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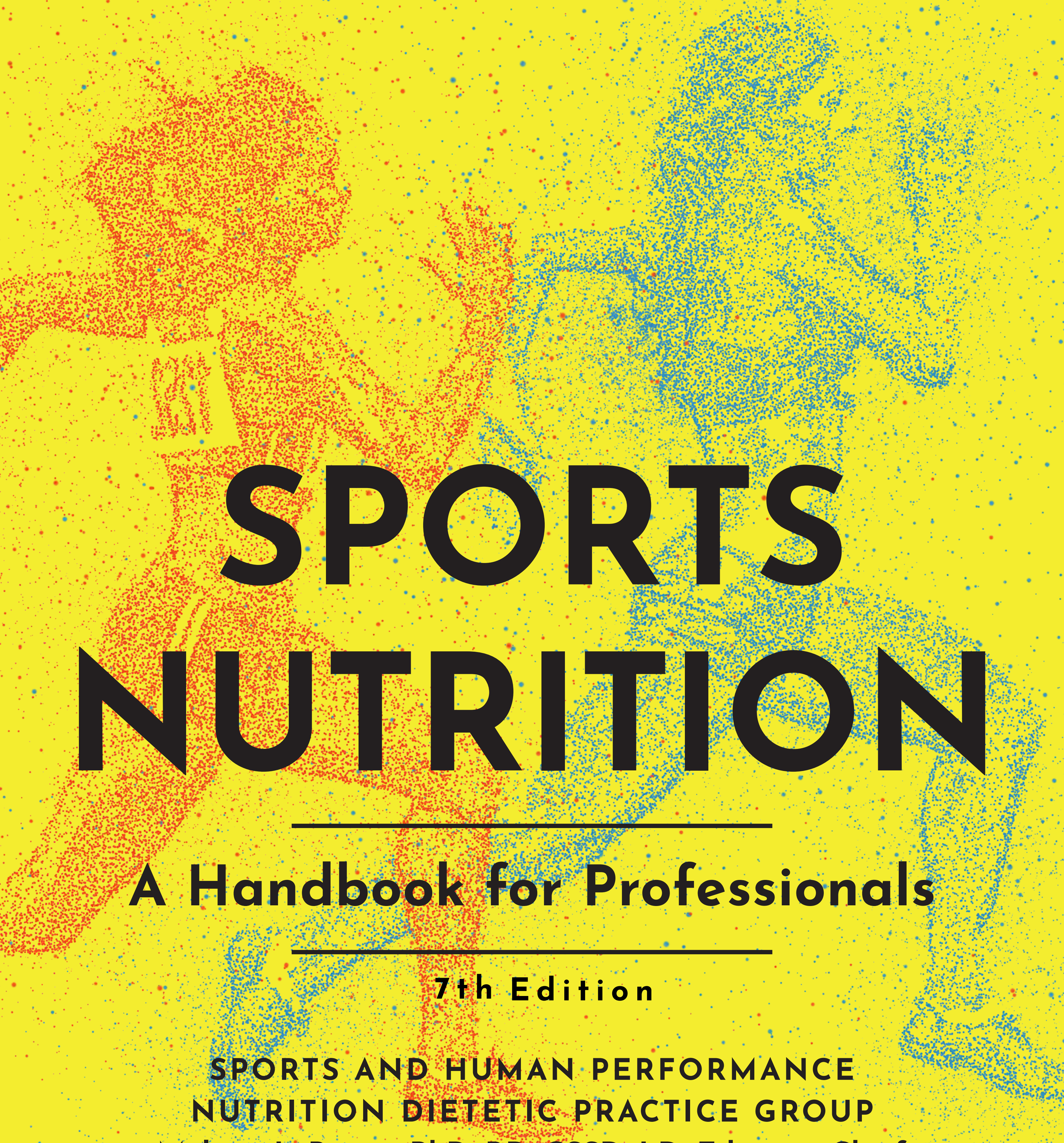

