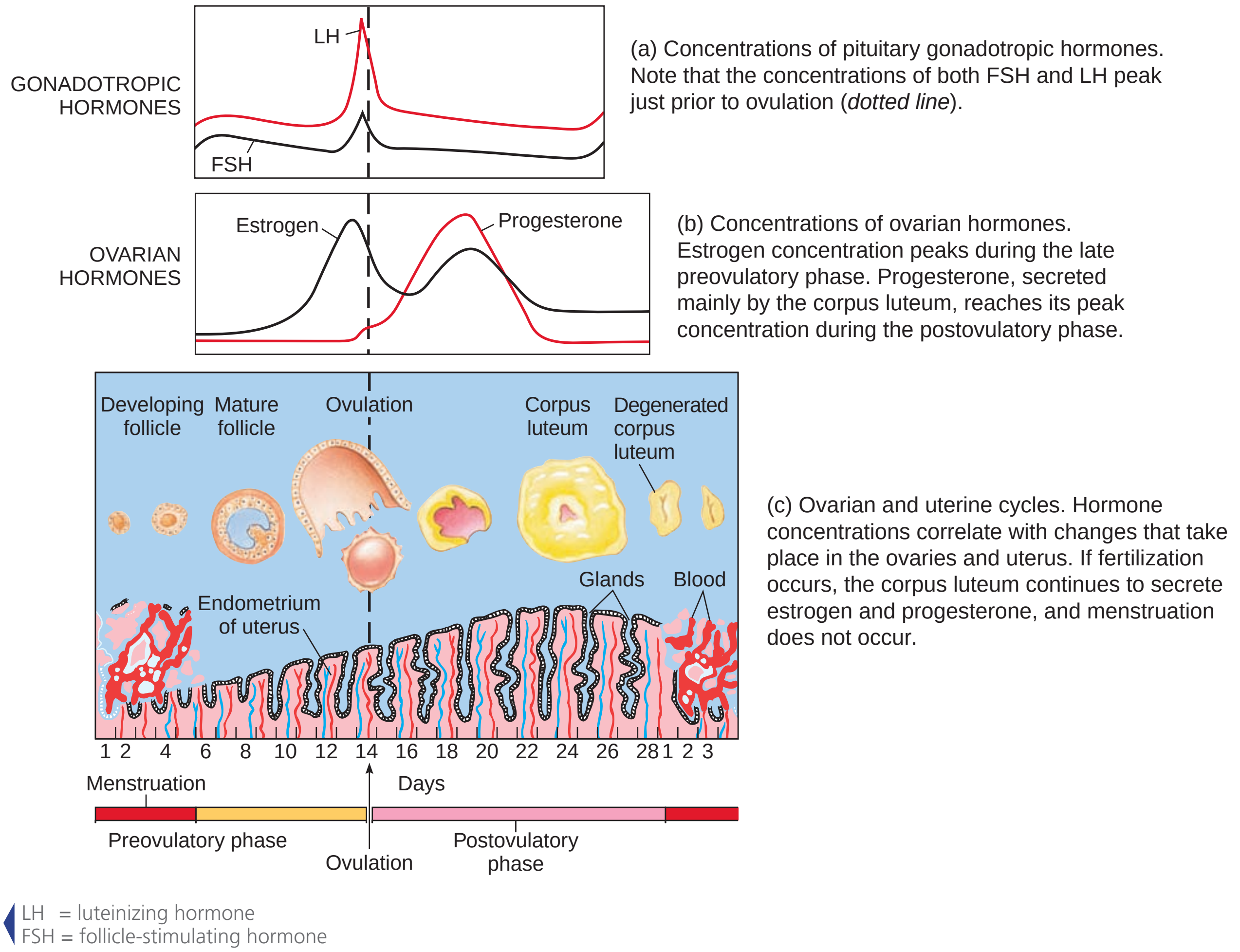


Figure 13.5 Hormonal Fluctuations during the Menstrual Cycle

A current theory of amenorrhea in athletes is that chronic low energy availability disrupts the normal secretion of luteinizing hormone, resulting in a disruption of menses.

In the past, amenorrhea in athletes was attributed to low body fat stores and the stress of exercise. These factors are no longer believed to play causative roles. Rather, the amenorrhea seems to be due to an energy deficit that alters the secretion of **luteinizing hormone** (LH). Menstruation is regulated by a number of hormones, including follicle-stimulating hormone (FSH), luteinizing hormone (LH), and estrogen. Figure 13.5 illustrates the expected hormonal fluctuations associated with menstruation, although many variations are seen. During the first few days of the menstrual cycle the growth of one egg is accelerated. One to two days prior to ovulation, there is a surge in LH secretion so that ovulation can occur. The unfertilized egg grows and secretes estrogen and progesterone, hormones that inhibit the secretion of LH and FSH (Guyton and Hall, 2005). The current prevailing theory is that low energy availability disrupts the normal secretion of luteinizing hormone, resulting in amenorrhea (IOC, 2005).

Athletes that begin intense training at an early age, such as gymnasts or distance runners, may exhibit primary amenorrhea, that is, they have never menstruated. This intense training may lead to the chronic energy deficit before the onset of puberty. Other athletes may begin menstruating normally but develop secondary amenorrhea later when the training demands of their sport escalate. Ironically, many athletes view the lack of menstrual periods as being advantageous. It may be perceived as evidence that they are lean or it may simply be a relief from the inconvenience of the monthly period. Athletes may also have the mistaken idea that amenorrhea may act as birth control, and that pregnancy is not possible during the time when menstruation is not present. Instead of being advantageous, amenorrhea should be recognized as undesirable and potentially harmful to health.

Amenorrheic athletes typically have low energy (kcal) intake as well as low nutrient intake. Of particular concern are the vitamins and minerals that are necessary for bone formation, such as calcium and vitamin D. Other nutrients that are commonly lacking are the B vitamins, iron, and zinc. Increasing total energy intake may reverse the amenorrhea and will likely provide more vitamins and minerals as well (Manore, 2002).

OSTEOPOROSIS

Amenorrhea is associated with low estrogen secretion. One of the actions of estrogen is protection against calcium loss from bone, and a low estrogen concentration results in loss of bone calcium and alterations in bone microarchitecture (Figure 13.6). As the mineral density of the bone declines, its structure deteriorates and there is a greater risk for fracture. Of great concern to athletes are stress fractures, small cracks or incomplete breaks in weight-bearing bones, typically the tibia and fibula. Amenorrheic athletes are at greater risk for stress fractures than athletes with normal menstruation.

The loss of calcium from bone is progressive. Dual energy X-ray absorptiometry (DEXA) can determine bone mineral density (BMD). The results of this test place females in one of three categories: 1) normal, 2) **osteopenia** (low BMD), or 3) osteoporosis. In general, athletes who are menstruating have normal or above-normal BMD because weight-bearing exercise has a positive effect on the deposition of calcium in bone. However, numerous studies have documented that trained athletes with amenorrhea may exhibit low bone mineral density or osteoporosis. Beginning in the 1980s, Drinkwater and colleagues demonstrated that bone loss occurred in regularly exercising athletes that were amenorrheic (1984, 1986, 1990). Athletes who are not menstruating are at risk first for osteopenia and then for osteoporosis. Khan et al. (2002) note that at least one study showed that 22 to 50 percent of the subjects, amenorrheic runners and ballet dancers, had varying degrees of osteopenia. In two studies of amenorrheic female distance runners between the ages of 20 and 30, 10 to 13 percent were diagnosed with osteoporosis.

Cobb and colleagues (2003) studied 91 well-trained female distance runners ages 18 to 26 years. Thirty-three athletes had zero to nine menstrual periods in a year while the remaining subjects (58 athletes) had normal menstruation. Bone mineral density was determined by DEXA for the entire body as well as the hip and spine. When BMD was compared to those with **eumenorrhea** (i.e., normal menstruation), the amenorrheic athletes had 3 percent less in the entire body, 6 percent less in the hip, and 5 percent less in the spine. Based on spine measurements, two of the amenorrheic runners were classified as osteoporotic and nearly half were osteopenic. In comparison, none of the eumenorrheic athletes were osteoporotic and only 26 percent were osteopenic.

D.P Motta, Department of Anatomy, University of "La Sapienza" Rome/SPL/ Photo Researchers, Inc.

Figure 13.6 Healthy (left) and Osteoporotic (right) Bone Compared

An osteoporotic bone has a decreased amount of bone mineral and a change in the bone architecture.

The IOC report (2005) states that amenorrhea that lasts longer than six months will likely have a negative effect on the athlete's bone mineral density. This loss of bone calcium is especially disturbing because it is occurring during a period of life when bone mineral density should be increasing. Keen and Drinkwater (1997) were able to study some of the athletes from their original studies in a follow-up investigation eight years later. Of particular interest were comparisons between those who exhibited regular menstruation or intermittent menstruation/amenorrhea both originally and at follow-up. There was a significance difference in bone density between the two groups, with those in the group in which intermittent menstruation/amenorrhea persisted having ~ 85 percent of the bone density of those with regular menstruation. Early intervention for amenorrheic athletes is important to prevent irreversible loss of bone mineral density. The Spotlight on Enrichment: Normal Bone Density in a Former Amenorrheic, Osteoporotic Distance Runner reviews a case study of an athlete who successfully reversed low bone mineral density with increased food intake and decreased exercise that led to weight gain (Fredericson and Kent, 2005).

A number of cross-sectional studies of young women have shown that physically active and athletic women typically demonstrate higher bone mineral

Luteinizing hormone: One of the menstrual cycle hormones associated with ovulation.

Osteopenia: Low bone mineral density; a risk factor for osteoporosis.

Eumenorrhea: Normal menstruation.

density (ACSM, 1995). This is particularly true for women who participate in weight-bearing sports or activities. However, exercise does not guarantee increased bone density, as bone loss has been demonstrated in regularly exercising athletes that were amenorrheic (Drinkwater et al., 1984, 1986, 1990). The risk of osteoporosis is a long-term health concern, but the bone loss associated with amenorrhea may have more immediate consequences for these athletes. Menstrual irregularity, and the associated bone mineral loss, is associated with a greater incidence of stress fractures in runners, particularly in the lower leg. A study of female collegiate runners (Barrow and Saha, 1988) revealed a much higher percentage of stress fractures in runners reporting an irregular menstrual history (zero to five menses a year) compared to runners reporting regular menstruation (10 to 13 menses per year) (see Figure 13.7).

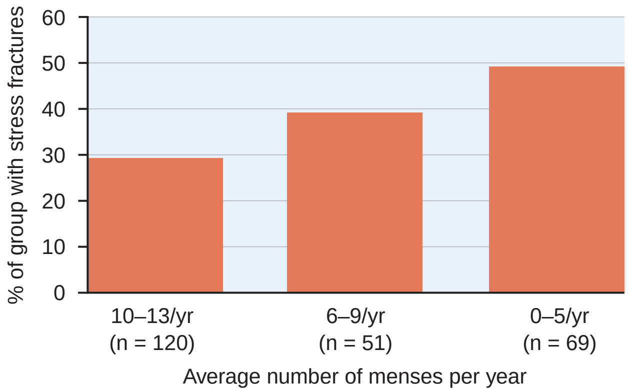


Figure 13.7 Prevalence of Stress Fractures According to Menstrual History

Barrow, G.W. & Saha, S. (1988). Menstrual irregularity and stress fractures in collegiate female distance runners. *American Journal of Sports Medicine*. 16(3), 209–216.

PREVALENCE OF THE FEMALE ATHLETE TRIAD

Any physically active female is at risk for developing the Female Athlete Triad (see Table 13.3). Torstveit and Sundgot-Borgen (2005b) studied 186 elite athletes and 145 age-matched controls. The elite athletes trained an average of approximately 14 hours per week while the controls were physically active for a little more than 5 hours per week. Additionally, the activity of the control group was of lesser intensity than the elite athletes. Eight elite athletes (4.3 percent) met all the criteria for the Female Athlete Triad—disordered eating or eating disorder leading to low energy availability, menstrual dysfunction, and low bone mineral density (BMD). Five members of the control group (3.4 percent) also met these criteria. This study suggests that elite and recreational athletes as well as women who are not physically active may be at risk. An earlier study by the same authors found that female athletes competing in sports that emphasize leanness or low body weight were more likely to be at risk for the Triad than female athletes in other sports (Torstveit and Sundgot-Borgen, 2005a).

Table 13.3 also illustrates the prevalence of two of the three Triad components in elite athletes and controls. In the same way that disordered eating can progress along a continuum to an eating disorder, there appears to be a progression in the development of amenorrhea and osteoporosis. While only 4.3 percent of the elite athletes met the full criteria, 26.9 percent (50 elite athletes) exhibited disordered eating or eating disorders and menstrual dysfunction (but not low bone

SPOTLIGHT ON ENRICHMENT

Normal Bone Density in a Former Amenorrheic, Osteoporotic Distance Runner

Fredericson and Kent (2005) report the results of a case study of a distance runner who successfully reversed low bone mineral density (BMD) with improved energy intake that led to weight gain. The case study covers an eight-year period from approximately age 23 to age 31. The subject ran competitively from age 12 through age 25. She had a personal best marathon time of 2:41 (2 hours, 41 minutes). While running competitively, she typically ran 80 to 90 miles/wk (~ 134 to 150 km/wk).

This runner began to restrict energy and fat intake at age 13. She had a low weight for height through age 25. Weight at age 23 was approximately 107 lb (48.6 kg) and Body Mass Index (BMI) was 15.8 (healthy weight BMI = 18.5 to 24.9). She had primary amenorrhea until age 23 and BMD measured at this time was found to be the equivalent of a 13-year-old.

At age 25 the runner became concerned about her long-term health and made numerous lifestyle changes. She reduced her mileage to 20 to 50 miles/wk (~ 33 to 83.5 km/wk). She began to increase both her energy and fat intakes for the purpose of weight gain. In the first four months weight increased from (~ 111 lb (50.4 kg) to ~ 122.5 lb (55.7 kg) and then gradually increased to ~ 144 lb (65.5 kg) by age 31, during which time normal menstruation resumed. Concurrent with weight gain, she dramatically improved her BMD, which eventually was in the normal range for her chronological age.

This case study cannot be extrapolated to other amenorrheic runners, but it does document that resumption of menses and dramatic gains in BMD did occur in this individual with lifestyle intervention that resulted in the attainment of a sustainable weight.

Table 13.3 Prevalence of the Female Athlete Triad Components

	Female Athlete Triad (all three components)	Disordered eating + menstrual dysfunction	Disordered eating + low bone mineral density	Menstrual dysfunction + low bone mineral density
Elite athletes (N = 186)	4.3% (N = 8)	26.9% (N = 50)	10.2% (N = 19)	5.4% (N = 10)
Control group (N = 145)	3.4% (N = 5)	13.8% (N = 20)	15.2% (N = 22)	12.4% (N = 18)

Adapted from: Torstveit, M.K. & Sundgot-Borgen, J. (2005). The female athlete triad exists in both elite athletes and controls. *Medicine and Science in Sports and Exercise*. 37(9): 1449–1459.

Note: 87 of 186 elite athletes and 65 of 145 subjects in the control group demonstrated two of the three or all three components of the Female Athlete Triad.

mineral density). Twenty-two controls (15.2 percent) had disordered eating and low BMD but not menstrual dysfunction. The Triad may progress in stages and there is some evidence that the elite athletes have a more severe condition than the controls. Although prevalence data are still emerging, screening is very important for early detection of any component of the Triad.

PREVENTION, INTERVENTION, AND TREATMENT

The prevention of the Female Athlete Triad begins with preventing persistent energy deficits. Athletes in sports known to be at risk for the Triad should work with a physician, a sports dietitian, and an exercise physiologist to identify a biologically comfortable body composition and (low) body weight. A low body weight must be consistent with good performance and not compromise the athlete's physical or mental health, so establishing appropriate goals are essential (see Chapter 11). Once weight and body composition goals are determined, the athlete's training plan can be developed, a diet plan can be devised, and a follow-up schedule can be established. Athletes can achieve a low but biologically comfortable weight with short-term, monitored, and safe diet and exercise programs that promote slow weight loss. Close contact and communication with trusted health and sports professionals can help athletes prevent "slipping over the line" from disciplined eating and training to disordered eating and excessive exercise. These professionals can also help athletes define and distinguish appropriate weight and body composition from inappropriate and potentially harmful weight and body composition.

In a perfect world, the Female Athlete Triad would always be prevented through the use of excellent screening tools to identify athletes who may be at risk for disordered eating and immediate intervention with those who exhibit disordered eating. The world is not perfect, so there are athletes whose eating becomes progressively more pathological and who need treatment. The course of treatment may be long, especially if deep-seated psychological issues need to be resolved. Changes in diet and exercise to prevent low energy intake and high energy expenditure are needed to resolve the athlete's amenorrhea. While amenorrhea is present, oral contraceptives (a source of estrogen) may be prescribed to prevent or slow calcium loss from bone (IOC, 2005). Because there is emerging evidence that menstrual dysfunction and low bone mineral density may be present in the absence of disordered eating or eating disorders, screening for these two components is recommended as part of a routine physical exam.

In the case of Karen, the cross country runner, the low energy availability was a result of increasingly severe disordered eating and exercise dependence, which resulted in amenorrhea. Karen was aware that she was menstruating only periodically but she kept this information a secret. Amenorrheic athletes are at a greater risk for stress fractures than athletes with normal menstruation, so it is not a surprise that Karen was diagnosed with a stress fracture. A DEXA scan would be needed to determine if bone mineral density was already low.

Karen's story could end in several ways. The best-case scenario is for her to receive and complete treatment for her eating disorder, including the underlying psychological issues related to control and self-esteem. If appropriate, she could eventually be cleared to train and compete, although she would need to meet certain criteria such as maintenance of a minimum body weight and normal menstruation. Sadly, Karen's story could also be one of declining health that leads to an early death. She could refuse treatment and continue her same patterns of behavior. Refusing treatment would result in her being removed from the team, but she could continue to engage in excessive exercise and disordered eating until she died, typically of a medical condition (e.g., cardiac arrest, electrolyte imbalance, severe dehydration) or suicide. Early intervention is the best way to ensure the best-case scenario.

What's the point? Any female athlete can be at risk for the Female Athlete Triad. Low energy availability, hormonal disruption, and low bone mineral density are serious physiological issues that need to be prevented or reversed.

Establishing a Culture That Supports "Normal" Eating: Role of Coaches Disordered eating and eating disorders do not develop in a vacuum. The IOC Medical Commission (2005) notes that several factors may influence their development. Western cultures emphasize thinness, and females frequently restrict food intake to lose weight. Females who equate thinness with success are more susceptible to developing eating disorders. From the female athlete's perspective, "success" may include being thinner than a teammate or receiving more attention from her coach because of her thin body. Female athletes in sports in which thinness is desirable can face extraordinary pressures, especially as they try to reach the elite levels of their sports. Decreasing body weight or reducing body fat can, and often does, lead to improved performance initially and a desirable appearance in revealing clothing. However, a belief that an ever-lower body weight or body fat percentage is beneficial is not only incorrect (it leads to poorer performance), but this belief is a powerful risk factor for the development of an eating disorder.

There is evidence that certain personality traits such as perfectionism, obsessive-compulsive behavior, overcompliance, and extreme competitiveness and goal setting are associated with disordered eating. Ironically, these are traits that are valued by coaches and extolled in the media because many highly successful athletes exhibit these behaviors. Thus, athletes may be positively reinforced for the same behaviors that put them at risk for disordered eating (IOC, 2005).

No one person can change the way society views and values the appearance of the human body. Nor can one person shape the athlete's personality or beliefs about body weight and body image. However, the one person who may have the most influence over the athlete's behavior may be the coach. For this reason, the IOC Medical Commission recommends that coaches not be involved in determining the athlete's weight or body composition, nor should they suggest to the athlete that body weight should be reduced. This keeps coaches from establishing and judging the athlete's weight or body composition and helps coaches prevent inadvertent reinforcement of disordered eating or excessive exercise.

However, many coaches are involved in weight-related issues. A 2003 survey of U.S. collegiate coaches of female gymnastics, swimming, basketball, softball, track, and volleyball teams found that 44 percent of those surveyed weighed athletes, assessed body composition (44 percent), and suggested losing weight by restricting food (33 percent) or increasing workouts (29 percent). Weight, body composition assessment, and a plan for weight (fat) loss are best carried out by trained professionals other than coaches because athletes are directly affected by coaches' decisions and coaches can be a powerful influence on the athlete's behavior and health (Heffner et al., 2003).

Many coaches work hard to prevent eating disorders. After a diagnosis of anorexia athletica or Female Athlete Triad has been made, coaches often wonder what role they may have played in its development. Coaches do not *cause* eating disorders or other related conditions, but they must be careful not to unwittingly create conditions that encourage them. Coaches must be careful about how they reinforce behavior because the attention, or lack of attention, can reinforce inappropriate eating and exercise behaviors. In sports whose athletes are known to be at risk for anorexia athletica and the Female Athlete Triad, it is very important that each athlete have ongoing medical, nutritional, and training advice and that optimal and minimum body weights be determined and monitored by someone other than the coach (see Chapter 11).

Returning to Karen's story one last time, she had high goals even as an adolescent. She was a perfectionist, as evidenced by her perfect high school grades and her desire to repeat that achievement in college. Her obsession about food and exercise was probably a natural fit

THE EXPERTS IN. . .

Eating Disorders in Athletes

Two internationally known researchers in the field of disordered eating in athletes are Monica Torstveit, M.S., and Jorunn Sundgot-Borgen, Ph.D. These researchers are able to study the entire population of elite Norwegian athletes, particularly female athletes, and have been instrumental in describing and understanding elite athletes' eating behaviors. In the United States, two prominent researchers are Katherine Beals, Ph.D., R.D., and Melinda Manore, Ph.D., R.D. Both are sports dietitians and university faculty members and their research has broadened knowledge in the areas of disordered eating, eating disorders, and energy availability, particularly in female collegiate athletes. Barbara Drinkwater, Ph.D., has conducted landmark studies on bone mineral content of athletes based on their menstruation status. Members of the IOC and ACSM committees issuing position papers on the Female Athlete Triad are all experts in their respective fields.

The Internet Café

Where Do I Find Reliable Information about Disordered Eating in Athletes?

Both the International Olympic Committee Consensus Statement on the Female Athlete Triad and the American College of Sports Medicine position stand are available on the Internet. These reports are excellent resources for anyone who wishes to know more about these conditions. Access the IOC report at **http://www.olympic.org/uk/organisation/commissions/medical/index_uk.asp** and the ACSM report at **http://www.acsm.org/index.asp.** In each case enter Female Athlete Triad in the website search box.

The National Eating Disorders Association is the largest nonprofit group in the United States in the area of disordered eating and eating disorders. They publish and distribute materials, including some targeted to athletes, and operate a referral helpline. **http://www.nationaleatingdisorders.org.**

The National Institute on Drug Abuse funded the development of curricula targeted to high school athletes. ATHENA (Athletes Targeting Healthy Exercise & Nutrition Alternatives) is designed to promote healthy nutrition and exercise behaviors and reduce disordered eating and body image distortion. ATLAS (Athletes Training and Learning to Avoid Steroids) emphasizes the impact that anabolic steroids and other substances (e.g., alcohol) have on performance and the positive performance effects of nutrition and training. Both programs can be purchased. More information is available at **http:// www.ohsu.edu/hpsm/athena.html.**

with her overachieving, competitive personality. She had unresolved family problems when she left for college and then found herself faced with new situations that were stressful and that she could not fully control. She had an athletic scholarship, but it was not guaranteed. Other athletes were not only better performers, but Karen perceived that they were thinner. By her junior year in college she was lonely, isolated, starving, injured, and sick.