SPORTS NUTRITION

A Handbook for Professionals

7th Edition

SPORTS AND HUMAN PERFORMANCE NUTRITION DIETETIC PRACTICE GROUP

Melissa L. Brown, PhD, RD, CSSD, LD, Editor in Chief

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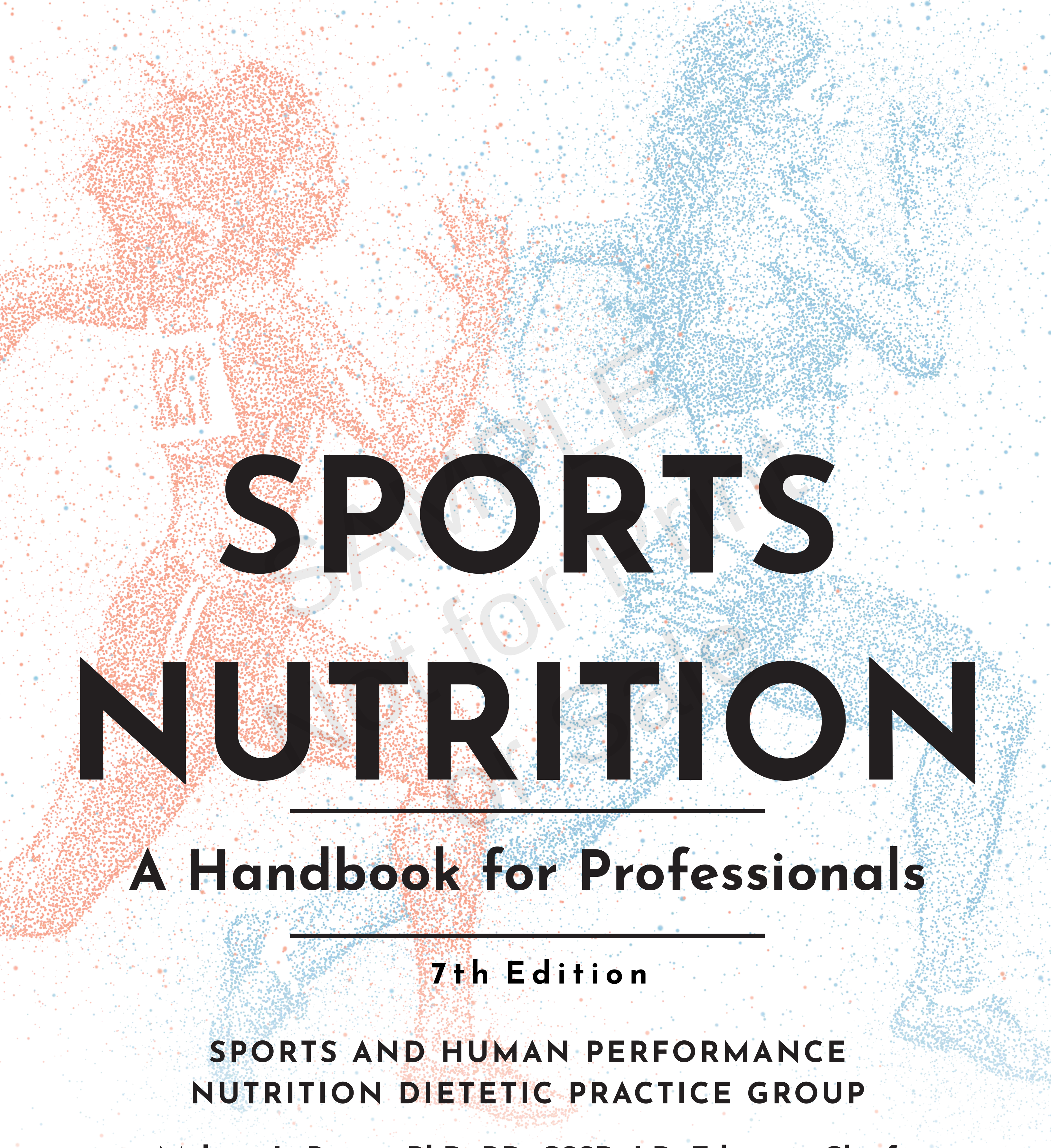

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"Success is no accident. It is hard work, perseverance, learning, studying, sacrifice, and most of all, love of what you are doing or learning to do."

—Pelé (Edson Arantes do Nascímento)
Brazilian professional soccer star
recipient of the International Peace Award, 1978
Athlete of the Century, L'Equipe, 1980
Athlete of the Century, International Olympic Committee, 1980

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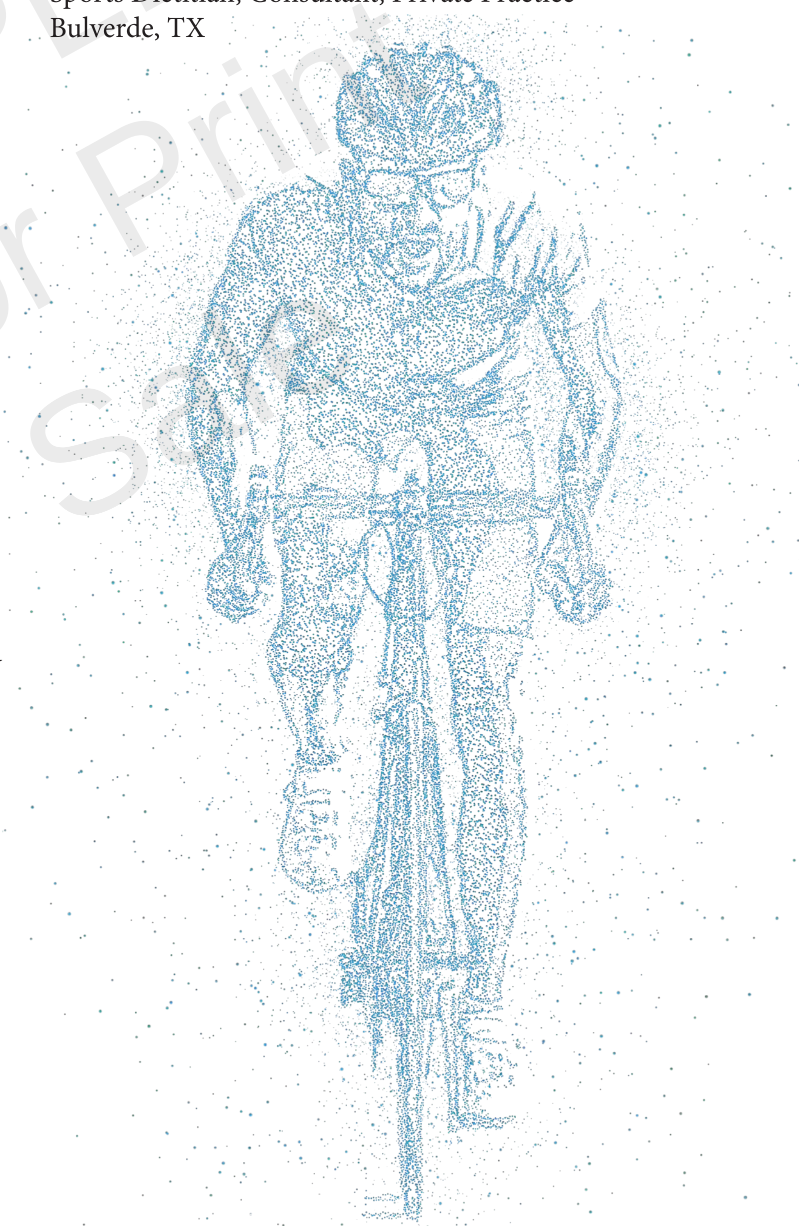

Foreword

As a sports nutrition veteran, I look back on my rookie years when we made do with the few resources we had available at the time. These limitations resulted in hours of research, conversations with others in the field to further our education, and the need to develop materials with clinical and relevant applications to sports nutrition. Nutrition operations management, budget creation, and supplement ordering were part of the "learn as you go" playbook. In addition, we learned to nurture collaborations with the sports medicine, training, strength and conditioning, and foodservice staff through open, constructive, and productive conversations.

As one of the few females in the field, it was quite daunting to learn how to be assertive, progressive, innovative, and creative as a department of 1 while aiming to be available and accessible to all athletes. Understanding the nuances, energy demands, and particulars of every sport, in addition to counseling on physique, physiology, performance, and practicality resulted in long days and significant challenges.

The seventh edition of *Sports Nutrition: A Handbook for Professionals* is the GPS to help both new and seasoned sports dietitians navigate the complexities of performance nutrition. The job demands a knowledge and mastery of exercise physiology, the energy demands of sports, fuel substrates, and hydration, and so we must have clinical competency in these areas. Additionally, the world of sport has expanded beyond collegiate and professional sports to include a need for our services in middle, club, and high school sports, and in working with masters athletes, the military, tactical first responders, and performance artists. All of this information is found within the pages of the book you are about to read.

Our audience pushes the boundaries in the quest to excel, therefore we must be able to respond with creative and compelling solutions. The abundance of misinformation and disinformation concerning body composition and weight management can detract from athlete performance and health. As sports dietitians we need to be able to help our athletes create plans that are attainable, sustainable, and maintainable.