Karen began to view her coach as a substitute for both her family and friends. She perceived that her coach thought that she needed to lose weight and she may not have realized the difference between being "lean" (i.e., having a relatively high percentage of lean body mass and a relatively low percentage of body fat) and being "thin." It is impossible to know what comments were made, but coaches should be aware that even an innocent comment about weight or body composition could be misconstrued.

Summary

Normal eating is flexible. It is neither overly restricted nor without restraint. Athletes need a well-planned, nutritious diet that supports their training. For a highly trained athlete, dietary intake should be **disciplined,** but without **obsession.** When viewed on a continuum, normal eating may progress to **disordered eating,** which may progress to an **eating disorder.** Criteria have been established for three eating disorders—**anorexia nervosa, bulimia nervosa**, and **eating disorders not otherwise specified.** All are psychiatric disorders and can damage the athlete's mental and physical health.

Anorexia athletica is characterized by a low body weight and low body fat mass, weight cycling, restriction of food intake, and excessive exercise in athletes. At greatest risk for anorexia athletica or other disordered eating patterns are those in sports in which low body weight or a thin appearance is advantageous. However, any athlete, male or female, may exhibit disordered eating. Restricting energy intake ("dieting"), especially in low body weight females, can be a factor in triggering disordered eating. A fine line can exist between the normal eating pattern of an elite athlete with a rigorous training program and a disordered eating pattern that progresses to an eating disorder, but there are ways to distinguish based on the athlete's behaviors, attitudes, and performance.

KEEPING IT IN PERSPECTIVE

Eating, Exercising, Weight, and Performance

Perhaps no area of sports nutrition requires more perspective than the eating and exercise behaviors that support an appropriate weight and excellent performance. It is not rigorous training or disciplined eating per se that creates problems for the athlete's physical and mental health. For those struggling with psychological issues such as control and self-esteem, it is the obsession with exercise and eating that results in a loss of perspective that creates, and then drives, increasingly abnormal eating and exercise behaviors. A low body weight or low body fat mass, appropriately defined, can be a factor in improving performance. If a low body weight is never defined, inappropriately chosen, or becomes the sole or primary goal (replacing the original goal of improved performance), then the proper perspective has been lost. Food and exercise then become the means to an (unachievable) end and performance and health, both physical and mental, suffer. Eating is for fuel and fun, and when that perspective is lost, the athlete is on a slippery slope.

Prevention is key; failing that, early intervention is critical because treatment is more successful if the disordered eating is less severe. If disordered eating or an eating disorder is suspected, the athlete should be referred for further evaluation and, if confirmed, treatment. Psychological counseling is a required part of therapy because these are **psychiatric** diseases. Coaches do not cause eating disorders, but they must be careful that they do not create conditions that inadvertently contribute to them. An International Olympic Committee report suggests that coaches not be involved in determining an athlete's weight or body composition goals.

The Female Athlete Triad describes three interrelated conditions—disordered eating (resulting in low energy availability), **amenorrhea** (a sign of hormonal disruption), and **osteoporosis** (evidence of low bone mineral density). Low energy availability results when energy intake is not equal to energy expenditure and may be a result of disordered eating. An energy deficit over time can lead to amenorrhea and osteoporosis. Any of the three components of the Triad can damage the athlete's mental or physical health.

Eating a nutritious diet supports training, which can improve performance. Obsessions about food intake or **exercise dependence** are detrimental to training, performance, and the athlete's physical and mental health. Trying to attain and maintain a biologically uncomfortable low body weight puts the athlete at risk for developing a disordered eating pattern.

Post-Test Reassessing Knowledge of Disordered Eating and Exercise Dependence

Now that you have more knowledge about disordered eating and exercise dependence, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. Disordered eating and eating disorders only affect female athletes.
2. Anorexia athletica means that an athlete has a classic case of anorexia nervosa.
3. Disordered eating and eating disorders are more likely to be seen among elite female athletes in sports such as distance running and gymnastics.
4. Coaches cause athletes to develop eating disorders.
5. A good diagnostic criterion for exercise dependence is the volume of exercise training (i.e., frequency and duration of exercise).

Review Questions

1. What is normal eating? How might normal eating in highly trained athletes differ from nonathletes?
2. What distinguishes normal eating from disordered eating or an eating disorder?
3. How does anorexia athletica differ from anorexia nervosa?
4. Do the following factors have an effect on the prevalence of any of the eating disorders—age, gender, dieting to lose weight, injury, and personality characteristics? Describe the individual who is at the greatest risk for developing anorexia athletica.
5. Why are the eating disorders referred to as mental or psychiatric diseases?
6. What characteristics do well-trained athletes without disordered eating share with those athletes who demonstrate disordered eating and exercise behaviors? How could a coach distinguish these two groups of athletes?
7. Describe the appropriate intervention if disordered eating is suspected.
8. Name the three components of the Female Athlete Triad and explain how each is independent of and related to the other components.
9. Discuss the dimensions of exercise dependence.
10. Explain the difference between exercise dependence and overtraining.

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APPENDIX B The DASH (Dietary Approaches to Stop Hypertension) Eating Plan

The Dash Eating Plan at 1,600-, 2,000-, 2,600-, and 3,100-Calorie Levels[a]

Food Groups	1,600 Calories	2,000 Calories	2,600 Calories	3,100 Calories	Serving Sizes	Examples and Notes	Significance of Each Food Group to the DASH Eating Plan
Grains[b]	6 servings	7–8 servings	10–11 servings	12–13 servings	1 slice bread, 1 oz dry cereal,[c] ½ cup cooked rice, pasta, or cereal	Whole wheat bread, English muffin, pita bread, bagel, cereals, grits, oatmeal, crackers, unsalted pretzels, and popcorn	Major sources of energy and fiber
Vegetables	3–4 servings	4–5 servings	5–6 servings	6 servings	1 cup raw leafy vegetable, ½ cup cooked vegetable, 6 oz vegetable juice	Tomatoes, potatoes, carrots, green peas, squash, broccoli, turnip greens, collards, kale, spinach, artichokes green beans, lima beans, sweet potatoes	Rich sources of potassium, magnesium, and fiber
Fruits	4 servings	4–5 servings	5–6 servings	6 servings	6 oz fruit juice, 1 medium fruit, ¼ cup dried fruit, ½ cup fresh, frozen, or canned fruit	Apricots, bananas, dates, grapes, oranges, orange juice, grapefruit, grapefruit juice, mangoes, melons, peaches, pineapples, prunes, raisins, strawberries, tangerines	Important sources of potassium, magnesium, and fiber
Low-fat or fat-free	2–3 servings	2–3 servings	3 servings	3–4 servings	8 oz milk 1 cup yogurt **1**½ oz cheese	Fat-free or low-fat milk, fat-free or low-fat buttermilk, fat-free or low-fat regular or frozen yogurt, low-fat and fat-free cheese	Major sources of calcium and protein
Meat, poultry, fish	1–2 servings	2 or less servings	2 servings	2–3 servings	3 oz cooked meats, poultry, or fish	Select only lean; trim away visible fats; broil, roast, or boil instead of frying; remove skin from poultry	Rich sources of protein and magnesium
Nuts, seeds, legumes	3–4 servings	4–5 servings	1 serving	1 serving	½ cup or **1**½ oz nuts, 2 Tbsp or ½ oz seeds, ½ cup cooked dry beans or peas	Almonds, filberts, mixed nuts, peanuts, walnuts, sunflower seeds, kidney beans, lentils	Rich sources of energy, magnesium, potassium, protein, and fiber
Fat and oils[d]	2 servings	2–3 servings	3 servings	4 servings	1 tsp soft margarine, 1 Tbsp low-fat, 2 Tbsp light salad dressing, 1 tsp vegetable oil	Soft margarine, low-fat mayonnaise, light salad dressing, vegetable oil (such as olive, corn, canola, or safflower)	DASH has 27 percent of calories as fat (low in saturated fat), including fat in or added to foods
Sweets	0 servings	5 servings/ week	2 servings	2 servings	1 Tbsp sugar, 1 Tbsp jelly or jam, ½ oz jelly beans, **8** oz lemonade	Maple syrup, sugar, jelly, jam, fruit-flavored gelatin, jelly beans, hard candy, fruit punch sorbet, ices	Sweets should be low in fat

The number of daily servings to choose from each food group depends on a person's energy requirement.

[a]NIH publication No. 03–4082; Karanja N.M., et al. *JADA* 8:S19–S27, 1999.

[b]Whole grains are recommended for most servings to meet fiber recommendations.

[c]Equals ½–**1**¼ cups, depending on cereal type check the product's Nutrition Facts Label.

[d]Fat content changes serving counts for fats and oils: For example, 1 Tbsp of regular salad dressing equals 1 serving; 1 Tbsp of a low-fat dressing equals **½** serving; 1 Tbsp of a fat-free dressing equals 0 servings.

Source: U.S. Department of Agriculture and U.S. Department of Health and Human Services, *Dietary Guidelines for Americans 2005,* 6th edition, available online at www.healthierus.gov or call (888) 878–3256.

APPENDIX C MyPyramid

FOOD INTAKE PATTERNS

The suggested amounts of food to consume from the basic food groups, subgroups, and oils to meet recommended nutrient intakes at 12 different calorie levels. Nutrient and energy contributions from each group are calculated according to the nutrient-dense forms of foods in each group (e.g., lean meats and fat-free milk). The table also shows the discretionary calorie allowance that can be accommodated within each calorie level, in addition to the suggested amounts of nutrient-dense forms of foods in each group.

Daily Amount of Food From Each Group

Calorie Level[1]	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200
Fruits[2]	1 cup	1 cup	1.5 cups	1.5 cups	1.5 cups	2 cups	2 cups	2 cups	2 cups	2.5 cups	2.5 cups	2.5 cups
Vegetables[3]	1 cup	1.5 cups	1.5 cups	2 cups	2.5 cups	2.5 cups	3 cups	3 cups	3.5 cups	3.5 cups	4 cups	4 cups
Grains[4]	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	6 oz-eq	6 oz-eq	7 oz-eq	8 oz-eq	9 oz-eq	10 oz-eq	10 oz-eq	10 oz-eq
Meat and Beans[5]	2 oz-eq	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	5.5 oz-eq	6 oz-eq	6.5 oz-eq	6.5 oz-eq	7 oz-eq	7 oz-eq	7 oz-eq
Milk[6]	2 cups	2 cups	2 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups	3 cups
Oils[7]	3 tsp	4 tsp	4 tsp	5 tsp	5 tsp	6 tsp	6 tsp	7 tsp	8 tsp	8 tsp	10 tsp	11 tsp
Discretionary calorie allowance[8]	165	171	171	132	195	267	290	362	410	426	512	648

1. **Calorie Levels** are set across a wide range to accommodate the needs of different individuals. The attached table "Estimated Daily Calorie Needs" can be used to help assign individuals to the food intake pattern at a particular calorie level.
2. **Fruit Group** includes all fresh, frozen, canned, and dried fruits and fruit juices. In general, 1 cup of fruit or 100% fruit juice,or ½ cup of dried fruit can be considered as 1 cup from the fruit group.
3. **Vegetable Group** includes all fresh, frozen, canned, and dried vegetables and vegetable juices. In general, 1 cup of raw orcooked vegetables or vegetable juice, or 2 cups of raw leafy greens can be considered as 1 cup from the vegetable group.

Vegetable Subgroup Amounts are Per Week

Calorie Level	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200
Dark green veg.	1 c/wk	1.5 c/wk	1.5 c/wk	2 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk
Orange veg.	0.5 c/wk	1 c/wk	1 c/wk	1.5 c/wk	2 c/wk	2 c/wk	2 c/wk	2 c/wk	2.5 c/wk	2.5 c/wk	2.5 c/wk	2.5 c/wk
Legumes	0.5 c/wk	1 c/wk	1 c/wk	2.5 c/wk	3 c/wk	3 c/wk	3 c/wk	3 c/wk	3.5 c/wk	3.5 c/wk	3.5 c/wk	3.5 c/wk
Starchy veg.	1.5 c/wk	2.5 c/wk	2.5 c/wk	2.5 c/wk	3 c/wk	3 c/wk	6 c/wk	6 c/wk	7 c/wk	7 c/wk	9 c/wk	9 c/wk
Other veg.	3.5 c/wk	4.5 c/wk	4.5 c/wk	5.5 c/wk	6.5 c/wk	6.5 c/wk	7 c/wk	7 c/wk	8.5 c/wk	8.5 c/wk	10 c/wk	10 c/wk

4. **Grains Group** includes all foods made from wheat, rice, oats, cornmeal, barley, such as bread, pasta, oatmeal, breakfast cereals, tortillas, and grits. In general, 1 slice of bread, 1 cup of ready-to-eat cereal, or ½ cup of cooked rice, pasta, or cooked ceral can be considered as 1 ounce equivalenfrom the grains group. **At least half of all grains consumedshould be whole grains**.
5. **Meat & Beans Group** in general, 1 ounce of lean meat, poultry, or fish, 1 egg, 1 Tbsp. peanut butter, ¼ cup cooked drybeans, or ½ ounce of nuts or seeds can be considered as 1 ounce equivalent from the meat and beans group.
6. **Milk Group** includes all fluid milk products and foods made from milk that retain their calcium content, such as yogurt and cheese. Foods made from milk that have little to no calcium, such as cream cheese, cream, and butter, are not part of the group. Most milk group choices should be fat-free or low-fat.

In general, 1 cup of milk or yogurt, **1**½ ounces of natural cheese, or 2 ounces of processed cheese can be considered as 1 cup from the milk group.

7. **Oils** include fats from many different plants and from fish that are liquid at room temperature, such as canola, corn, olive, soybean, and sunflower oil. Some foods are naturally high in oils, like nuts, olives, some fish, and avocados. Foods that are mainly oil include mayonnaise, certain salad dressings, and soft margarine.
8. **Discretionary Calorie Allowance** is the remaining amount of calories in a food intake pattern after accounting for the calories needed for all food groups—using forms of foods that are fat-free or low-fat and with no added sugars.

ESTIMATED DAILY CALORIE NEEDS

To determine which food intake pattern to use foan individual, the following chart gives an estimate of individual calorie needs. The calorie range for each age/sex group is based on physical activity level, from sedentary to active.

Sedentary means a lifestyle that includes only the light physical activity associated with typical day-to-day life.

Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3 to 4 miles per hour, in addition to the light physical activity associated with typical day-to-day life.

		Calorie Range		
		Sedentary	→	Active
Children	2–3 years	1,000	→	1,400
Females	4–8 years	1,200	→	1,800
	9–13	1,600	→	2,200
	14–18	1,800	→	2,400
	19–30	2,000	→	2,400
	31–50	1,800	→	2,200
	51+	1,600	→	2,200
Males	4–8 years	1,400	→	2,000
	9–13	1,800	→	2,600
	14–18	2,200	→	3,200
	19–30	2,400	→	3,000
	31–50	2,200	→	3,000
	51+	2,000	→	2,800

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APPENDIX F Sample 24-Hour Physical Activity Log

Time	Activity	Time in Activity (min)	Code Number*	Intensity (METs)*	Expenditure Rate (kcal/hr)**	Time in Activity (hr)	Total kcals Expdended (kcal)***
12:00 a.m.							
1:00 a.m.							
2:00 a.m.							
3:00 a.m.							
4:00 a.m.							
5:00 a.m.							
6:00 a.m.							
7:00 a.m.							
8:00 a.m.							
9:00 a.m.							
10:00 a.m.							
11:00 a.m.							
12:00 p.m.							
1:00 p.m.							
2:00 p.m.							
3:00 p.m.							
4:00 p.m.							
5:00 p.m.							
6:00 p.m.							
7:00 p.m.							
8:00 p.m.							
9:00 p.m.							
10:00 p.m.							
11:00 p.m.							

*Ainsworth, B.E., Haskell, W.L., Leon, A.S., Jacobs, Jr., D.R., Montoye, H.J., Sallis, J.F., et al. (1993). Compendium of physical activities: classification of energy costs of human physical activities. *Medicine and Science in Sports and Exercise,* 25(1), 71–80.

*Ainsworth, B.E., Haskell, W.L. Whitt, M.C., Irwin, M.L., Swartz, A.M., Strath, S.J., O'Brien, W.L. Basset, Jr., D.R., Schmitz, K.H., Emplancourt, P.O., Jacobs, D.R. & Leon, A.S. (2000). Compendium of physical activities an update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise,* 32(9), S498–S516.

**kcal expenditure rate is determined by multiplying the MET value for the activity × weight in kg × RMR (1.0 for men and 0.9 for women). For example, a 61 kg female walks at a moderate pace for 30 minutes, which is a MET value of 3.3. The kcal expenditure rate for this activity is: 3.3 x 61 x 0.9 = 181 kcal/hour.

***Total kcal expenditure for each activity is determined by multiplying the kcal expenditure rate by the time in the activity in hours (divide time in minutes by 60). For example, the 61 kg female that walked at a moderate pace for 30 minutes expended 181 kcals per hour, but walked for only a half hour. Total kcals expended was: 181 kcal/hour × 0.5 hour = 90.5 kcals.

APPENDIX G The Compendium of Physical Activities

The Compendium of Physical Activities Tracking Guide

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
01009	8.5	01009	8.5	bicycling	bicycling, BMX or mountain
01010	4.0	01010	4.0	bicycling	bicycling, <10 mph, leisure, to work or for pleasure (Taylor Code 115)
		01015	8.0	bicycling	bicycling, general
01020	6.0	01020	6.0	bicycling	bicycling, 10–11.9 mph, leisure, slow, light effort
01030	8.0	01030	8.0	bicycling	bicycling, 12–13.9 mph, leisure, moderate effort
01040	10.0	01040	10.0	bicycling	bicycling, 14–15.9 mph, racing or leisure, fast, vigorous effort
01050	12.0	01050	12.0	bicycling	bicycling, 16–19 mph, racing/not drafting or >19 mph drafting, very fast, racing general
01060	16.0	01060	16.0	bicycling	bicycling, >20 mph, racing, not drafting
01070	5.0	01070	5.0	bicycling	unicycling
02010	5.0	02010	7.0	conditioning exercise	bicycling, stationary, general
02011	3.0	02011	3.0	conditioning exercise	bicycling, stationary, 50 watts, very light effort
02012	5.5	02012	5.5	conditioning exercise	bicycling, stationary, 100 watts, light effort
02013	7.0	02013	7.0	conditioning exercise	bicycling, stationary, 150 watts, moderate effort
02014	10.5	02014	10.5	conditioning exercise	bicycling, stationary, 200 watts, vigorous effort
02015	12.5	02015	12.5	conditioning exercise	bicycling, stationary, 250 watts, very vigorous effort
02020	8.0	02020	8.0	conditioning exercise	calisthenics (e.g., pushups, situps, pullups, jumping jacks), heavy, vigorous effort
02030	4.5	02030	3.5	conditioning exercise	calisthenics, home exercise, light or moderate effort, general (example: back exercises), going up & down from floor (Taylor Code 150)
02040	8.0	02040	8.0	conditioning exercise	circuit training, including some aerobic movement with minimal rest, general
02050	6.0	02050	6.0	conditioning exercise	weight lifting (free weight, nautilus or universal-type), power lifting or body building, vigorous effort (Taylor Code 210)
02060	5.5	02060	5.5	conditioning exercise	health club exercise, general (Taylor Code 160)
02065	6.0	02065	9.0	conditioning exercise	stair-treadmill ergometer, general
02070	9.5	02070	7.0	conditioning exercise	rowing, stationary ergometer, general
02071	3.5	02071	3.5	conditioning exercise	rowing, stationary, 50 watts, light effort
02072	7.0	02072	7.0	conditioning exercise	rowing, stationary, 100 watts, moderate effort
02073	8.5	02073	8.5	conditioning exercise	rowing, stationary, 150 watts, vigorous effort
02074	12.0	02074	12.0	conditioning exercise	rowing, stationary, 200 watts, very vigorous effort
02080	9.5	02080	7.0	conditioning exercise	ski machine, general
02090	6.0	02090	6.0	conditioning exercise	slimnastics, jazzercise
02100	4.0	02100	2.5	conditioning exercise	stretching, hatha yoga
		02101	2.5	conditioning exercise	mild stretching
02110	6.0	02110	6.0	conditioning exercise	teaching aerobic exercise class
02120	4.0	02120	4.0	conditioning exercise	water aerobics, water calisthenics
02130	3.0	02130	3.0	conditioning exercise	weight lifting (free, nautilus or universal-type), light or moderate effort, light workout, general
02135	1.0	02135	1.0	conditioning exercise	whirlpool, sitting
03010	6.0	03010	4.8	dancing	ballet or modern, twist, jazz, tap, jitterbug

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
03015	6.0	03015	6.5	dancing	aerobic, general
		03016	8.5	dancing	aerobic, step, with 6–8 inch step
		03017	10.0	dancing	aerobic, step, with 10–12 inch step
03020	5.0	03020	5.0	dancing	aerobic, low impact
03021	7.0	03021	7.0	dancing	aerobic, high impact
03025	4.5	03025	4.5	dancing	general, Greek, Middle Eastern, hula, flamenco, belly, and swing dancing
03030	5.5	03030	5.5	dancing	ballroom, dancing fast (Taylor Code 125)
		03031	4.5	dancing	ballroom, fast (disco, folk, square), line dancing, Irish step dancing, polka, contra, country
03040	3.0	03040	3.0	dancing	ballroom, slow (e.g., waltz, foxtrot, slow dancing), samba, tango, 19th C, mambo, chacha
		03050	5.5	dancing	Anishinaabe Jingle Dancing or other traditional American Indian dancing
04001	4.0	04001	3.0	fishing and hunting	fishing, general
04010	4.0	04010	4.0	fishing and hunting	digging worms, with shovel
04020	5.0	04020	4.0	fishing and hunting	fishing from river bank and walking
04030	2.5	04030	2.5	fishing and hunting	fishing from boat, sitting
04040	3.5	04040	3.5	fishing and hunting	fishing from river bank, standing (Taylor Code 660)
04050	6.0	04050	6.0	fishing and hunting	fishing in stream, in waders (Taylor Code 670)
04060	2.0	04060	2.0	fishing and hunting	fishing, ice, sitting
04070	2.5	04070	2.5	fishing and hunting	hunting, bow and arrow or crossbow
04080	6.0	04080	6.0	fishing and hunting	hunting, deer, elk, large game (Taylor Code 170)
04090	2.5	04090	2.5	fishing and hunting	hunting, duck, wading
04100	5.0	04100	5.0	fishing and hunting	hunting, general
04110	6.0	04110	6.0	fishing and hunting	hunting, pheasants or grouse (Taylor Code 680)
04120	5.0	04120	5.0	fishing and hunting	hunting, rabbit, squirrel, prairie chick, raccoon, small game (Taylor Code 690)
04130	2.5	04130	2.5	fishing and hunting	pistol shooting or trap shooting, standing
05010	2.5	05010	3.3	home activities	carpet sweeping, sweeping floors
05020	4.5	05020	3.0	home activities	cleaning, heavy or major (e.g., wash car, wash windows, clean garage), vigorous effort
		05021	3.5	home activities	mopping
		05025	2.5	home activities	multiple household tasks all at once, light effort
		05026	3.5	home activities	multiple household tasks all at once, moderate effort
		05027	4.0	home activities	multiple household tasks all at once, vigorous effort
05030	3.5	05030	3.0	home activities	cleaning, house or cabin, general
05040	2.5	05040	2.5	home activities	cleaning, light (dusting, straightening up, changing linen, carrying out trash)
05041	2.3	05041	2.3	home activities	wash dishes-standing or in general (not broken into stand/walk components)
05042	2.3	05042	2.5	home activities	wash dishes; clearing dishes from table-walking
		05043	3.5	home activities	vacuuming
		05045	6.0	home activities	butchering animals
05050	2.5	05050	2.0	home activities	cooking or food preparation-standing or sitting or in general (not broken into stand/walk components), manual appliance