Sports Nutrition: A Handbook for Professionals needs to be part of every sports dietitian's fuel kit. The information gleaned from this book will help our individual athletes, teams, and support staff strategize, optimize, and realize their goals. Being proficient and clinically competent not only enhances our scope of practice but leverages the role of the sports dietitian as an integral part of the performance team.

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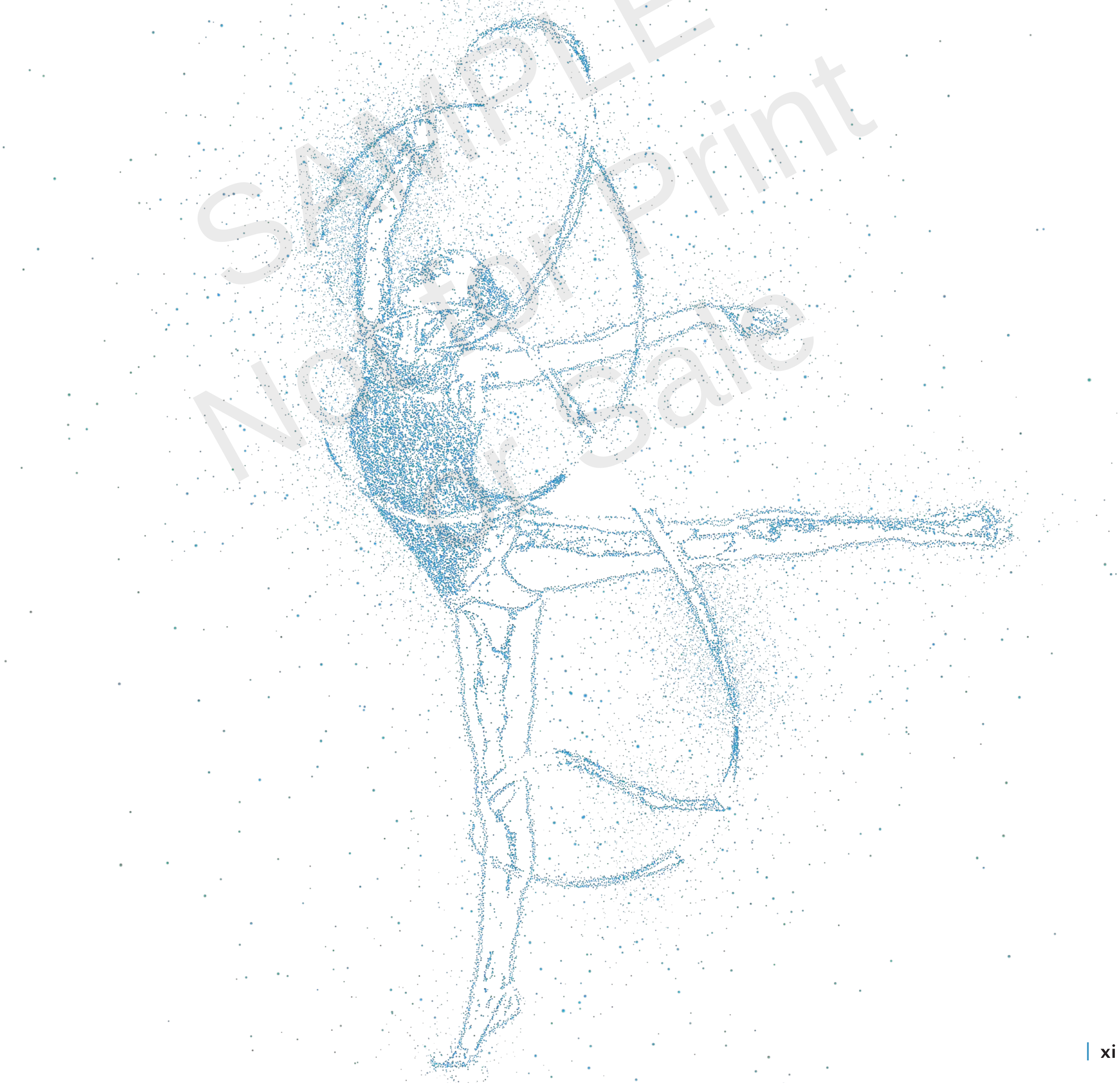
We would like to extend our appreciation to the authors and reviewers who contributed to the seventh edition of *Sports Nutrition* as well as the Academy Publications team for seeing this project through. We would like to specifically thank Stacey Zettle, MS, RDN, for her guidance, dedication, knowledge, and patience throughout this process and for keeping us on schedule. We would like to acknowledge those who came before us, for without them, there would be no seventh edition. Therefore, to the editors of the sixth edition, Dr Christine Karpinski and Dr Christine Rosenbloom, we thank you! You are both pillars in the sports nutrition field and role models to all. Lastly, we thank our families for their support and understanding through the long hours of work that have gone into this new edition.