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
05051	2.5	05051	2.5	home activities	serving food, setting table-implied walking or standing
05052	2.5	05052	2.5	home activities	cooking or food preparation-walking
		05053	2.5	home activities	feeding animals
05055	2.5	05055	2.5	home activities	putting away groceries (e.g., carrying groceries, shopping without a grocery cart), carrying packages
05056	8.0	05056	7.5	home activities	carrying groceries upstairs
		05057	3.0	home activities	cooking Indian bread on an outside stove
05060	3.5	05060	2.3	home activities	food shopping with or without a grocery cart, standing or walking
05065	2.0	05065	2.3	home activities	non-food shopping, standing or walking
05066	2.3			home activities	walking shopping (non-grocery shopping)
05070	2.3	05070	2.3	home activities	ironing
05080	1.5	05080	1.5	home activities	sitting-knitting, sewing, lt. wrapping (presents)
05090	2.0	05090	2.0	home activities	implied standing-laundry, fold or hang clothes, put clothes in washer or dryer, packing suitcase
05095	2.3	05095	2.3	home activities	implied walking-putting away clothes, gathering clothes to pack, putting away laundry
05100	2.0	05100	2.0	home activities	making bed
05110	5.0	05110	5.0	home activities	maple syruping/sugar bushing (including carrying buckets, carrying wood)
05120	6.0	05120	6.0	home activities	moving furniture, household items, carrying boxes
05130	5.5	05130	3.8	home activities	scrubbing floors, on hands and knees, scrubbing bathroom, bathtub
05140	4.0	05140	4.0	home activities	sweeping garage, sidewalk or outside of house
05145	7.0			home activities	moving household items, carrying boxes
05146	3.5	05146	3.5	home activities	standing-packing/unpacking boxes, occasional lifting of household items light-moderate effort
05147	3.0	05147	3.0	home activities	implied walking-putting away household items-moderate effort
		05148	2.5	home activities	watering plants
		05149	2.5	home activities	building a fire inside
05150	9.0	05150	9.0	home activities	moving household items upstairs, carrying boxes or furniture
05160	2.5	05160	2.0	home activities	standing-light (pump gas, change light bulb, etc.)
05165	3.0	05165	3.0	home activities	walking-light, non-cleaning (readying to leave, shut/lock doors, close windows, etc.)
05170	2.5	05170	2.5	home activities	sitting-playing with child(ren)-light, only active periods
05171	2.8	05171	2.8	home activities	standing-playing with child(ren)-light, only active periods
05175	4.0	05175	4.0	home activities	walk/run-playing with child(ren)-moderate, only active periods
05180	5.0	05180	5.0	home activities	walk/run-playing with child(ren)-vigorous, only active periods
		05181	3.0	home activities	carrying small children
05185	3.0	05185	2.5	home activities	child care: sitting/kneeling-dressing, bathing, grooming, feeding, occasional lifting of child-light effort, general
05186	3.5	05186	3.0	home activities	child care: standing-dressing, bathing, grooming, feeding, occasional lifting of child-light effort
		05187	4.0	home activities	elder care, disabled adult, only active periods
		05188	1.5	home activities	reclining with baby
		05190	2.5	home activities	sit, play ing with animals, light, only active periods

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
		05191	2.8	home activities	stand, playing with animals, light, only active periods
		05192	2.8	home activities	walk/run, playing with animals, light, only active periods
		05193	4.0	home activities	walk/run, playing with animals, moderate, only active periods
		05194	5.0	home activities	walk/run, playing with animals, vigorous, only active periods
		05195	3.5	home activities	standing-bathing dog
06010	3.0	06010	3.0	home repair	airplane repair
06020	4.5	06020	4.0	home repair	automobile body work
06030	3.0	06030	3.0	home repair	automobile repair
06040	3.0	06040	3.0	home repair	carpentry, general, workshop (Taylor Code 620)
06050	6.0	06050	6.0	home repair	carpentry, outside house, installing rain gutters,building a fence, (Taylor Code 640)
06060	4.5	06060	4.5	home repair	carpentry, finishing or refinishing cabinets or furniture
06070	7.5	06070	7.5	home repair	carpentry, sawing hardwood
06080	5.0	06080	5.0	home repair	caulking, chinking log cabin
06090	4.5	06090	4.5	home repair	caulking, except log cabin
06100	5.0	06100	5.0	home repair	cleaning gutters
06110	5.0	06110	5.0	home repair	excavating garage
06120	5.0	06120	5.0	home repair	hanging storm windows
06130	4.5	06130	4.5	home repair	laying or removing carpet
06140	4.5	06140	4.5	home repair	laying tile or linoleum, repairing appliances
06150	5.0	06150	5.0	home repair	painting, outside home (Taylor Code 650)
06160	4.5	06160	3.0	home repair	painting, papering, plastering, scraping, inside house, hanging sheet rock, remodeling
		06165	4.5	home repair	painting, (Taylor Code 630)
06170	3.0	06170	3.0	home repair	put on and removal of tarp-sailboat
06180	6.0	06180	6.0	home repair	roofing
06190	4.5	06190	4.5	home repair	sanding floors with a power sander
06200	4.5	06200	4.5	home repair	scraping and painting sailboat or powerboat
06210	5.0	06210	5.0	home repair	spreading dirt with a shovel
06220	4.5	06220	4.5	home repair	washing and waxing hull of sailboat, car, powerboat, airplane
06230	4.5	06230	4.5	home repair	washing fence, painting fence
06240	3.0	06240	3.0	home repair	wiring, plumbing
07010	0.9	07010	1.0	inactivity quiet	lying quietly, watching television
		07011	1.0	inactivity quiet	lying quietly, doing nothing, lying in bed awake, listening to music (not talking or reading)
07020	1.0	07020	1.0	inactivity quiet	sitting quietly and watching television
		07021	1.0	inactivity quiet	sitting quietly, sitting smoking, listening to music (not talking or reading), watching a movie in a theate
07030	0.9	07030	0.9	inactivity quiet	sleeping
07040	1.2	07040	1.2	inactivity quiet	standing quietly (standing in a line)
07050	1.0	07050	1.0	inactivity light	reclining-writing
07060	1.0	07060	1.0	inactivity light	reclining-talking or talking on phone

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
07070	1.0	07070	1.0	inactivity light	reclining-reading
		07075	1.0	inactivity light	meditating
08010	5.0	08010	5.0	lawn and garden	carrying, loading or stacking wood, loading/unloading or carrying lumber
08020	6.0	08020	6.0	lawn and garden	chopping wood, splitting logs
08030	5.0	08030	5.0	lawn and garden	clearing land, hauling branches, wheelbarrow chores
08040	5.0	08040	5.0	lawn and garden	digging sandbox
08050	5.0	08050	5.0	lawn and garden	digging, spading, filling garden, composting, (Taylor Code 590)
08060	6.0	08060	6.0	lawn and garden	gardening with heavy power tools, tilling a garden, chain saw
08080	5.0	08080	5.0	lawn and garden	laying crushed rock
08090	5.0	08090	5.0	lawn and garden	laying sod
08095	5.5	08095	5.5	lawn and garden	mowing lawn, general
08100	2.5	08100	2.5	lawn and garden	mowing lawn, riding mower (Taylor Code 550)
08110	6.0	08110	6.0	lawn and garden	mowing lawn, walk, hand mower (Taylor Code 570)
08120	4.5	08120	5.5	lawn and garden	mowing lawn, walk, power mower
		08125	4.5	lawn and garden	mowing lawn, power mower (Taylor Code 590)
08130	4.5	08130	4.5	lawn and garden	operating snow blower, walking
08140	4.0	08140	4.5	lawn and garden	planting seedlings, shrubs
08150	4.5	08150	4.5	lawn and garden	planting trees
08160	4.0	08160	4.3	lawn and garden	raking lawn
		08165	4.0	lawn and garden	raking lawn (Taylor Code 600)
08170	4.0	08170	4.0	lawn and garden	raking roof with snow rake
08180	3.0	08180	3.0	lawn and garden	riding snow blower
08190	4.0	08190	4.0	lawn and garden	sacking grass, leaves
08200	6.0	08200	6.0	lawn and garden	shoveling snow, by hand (Taylor Code 610)
08210	4.5	08210	4.5	lawn and garden	trimming shrubs or trees, manual cutter
08215	3.5	08215	3.5	lawn and garden	trimming shrubs or trees, power cutter, using leaf blower, edger
08220	2.5	08220	2.5	lawn and garden	walking, applying fertilizer or seeding a lawn
08230	1.5	08230	1.5	lawn and garden	watering lawn or garden, standing or walking
08240	4.5	08240	4.5	lawn and garden	weeding, cultivating garden (Taylor Code 580)
08245	5.0	08245	4.0	lawn and garden	gardening, general
		08246	3.0	lawn and garden	picking fruit off trees, picking fruits/vegetables, moderate effort
08250	3.0	08250	3.0	lawn and garden	implied walking/standing-picking up yard, light, picking flowers or vegetables
		08251	3.0	lawn and garden	walking, gathering gardening tools
09010	1.5	09010	1.5	miscellaneous	sitting-card playing, playing board games
09020	2.0	09020	2.3	miscellaneous	standing-drawing (writing), casino gambling, duplicating machine
09030	1.3	09030	1.3	miscellaneous	sitting-reading, book, newspaper, etc.
09040	1.8	09040	1.8	miscellaneous	sitting-writing, desk work, typing

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
09050	1.8	09050	1.8	miscellaneous	standing-talking or talking on the phone
09055	1.5	09055	1.5	miscellaneous	sitting-talking or talking on the phone
09060	1.8	09060	1.8	miscellaneous	sitting-studying, general, including reading and/or writing
09065	1.8	09065	1.8	miscellaneous	sitting-in class, general, including note-taking or class discussion
09070	1.8	09070	1.8	miscellaneous	standing-reading
		09071	2.0	miscellaneous	standing-miscellaneous
		09075	1.5	miscellaneous	sitting-arts and crafts, light effort
		09080	2.0	miscellaneous	sitting-arts and crafts, moderate effort
		09085	1.8	miscellaneous	standing-arts and crafts, light effort
		09090	3.0	miscellaneous	standing-arts and crafts, moderate effort
		09095	3.5	miscellaneous	standing-arts and crafts, vigorous effort
		09100	1.5	miscellaneous	retreat/family reunion activities involving sitting, relaxing, talking, eating
		09105	2.0	miscellaneous	touring/traveling/vacation involving walking and riding
		09110	2.5	miscellaneous	camping involving standing, walking, sitting, light-to-moderate effort
		09115	1.5	miscellaneous	sitting at a sporting event, spectator
10010	1.8	10010	1.8	music playing	accordion
10020	2.0	10020	2.0	music playing	cello
10030	2.5	10030	2.5	music playing	conducting
10040	4.0	10040	4.0	music playing	drums
10050	2.0	10050	2.0	music playing	flute (sitting)
10060	2.0	10060	2.0	music playing	horn
10070	2.5	10070	2.5	music playing	piano or organ
10080	3.5	10080	3.5	music playing	trombone
10090	2.5	10090	2.5	music playing	trumpet
10100	2.5	10100	2.5	music playing	violin
10110	2.0	10110	2.0	music playing	woodwind
10120	2.0	10120	2.0	music playing	guitar, classical, folk (sitting)
10125	3.0	10125	3.0	music playing	guitar, rock and roll band (standing)
10130	4.0	10130	4.0	music playing	marching band, playing an instrument, baton twirling (walking)
10135	3.5	10135	3.5	music playing	marching band, drum major (walking)
11010	4.0	11010	4.0	occupation	bakery, general, moderate effort
		11015	2.5	occupation	bakery, light effort
11020	2.3	11020	2.3	occupation	bookbinding
11030	6.0	11030	6.0	occupation	building road (including hauling debris, driving heavy machinery)
11035	2.0	11035	2.0	occupation	building road, directing traffic (standing)
11040	3.5	11040	3.5	occupation	carpentry, general
11050	8.0	11050	8.0	occupation	carrying heavy loads, such as bricks
11060	8.0	11060	8.0	occupation	carrying moderate loads upstairs, moving boxes (16–40 pounds)

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
11070	2.5	11070	2.5	occupation	chambermaid, making bed (nursing)
11080	6.5	11080	6.5	occupation	coal mining, drilling coal, rock
11090	6.5	11090	6.5	occupation	coal mining, erecting supports
11100	6.0	11100	6.0	occupation	coal mining, general
11110	7.0	11110	7.0	occupation	coal mining, shoveling coal
11120	5.5	11120	5.5	occupation	construction, outside, remodeling
		11121	3.0	occupation	custodial work-buffing the floor with electric buffer
		11122	2.5	occupation	custodial work-cleaning sink and toilet, light effort
		11123	2.5	occupation	custodial work-dusting, light effort
		11124	4.0	occupation	custodial work-feathering arena floor, moderate effort
		11125	3.5	occupation	custodial work-general cleaning, moderate effort
		11126	3.5	occupation	custodial work-mopping, moderate effort
		11127	3.0	occupation	custodial work-take out trash, moderate effort
		11128	2.5	occupation	custodial work-vacuuming, light effort
		11129	3.0	occupation	custodial work-vacuuming, moderate effort
11130	3.5	11130	3.5	occupation	electrical work, plumbing
11140	8.0	11140	8.0	occupation	farming, baling hay, cleaning barn, poultry work, vigorous effort
11150	3.5	11150	3.5	occupation	farming, chasing cattle, non-strenuous(walking), moderate effort
		11151	4.0	occupation	farming, chasing cattle or other livestock on horseback, moderate effort
		11152	2.0	occupation	farming, chasing cattle or other livestock, driving, light effort
11160	2.5	11160	2.5	occupation	farming, driving harvester, cutting hay, irrigation work
11170	2.5	11170	2.5	occupation	farming, driving tractor
11180	4.0	11180	4.0	occupation	farming, feeding small animals
11190	4.5	11190	4.5	occupation	farming, feeding cattle, horses
		11191	4.5	occupation	farming, hauling water for animals, general hauling water
		11192	6.0	occupation	farming, taking care of animals (grooming, brushing, shearing sheep, assisting with birthing, medical care, branding)
11200	8.0	11200	8.0	occupation	farming, forking straw bales, cleaning corral or barn, vigorous effort
11210	3.0	11210	3.0	occupation	farming, milking by hand, moderate effort
11220	1.5	11220	1.5	occupation	farming, milking by machine, light effort
11230	5.5	11230	5.5	occupation	farming, shoveling grain, moderate effort
11240	12.0	11240	12.0	occupation	fire fighter, general
11245	11.0	11245	11.0	occupation	fire fighter, climbing ladder with full gear
11246	8.0	11246	8.0	occupation	firefighter, hauling hoses on ground
11250	17.0	11250	17.0	occupation	forestry, ax chopping, fast
11260	5.0	11260	5.0	occupation	forestry, ax chopping, slow
11270	7.0	11270	7.0	occupation	forestry, barking trees

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
11280	11.0	11280	11.0	occupation	forestry, carrying logs
11290	8.0	11290	8.0	occupation	forestry, felling trees
11300	8.0	11300	8.0	occupation	forestry, general
11310	5.0	11310	5.0	occupation	forestry, hoeing
11320	6.0	11320	6.0	occupation	forestry, planting by hand
11330	7.0	11330	7.0	occupation	forestry, sawing by hand
11340	4.5	11340	4.5	occupation	forestry, sawing, power
11350	9.0	11350	9.0	occupation	forestry, trimming trees
11360	4.0	11360	4.0	occupation	forestry, weeding
11370	4.5	11370	4.5	occupation	furriery
11380	6.0	11380	6.0	occupation	horse grooming
11390	8.0	11390	8.0	occupation	horse racing, galloping
11400	6.5	11400	6.5	occupation	horse racing, trotting
11410	2.6	11410	2.6	occupation	horse racing, walking
11420	3.5	11420	3.5	occupation	locksmith
11430	2.5	11430	2.5	occupation	machine tooling, machining, working sheet meta
11440	3.0	11440	3.0	occupation	machine tooling, operating lathe
11450	5.0	11450	5.0	occupation	machine tooling, operating punch press
11460	4.0	11460	4.0	occupation	machine tooling, tapping and drilling
11470	3.0	11470	3.0	occupation	machine tooling, welding
11480	7.0	11480	7.0	occupation	masonry, concrete
11485	4.0	11485	4.0	occupation	masseur, masseuse (standing)
11490	7.0	11490	7.5	occupation	moving, pushing heavy objects, 75 lbs or more (desks, moving van work)
		11495	12.0	occupation	skindiving or SCUBA diving as a frogman (Navy Seal)
11500	2.5	11500	2.5	occupation	operating heavy duty equipment/automated, not driving
11510	4.5	11510	4.5	occupation	orange grove work
11520	2.3	11520	2.3	occupation	printing (standing)
11525	2.5	11525	2.5	occupation	police, directing traffic (standing)
11526	2.0	11526	2.0	occupation	police, driving a squad car (sitting)
11527	1.3	11527	1.3	occupation	police, riding in a squad car (sitting)
11528	8.0	11528	4.0	occupation	police, making an arrest (standing)
11530	2.5	11530	2.5	occupation	shoe repair, general
11540	8.5	11540	8.5	occupation	shoveling, digging ditches
11550	9.0	11550	9.0	occupation	shoveling, heavy (more than 16 pounds/minute)
11560	6.0	11560	6.0	occupation	shoveling, light (less than 10 pounds/minute)
11570	7.0	11570	7.0	occupation	shoveling, moderate (10 to 15 pounds/minute)
11580	1.5	11580	1.5	occupation	sitting-light office work, general (chemistry lab work, light use of hand tools, watch repair or micro-assembly, light assembly/repair).sitting, reading, driving at work

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
11585	1.5	11585	1.5	occupation	sitting meetings, general, and/or with talking involved, eatting at a business meeting
11590	2.5	11590	2.5	occupation	sitting; moderate (heavy levers, riding mower/forklift, crane operation) teaching stretching or yoga
11600	2.5	11600	2.3	occupation	standing; light (bartending, store clerk, assembling, filing, duplicating, putting up a Christmas tree), standing and talking at work, changing clothes when teaching physical education
11610	3.0	11610	3.0	occupation	standing; light/moderate (assemble/repair heavy parts, welding, stocking, auto repair, pack boxes for moving, etc.), patient care (as in nursing)
		11615	4.0	occupation	lifting items continuously, 10–20 lbs, with limited walking or resting
11620	3.5	11620	3.5	occupation	standing; moderate (assembling at fast rate, intermittent, lifting 50 lbs, hitch/twisting ropes)
11630	4.0	11630	4.0	occupation	standing; moderate/heavy (lifting more than 50 lbs, masonry, painting, paper hanging)
11640	5.0	11640	5.0	occupation	steel mill, fettling
11650	5.5	11650	5.5	occupation	steel mill, forging
11660	8.0	11660	8.0	occupation	steel mill, hand rolling
11670	8.0	11670	8.0	occupation	steel mill, merchant mill rolling
11680	11.0	11680	11.0	occupation	steel mill, removing slag
11690	7.5	11690	7.5	occupation	steel mill, tending furnace
11700	5.5	11700	5.5	occupation	steel mill, tipping molds
11710	8.0	11710	8.0	occupation	steel mill, working in general
11720	2.5	11720	2.5	occupation	tailoring, cutting
11730	2.5	11730	2.5	occupation	tailoring, general
11740	2.0	11740	2.0	occupation	tailoring, hand sewing
11750	2.5	11750	2.5	occupation	tailoring, machine sewing
11760	4.0	11760	4.0	occupation	tailoring, pressing
		11765	3.5	occupation	tailoring, weaving
11766	6.5	11766	6.5	occupation	truck driving, loading and unloading truck (standing)
11770	1.5	11770	1.5	occupation	typing, electric, manual or computer
11780	6.0	11780	6.0	occupation	using heavy power tools such as pneumatic tools (jackhammers, drills, etc.)
11790	8.0	11790	8.0	occupation	using heavy tools (not power) such as shovel, pick, tunnel bar, spade
11791	2.0	11791	2.0	occupation	walking on job, less than 2.0 mph (in office or lab area), very slow
11792	3.5	11792	3.3	occupation	walking on job, 3.0 mph, in office, moderate speed, not carrying anything
11793	4.0	11793	3.8	occupation	walking on job, 3.5 mph, in office, brisk speed, not carrying anythinc
11795	3.0	11795	3.0	occupation	walking, 2.5 mph, slowly and carrying light objects less than 25 pounds
		11796	3.0	occupation	walking, gathering things at work, ready to leave
11800	4.0	11800	4.0	occupation	walking, 3.0 mph, moderately and carrying light objects less than 25 lbs
		11805	4.0	occupation	walking, pushing a wheelchair
11810	4.5	11810	4.5	occupation	walking, 3.5 mph, briskly and carrying objects less than 25 pounds
11820	5.0	11820	5.0	occupation	walking or walk downstairs or standing, carrying objects about 25 to 49 pounds
11830	6.5	11830	6.5	occupation	walking or walk downstairs or standing, carrying objects about 50 to 74 pounds

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
11840	7.5	11840	7.5	occupation	walking or walk downstairs or standing, carrying objects about 75 to 99 pounds
11850	8.5	11850	8.5	occupation	walking or walk downstairs or standing, carrying objects about 100 pounds or over
11870	3.0	11870	3.0	occupation	working in scene shop, theater actor, backstage employee
		11875	4.0	occupation	teach physical education, exercise, sports classes (non-sport play)
		11876	6.5	occupation	teach physical education, exercise, sports classes (participate in the class)
12010	6.0	12010	6.0	running	jog/walk combination (jogging component of less than 10 minutes) (Taylor Code 180)
12020	7.0	12020	7.0	running	jogging, general
		12025	8.0	running	jogging, in place
		12027	4.5	running	jogging on a mini-tramp
12030	8.0	12030	8.0	running	running, 5 mph (12 min/mile)
12040	9.0	12040	9.0	running	running, 5.2 mph (11.5 min/mile)
12050	10.0	12050	10.0	running	running, 6 mph (10 min/mile)
12060	11.0	12060	11.0	running	running, 6.7 mph (9 min/mile)
12070	11.5	12070	11.5	running	running, 7 mph (8.5 min/mile)
12080	12.5	12080	12.5	running	running, 7.5 mph (8 min/mile)
12090	13.5	12090	13.5	running	running, 8 mph (7.5 min/mile)
12100	14.0	12100	14.0	running	running, 8.6 mph (7 min/mile)
12110	15.0	12110	15.0	running	running, 9 mph (6.5 min/mile)
12120	16.0	12120	16.0	running	running, 10 mph (6 min/mile)
12130	18.0	12130	18.0	running	running, 10.9 mph (5.5 min/mile)
12140	9.0	12140	9.0	running	running, cross country
12150	8.0	12150	8.0	running	running (Taylor Code 200)
12160	8.0			running	running, in place
12170	15.0	12170	15.0	running	running, stairs, up
12180	10.0	12180	10.0	running	running, on a track, team practice
12190	8.0	12190	8.0	running	running, training, pushing a wheelchair
12195	3.0			running	running, wheeling, general
13000	2.5	13000	2.0	self care	standing-getting ready for bed, in general
13009	1.0	13009	1.0	self care	sitting on toilet
13010	2.0	13010	1.5	self care	bathing (sitting)
13020	2.5	13020	2.0	self care	dressing, undressing (standing or sitting)
13030	1.5	13030	1.5	self care	eating (sitting)
13035	2.0	13035	2.0	self care	talking and eating or eating only (standing)
		13036	1.0	self care	taking medication, sitting or standing
13040	2.5	13040	2.0	self care	grooming (washing, shaving, brushing teeth, urinating, washing hands, putting on make-up), sitting or standing
		13045	2.5	self care	hairstyling
		13046	1.0	self care	having hair or nails done by someone else, sitting

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
13050	4.0	13050	2.0	self care	showering, toweling off (standing)
14010	1.5	14010	1.5	sexual activity	active, vigorous effort
14020	1.3	14020	1.3	sexual activity	general, moderate effort
14030	1.0	14030	1.0	sexual activity	passive, light effort, kissing, hugging
15010	3.5	15010	3.5	sports	archery (non-hunting)
15020	7.0	15020	7.0	sports	badminton, competitive (Taylor Code 450)
15030	4.5	15030	4.5	sports	badminton, social singles and doubles, general
15040	8.0	15040	8.0	sports	basketball, game (Taylor Code 490)
15050	6.0	15050	6.0	sports	basketball, non-game, general (Taylor Code 480)
15060	7.0	15060	7.0	sports	basketball, officiating (Taylor Code 500)
15070	4.5	15070	4.5	sports	basketball, shooting baskets
15075	6.5	15075	6.5	sports	basketball, wheelchair
15080	2.5	15080	2.5	sports	billiards
15090	3.0	15090	3.0	sports	bowling (Taylor Code 390)
15100	12.0	15100	12.0	sports	boxing, in ring, general
15110	6.0	15110	6.0	sports	boxing, punching bag
15120	9.0	15120	9.0	sports	boxing, sparring
15130	7.0	15130	7.0	sports	broomball
15135	5.0	15135	5.0	sports	children's games (hopscotch, 4-square, dodge ball, playground apparatus, t-ball, tetherball, marbles, jacks, acrace games)
15140	4.0	15140	4.0	sports	coaching: football, soccer, basketball, baseball, swimming, etc.
15150	5.0	15150	5.0	sports	cricket (batting, bowling)
15160	2.5	15160	2.5	sports	croquet
15170	4.0	15170	4.0	sports	curling
15180	2.5	15180	2.5	sports	darts, wall or lawn
15190	6.0	15190	6.0	sports	drag racing, pushing or driving a car
15200	6.0	15200	6.0	sports	fencing
15210	9.0	15210	9.0	sports	football, competitive
15230	8.0	15230	8.0	sports	football, touch, flag, general (Taylor Code 510)
15235	2.5	15235	2.5	sports	football or baseball, playing catch
15240	3.0	15240	3.0	sports	frisbee playing, general
15250	3.5	15250	8.0	sports	frisbee, ultimate
15255	4.5	15255	4.5	sports	golf, general
15260	5.5			sports	golf carrying clubs
		15265	4.5	sports	golf, walking and carrying clubs (See footnote at end of the Compendium)
15270	3.0	15270	3.0	sports	golf, miniature, driving range
15280	5.0			sports	golf, pulling clubs
		15285	4.3	sports	golf, walking and pulling clubs (See footnote at end of the Compendium)

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
15290	3.5	15290	3.5	sports	golf, using power cart (Taylor Code 070)
15300	4.0	15300	4.0	sports	gymnastics, general
15310	4.0	15310	4.0	sports	hacky sack
15320	12.0	15320	12.0	sports	handball, general (Taylor Code 520)
15330	8.0	15330	8.0	sports	handball, team
15340	3.5	15340	3.5	sports	hand gliding
15350	8.0	15350	8.0	sports	hockey, field
15360	8.0	15360	8.0	sports	hockey, ice
15370	4.0	15370	4.0	sports	horseback riding, general
15380	3.5	15380	3.5	sports	horseback riding, saddling horse, grooming horse
15390	6.5	15390	6.5	sports	horseback riding, trotting
15400	2.5	15400	2.5	sports	horseback riding, walking
15410	3.0	15410	3.0	sports	horseshoe pitching, quoits
15420	12.0	15420	12.0	sports	jai alai
15430	10.0	15430	10.0	sports	judo, jujitsu, karate, kick boxing, tae kwan dc
15440	4.0	15440	4.0	sports	juggling
15450	7.0	15450	7.0	sports	kickball
15460	8.0	15460	8.0	sports	lacrosse
15470	4.0	15470	4.0	sports	motor-cross
15480	9.0	15480	9.0	sports	orienteering
15490	10.0	15490	10.0	sports	paddleball, competitive
15500	6.0	15500	6.0	sports	paddleball, casual, general (Taylor Code 460)
15510	8.0	15510	8.0	sports	polo
15520	10.0	15520	10.0	sports	racquetball, competitive
15530	7.0	15530	7.0	sports	racquetball, casual, general (Taylor Code 470)
15535	11.0	15535	11.0	sports	rock climbing, ascending rock
15540	8.0	15540	8.0	sports	rock climbing, rappelling
15550	12.0	15550	12.0	sports	rope jumping, fast
15551	10.0	15551	10.0	sports	rope jumping, moderate, general
15552	8.0	15552	8.0	sports	rope jumping, slow
15560	10.0	15560	10.0	sports	rugby
15570	3.0	15570	3.0	sports	shuffleboard, lawn bowling
15580	5.0	15580	5.0	sports	skateboarding
15590	7.0	15590	7.0	sports	skating, roller (Taylor Code 360)
		15591	12.0	sports	roller blading (in-line skating)
15600	3.5	15600	3.5	sports	sky diving
15605	10.0	15605	10.0	sports	soccer, competitive
15610	7.0	15610	7.0	sports	soccer, casual, general (Taylor Code 540)

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
15620	5.0	15620	5.0	sports	Softball or baseball, fast or slow pitch, general (Taylor Code 440)
15630	4.0	15630	4.0	sports	Softball, officiating
15640	6.0	15640	6.0	sports	Softball, pitching
15650	12.0	15650	12.0	sports	squash (Taylor Code 530)
15660	4.0	15660	4.0	sports	table tennis, ping pong (Taylor Code 410)
15670	4.0	15670	4.0	sports	tai chi
15675	7.0	15675	7.0	sports	tennis, general
15680	6.0	15680	6.0	sports	tennis, doubles (Taylor Code 430)
		15685	5.0	sports	tennis, doubles
15690	8.0	15690	8.0	sports	tennis, singles (Taylor Code 420)
15700	3.5	15700	3.5	sports	trampoline
15710	4.0	15710	4.0	sports	volleyball (Taylor Code 400)
		15711	8.0	sports	volleyball, competitive, in gymnasium
15720	3.0	15720	3.0	sports	volleyball, non-competitive, 6-9 member team, general
15725	8.0	15725	8.0	sports	volleyball, beach
15730	6.0	15730	6.0	sports	wrestling (one match = 5 minutes)
15731	7.0	15731	7.0	sports	wallyball, general
		15732	4.0	sports	track and field (shot, discus, hammer throw)
		15733	6.0	sports	track and field (high jump, long jump, triple jump, javelin, pole vault)
		15734	10.0	sports	track and field (steeplechase, hurdles)
16010	2.0	16010	2.0	transportation	automobile or light truck (not a semi) driving
		16015	1.0	transportation	riding in a car or truck
		16016	1.0	transportation	riding in a bus
16020	2.0	16020	2.0	transportation	flying airplane
16030	2.5	16030	2.5	transportation	motor scooter, motorcycle
16040	6.0	16040	6.0	transportation	pushing plane in and out of hangai
16050	3.0	16050	3.0	transportation	driving heavy truck, tractor, bus
17010	7.0	17010	7.0	walking	backpacking (Taylor Code 050)
17020	3.5	17020	3.5	walking	carrying infant or 15 pound load (e.g., suitcase), level ground or downstair
17025	9.0	17025	9.0	walking	carrying load upstairs, general
17026	5.0	17026	5.0	walking	carrying 1 to 15 lb load, upstairs
17027	6.0	17027	6.0	walking	carrying 16 to 24 lb load, upstairs
17028	8.0	17028	8.0	walking	carrying 25 to 49 lb load, upstairs
17029	10.0	17029	10.0	walking	carrying 50 to 74 lb load, upstairs
17030	12.0	17030	12.0	walking	carrying 74+ lb load, upstairs
		17031	3.0	walking	loading/unloading a car
17035	7.0	17035	7.0	walking	climbing hills with 0 to 9 pound load

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
17040	7.5	17040	7.5	walking	climbing hills with 10 to 20 pound load
17050	8.0	17050	8.0	walking	climbing hills with 21 to 42 pound load
17060	9.0	17060	9.0	walking	climbing hills with 42+ pound load
17070	3.0	17070	3.0	walking	downstairs
17080	6.0	17080	6.0	walking	hiking, cross country (Taylor Code 040)
		17085	2.5	walking	bird watching
17090	6.5	17090	6.5	walking	marching, rapidly, military
17100	2.5	17100	2.5	walking	pushing or pulling stroller with child or walking with children
		17105	4.0	walking	pushing a wheelchair, non-occupational setting
17110	6.5	17110	6.5	walking	race walking
17120	8.0	17120	8.0	walking	rock or mountain climbing (Taylor Code 060)
17130	8.0	17130	8.0	walking	up stairs, using or climbing up ladder (Taylor Code 030)
17140	4.0	17140	5.0	walking	using crutches
17150	2.0	17150	2.0	walking	walking, household walking
		17151	2.0	walking	walking, less than 2.0 mph, level ground, strolling, very slow
		17152	2.5	walking	walking, 2.0 mph, level, slow pace, firm surface
17160	2.5	17160	3.5	walking	walking for pleasure (Taylor Code 010)
		17161	2.5	walking	walking from house to car or bus, from car or bus to go places, from car or bus to and from the worksite
		17162	2.5	walking	walking to neighbor's house or family's house for social reasons
		17165	3.0	walking	walking the dog
17170	3.0	17170	3.0	walking	walking, 2.5 mph, firm surface
17180	3.0	17180	2.8	walking	walking, 2.5 mph, downhill
17190	3.5	17190	3.3	walking	walking, 3.0 mph, level, moderate pace, firm surface
17200	4.0	17200	3.8	walking	walking, 3.5 mph, level, brisk, firm surface, walking for exercise
17210	6.0	17210	6.0	walking	walking, 3.5 mph, uphill
17220	4.0	17220	5.0	walking	walking, 4.0 mph, level, firm surface, very brisk pace
17230	4.5	17230	6.3	walking	walking, 4.5 mph, level, firm surface, very, very brisk
		17231	8.0	walking	walking, 5.0 mph
17250	3.5	17250	3.5	walking	walking, for pleasure, work break
17260	5.0	17260	5.0	walking	walking, grass track
17270	4.0	17270	4.0	walking	walking, to work or class (Taylor Code 015)
		17280	2.5	walking	walking to and from an outhouse
18010	2.5	18010	2.5	water activities	boating, power
18020	4.0	18020	4.0	water activities	canoeing, on camping trip (Taylor Code 270)
		18025	3.3	water activities	canoeing, harvesting wild rice, knocking rice off the stalks
18030	7.0	18030	7.0	water activities	canoeing, portaging
18040	3.0	18040	3.0	water activities	canoeing, rowing, 2.0–3.9 mph, light effort
18050	7.0	18050	7.0	water activities	canoeing, rowing, 4.0–5.9 mph, moderate effort

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
18060	12.0	18060	12.0	water activities	canoeing, rowing, >6 mph, vigorous effort
18070	3.5	18070	3.5	water activities	canoeing, rowing, for pleasure, general (Taylor Code 250)
18080	12.0	18080	12.0	water activities	canoeing, rowing, in competition, or crew or sculling (Taylor Code 260)
18090	3.0	18090	3.0	water activities	diving, springboard or platform
18100	5.0	18100	5.0	water activities	kayaking
18110	4.0	18110	4.0	water activities	paddle boat
18120	3.0	18120	3.0	water activities	sailing, boat and board sailing, windsurfing, ice sailing, general (Taylor Code 235)
18130	5.0	18130	5.0	water activities	sailing, in competition
18140	3.0	18140	3.0	water activities	sailing, Sunfish/Laser/Hobby Cat, Keel boats, ocean sailing, yachting
18150	6.0	18150	6.0	water activities	skiing, water (Taylor Code 220)
18160	7.0	18160	7.0	water activities	skimobiling
18170	12.0			water activities	
18180	16.0	18180	16.0	water activities	skindiving, fast
18190	12.5	18190	12.5	water activities	skindiving, moderate
18200	7.0	18200	7.0	water activities	skindiving, scuba diving, general (Taylor Code 310)
18210	5.0	18210	5.0	water activities	snorkeling (Taylor Code 320)
18220	3.0	18220	3.0	water activities	surfing, body or board
18230	10.0	18230	10.0	water activities	swimming laps, freestyle, fast, vigorous effort
18240	8.0	18240	7.0	water activities	swimming laps, freestyle, slow, moderate or light effort
18250	8.0	18250	7.0	water activities	swimming, backstroke, general
18260	10.0	18260	10.0	water activities	swimming, breaststroke, general
18270	11.0	18270	11.0	water activities	swimming, butterfly, general
18280	11.0	18280	11.0	water activities	swimming, crawl, fast (75 yards/minute), vigorous effort
18290	8.0	18290	8.0	water activities	swimming, crawl, slow (50 yards/minute), moderate or light effort
18300	6.0	18300	6.0	water activities	swimming, lake, ocean, river (Taylor Codes 280, 295)
18310	6.0	18310	6.0	water activities	swimming, leisurely, not lap swimming, general
18320	8.0	18320	8.0	water activities	swimming, sidestroke, general
18330	8.0	18330	8.0	water activities	swimming, synchronized
18340	10.0	18340	10.0	water activities	swimming, treading water, fast vigorous effort
18350	4.0	18350	4.0	water activities	swimming, treading water, moderate effort, general
		18355	4.0	water activities	water aerobics, water calisthenics
18360	10.0	18360	10.0	water activities	water polo
18365	3.0	18365	3.0	water activities	water volleyball
		18366	8.0	water activities	water jogging
18370	5.0	18370	5.0	water activities	Whitewater rafting, kayaking, or canoeing
19010	6.0	19010	6.0	winter activities	moving ice house (set up/drill holes, etc.)
19020	5.5	19020	5.5	winter activities	skating, ice, 9 mph or less

continued

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
19030	7.0	19030	7.0	winter activities	skating, ice, general (Taylor Code 360)
19040	9.0	19040	9.0	winter activities	skating, ice, rapidly, more than 9 mph
19050	15.0	19050	15.0	winter activities	skating, speed, competitive
19060	7.0	19060	7.0	winter activities	ski jumping (climb up carrying skis)
19075	7.0	19075	7.0	winter activities	skiing, general
19080	7.0	19080	7.0	winter activities	skiing, cross country, 2.5 mph, slow or light effort, ski walking
19090	8.0	19090	8.0	winter activities	skiing, cross country, 4.0–4.9 mph, moderate speed and effort, general
19100	9.0	19100	9.0	winter activities	skiing, cross country, 5.0–7.9 mph, brisk speed, vigorous effort
19110	14.0	19110	14.0	winter activities	skiing, cross country, >8.0 mph, racing
19130	16.5	19130	16.5	winter activities	skiing, cross country, hard snow, uphill, maximum, snow mountaineering
19150	5.0	19150	5.0	winter activities	skiing, downhill, light effort
19160	6.0	19160	6.0	winter activities	skiing, downhill, moderate effort, general
19170	8.0	19170	8.0	winter activities	skiing, downhill, vigorous effort, racing
19180	7.0	19180	7.0	winter activities	sledding, tobogganing, bobsledding, luge (Taylor Code 370)
19190	8.0	19190	8.0	winter activities	snow shoeing
19200	3.5	19200	3.5	winter activities	snowmobiling
		20000	1.0	religious activities	sitting in church, in service, attending a ceremony, sitting quietly
		20001	2.5	religious activities	sitting, playing an instrument at church
		20005	1.5	religious activities	sitting in church, talking or singing, attending a ceremony, sitting, active participatior
		20010	1.3	religious activities	sitting, reading religious materials at home
		20015	1.2	religious activities	standing in church (quietly), attending a ceremony, standing quieth
		20020	2.0	religious activities	standing, singing in church, attending a ceremony, standing, active participatior
		20025	1.0	religious activities	kneeling in church/at home (praying)
		20030	1.8	religious activities	standing, talking in church
		20035	2.0	religious activities	walking in church
		20036	2.0	religious activities	walking, less than 2.0 mph-very slow
		20037	3.3	religious activities	walking, 3.0 mph, moderate speed, not carrying anything
		20038	3.8	religious activities	walking, 3.5 mph, brisk speed, not carrying anything
		20039	2.0	religious activities	walk/stand combination for religious purposes, ushei
		20040	5.0	religious activities	praise with dance or run, spiritual dancing in church
		20045	2.5	religious activities	serving food at church
		20046	2.0	religious activities	preparing food at church
		20047	2.3	religious activities	washing dishes/cleaning kitchen at church
		20050	1.5	religious activities	eating at church
		20055	2.0	religious activities	eating/talking at church or standing eating, American Indian Feast day
		20060	3.0	religious activities	cleaning church
		20061	5.0	religious activities	general yard work at church
		20065	2.5	religious activities	standing-moderate (lifting 50 lbs., assembling at fast rate)

1993		2000			
Compcode	METS	Compcode	METS	Heading	Description
		20095	4.0	religious activities	standing-moderate/heavy work
		20100	1.5	religious activities	typing, electric, manual, or computer
		21000	1.5	volunteer activities	sitting-meeting, general, and/or with talking involved
		21005	1.5	volunteer activities	sitting-light office work, in general
		21010	2.5	volunteer activities	sitting-moderate work
		21015	2.3	volunteer activities	standing-light work (filing, talking, assembling)
		21016	2.5	volunteer activities	sitting, child care, only active periods
		21017	3.0	volunteer activities	standing, child care, only active periods
		21018	4.0	volunteer activities	walk/run play with children, moderate, only active periods
		21019	5.0	volunteer activities	walk/run play with children, vigorous, only active periods
		21020	3.0	volunteer activities	standing-light/moderate work (pack boxes, assemble/repair, set up chairs/furniture
		21025	3.5	volunteer activities	standing-moderate (lifting 50 lbs., assembling at fast rate)
		21030	4.0	volunteer activities	standing-moderate/heavy work
		21035	1.5	volunteer activities	typing, electric, manual, or computer
		21040	2.0	volunteer activities	walking, less than 2.0 mph, very slow
		21045	3.3	volunteer activities	walking, 3.0 mph, moderate speed, not carrying anything
		21050	3.8	volunteer activities	walking, 3.5 mph, brisk speed, not carrying anything
		21055	3.0	volunteer activities	walking, 2.5 mph slowly and carrying objects less than 25 pounds
		21060	4.0	volunteer activities	walking, 3.0 mph moderately and carrying objects less than 25 pounds, pushing something
		21065	4.5	volunteer activities	walking, 3.5 mph, briskly and carrying objects less than 25 pounds
		21070	3.0	volunteer activities	walk/stand combination, for volunteer purposes

Blue text = row activity was added to description of that specific compendium code

compcode and METS columns are blank under 1993 this means that the 2000 compcode and METS was added to the new addition to the componedium

compcode and METS columns are blank under 2000 this means that the 1993 compcode and METS was Moved from the new addition of the componedium

METS for certain golfing activities were revised downward from 1993 estimates based on measurement of the activity using indirect calorimetry.

APPENDIX H Percentile Values for Maximal Aerobic Power (ml • kg^{-1} • min^{-1})*

Percentile values for maximal oxygen uptake (mL · kg^{-1} · min^{-1}) in men*

	Age (yr)				
Percentile	20–29 (*N* = 2,234)	30–39 (*N* = 11,158)	40–49 (*N* = 13,109)	50–59 (*N* = 5,641)	60+ (*N* = 1,244)
90	55.1	52.1	50.6	49.0	44.2
80	52.1	50.6	49.0	44.2	41.0
70	49.0	47.4	45.8	41.0	37.8
60	47.4	44.2	44.2	39.4	36.2
50	44.2	42.6	41.0	37.8	34.6
40	42.6	41.0	39.4	36.2	33.0
30	41.0	39.4	36.2	34.6	31.4
20	37.8	36.2	34.6	31.4	28.3
10	34.6	33.0	31.4	29.9	26.7

*Data were obtained from the initial examination of apparently healthy men enrolled in the Aerobics Center Longitudinal Study (ACLS), 1970 to 2002. The study population for the data set was predominantly White and college educated. Maximal treadmill exercise tests were administered using a modified Balke protocol. Maximal oxygen uptake was estimated from the final treadmill speed and grade using the current ACSM equations found in this edition of the *Guidelines*. The data are provided courtesy of the ACLS investigators. The Cooper Institute, Dallas, TX. The ACLS is supported in part by a grant from the National Institute on Aging (AG06945), SN Blair, Principal Investigator. The following may be used as descriptors for the percentile rankings: well above average (90), above average (70), average (50), below average (30), and well below average (10).

Percentile values for maximal oxygen uptake (mL · kg^{-1} · min^{-1}) in women*

	Age (yr)				
Percentile	20–29 (*N* = 1,223)	30–39 (*N* = 3,895)	40–49 (*N* = 4,001)	50–59 (*N* = 2,032)	60+ (*N* = 465)
90	49.0	45.8	42.6	37.8	34.6
80	44.2	41.0	39.4	34.6	33.0
70	41.0	39.4	36.2	33.0	31.4
60	39.4	36.2	34.6	31.4	38.3
50	37.8	34.6	33.0	29.9	26.7
40	36.2	33.0	31.4	28.3	25.1
30	33.0	31.4	29.9	26.7	23.5
20	31.4	29.9	28.3	25.1	21.9
10	28.3	26.7	25.1	21.9	20.3

*Data were obtained from the initial examination of apparently healthy women enrolled in the Aerobics Center Longitudinal Study (ACLS), 1970 to 2002. The study population for the data set was predominantly White and college educated. Maximal treadmill exercise tests were administered using a modified Balke protocol. Maximal oxygen uptake was estimated from the final treadmill speed and grade using the current ACSM equations found in this edition of the *Guidelines*. The data are provided courtesy of the ACLS investigators. The Cooper Institute, Dallas, TX. The ACLS is supported in part by a grant from the National Institute on Aging (AG06945), SN Blair, Principal Investigator. The following may be used as descriptors for the percentile rankings: well above average (90), above average (70), average (50), below average (30), and well below average (10).

Whaley, M.H., Brubaker, P.H., Otto, R.M. & Armstrong, L.E., *American College of Sports Medicine* (2006). ACSM's Guidelines for Exercise Testing and Prescription, 7th ed., Philadelphia, PA: Lippincott, Williams & Wilkins.

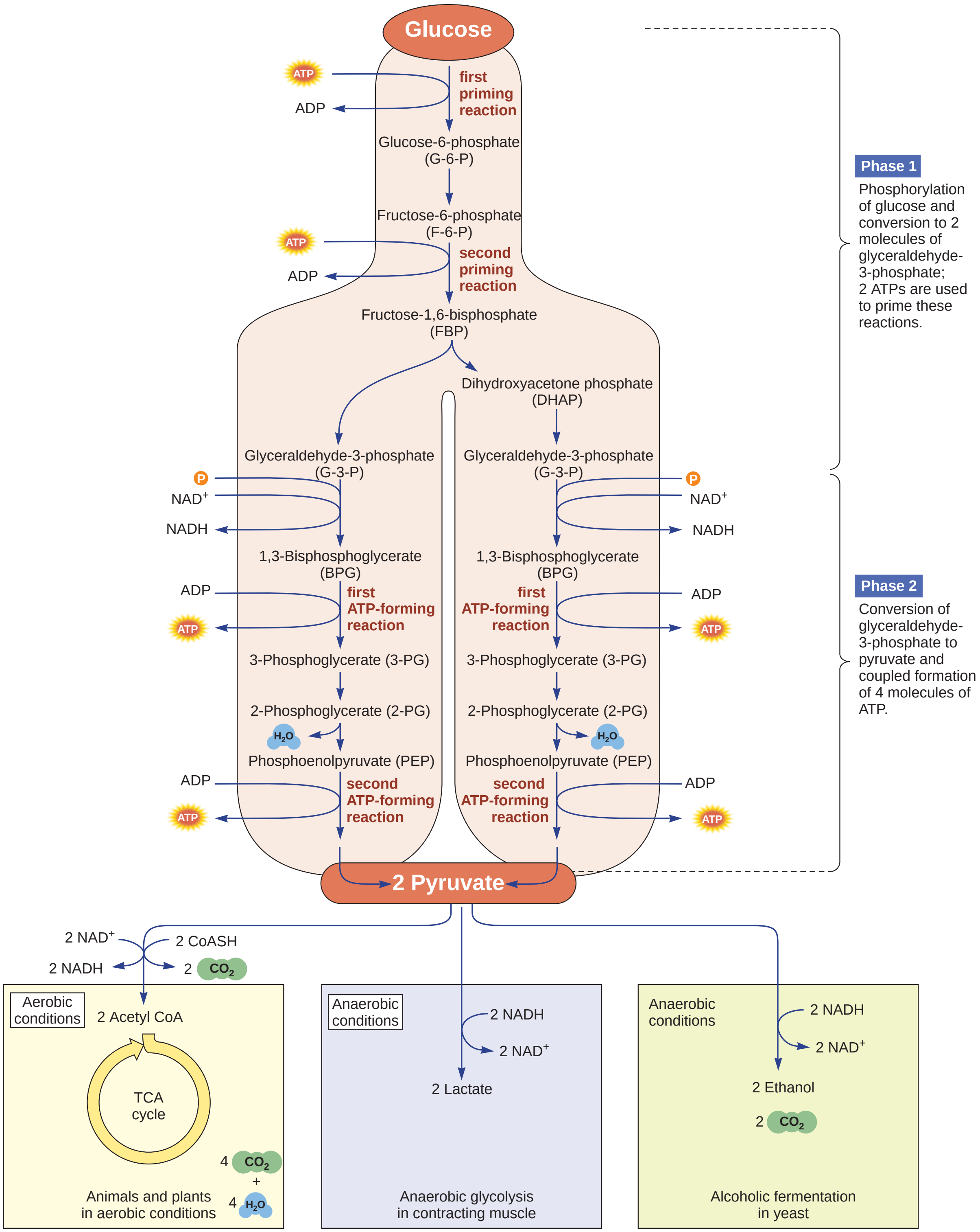
APPENDIX I Respiratory Exchange Ratio (RER)

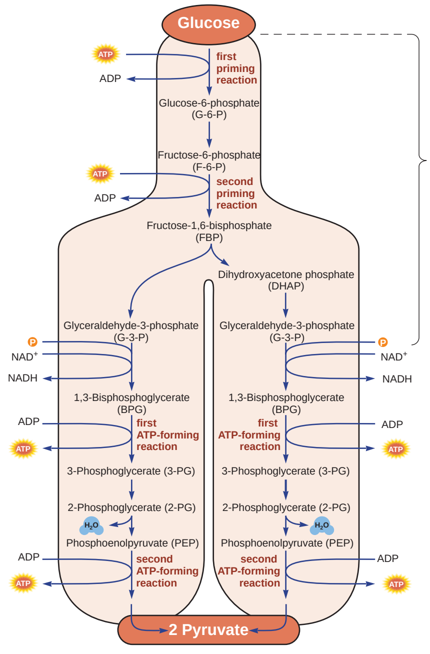
Non-Protein Respiratory Exchange Ratio, Caloric Values for Oxygen Consumption, and Percentages of Energy from Carbohydrate and Fat*

RER	Kcal/Liter O_2	Percent CHO	Percent FAT
0.70	4.686	0.0	100.0
0.71	4.690	1.4	98.6
0.72	4.702	4.8	95.2
0.73	4.714	8.2	91.8
0.74	4.727	11.6	88.4
0.75	4.739	15.0	85.0
0.76	4.752	18.4	81.6
0.77	4.764	21.8	78.2
0.78	4.776	25.2	74.8
0.79	4.789	28.6	71.4
0.80	4.801	32.0	68.0
0.81	4.813	35.4	64.6
0.82	4.825	38.8	61.2
0.83	4.838	42.2	57.8
0.84	4.850	45.6	54.5
0.85	4.863	49.0	51.0
0.86	4.875	52.4	47.6
0.87	4.887	55.8	44.2
0.88	4.900	59.2	40.8
0.89	4.912	62.6	37.4
0.90	4.924	66.0	34.0
0.91	4.936	69.4	30.6
0.92	4.948	72.8	27.2
0.93	4.960	76.2	23.8
0.94	4.973	79.6	20.4
0.95	4.985	83.0	17.0
0.96	4.997	86.4	13.6
0.97	5.010	89.8	10.2
0.98	5.022	93.2	6.8
0.99	5.034	96.6	3.4
1.00	5.047	100.0	0.0

*Carpenter, Thorne M. (1964). Tables, factors, and formulas for computing respiratory exchange and biological transformations of energy. Carnegie Institution of Washington. Washington, DC. Fourth Edition. p. 104.

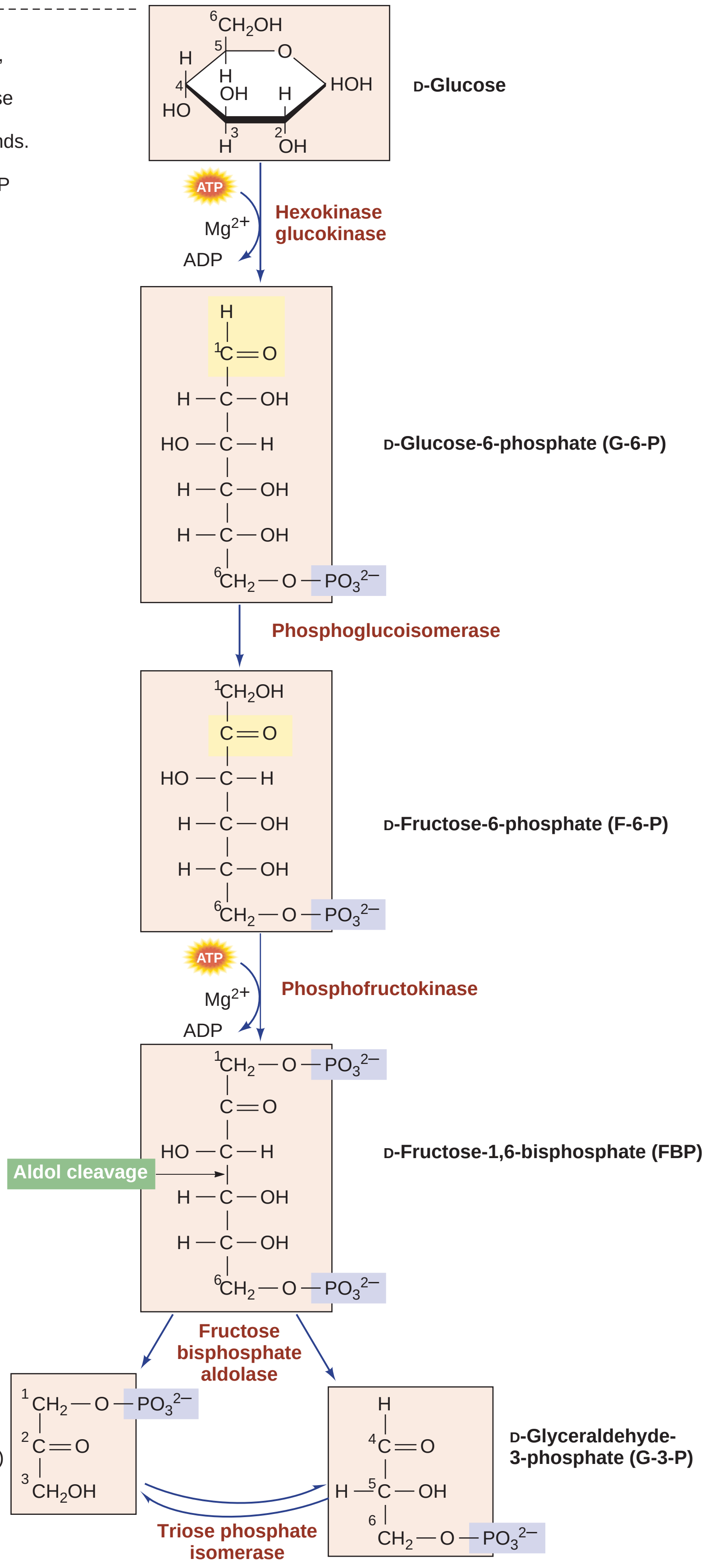
APPENDIX J The Glycolytic Pathway and the Tricarboxylic Acid Cycle

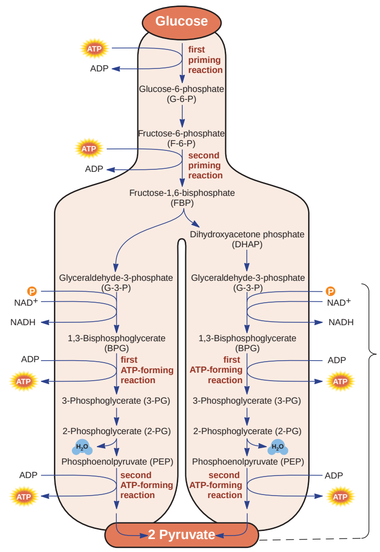




In the first five steps of glycolysis, one 6-carbon molecule of glucose is split into two 3-carbon compounds.

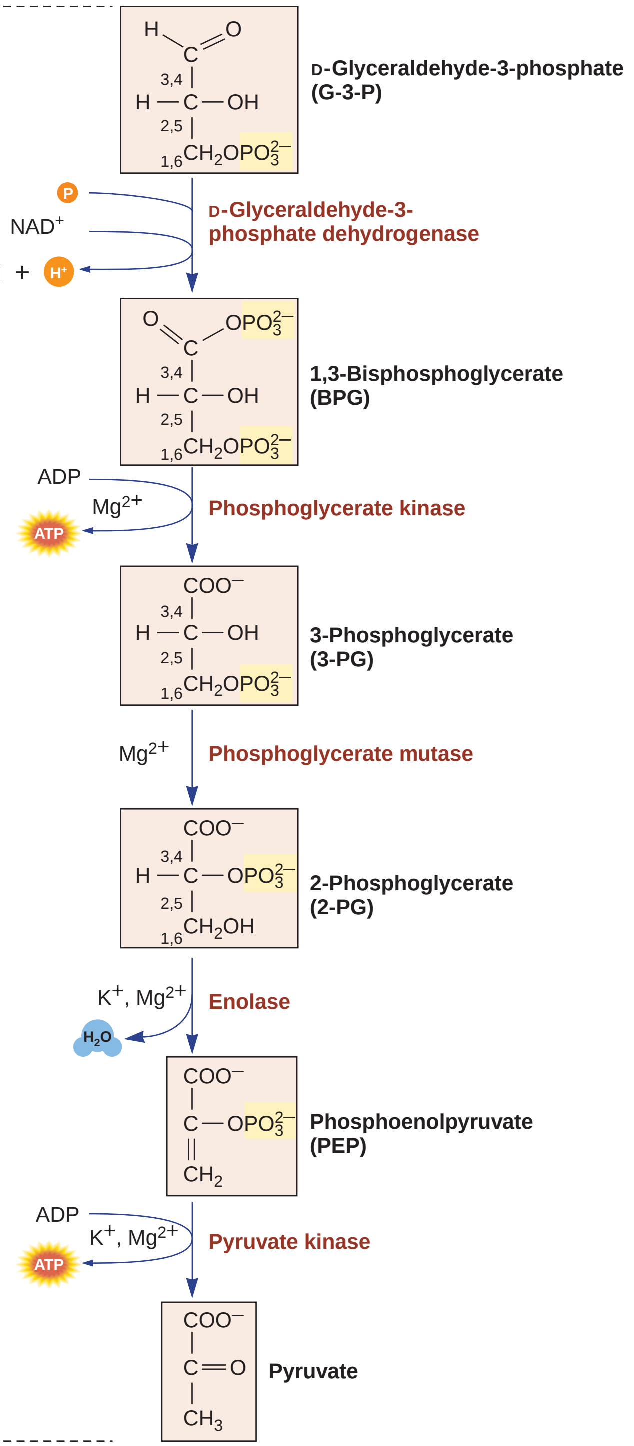
2 molecules of ATP are required to prime these reactions.

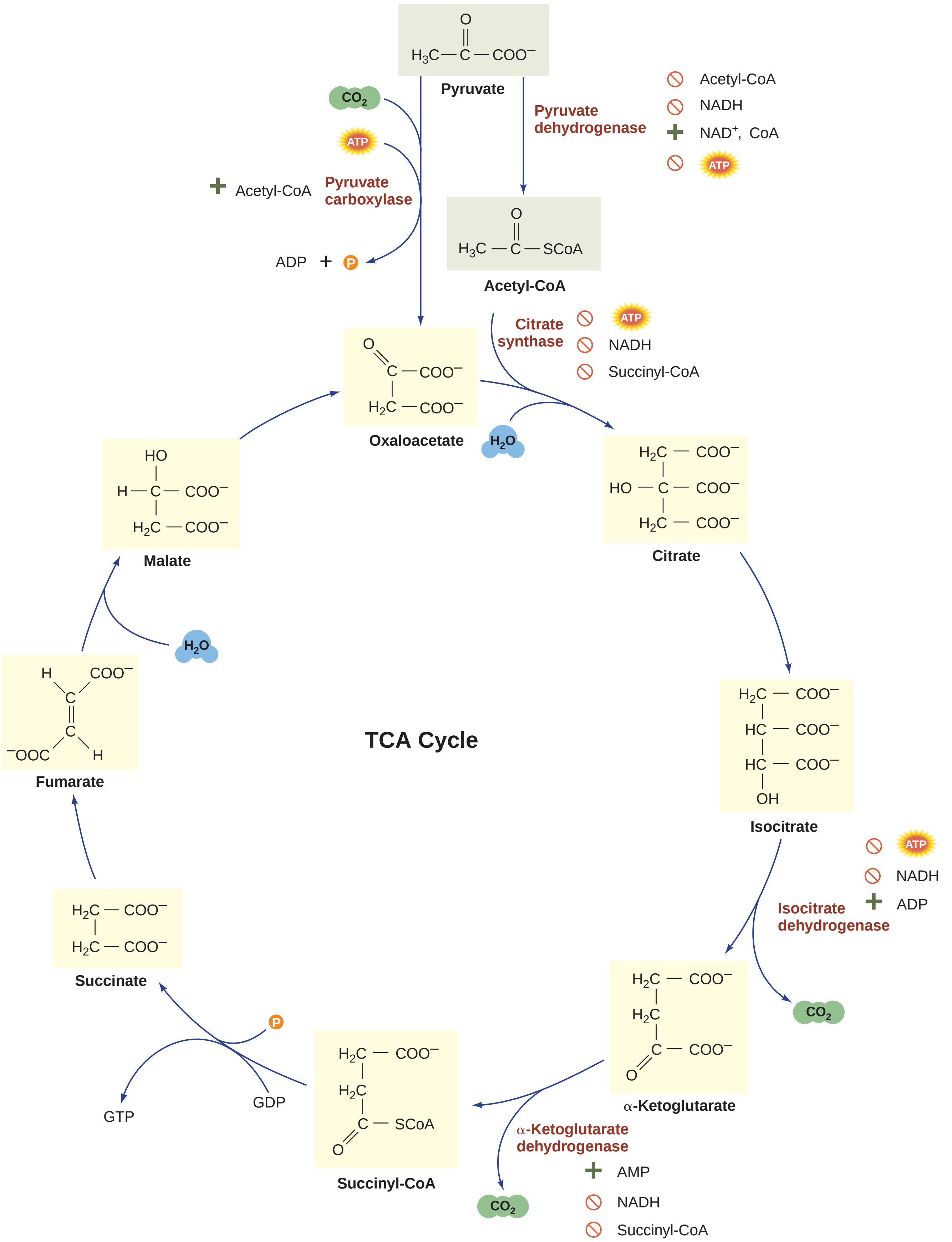




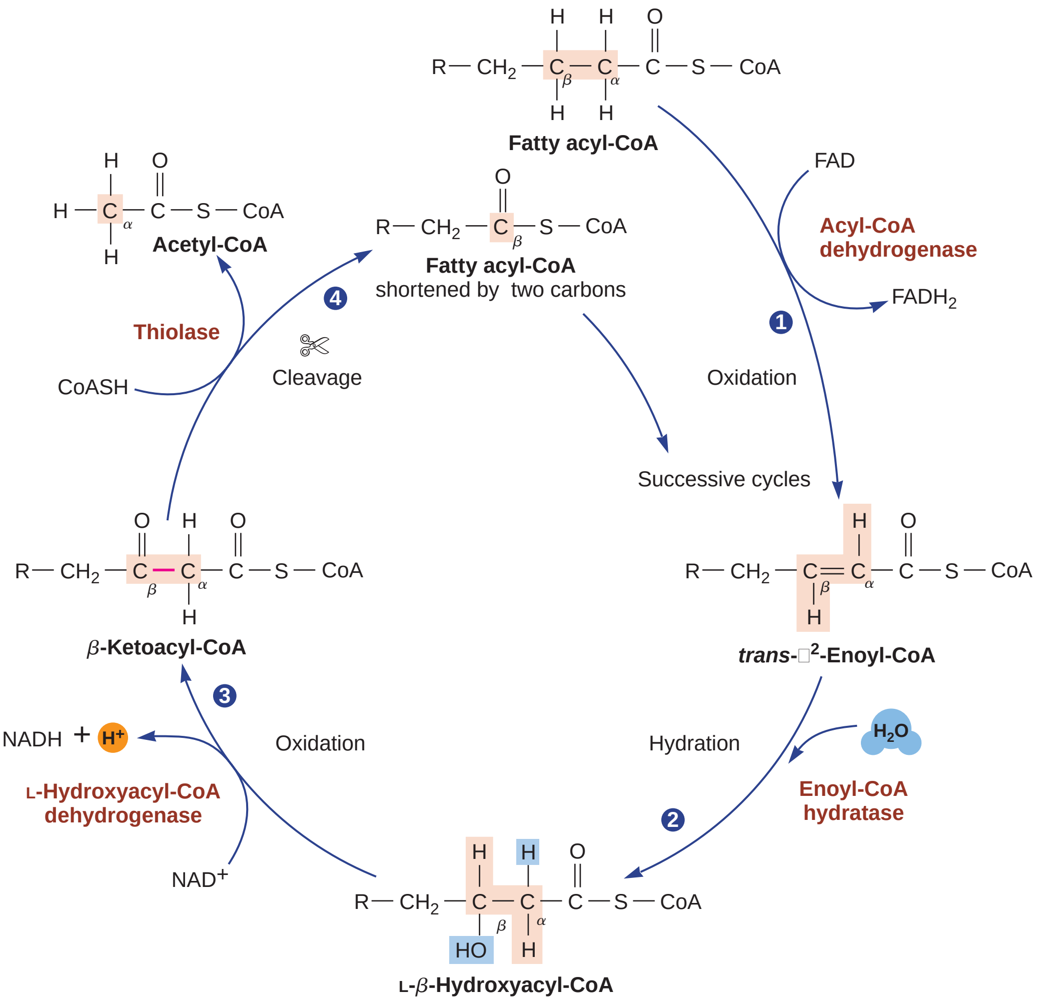
In the second phase of glycolysis, glyceraldehyde-3-phosphate is converted to pyruvate.

These reactions yield 4 molecules of ATP, 2 for each molecule of pyruvate produced.




Pyruvate
Pyruvate dehydrogenase
Acetyl-CoA
NADH
NAD+, CoA
ATP
CO2
Pyruvate carboxylase
Acetyl-CoA
ADP + P
Acetyl-CoA
Citrate synthase
NADH
Succinyl-CoA
Oxaloacetate
H2O
Citrate
Malate
Isocitrate
Isocitrate dehydrogenase
ADP
Fumarate
TCA Cycle
Succinate
GTP
GDP
Succinyl-CoA
α-Ketoglutarate
α-Ketoglutarate dehydrogenase
AMP

APPENDIX K Beta-Oxidation of Fatty Acids



APPENDIX L National Collegiate Athletic Association (NCAA) Bylaw 31.2.3 Ineligibility for Use of Banned Drugs

31.2.3 INELIGIBILITY FOR USE OF BANNED DRUGS

Bylaw 18.4.1.5 provides that a student-athlete who as a result of a drug test administered by the NCAA is found to have utilized a substance on the list of banned drug classes, shall be declared ineligible for further participation in postseason and regular-season competition during the time period ending one calendar year after the student-athlete's positive drug test. The student-athlete shall be charged with the loss of a minimum of one season of competition in all sports if the season of competition has not yet begun or a minimum of the equivalent of one full season of competition in all sports if the student-athlete tests positive during his or her season of competition (i.e., the remainder of contests in the current season and contests in the subsequent season up to the period of time in which the student-athlete was declared ineligible during the previous year). The student-athlete shall remain ineligible until the student-athlete tests negative (in accordance with the testing methods authorized by the Executive Committee) and the student-athlete's eligibility is restored by the Committee on Student-Athlete Reinstatement. *(Revised: 1/16/93, 1/9/96 effective 8/1/96, 1/14/97 effective 8/1/97, 3/10/04, 4/28/05, effective 8/1/05)*

31.2.3.1 Breach of NCAA Drug-Testing Program Protocol A student-athlete who is in breach of the NCAA drug-testing program protocol (e.g., no-show, tampering with sample) shall be considered to have tested positive for the use of any drug other than a "street" drug. *(Revised: 4/28/05, effective 5/1/05)*

31.2.3.2 Testing Positive on Second Occasion If the student-athlete, who tested positive for any drug other than a "street drug" (see Bylaw 31.2.3.4), tests positive a second time for the use of any drug, other than a "street drug", he or she shall lose all remaining regular-season and postseason eligibility in all sports. If the student-athlete tests positive for the use of a "street drug" after being restored to eligibility, he or she shall lose a minimum of one additional season of competition in all sports and also shall remain ineligible for regular-season and postseason competition at least through the next calendar year. Bylaw 18.4.1.5.2 also provides that the Executive Committee shall adopt a list of banned drugs and authorize methods for drug testing of student-athletes on a year-round basis. *(Revised: 4/28/05, effective 8/1/05)*

31.2.3.3 Appeals An institution may appeal the duration of ineligibility to the Committee on Competitive Safeguards and Medical Aspects of Sports (or a designated subcommittee). In all sports, the committee may reduce the legislated penalty to withholding the student-athlete from the next 50 percent of the season of competition or provide complete relief from the legislated penalty. If the committee requires the student-athlete to fulfill the legislated penalty or be withheld from the next 50 percent of the season of competition in all sports, the student-athlete shall remain ineligible until the prescribed penalty is fulfilled, the student-athlete retests negative and the student-athlete's eligibility is restored by the Committee on Student-Athlete Reinstatement. *(Adopted: 4/28/05 effective 8/1/05)*

31.2.3.4 Banned Drugs The following is the list of banned-drug classes. The Committee on Competitive Safeguards and Medical Aspects of Sports (or a designated subcommittee) has the authority to identify specific banned drugs and exceptions within each class. The institution and student-athlete shall be held accountable for all banned-drug classes. The current list of specific banned drugs and exceptions is located on the NCAA Web site (i.e., www.ncaa.org) or may be obtained from the national office. *(Revised: 8/15/89, 7/10/90, 12/3/90, 5/4/92, 5/6/93, 10/29/97, 4/26/01, 2/10/06)*

a. Stimulants; (*Revised: 2/10/06*)
b. Anabolic agents; (*Revised: 2/10/06*)
c. Diuretics; (*Revised: 2/10/06*)
d. Street drugs; (*Revised: 2/10/06*)
e. Peptide hormones and analogues; (*Revised: 2/10/06*)

31.2.3.4.1 Drugs and Procedures Subject to Restrictions The use of the following drugs and/or procedures is subject to certain restrictions and may or may not be permissible, depending on limitations expressed in these guidelines and/or quantities of these substances used: *(Revised: 8/15/89)*

(a) **Blood Doping** The practice of blood doping (the intravenous injection of whole blood, packed red blood cells or blood substitutes) is prohibited, and any evidence confirming use will be cause for action consistent with that taken for a positive drug test. *(Revised: 8/15/89, 5/4/92)*

(b) **Local Anesthetics** The Executive Committee will permit the limited use of local anesthetics under the following conditions:

(1) That procaine, xylocaine, carbocaine or any other local anesthetic may be used, but not cocaine; *(Revised: 12/9/91, 5/6/93)*

(2) That only local or topical injections can be used (i.e., intravenous injections are not permitted); and

(3) That use is medically justified only when permitting the athlete to continue the competition without potential risk to his or her health.

(c) **Manipulation or Urine Samples** The Executive Committee bans the use of substances and methods that alter the integrity and/or validity of urine samples provided during NCAA drug testing. Examples of banned methods are catheterization, urine substitution and/or tampering or modification of renal excretion by the use of diuretics, probenecid, bromantan or related compounds, and epitestosterone administration. *(Revised: 8/15/89, 6/17/92, 7/22/97)*

(d) **Beta 2 Agonists** The use of beta 2 agonists is permitted by inhalation only. *(Adopted: 8/13/93)*

(e) **Additional Analysis** Drug screening for select nonbanned substances may be conducted for nonpunitive purposes. *(Revised: 8/15/89)*

31.2.3.4.2 Positive Drug Test — Non-NCAA Athletics Organization A student-athlete under a drug-testing suspension from a national or international sports governing body that has adopted the World Anti-Doping Agency (WADA) code shall not participate in NCAA intercollegiate competition for the duration of the suspension. *(Adopted: 1/14/97 effective 8/1/97, Revised: 4/28/05 effective 8/1/05)*

31.2.3.5 Medical Exceptions Exceptions for categories (a), (c) and (e) under Bylaw 31.2.3.4 and substances banned for specific sports may be made by the Executive Committee for those student-athletes with a documented medical history demonstrating the need for regular use of such a drug. *(Revised: 8/5/99, 2/10/06)*

31.2.3.6 Methods for Drug Testing The methods and any subsequent modifications authorized by the Executive Committee for drug testing of student-athletes shall be summarized in The NCAA News and posted on the NCAA Web site. Copies of the modifications shall be available to member institutions.

31.2.3.7 Events Identified for Drug Tests The Executive Committee shall determine the regular-season and postseason competition for which drug tests shall be made and the procedures to be followed in disclosing its determinations.

31.2.3.8 Individual Eligibility — Team Sanctions Executive regulations pertaining to team-eligibility sanctions for positive tests resulting from the NCAA drug-testing program shall apply only in the following situation: If a student-athlete is declared ineligible prior to an NCAA team championship or a licensed postseason football game and the institution knowingly allows him or her to participate, all team-ineligibility sanctions shall apply (i.e., the team shall be required to forfeit its awards and any revenue distribution it may have earned, and the team's and student-athlete's performances shall de deleted from NCAA records). In the case of licensed postseason football contests, the team's and student-athlete's performances shall be deleted from NCAA records. *(Revised: 1/10/90)*

NCAA Division 1 Manual 2006–07 NCAA Division Manual, 2006 pp. 422–423.

APPENDIX M Normative Values for Percent Body Fat for Adult Men and Women by Decade

Body Composition (% Body Fat) for Men*

	Age				
Percentile	20–29	30–39	40–49	50–59	60+
90	7.1	11.3	13.6	15.3	15.3
80	9.4	13.9	16.3	17.9	18.4
70	11.8	15.9	18.1	19.8	20.3
60	14.1	17.5	19.6	21.3	22.0
50	15.9	19.0	21.1	22.7	23.5
40	17.4	20.5	22.5	24.1	25.0
30	19.5	22.3	24.1	25.7	26.7
20	22.4	24.2	26.1	27.5	28.5
10	25.9	27.3	28.9	30.3	31.2

*Data provided by the Institute for Aerobics Research, Dallas, TX (1994). Study population for the data set was predominantly White and college educated. The following may be used as descriptors for the percentile rankings: well above average (90), above average (70), average (50), below average (30), and well below average (10).

Body Composition (% Body Fat) for Women*

	Age				
Percentile	20–29	30–39	40–49	50–59	60+
90	14.5	15.5	18.5	21.6	21.1
80	17.1	18.0	21.3	25.0	25.1
70	19.0	20.0	23.5	26.6	27.5
60	20.6	21.6	24.9	28.5	29.3
50	22.1	23.1	26.4	30.1	30.9
40	23.7	24.9	28.1	31.6	32.5
30	25.4	27.0	30.1	33.5	34.3
20	27.7	29.3	32.1	35.6	36.6
10	32.1	32.8	35.0	37.9	39.3

*Data provided by the Institute for Aerobics Research, Dallas, TX (1994). Study population for the data set was predominantly White and college educated. The following may be used as descriptors for the percentile rankings: well above average (90), above average (70), average (50), below average (30), and well below average (10).

Whaley, M.H., Brubaker, P.H., Otto, R.M. & Armstrong, L.E., *American College of Sports Medicine* (2006). ACSM's Guidelines for Exercise Testing and Prescription, 7th ed., Philadelphia, PA: Lippincott, Williams & Wilkins.

APPENDIX N Body Mass Index (BMI)

Find your height along the left-hand column and look across the row until you find the number that is closest to your weight. The number at the top of that column identifies your BMI. Chapter 12 describes how BMI correlates with disease risks and defines obesity. A healthy weight range is considered to be a BMI between 18.5–24.9.

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Height	**Body Weight (pounds)**																						
4′10″	86	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167	172	177	181	186	191
4′11″	89	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173	178	183	188	193	198
5′0″	92	97	102	107	112	118	123	128	133	138	143	148	153	158	163	168	174	179	184	189	194	199	204
5′1″	95	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185	190	195	201	206	211
5′2″	98	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191	196	202	207	213	218
5′3″	102	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	191	197	203	208	214	220	225
5′4″	105	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204	209	215	221	227	232
5′5″	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210	216	222	228	234	240
5′6″	112	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	210	216	223	229	235	241	247
5′7″	115	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223	230	236	242	249	255
5′8″	118	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230	236	243	249	256	262
5′9″	122	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236	243	250	257	263	270
5′10″	126	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243	250	257	264	271	278
5′11″	129	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250	257	265	272	279	286
6′0″	132	140	147	154	162	169	177	184	191	199	206	213	221	228	235	242	250	258	265	272	279	287	294
6′1″	136	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265	272	280	288	295	302
6′2″	141	148	155	163	171	179	186	194	202	210	218	225	233	241	249	256	264	272	280	287	295	303	311
6′3″	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279	287	295	303	311	319
6′4″	148	156	164	172	180	189	197	205	213	221	230	238	246	254	263	271	279	287	295	304	312	320	328
6′5″	151	160	168	176	185	193	202	210	218	227	235	244	252	261	269	277	286	294	303	311	319	328	336
6′6″	155	164	172	181	190	198	207	216	224	233	241	250	259	267	276	284	293	302	310	319	328	336	345
	Under weight (<18.5)			**Healthy Weight** (18.5–24.9)						**Overweight** (25–29.9)								**Obese** (≥30)					

APPENDIX O Answers to Post-Test Questions

CHAPTER 1: REASSESSING KNOWLEDGE OF SPORTS NUTRITION

1. An athlete's diet is a modification of the general nutrition guidelines made for healthy adults.

   This statement is true. Many of the principles listed in the Dietary Guidelines apply to all people, including athletes. These general nutrition principles can then be modified to fit the demands of training.

2. Nutrition periodization refers to a nutrition plan that is developed to match an athlete's training program.

   This statement is true. Nutrition supports training so nutrition periodization is needed to match training periodization.

3. In the United States, dietary supplements are regulated in the same way as over-the-counter medications.

   This statement is false. Dietary supplements are loosely regulated under the Dietary Supplement Health and Education Act. The active ingredients in over-the-counter medications must be standardized by law, which is not the case for dietary supplements.

4. The scientific aspect of sports nutrition is developing very quickly and quantum leaps are being made in knowledge of sports nutrition.

   This statement is false. Scientific knowledge of sports nutrition is increasing but its progress is *slow*, as is the case for most science-based disciplines.

5. To legally use the title of sports nutritionist in the United States, a person must have a bachelor's degree in nutrition.

   This statement is false. Nutritionist is a broad term and anyone in the United States can claim to be a sports nutritionist. The certification of sports nutritionists who possess at least a bachelor's degree is in its infancy.

CHAPTER 2: REASSESSING KNOWLEDGE OF ENERGY

1. The body creates energy from the food that is consumed.

   This statement is false. The body cannot *create* energy. Through the process called bioenergetics, the body *transforms* the energy that is contained in food to forms that are usable in the body.

2. The scientific unit of measure of energy is the calorie.

   This statement is false. The unit of measure for energy in SI units is the joule, which is equal to 0.24 calories. Although the term *calorie* (lower case *c*) is widely used in nonscientific writing in the United States, it is technically incorrect.

3. A person's resting metabolic rate can change in response to a variety of factors such as age, food intake, or environmental temperature.

   This statement is true. The two major factors affecting metabolic rate over which people have the most control are building and maintaining muscle mass through strength training and avoidance of a starvation state.

4. Physical activity is responsible for the largest amount of energy expended during the day for the average adult in the United States.

   This statement is false. Resting metabolism makes up approximately 70% of the day's energy expenditure in a sedentary adult, while physical activity comprises only ~20% of the total energy expenditure.

5. The energy source used by all cells in the body is adenosine triphosphate (ATP).

   This statement is true. ATP is referred to as the common energy currency.

CHAPTER 3: REASSESSING KNOWLEDGE OF ENERGY SYSTEMS AND EXERCISE

1. The direct source of energy for force production by muscle is ATP.

   This statement is true.

2. Creatine supplements result in immediate increases in strength, speed, and power.

   This statement is false. Creatine supplementation may be effective for some strength athletes because it allows them to train harder, such as completing more weight-lifting repetitions. Over time, this increase in the training stimulus allows the athlete to potentially become stronger, faster, or more powerful.

3. Lactate is a metabolic waste product that causes fatigue.

   This statement is false. Lactate is an important metabolic product that can be utilized by other cells as a source of energy; the liver can use lactate to make glucose. The accumulation of lactate molecules does not cause fatigue; one likely cause is the metabolic acidosis that is associated with high-intensity exercise when glycolysis is used at a high rate.

4. The aerobic energy system is not active during high-intensity anaerobic exercise.

   This statement is false. All energy systems are active at all times. Aerobic metabolism may not be the predominant energy system during high-intensity exercise described as anaerobic; it will increase in activity to replace creatine phosphate and oxidize lactate after anaerobic exercise.

5. At rest and during low levels of physical activity, fat is the preferred source of fuel for the aerobic energy system.

   This statement is true.

CHAPTER 4: REASSESSING KNOWLEDGE OF CARBOHYDRATE

1. The body uses carbohydrate primarily in the form of fruit sugar, fructose.

   This statement is false. The predominant form of carbohydrate used by the body is glucose and its storage form, glycogen.

2. Sugars such as sucrose (table sugar) are unhealthy and should rarely be a part of an athlete's diet.

   This statement is false. While excessive consumption of sugars may be related to obesity and other long-term health concerns, there are specific circumstances in which the consumption of sugars may be advantageous for athletes (e.g., sports drinks during endurance exercise and high glycemic index food immediately following exercise). That said, athletes should get the majority of their carbohydrates from plant-based foods and high-fiber complex carbohydrates.

3. Low levels of muscle glycogen and blood glucose are often associated with fatigue, particularly during moderate- to high-intensity endurance exercise.

   This statement is true.

4. A diet that contains 70 percent of total kilocalories as carbohydrate will provide the necessary amount of carbohydrate for an athlete.

   This statement is false. This statement could be true if the total amount of energy (kcal) consumed by the athlete is sufficient. An athlete's diet may contain 70 percent of its energy from carbohydrate, but an insufficient number of grams of carbohydrate if the athlete's diet is very low in total calories.

5. Most athletes consume enough carbohydrates daily.

   This statement is false. Most athletes fail to consume the recommended amount of carbohydrate daily and risk having low muscle and liver glycogen stores, which could negatively affect training and performance.

CHAPTER 5: REASSESSING KNOWLEDGE OF PROTEIN

1. Skeletal muscle is the primary site for protein metabolism and is the tissue that regulates protein breakdown and synthesis throughout the body.

   This statement is false. Skeletal muscle is an important site for protein metabolism but the liver plays a primary role both in protein metabolism and its regulation.

2. In prolonged endurance exercise, approximately 3 percent to 5 percent of the total energy used is provided by amino acids.

   This statement is true. Although carbohydrate and fat provide the majority of the energy used in prolonged endurance exercise, when carbohydrate stores are low, energy is provided by amino acids. Research studies suggest that of the total energy used, 3 percent to 5 percent is derived from amino acids.

3. To increase skeletal muscle mass, the body must be in positive nitrogen balance, which requires an adequate amount of protein and energy (calories).

   This statement is true. Energy and protein intake are closely related, and sufficient (but not excessive) amounts of both are needed to achieve positive nitrogen balance and skeletal muscle growth.

4. The daily recommended protein intake for strength athletes is 2.0 to 3.0 g/kg body weight, twice that recommended for endurance athletes.

   This statement is false. The daily recommended protein intake for strength athletes is typically 1.6 to 1.7 g/kg, *slightly higher* than the 1.2 to 1.4 g/kg recommended for endurance athletes.

5. Strength athletes usually need protein supplements because it is difficult to obtain a sufficient amount of protein from food alone.

   This statement is false. Obtaining sufficient protein from food alone is not difficult and surveys of athletes have shown that many consume more than is recommended. Protein supplements may be desirable for athletes for reasons such as convenience, but are optional and not necessary.

CHAPTER 6: REASSESSING KNOWLEDGE OF FAT

1. A low-calorie, low-carbohydrate diet that results in ketosis is dangerous for athletes because it leads to the medical condition known as ketoacidosis.

   This statement is false. The majority of athletes do not have diabetes, and ketosis in those without diabetes rarely leads to ketoacidosis. Such diets would not likely be advantageous for athletes, however, because the low-carbohydrate and low-caloric content is a factor that could undermine training and performance.

2. At rest, the highest percentage of total energy expenditure is from fat and not carbohydrate.

   This statement is true. At rest the body has plenty of time to mobilize and oxidize fats and a sufficient amount of oxygen is available for fat metabolism. As activity intensity increases, the percentage of energy derived from fat declines and that from carbohydrate increases.

3. To lose body fat, it is best to perform low-intensity exercise, which keeps one in the fat-burning zone.

   This statement is false. The most important factor for loss of body fat is total energy expenditure, regardless of the nutrient source.

4. To improve performance, endurance athletes should ingest caffeine because more free fatty acids are oxidized for energy and muscle glycogen is spared.

   This statement is false. While caffeine does increase the mobilization of fatty acids, there is no evidence that fatty acid oxidation is increased or that muscle glycogen is spared. Caffeine's likely effect is the stimulation of the central nervous system.

5. Athletes typically need to follow a very-low-fat diet.

   This statement is false. Athletes may consume less fat than the general population because carbohydrate and protein needs are higher for trained athletes than for sedentary individuals. However, a *very*-low-fat diet may have a negative affect on performance and health.

CHAPTER 7: REASSESSING KNOWLEDGE OF WATER AND ELECTROLYTES

1. The two major aspects of fluid balance are the volume of water and the concentration of the substances in the water.

   This statement is true. The body must have an adequate volume of water to maintain a state of euhydration, a challenge for athletes because of substantial sweat losses and voluntary dehydration. Fluid balance also depends on the concentration of solutes such as sodium and potassium.

2. Now that sports beverages are precisely formulated, it is rare that water would be a better choice than a sports beverage for a trained athlete.

   This statement is false. In some cases water is a better choice than a sports beverage.

3. Athletes should avoid caffeinated drinks because caffeine is a potent diuretic.

   This statement is false. Completely avoiding caffeinated beverages is a recommendation that is no longer made to athletes. Athletes are advised to consume less than 300 mg of caffeine daily, about the amount found in 3 cups of caffeinated coffee.

4. A rule of thumb for endurance athletes is to drink as much water as possible.

   This statement is false. Endurance athletes who drink as much water as possible run the risk of hyponatremia (low blood sodium). Endurance athletes should try to match fluid intake with fluid loss and replenish sodium as needed.

5. Under most circumstances, athletes will not voluntarily drink enough fluid to account for all of water loss during exercise.

   This statement is true. Voluntary dehydration occurs because the human thirst mechanism is imprecise and slow to respond to loss of body water. Furthermore, gastric distress can occur if water intake is greater than water absorption from the gastrointestinal tract or the emptying of water from the stomach is slow. To avoid gastric distress, athletes may not voluntarily drink enough fluid to match fluid loss during exercise.

CHAPTER 8: REASSESSING KNOWLEDGE OF VITAMINS

1. Exercise increases the usage of vitamins, so most athletes need more vitamins than sedentary people.

   This statement is false. In general, exercise does not increase the usage of vitamins. In those cases in which usage may be increased, the additional amount needed would likely be small and easily provided by a vitamin-rich diet.

2. Vitamins provide energy.

   This statement is false. Vitamins help to *regulate* the reactions that produce energy from carbohydrates, proteins, and fats, but the vitamins themselves do not provide any energy (i.e., contain kilocalories).

3. The amount of vitamins an athlete consumes is generally related to the amount of kilocalories consumed.

   This statement is true. When caloric intake is sufficient vitamin intake tends to be adequate and when caloric intake is restricted vitamin intake tends to be low. However, there may be exceptions to this rule such as when a person eats an excess of kilocalories but much of the food is of low-nutrient density.

4. When antioxidant vitamins are consumed in excess, they act like pro-oxidants instead of antioxidants.

   This statement is true. There is evidence that antioxidant vitamins consumed in excess can act as pro-oxidants.

5. Vitamin supplements are better regulated than other dietary supplements because the U.S. Food and Drug Administration sets a maximum dose (amount) for each vitamin.

   This statement is false. Vitamin supplements are regulated under the same law that regulates other supplements. The manufacturer establishes the dose (amount) contained in each vitamin supplement. Doses that exceed the Tolerable Upper Intake Level can be, and are, found in vitamin supplements available for sale in the United States.

CHAPTER 9: REASSESSING KNOWLEDGE OF MINERALS

1. The basic functions of minerals include building body tissues, regulating physiological processes, and providing energy.

   This statement is false. Only carbohydrates, fats, proteins, and alcohol can be metabolized for energy. Minerals do help build body tissues and regulate physiological processes.

2. In general, the body absorbs a high percentage of the minerals consumed.

   This statement is false. The body does not easily excrete most minerals once they have been absorbed, so it must be careful not to overabsorb them. Mineral absorption from food is generally low or moderate.

3. In most cases, exercise does not increase mineral requirements above what is recommended for healthy, lightly active individuals.

   This statement is true. A small amount of some minerals may be lost through sweat or urine as a result of exercise, but the magnitude of that loss is small. The recommendations for daily mineral intake, the Dietary Reference Intakes, should be sufficient to cover any additional losses in most cases.

4. If dietary calcium is inadequate over a long period of time the body maintains its blood calcium concentration by reabsorbing skeletal calcium.

   This statement is true. Calcium is necessary for proper muscle contraction and nerve conduction and blood calcium must be maintained within the normal physiological range. Calcium found in the skeleton, particularly trabecular bone, can be reabsorbed into the blood to help maintain a normal blood calcium concentration.

5. Iron-deficiency anemia has a negative impact on performance.

   This statement is true. Iron-deficiency anemia results in decreased hemoglobin production, which reduces the amount of oxygen that can be delivered to muscle.

CHAPTER 10: REASSESSING KNOWLEDGE OF DIET PLANNING FOR ATHLETES

1. When planning dietary intake, athletes should first consider how much dietary fat would be needed.

   This statement is false. Energy intake provides the framework for planning nutrient intake. Carbohydrate and protein needs are considered first and then the amount of dietary fat needed is determined.

2. The key to eating nutritiously without consuming excess kilocalories is to choose foods that have a high nutrient density.

   This statement is true. A nutrient-dense food contains a high concentration of nutrients in relation to total kilocalories. Nutrient-dense foods are especially important in the diet plan of an athlete who wants to restrict kilocalories to lose weight as body fat.

3. There is no room in the athlete's diet for fast foods.

   This statement is false. Fast foods, especially those that are smaller portions and have not been fried, can easily fit into an athlete's diet plan. However, many fast foods are too high in energy (kcal), fat, and sugar to be everyday foods for the athlete.

4. After exercise, athletes should wait about an hour before consuming food or fluids.

   This statement is false. Food and fluid consumption should begin as soon as possible after exercise ends. Carbohydrates, proteins, water, and electrolytes are needed for restoration and the timing of intake affects recovery.

5. To achieve optimum performance, most athletes will need to use some dietary supplements.

   This statement is false. Training, and a diet to support training, is crucial to achieving optimum performance. The majority of dietary supplements marketed to athletes, especially those sold for the purposes of energy production and weight reduction, are not effective. Most athletes will not need to use dietary supplements to achieve optimum performance.

CHAPTER 11: REASSESSING KNOWLEDGE OF BODY COMPOSITION AND BODY WEIGHT

1. Percent body fat and fat mass can be precisely measured in athletes with a number of different methods.

   This statement is false. Percent body fat and fat mass cannot be measured *precisely*. All methods of determining body compositions are estimates and have some measurement error inherent in the procedure. The subjects and/or the technician can introduce additional error.

2. The most accurate method of measuring body fat for any athlete is underwater weighing.

   This statement is false. Although underwater weighing is widely used and is reasonably accurate for many athletes, it may not be the most accurate method for *all* athletes. Some athletes do not like being submerged underwater and have difficulty exhaling as much air as possible, which introduces more error. Not only would the athlete be more comfortable with another method, the measurement would be more accurate because of subject compliance.

3. In sports in which body weight must be moved or transported over a distance (e.g., distance running), it is a performance advantage to have the lowest weight possible.

   This statement is false. A low weight may be advantageous for athletes in sports in which weight must be moved, such as long distance running, but the *lowest* weight possible is not always associated with good performance. Too many athletes attain the lowest weight possible and then see their performance decline due to low glycogen stores, loss of lean body mass, dehydration, and compromised immune system function.

4. To increase muscle mass, most athletes need a substantial increase in their usual protein intake.

   This statement is false. Increasing muscle mass requires resistance exercise, sufficient energy (kcal), and a *small* increase in protein intake. Substantial increases in dietary proteins are not necessary because most strength athletes are already consuming more than adequate amounts. Higher protein intakes, in the absence of adequate calories and resistance exercise, will not result in an increase in muscle mass.

5. For athletes who want to restrict energy intake to lose body fat, the recommended time to do so is at the beginning of the preseason or during the off-season.

   This statement is true. Trying to restrict energy intake when training volume is high or during the competitive season may negatively impact training and performance. The recommended time to lose body fat is early in the preseason or during the active recovery period (off-season).

CHAPTER 12: REASSESSING KNOWLEDGE OF HEALTH, FITNESS, AND CHRONIC DISEASES

1. There are many contradictions among diet and exercise recommendations that are issued by health promotion organizations.

   This statement is false. Although there are some differences, most of the guidelines are remarkably consistent recommending routine physical activity and the consumption of fruits, vegetables, whole grains, low-fat protein foods, and heart-healthy fats.

2. Elite endurance athletes do not develop hypertension but lesser-trained athletes do.

   This statement is false. Being an elite endurance athlete lowers the risk for developing high blood pressure, but does not eliminate it. Regular exercise helps reduce the risk for hypertension for most people. The majority of people who have high blood pressure are sedentary.

3. Type 2 diabetes is caused by eating too much sugar.

   This statement is false. Type 2 diabetes is typically a result of insulin resistance or a relative lack of insulin compared to the amount needed. A diet high in sugar can contribute to weight gain, which is a factor in type 2 diabetes.

4. A sedentary lifestyle is associated with a higher risk for heart disease, certain types of cancer, and diabetes.

   This statement is true. "Everyone is an athlete," and a sedentary lifestyle is detrimental for many reasons, including a higher risk for developing several chronic diseases.

5. Being physically active helps to reduce disease risk even if a person is obese.

   This statement is true. While attaining and maintaining a healthy weight is preferable, physical activity has health benefits regardless of body weight. Overweight and obese people should be encouraged to be physically active.

CHAPTER 13: REASSESSING KNOWLEDGE OF DISORDERED EATING AND EXERCISE DEPENDENCE

1. Disordered eating and eating disorders only affect female athletes.

   This statement is false. Disordered eating and eating disorders *primarily* affect female athletes but not *only* female athletes. These conditions may not be well recognized or reported in male athletes, which may delay treatment.

2. Anorexia athletica means that an athlete has a classic case of anorexia nervosa.

   This statement is false. Although they share some features, the diagnostic criteria are different for these two conditions.

3. Disordered eating and eating disorders are more likely to be seen among elite female athletes in sports such as distance running and gymnastics.

   This statement is true. Female gymnasts and distance runners are at risk because their sports emphasize and encourage low body weights. Although any athlete can be at risk for disordered eating and eating disorders, elite athletes in these sports are known to have a higher prevalence of these disorders.

4. Coaches cause athletes to develop eating disorders.

   This statement is false. Coaches do not *cause* athletes to develop eating disorders. However, coaches must be careful that their actions do not contribute to or reinforce abnormal or pathological behaviors in athletes.

5. A good diagnostic criterion for exercise dependence is the volume of exercise training (i.e., frequency and duration of exercise).

   This statement is false. The volume of exercise training may vary widely for athletes in different sports or for individual athletes at different times of the season. For example, an amount of running that may be considered excessive for a tennis player may be appropriate for a collegiate cross country runner.

Glossary

Acetyl CoA A chemical compound that is an important entry point into the Krebs cycle.

Activities of Daily Living (ADL) Personal care activities (e.g., bathing, grooming, dressing) and the walking that is necessary for day-to-day living.

Acute Short-term, brief or quick. Opposite of chronic.

Adenosine Diphosphate (ADP) A chemical compound formed by the breakdown of ATP to release energy.

Adenosine Triphosphate (ATP) A chemical compound that provides most of the energy to cells.

Adipocytes Cells that manufacture and store fat.

Adipose tissue Fat tissue. Made up of adipocytes (fat cells).

Adonis Greek mythological character described as an extremely handsome young man.

Aerobic "With oxygen." Used in reference to exercise that primarily uses the oxygen-dependent energy system, oxidative phosphorylation.

Alanine An amino acid.

All-cause mortality All deaths, not just deaths caused by a certain disease, such as cardiovascular disease.

Alpha-keto acid (α-keto acid) The chemical compound that is a result of the deamination (i.e. nitrogen removal) of amino acids.

Alpha-linolenic acid An essential fatty acid.

Ambient In the immediate surrounding area.

Amenorrhea Absence or suppression of menstruation.

Amine An organic compound containing nitrogen, similar to a protein.

Amino acid The basic component of all proteins.

Amino acid pool The amino acids circulating in the plasma or in the fluid found within or between cells.

Anabolism Metabolic processes involving the synthesis of simple molecules into complex molecules.

Anaerobic "Without oxygen." Used in reference to exercise that primarily uses one or both of the energy systems that are not dependent on oxygen, creatine phosphate, or anaerobic glycolysis.

Anaerobic glycolysis A series of chemical steps that break down glucose without the use of oxygen to rephosphorylate ADP to ATP.

Anemia A condition characterized by a reduced oxygen-carrying capacity by the red blood cells.

Anhydrous Containing no water.

Anion A negatively charged ion.

Anorexia athletica Overly restrictive caloric intake and/or excessive exercise in an athlete to attain or maintain a low body weight as a way to improve performance.

Anorexia nervosa A life-threatening eating disorder characterized by a refusal to maintain a minimum body weight.

Anthropometric Body measurements such as height, weight, waist circumference, or skinfold thickness.

Antioxidant Substance that inhibits oxidative reactions and protects cells and tissues from damage.

Aqueous Consisting mostly of water.

Artificial sweetener Laboratory-manufactured compound that provides a sweet taste but few or no calories. Technically known as a nonnutritive sweetener.

Aspirin Medication used to relieve pain, reduce inflammation, and lower fever. Active ingredient is salicylic acid.

Atherosclerosis Narrowing and hardening of the arteries.

Atherosclerotic heart disease Atherosclerosis that occurs in coronary arteries, restricting blood flow to the heart.

Athletic amenorrhea Absence or suppression of menstruation as a result of athletic training.

Atrophy A wasting or decrease in organ or tissue size.

Attenuate To reduce the size or strength of.

Basal Metabolic Rate (BMR) A measure of the amount of energy per unit time necessary to keep the body alive at complete rest.

Beta-carotene One form of carotene, a precursor to vitamin A.

Beta oxidation Chemical process of breaking down fatty-acid chains for aerobic metabolism.

Bicarbonate loading Consumption of sodium bicarbonate or sodium citrate prior to high-intensity exercise to neutralize the acid produced during high-intensity exercise.

Bioavailability The extent to which a nutrient can be absorbed, metabolized, and utilized by the body.

Bioenergetics The process of converting food into biologically useful forms of energy.

Blood doping Intravenous (IV) infusion of the athlete's previously withdrawn blood for the purpose of increasing oxygen-carrying capacity.

Blood glucose The type of sugar found in the blood.

Bone mass Total amount of bone in the body. Expressed in pounds or kilograms.

Bran The husk of the cereal grain.

Branched Chain Amino Acid (BCAA) One of three amino acids (leucine, isoleucine, and valine) that has a side chain that is branched.

Bulimia nervosa An eating disorder characterized by bingeing and purging cycles.

Calcitriol 1,25-dihydroxyvitamin D3, a hormonally active form of vitamin D.

Calorie The amount of heat energy required to raise the temperature of 1 gram of water by 1°C.

Calorimeter A device that measures energy content of food or energy expenditure.

Carbohydrate One of the six classes of nutrients; sugars and starches.

Carbohydrate loading A diet and exercise protocol used to attain maximum glycogen stores prior to an important competition.

Carbohydrates Sugars, starches, and cellulose. Chemical compound made from carbon, hydrogen, and oxygen.

Carbon dioxide production ($\dot{V}_{CO2}$) The amount of carbon dioxide that is produced and eliminated by the body through the lungs.

Carbon skeleton The carbon-containing structure that remains after an amino acid has been deaminated (i.e. nitrogen removed).

Carboxyl group A group of atoms (COOH).

Cardiovascular disease A broad term that refers to all diseases of the cardiovascular system (e.g., heart, arteries, veins).

Cardiovascular fitness Ability to perform endurance-type activities, determined by the heart's ability to provide a sufficient amount of oxygen-laden blood to exercising muscles and the ability of those muscles to take up and use the oxygen.

Carotenoid A precursor to vitamin A, characterized by an orange or red pigment.

Catabolism Metabolic processes involving the breakdown of complex molecules into simpler molecules.

Case study An analysis of a person or a particular situation.

Catalyze Increase the rate of, such as speeding up a chemical reaction.

Cation A positively charged ion.

Causation One variable causes an effect. Also known as causality.

Cellulose The main constituent of the cell walls of plants.

Chitosan A dietary supplement derived from shellfish that is advertised as an aid to weight loss.

Cholesterol A fatlike substance that is manufactured in the body and is found in animal foods.

Chondrocyte A cartilage cell.

Chronic Lasts for a long period of time. Opposite of acute.

Chylomicron A large protein and fat molecule that helps to transport fat.

Citrate/citric acid Chemical compound that is one of the intermediate compounds in the Krebs cycle; the first compound formed in the Krebs cycle by the combination of oxaloacetate and acetyl CoA.

Cis Describes a chemical formation where groups are on the same side of the double bond between carbons.

Clinical, clinically Of or relating to symptoms of disease.

Clinical deficiency Severe lack of, resulting in recognizable medical signs and symptoms.

Complementary proteins The pairing of two incomplete proteins to provide sufficient quantity and quality of amino acids.

Complete protein Protein that contains all the indispensable amino acids in the proper concentrations and proportions to each other to prevent amino acid deficiencies and to support growth.

Conditionally indispensable amino acid Under normal conditions, an amino acid that can be manufactured by the body in sufficient amounts, but under physiologically stressful conditions an insufficient amount may be produced.

Consensus General agreement among members of a group.

Contraindicated Inadvisable because of a likely adverse reaction.

Control group The subjects in a scientific experiment that do not receive a treatment or who receive a placebo. Also known as a nontreatment or placebo group. Subjects in the control group mirror the characteristics of the subjects in the experimental group so the groups can be compared.

Coronary artery disease Reduction of blood flow to the coronary arteries typically caused by atherosclerosis. Also known as coronary heart disease.

Correlation A relationship between variables. Does not imply that one causes the other.

Cortisol A glucocorticoid hormone that is secreted by the adrenal cortex that stimulates protein and fat breakdown and counters the effects of insulin.

Counter-regulatory Counter refers to opposing; regulatory is a mechanism that controls a process. Counter-regulatory refers to two or more compounds that oppose each other's actions.

Crash diet Severe restriction of food intake in an attempt to lose large amounts of body fat rapidly.

Creatine An amine, a nitrogen-containing chemical compound.

Creatine Kinase (CK) Enzyme that catalyzes the creatine phosphate energy system.

Creatine phosphate Organic compound that stores potential energy in its phosphate bonds.

Creatinine Waste product excreted in the urine.

Criterion Accepted standard by which other decisions are judged.

Cytochrome Oxidase (CO) The rate-limiting enzyme of the Krebs cycle.

Daily Value (DV) A term used on food labels; estimates the amount of certain nutrients needed each day. Not as specific as Dietary Reference Intakes.

Deamination Process of removing and eliminating a nitrogen group.

Dehydration The process of going from a state of euhydration to hypohydration.

Denature To change the chemical structure of a protein by chemical or mechanical means.

Densitometry Measurement of body density.

Diabesity Diabetes that is associated with overweight or obesity.

Diabetes A medical disorder of carbohydrate metabolism. May be due to inadequate insulin production (type 1) or decreased insulin sensitivity (type 2) .

Diacylglycerol A two-unit fat.

Diet The food and drink normally consumed; the restriction of food and drink for the purpose of weight loss.

Dietary prescription An individualized plan for an appropriate amount of kilocalories, carbohydrates, proteins, fats and alcohol daily.

Dietary Reference Intakes (DRI) Standard for essential nutrients and other components of food needed by a healthy individual.

Diglyceride A two-unit fat, known technically as a diacylglycerol.

Dipeptide Two amino acids linked by peptide bonds.

Direct calorimetry A scientific method of determining energy content of food or energy expenditure by measuring changes in thermal or heat energy.

Disaccharide A two-sugar unit. Di = two, saccharide = sugar. Sucrose, lactose, and maltose are disaccharides.

Discipline Moderate self-control or restraint.

Disordered Eating (DE) A deviation from normal eating.

Dispensable amino acid Amino acid that the body can manufacture.

Dissociate The breakdown of a compound into simpler components, such as molecules, atoms or ions.

Diuretic Causing an increase output of urine.

Dose-response studies A research experiment for the purpose of finding out the degree of result that occurs for a given amount.

Double bond A chemical bond between two atoms that share two pairs of electrons.

Doubly Labeled Water (DLW) A measurement technique for determining energy expenditure over a long time period using radioactively labeled hydrogen and oxygen.

Dual-Energy X-ray Absorptiometry (DEXA) Imaging procedure for measuring bone mineral density.

Dyslipidemia Abnormal concentration of blood lipids (e.g., cholesterol, lipoproteins, triglycerides).

Eating Disorders (ED) A substantial deviation from normal eating, which meets established diagnostic criteria (e.g., anorexia nervosa, bulimia nervosa, anorexia athletica).

Eating Disorders Not Otherwise Specified (EDNOS) A "mixed eating disorder" in which pathological behaviors are present but the diagnostic criteria are not met for either anorexia nervosa or bulimia nervosa.

Edema An abnormal buildup of fluid between cells.

Effective Causing a result, especially one that is intended or desired.

Eicosanoid A class of compounds manufactured from polyunsaturated fatty acids that are involved in cellular activity, including mediating inflammation.

Electrolyte A substance that will dissociate into ions in solution and is capable of conducting electricity.

Electron transport chain A series of electron-passing reactions that provides energy for ATP formation.

Emaciated Extremely thin; may be a result of self-starvation.

Emulsified Suspending small droplets of one liquid in another liquid, resulting in a mixture of two liquids that normally tend to separate, e.g., oil and water.

Endergonic Chemical reactions that store energy.

Endocrine Relating to glands that secrete hormones.

Endogenous Originating from within the body.

Endosperm Tissue that surrounds and nourishes the embryo inside a plant seed.

Enema Insertion of a liquid via the rectum to induce a bowel movement.

Energy The ability to perform work.

Energy deficit Result of consuming less energy (kcal) than expended.

Enzyme A protein-containing compound that catalyzes biochemical reactions associated with the development of female sex characteristics.

Epidemiology The study of health-related events in a population.

Epinephrine Adrenaline. A stress hormone.

Equivocal Open to more than one interpretation; difficult to interpret or understand.

Ergogenic Ability to generate or improve work. Ergo = work, genic = formation or generation.

Erythrocyte Red blood cell.

Erythropoiesis The production of red blood cells.

Erythropoietin Hormone that stimulates the development of red blood cells in the bone marrow.

Essential Amino Acid (EAA) See indispensable amino acid.

Essential fat Minimum amount of body fat necessary for proper physiological functioning; estimated to be approximately 3 percent of body weight for males and 12 percent for females.

Esterification The process of forming a triglyceride (triacylglycerol) from a glycerol molecule and three fatty acids.

Estimated Energy Requirement (EER) The estimated amount of energy that needs to be consumed to maintain the body's energy balance.

Estrogen Female sex hormone.

Ethical Consistent with agreed principles of correct moral conduct.

Euhydration "Good" hydration (eu = good); a normal or adequate amount of water for proper physiological function.

Eumenorrhea Normal menstruation.

Evidence-based recommendations Recommendations based on scientific studies that document effectiveness.

Excess Post-exercise Oxygen Consumption (EPOC) See oxygen debt.

Excretion The process of eliminating compounds from the body, typically in reference to urine and feces.

Exercise dependence An unhealthy preoccupation with exercising.

Exercise prescription An individualized plan for frequency, intensity, duration, and mode of physical activity.

Exergonic Chemical reactions that release energy.

Exogenous Originating from outside of the body.

Experimental group The subjects in a scientific experiment who receive a treatment or intervention; also known as a treatment group.

Experimental study A research experiment that tests a specific question or hypothesis.

Extracellular fluid All fluids found outside cells. Includes interstitial fluid and plasma.

Fasting Abstaining from food or drink.

Fat One of the six classes of nutrients; most often found in food as three fatty acids attached to glycerol.

Fat blocker A compound that prevents fat found in food from being absorbed.

Fat-Free Mass (FFM) Total amount of all tissues in the body exclusive of fat; includes muscle, bone, fluids, organs, etc. Expressed in pounds or kilograms.

Fatigue Decreased capacity to do mental or physical work.

Fat Mass (FM) Total amount of fat in the body. Expressed in pounds or kilograms.

Fat substitute Compounds that replace the fat that would be found naturally in a food. Most are made from proteins or carbohydrates.

Fatty acid Chains of carbons and hydrogens ending with a carbon with a double bond to oxygen and a single bond to an oxygen/hydrogen (carboxyl group).

Fermentation The breaking down of a substance into a simpler one by a microorganism, such as the production of alcohol from sugar by yeast.

Ferritin Iron-containing storage protein.

Fiber A component of food that resists digestion (e.g., pectin, cellulose).

Flavin Adenine Dinucleotide (FAD) A molecule involved in energy metabolism that contains a derivative of the vitamin riboflavin (vitamin B_2); is a hydrogen acceptor.

Fluid A liquid that contains mostly water.

Force production The generation of tension by contracting muscle.

Free radical A highly reactive molecule with an unpaired electron. Also known as reactive oxygen species (ROS).

Fructose Sugar found naturally in fruits and vegetables. May also be processed from corn syrup and added to foods. Fructose is a monosaccharide.

Galactose Sugar found naturally in food only as part of the disaccharide, lactose. Galactose is a monosaccharide.

Germ When referring to grains, the embryo of the plant seed.

Ghrelin A protein-based hormone secreted by the cells of the stomach and associated with appetite stimulation; counter regulatory to leptin.

Glucagon A hormone produced by the pancreas that raises blood glucose concentration by stimulating the conversion of glycogen to glucose in the liver. It also stimulates gluconeogenesis, the manufacture of glucose by the liver from other compounds. Glucagon is counter-regulatory to insulin.

Gluconeogenesis The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

Glucose Sugar found naturally in food usually as a component of food disaccharides and polysaccharides. Glucose is a monosaccharide.

Glycemic effect The effect that carbohydrate foods have on blood glucose and insulin secretion.

Glycemic Index (GI) A method of categorizing carbohydrate-containing foods based on the body's blood glucose response after carbohydrate ingestion, digestion, and absorption. The index is based on scores up to 100.

Glycemic Load (GL) A method of categorizing carbohydrate-containing foods based on both quality (using glycemic index) and quantity (amount consumed).

Glycemic response The effect that carbohydrate foods have on blood glucose concentration and insulin secretion.

Glycerol A carbon-, hydrogen-, and oxygen-containing molecule that is the backbone of all triglycerides. Glycerol is a sugar alcohol, not a fat.

Glycogen Storage form for carbohydrates in the body; a series of glucose molecules linked together.

Glycogenolysis The breakdown of liver glycogen to glucose and the release of that glucose into the blood.

Glycogen synthase The primary enzyme that controls the process of glycogen formation.

Glycolysis A series of linked chemical reactions that breaks down glucose for energy to replace ATP.

Good Manufacturing Practices (GMP) Quality control procedures for the manufacture of products ingested by humans to ensure quality and purity.

Guanosine Triphosphate (GTP) A high-energy phosphate compound produced in the Krebs cycle used to replenish ATP.

Guar gum A polysaccharide added to processed foods as a thickener.

Heart disease Diseases of the heart and its vessels. A more specific term than cardiovascular disease.

Hematocrit The percentage of the volume of blood that is composed of red blood cells.

Heme Iron. Also refers to a form of iron that is well absorbed (see nonheme).

High-density lipoprotein A fat transporter containing a high proportion of protein and a low proportion of triglyceride and cholesterol. Also known as "good cholesterol." Has a high affinity to remove cholesterol from the surface of arteries and transport it to the liver for metabolism.

High-energy phosphate A chemical compound that stores energy in its phosphate bonds.

Homeostasis A state of equilibrium.

Hormonal milieu The hormonal environment.

Hormone A chemical compound that has a regulatory or stimulatory effect.

Hormone-sensitive lipase An enzyme found in fat cells that helps to mobilize the fat stored there.

Hydrogenated/hydrogenation A chemical process that adds hydrogen. In food processing, used to make oils more solid.

Hydroxyapatite The principal storage form of calcium and phosphorus in the bone.

Hydroxyl group Formed when oxygen attaches to hydrogen (OH).

Hypercaloric An excessive amount of dietary kilocalories compared to what is needed to maintain body weight.

Hyperglycemia Elevated blood glucose. Hyper = excessive, glyc = sugar, emia = blood.

Hyperhydration A temporary excess of water; beyond the normal state of hydration.

Hyperinsulinemia Blood insulin concentration that is higher than the normal range.

Hypertension Blood pressure chronically elevated above normal resting levels.

Hyperthermia Abnormally high body temperature.

Hypertonic Having a higher osmotic pressure than another fluid.

Hypertrophy An increase in size due to enlargement, not an increase in number; in relation to muscle refers to an increase in the size of a muscle due to an increase in the size of individual muscle cells rather than an increase in the total number of muscle cells.

Hypervitaminosis Excessive intake of one or more vitamins.

Hypocaloric A low amount of dietary kilocalories compared to what is needed to maintain body weight.

Hypoglycemia Low blood glucose. Usually defined as a blood glucose concentration below 50 mg/dl (2.76 mmol/L). Hypo = under, glyc = sugar, emia = blood.

Hypohydration An insufficient amount of water; below the normal state of hydration.

Hypotonic Having a lower osmotic pressure than another fluid.

Hypovolemia Less than the normal volume.

Ibuprofen Medication used to relieve pain, reduce inflammation, and lower fever.

Ileum The lowest portion of the small intestine.

Incomplete protein Protein that lacks one or more of the indispensable amino acids in the proper concentrations and proportions to each other to prevent amino acid deficiencies and to support growth.

Incidence The number of new cases of an illness or condition.

Indirect calorimetry A scientific method of determining energy expenditure by measuring changes in oxygen consumption and/or carbon dioxide production.

Indispensable amino acid Amino acid that must be provided by the diet because the body cannot manufacture it.

Inherent Unable to be considered separately.

Insensible Imperceptible.

Insulin Hormone produced by the beta cells of the pancreas that helps to regulate carbohydrate metabolism among other actions.

Insulin resistance A condition in which the hormone insulin fails to stimulate tissues to take up the same amount of glucose.

Intensity The absolute or relative difficulty of physical activity or exercise.

Interindividual A comparison or observation made between people.

Interstitial Found between cells, tissues, or parts of an organ.

Interstitial fluid Fluid located between organs and systems. Not blood or lymph.

Inverse relationship Given two variables, when one increases the other decreases, and vice versa.

Isocitrate Dehydrogenase (IDH) The rate-limiting enzyme for the series of chemical reactions in the Krebs cycle.

Isoleucine A branched chain amino acid.

Isotonic Having an equal osmotic pressure to another fluid.

Jejunum The middle portion of the small intestine.

Joule (J) The International System of Units (SI) way to express energy; specifically, the work done by a force of 1 Newton acting to move an object 1 meter, or 1 Newton-meter. 1 calorie is equal to 4.184 Joules.

Ketoacidosis Medical condition in which the pH of the blood is more acidic than the body tissues.

Ketosis General definition is the production of ketone bodies (a normal metabolic pathway). Medical definition is an abnormal increase in blood ketone concentration.

Kilocalorie (kcal) A unit of expression of energy, equal to 1,000 calories (see calorie).

Kilojoule (kJ) A unit of expression of energy equal to 1,000 Joules (see Joule).

Kinetic energy Energy of motion.

Krebs cycle A series of oxidation-reduction reactions used to metabolize carbohydrates, fats, and proteins.

Labile protein reserve Proteins in the liver and other organs that can be broken down quickly to provide amino acids.

Lactate The metabolic end product of anaerobic glycolysis.

Lactose Sugar found naturally in milk. May also be added to processed foods. Lactose is a disaccharide made up of glucose and galactose.

Laxative A substance that promotes bowel movements.

Lean Body Mass (LBM) Total amount of all physiologically necessary tissue in the body; i.e., fat-free mass and essential body fat. Expressed in pounds or kilograms.

Legal Allowed under the law.

Legumes Plants that have a double-seamed pod containing a single row of beans. Lentils and beans are legumes.

Leptin A hormone produced in adipose tissue that suppresses appetite; considered counter regulatory to ghrelin.

Lethargy Physically slow or mentally dull.

Leukocyte White blood cell.

Linoleic acid An essential fatty acid.

Lipid General medical term for fats found in the blood.

Lipogenesis The production of fat.

Lipolysis The breakdown of a triglyceride (triacylglycerol) releasing a glycerol molecule and three fatty acids.

Lipoprotein A protein-based lipid (fat) transporter.

Lipoprotein lipase An enzyme that releases fatty acids from circulating triglycerides so the fatty acids can be absorbed by fat or muscle cells.

Low-density lipoprotein A fat transporter containing a moderate proportion of protein, a low proportion of triglyceride, and a high proportion of cholesterol. Also known as "bad cholesterol." Has a high affinity to deposit cholesterol on the surface of arteries.

Lumen Space inside a structure such as the blood vessels or the intestine.

Lutein One of the carotenoids with an orange pigment. Also found in some animal fats such as egg yolk.

Luteinizing hormone One of the menstrual cycle hormones associated with ovulation.

Lycopene One of the carotenoids with a red pigment.

Lymph A fluid containing mostly white blood cells.

Macrocycle An athlete's overall training period; often one year but may be longer or shorter.

Macronutrient Nutrient needed in relatively large amounts. The term includes energy, carbohydrates, proteins, fats, cholesterol, and fiber but frequently refers to carbohydrates, proteins, and fats.

Malaise A general feeling of sickness but a lack of any specific symptoms.

Maltose Sugar produced during the fermentation process that is used to make beer and other alcoholic beverages. Maltose is a disaccharide made up of two glucose molecules.

Masters athletes A separate division created by a sports-governing body for athletes older than a certain age. Minimum age varies according to the sport. Also referred to as veteran athletes.

Maximal oxygen consumption ($\dot{V}o_2max$) Highest amount of oxygen that can be utilized by the body; the maximal capacity of the aerobic energy system.

Megaloblastic anemia A type of anemia characterized by large red blood cells.

Menopause Period of time when menstruation diminishes and then ceases. Typically occurs around the age of 50.

Mesocycle Subdivision of the macrocycle; usually many weeks or a few months.

Metabolic acidosis Decrease in pH associated with high-intensity exercise.

Metabolic Equivalent (MET) Level of energy expenditure equal to that measured at rest. 1 MET = 3.5 ml/kg/min of oxygen consumption.

Metabolic resistance A term coined by Dr. Atkins to indicate the inability to lose weight or to continue to lose weight when consuming a diet containing less than 1,000 kcal or 25 g of carbohydrate daily.

Metabolic syndrome A disease characterized by a clustering of metabolic disorders and risk factors obesity, hypertension, dyslipidemia, glucose intolerance, and insulin resistance.

Metabolism All of the physical and chemical changes that take place within the cells of the body.

Microcycle Subdivision of the mesocycle and the smallest subdivision of the macrocycle; usually seven days but may be longer or shorter.

Micronutrient Nutrient needed in relatively small amounts. The term is frequently applied to all vitamins and minerals.

Mineral An inorganic element (e.g., calcium, iron).

Miscible Two or more liquids that can be mixed together.

Monoacylglycerol A one-unit fat.

Monoglyceride A one-unit fat, known technically as a monoacylglycerol.

Monosaccharide A one-sugar unit. Mono = one, saccharide = sugar. Glucose, fructose, and galactose are monosaccharides.

Monounsaturated fat A fat containing only one double bond between carbons. Olive oil is an example.

Mortality Death; the number of deaths in a population.

Muscle dysmorphia Pathological preoccupation with gaining muscle mass.

Muscle mass The total amount of skeletal muscle in the body. Expressed in pounds or kilograms.

Myofibrillar proteins The strandlike proteins that make up the force-producing elements of skeletal muscle, specifically the contractive proteins actin and myosin.

Nicotinamide Adenine Dinucleotide (NAD) Molecule involved in energy metabolism that contains a derivative of the vitamin niacin.

Nitrogen balance When total nitrogen (protein) intake is in equilibrium with total nitrogen loss.

Nonessential amino acid See dispensable amino acid.

Nonheme A form of iron with a lower rate of absorption (see heme).

Noninstitutionalized Not living in an institution such as a nursing home or mental health hospital.

Non-normative A pattern of behavior that deviates from what is considered to be normal.

Norepinephrine Noradrenaline. Hormone and neurotransmitter.

Nutrient dense A food containing a relatively high amount of nutrients compared to the caloric content.

Nutrition periodization The creation of a nutrition plan to support training that has been divided into distinct periods of time (see periodization).

Obese Medical definition is a body mass index greater than 30.

Obsession Idea or feeling that completely occupies the mind, sometimes associated with psychiatric disorders.

Oleic acid A fatty acid that contains 18 carbons.

Olestra A fat substitute that cannot be absorbed by the body.

Oligomenorrhea Menstrual periods that are infrequent or sparse.

Omega fatty acid A fatty acid that contains a double bond that is counted from the omega or terminal end. These fatty acids are characterized as omega-3, omega-6, or omega-9.

Osmolality Osmoles of solute per kilogram of solvent.

Osmolarity Osmoles of solute per liter of solution.

Osmosis Fluid movement through a semipermeable membrane from a greater concentration to a lesser concentration so the concentrations will equalize.

Osteoarthritis Degenerative joint disease characterized by pain and stiffness. Because it is so prevalent it is often referred to simply as arthritis, although there are numerous types of arthritis.

Osteoblast Bone-forming cell.

Osteoclast Bone-removing cell.

Osteopenia Low bone mineral density. A risk factor for osteoporosis.

Osteoporosis Disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture.

Overload An exercise stimulus that is of sufficient magnitude to cause enough stress to warrant long-term changes by the body.

Overweight Medical definition is a body mass index of 25–29.9.

Oxaloacetate Chemical compound that is one of the intermediate compounds in the Krebs cycle.

Oxidation-reduction The giving up of (oxidation) and acceptance of (reduction) electrons in chemical reactions; these reactions typically occur in pairs.

Oxidative phosphorylation The aerobic energy system.

Oxidative stress Damage to cells, organs, or tissues due to reactive oxygen species. Caused by an imbalance between pro-oxidants and antioxidants.

Oxidize/oxidation Chemical process of giving up electrons.

Oxygen consumption ($\dot{V}O_2$) The amount of oxygen used by the body in aerobic metabolism.

Oxygen debt The elevated oxygen consumption that occurs for a short time during the recovery period after an exercise bout has ended; also known as EPOC.

Oxygen deficit The lag in oxygen consumption at the beginning of an exercise bout.

Palmitate One of the most widely distributed fatty acids found in food and in stored body fat.

Pancreas An organ that produces and secretes the hormones insulin and glucagon into the blood. It also secretes digestive juices into the small intestine.

Pancreatic lipase An enzyme secreted by the pancreas that helps to breaks down large fatty acids.

Parathyroid hormone A hormone produced in the parathyroid that helps to raise blood calcium by stimulating bone calcium resorption.

Partial pressure The pressure exerted by one gas within a mixture of gases.

Pathological, pathology A condition that deviates from that which is considered normal.

Peptide Two or more amino acids linked by peptide bonds.

Percent Body Fat (% BF) Amount of fat relative to body mass. Expressed as a percent of total body weight.

Perfuse To spread a liquid (e.g., blood) into a tissue or organ.

Periodization Dividing a block of time into distinct periods. When applied to athletics, the creation of time periods with distinct training goals and/or a nutrition plan to support the training necessary to meet those goals.

Pernicious anemia Anemia caused by a lack of intrinsic factor, which is needed to absorb vitamin B_{12}.

Phosphocreatine See creatine phosphate.

Phosphofructokinase (PFK) The rate-limiting enzyme for glycolysis.

Phospholipid A fat that is similar to a triglyceride but contains phosphate.

Phytochemical Compounds that have biological activity but are not currently known to be required for normal functioning of the body. May have a beneficial effect on health or disease prevention.

Placebo An inactive substance.

Plaque When referring to cardiovascular disease, fatty streaks in vessels that have hardened.

Platelet A cell found in the blood that assists with blood clotting.

Plasma Fluid component of blood or lymph; does not include cells.

Plasma protein Any polypeptide that circulates in the fluid portion of the blood or lymph.

Plethysmography Measuring and recording changes in volume of the body or a body part.

Plyometric A specialized type of athletic training that involves powerful, explosive movements. These movements are preceded by rapid stretching of the muscles or muscle groups that are used in the subsequent movement.

Polypeptide Four or more amino acids linked by peptide bonds; often contain hundreds of amino acids.

Polysaccharide Chains of glucose molecules such as starch. Poly = many, saccharide = sugar.

Polyunsaturated fat A fatty acid with two or more double bonds.

Portal vein A vein that carries blood to the liver; usually refers to the vein from the intestines to the liver.

Potential energy Stored energy.

Power-to-weight ratio An expression of the ability to produce force in a short amount of time relative to body mass.

Prediction equation A statistical method that uses data from a sample population to predict the outcome for individuals not in the sample.

Prepubescent Stage of development just before the onset of puberty.

Prevalence The number of cases of a condition that exists in the population at a given point in time.

Pro-oxidant Compound that increases the formation of reactive oxygen species or free radicals.

Proprietary Privately owned and administered.

Prostaglandin A compound made from arachidonic acid (an omega-6 fatty acid) that has hormone-like (regulatory) activity.

Protein One of the six classes of nutrients; made up of amino acids.

Protein quality The amounts and types of amino acids contained in a protein and their ability to support growth and development.

Protein-sparing effect The consumption of sufficient calories in the form of carbohydrates and fats, which protects proteins from being used as energy before other protein-related functions are met.

Protein turnover The constant change in body proteins as a result of protein synthesis and breakdown.

Proteolysis The breakdown of proteins into amino acids.

Psychiatric Relating to the medical specialty concerned with the diagnosis and treatment of mental or behavioral disorders.

Psychotropic Capable of affecting the mind.

Psyllium The seed of a fleawort that swells when moist and is a functional fiber.

Pyruvate Chemical compound that is an important intermediate of glycolysis.

Rate Speed.

Rate-limiting enzyme In a series of chemical reactions, the enzyme that influences the rate of the entire series of reactions by changes in its activity.

Reactive oxygen species Oxygen ions, free radicals, and peroxides that are highly reactive because of the presence of unpaired electrons.

Reduce/reduction Chemical process of accepting electrons.

Reliability Ability to reproduce a measurement and/or the consistency of repeated measurements.

Rephosphorylation Reestablishing a chemical phosphate bond, as in adenosine diphosphate (ADP) reestablishing a third phosphate bond to become adenosine triphosphate (ATP).

Residual volume The amount of air left in the lungs after a maximal, voluntary exhalation.

Resorb, resorption To break down and assimilate something that was previously formed.

Respiratory Exchange Ratio (RER) Ratio of carbon dioxide production to oxygen consumption; used to determine percentage of fats and carbohydrates used for metabolism.

Resting Energy Expenditure (REE) The amount of energy required by the body to maintain a nonactive but alert state.

Resting Metabolic Rate (RMR) The amount of energy per unit time required by the body to maintain a nonactive but alert state.

Resting oxygen consumption Measurement of energy expenditure while a person is awake, reclining, and inactive Retinol Pre-formed vitamin A.

Safe Unlikely to cause harm, injury, or damage.

Sagittal Related to the median (middle) plane of the body or a body part.

Satiate To satisfy hunger.

Saturated fat A fat that contains no double bonds between carbons.

Scope of practice Legal scope of work based on academic training, knowledge, and experience.

Secretion The process of releasing a substance to the cell's exterior.

Self-efficacy The belief by an individual that he or she can effect change.

Sensible Perceptible.

Serum The fluid that separates from clotted blood. Similar to plasma but without the clotting agents.

Sleep apnea Brief periods during sleep when breathing stops.

Solute A substance dissolved in a solution.

Solvent A substance (usually a liquid) in which other substances are dissolved.

Specificity A training principle that stresses muscle in a manner similar to which they are to perform.

Sports nutrition The application of nutrition and exercise physiology principles to support and enhance training.

Starch A polysaccharide.

Static Not moving or changing.

Steady-state Exercise or activity at an intensity that is unchanging for a period of time.

Sterol A fat whose core structure contains four rings.

Subclinical Producing effects that are not detectable by usual clinical (medical) tests.

Subclinical deficiency Mild to moderate lack of; medical signs and symptoms are typically not present or are difficult to recognize.

Subcutaneous fat Fat that is stored in a layer under the skin.

Sucrose A disaccharide made of glucose and fructose.

Sugar Simple carbohydrates (mono- or disaccharides); In everyday language, used interchangeably with sucrose.

Supine Lying on the back with the face upward and the palms of the hands facing upward or away from the body.

Suprailium An area of the body directly above the crest of the ilium, the hip bone.

Systemic circulation Circulation of blood to all parts of the body other than the lungs.

Testosterone A steroid hormone associated with the development of male sex characteristics.

Thermic Effect of Food (TEF) The amount of energy required by the body to digest and absorb food.

Thermoregulation Maintenance of body temperature in the normal range.

Tonicity The ability of a solution to cause water movement.

Total Energy Expenditure (TEE) The amount of energy that is required by the body, typically determined over the course of a 24-hour day.

Toxicity State or relative degree of being poisonous.

Training A planned program of exercise with the goal of improving or maintaining athletic performance.

Trans Describes a chemical formation in which groups are on opposite sides of the double bond between carbons.

Translocation Moving from one place to another.

Transamination Removal and transfer of a nitrogen group to another compound.

Triacylglycerol A fat composed of three fatty acids attached to a glycerol molecule.

Triglyceride A fat made up of three fatty acids attached to a glycerol molecule, known technically as a triacylglyerol; major storage form of fat in the body.

Tripeptide Three amino acids linked by peptide bonds.

Ultraendurance Very prolonged endurance activities such as the Ironman Triathlons Ultra = excessive.

Unsaturated fat Fatty acids containing one or more double bonds between carbons.

Validity Ability to measure accurately what was intended to be measured.

Vegan One who does not eat food of animal origin.

Visceral fat Fat that is stored around the internal organs.

Visceral tissue Tissue of the major organs, such as the liver.

Vitamin Essential organic (carbon-containing) compound necessary in very small quantities for proper physiological function.

Volume An amount; when applied to exercise training, a term referring to the amount of exercise usually determined by the frequency and duration of activity.

Weight cycling Repeated weight loss and weight gain.

White paper Official, well-researched government report.

Whole food Generally used to describe unprocessed or minimally processed foods.

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Bolded page numbers indicate a figure.

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Chapter 2. 10 ms fig 2.8: 23 ms fig 2.18: From Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review by C. Compher, D. Frankfield, N. Keim, and L. Roth-Yousey: Evidence Analysis Working Group. This article was published in the Journal of the American Dietetic Association, Volume 106(6), pages 881-903. © Elsevier, 2006. **26 ms fig 2.20: 5 ms fig 2.4:** Conversion of kinetic energy to electrical energy from How Hydropower Plants Work. Courtesy of HowStuffWorks.com. **8 ms, fig 2.6:**

Chapter 3. 15 ms, fig 3.12: 22 ms fig 3.17: 23 ms fig 3.18: 24 ms fig 3.19: 24-6 ms fig 3.20: 3 ms fig 3.3: 8 ms fig 3.7: From J. Hirvonen, S. Rehunen, H. Rusko & M. Harkonen's Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise, in the European Journal of Applied Physiology and Occupational Physiology, Volume 56(3), pages 253-259, © 1987. With kind permission of Springer Science and Business Media. **9 ms fig 3.8:**

Chapter 4. 10 ms fig 4.7: 14 ms, fig 4.10: 15 ms, fig 4.11: 16 ms fig 4.12: 17-18 table 4.3: Adapted with permission from Sports Nutrition: A Practice manual for Professionals, 4th Edition. Dunford, M. (Ed). Chicago, Il: The American Dietetic Association. **2 ms fig 4.1: 23 ms, fig 4.13:** Drawn from the methods of J. Bergström, L. Hermansen, & B. Saltin's Diet, muscle glycogen, and physical performance in Acta Physiologica Scandinavica. Volume 71, pages 140-150, © 1967. Reprinted with permission from Blackwell Publishing Company. **24 ms, fig 4.14:** Drawn from the methods of W.M. Sherman, D.L. Costill, W.J. Fink, & J.M. Miller's The effect of exercise and diet manipulation on muscle glycogen and its subsequent use during performance, in Volume 2, pages 114-118, © 1981 by the International Journal of Sports Medicine. Reproduced with permission of Georg Thieme Verlag. **25 ms, fig 4.15: 26 ms, fig 4.16: 26 ms, fig 4.16: 28 ms table 4.5: 37 ms, table 4.8: 4 ms fig 4.2: 40 ms fig 4.17: 45-6 table 4.11: 6 ms fig. 4.3: 7 ms fig 4.4: 8 ms fig 4.5: 9 ms fig 4.6:**

Chapter 5. 1 ms fig 5.1: 10 ms fig 5.5: 12 ms fig 5.6: 2-3 ms table 5.1: 23 ms, fig 5.7: 25 MS, fig 5.7: 5 ms fig 5.2: 6 ms fig 5.3: 8 ms fig 5.4:

Chapter 6. 1 ms fig 6.1: 10 ms fig 6.7: 13 ms fig 6.9: 2 ms fig 6.2: 30 ms fig 6.13: 31 ms fig 6.14: 32 ms table 6.6: From the McDonald's website, www.mcdonalds.com © 2007 by McDonald's Corporation. Used with permission from McDonald's Corporation. **4 ms fig 6.3: 8 ms, fig 6.5: 9 ms fig 6.6:**

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Chapter 8. 12 ms table 8.4: 13 ms fig 8.3: 2-6 ms table 8.2: 7 ms table 8.3: 9 ms fig 8.1:

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Chapter 10. 11 ms fig 10.5: 17 ms fig. 10.10: 21-4 table 10.3: 27 ms table 10.4: 31 ms fig 10.14: 32 ms fig 10.15: 36 ms fig 10.13: From The Australian Institute of Sport Supplement Group Classification at www.ais.org.au/nutrition/SupClassification.asp, produced by the Australian Sports Commission. Reproduced with permission from the Australian Sports Commission.

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Chapter 12. 10 ms fig 12.4: 11 ms fig 12.5: 15 ms table 12.3: 17 ms fig. 12.6: 19 ms table 12.4: 24 ms table 12.6: Adadpted from "Diagnosis and management of the metabolic syndrome" by S.M.Grundy, J.I. Cleeman, S.R. Daniels, et al, © 2005, in Circulation 112: 2735-2752. **26 ms fig 12.8: 28 ms table 12.7: 30 ms table 12.8: 4-5 ms fig 12.1:** From the Position Stand on The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Adults, from Medicine and Science in Sports and Exercise, Volume 30(6), pages 975-991, © 1998. Reprinted with permission from Lippincott, Williams & Wilkins. **6 ms fig. 12.2:** From Actual causes of death in the United States, by A.H. Mokdad, J.S. Marks, D.F. Stroup, & J.L. Gerberding, in the Journal of the American Medical Association, Volume 291(10), pages 1238-1245, © 2005. Erratum in JAMA, © 2005: January 19, 293(3), pages 293-4 and 298. **8 ms, fig 12.3:**

Chapter 13. 10, fig 13.4: Female Athlete Triad, www.olympic.org/medical, © 2007, by the International Olympic Committee (IOC). Reproduced with permission of the International Olympic Committee (IOC). **12, fig 13.5: 16 ms fig 13.7:** From GW Barrow & S. Saha's "Menstrual irregularity and stress fractures in collegiate female distance runners," in the American Journal of Sports Medicine, Volume 16(3), pages 209-216, © 1988. **18 ms table 13.3: 3ms table 13.1:** From D. Bamber, I. M. Cockerill, S. Rodgers, & Carroll's "Diagnostic criteria for exercise dependence in women," in the British Journal of Sports Medicine, Volume 37, pages 393-400, © 2003. Reproduced with permission from the BMJ Publishing Group.

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