Melissa L. Brown, PhD, RD, CSSD, LD
Hope Barkoukis, PhD, RDN, LD, FAND



About the Editors

Melissa L. Brown, PhD, RD, CSSD, LD, has over 30 years of experience in the field of sports nutrition and is currently Chair of the Department of Nutrition and Public Health at the University of Saint Joseph in West Hartford, CT. Throughout her career, she has authored multiple peer-reviewed articles, contributed to several textbooks, given talks both nationally and internationally, and has been the recipient of many federally funded grants. In addition, Melissa has coauthored a series of CSSD exam prep materials through Pro-Style Nutrition Consulting, Inc.

Melissa has always been an athlete but did not become interested in sports nutrition until 1994 when she began her combined master's degree and dietetic internship at Rush University in Chicago. The mid-90s is often considered to be the start of sports nutrition and Melissa was incredibly fortunate to have been trained by some of the best in the field. Melissa has experience working with athletes at high school, collegiate, amateur adult, elite, and professional levels. She has also worked with teams and groups and has assisted with sports nutrition program development.

In addition to sports nutrition, Melissa also has decades of experience in the field of islet transplantation and diabetes research. To our knowledge, she is the only dietitian who has been trained to perform islet transplantations and maintains her islet and diabetes research laboratory to this day.

Hope Barkoukis, PhD, RDN, LD, FAND, is Chair of the Department of Nutrition in the School of Medicine at Case Western Reserve University, and the creator of/faculty lead for the Jack, Joseph, Morton Mandel Wellness & Preventive Care Pathway program for medical students. The Pathway introduces medical students to stress reduction techniques, social well-being habits, nutrition, exercise prescriptions, and culinary medicine. In 2018, the Pathway received the Alliance for a Healthier Generation's award for Innovation in Teaching future health care professionals.

Hope has advanced training in culinary arts and has presented countless culinary nutrition sessions for consumer and professional audiences. She has been coinvestigator on several National Institutes of Health research grants focused on dietary interventions and their impact on glucose metabolism, culinary medicine in medical education, and liver disease. Prior to assuming the role of Department Chair at Case Western Reserve Univeristy, Hope held various positions on the executive board of SCAN (Sports, Cardiovascular and Wellness Nutrition dietetic practice group) including Chair, and also had a private practice specializing in sports nutrition.

Overview of the 7th Edition

The much anticipated seventh edition of *Sports Nutrition: A Handbook for Professionals* builds upon the strong foundation set forth in previous editions. This new edition holds true to the need to provide fundamental sports nutrition information, clinical sports nutrition information, and practical applications of both. The seventh edition continues to offer cutting-edge research and evidence-based guidance for professionals working with athletes of all ages and levels.

This updated edition of *Sports Nutrition* is organized into 6 sections and is designed to be a complete reference manual for practicing professionals as well as a resource for undergraduate and graduate sports nutrition courses. We think that the changes made to this current edition will be of much benefit to the sports nutrition profession:

- We have enlisted 14 new authors for this edition. The manual is anchored by our esteemed returning authors who are a mix of board-certified specialist in sports dietetics (CSSD) RDNs, international sports RDNs, and our exercise physiologist colleagues.
- We have incorporated more practical information that you can implement into your daily practice. One way we accomplished this was by including learning objectives at the beginning of each chapter. These objectives then tie into the takeaway points provided at the end of the chapters.
- This edition includes updated references. If a related study was conducted since the last edition, you will most likely see it in the seventh edition.
- Brand-new chapters include Chapter 23, which provides an in-depth review of tactical performance nutrition; Chapter 25, which summarizes various dietary patterns important to athletes; and Chapter 26, which reviews fundamental knowledge related to sports nutrition operations and management.
- We have included guidelines from the most current position and practice papers.

Section 1 covers the foundation of sports nutrition. It begins with an overview of exercise physiology (Chapter 1), including a description of training principles and an important discussion about the scope of practice for sports RDNs. Chapters 2 through 6 utilize updated literature to provide practical advice on sports applications of dietary carbohydrates, protein, fat, vitamins, minerals, fluids, and electrolytes. Chapter 7 completes this section of the manual, focusing on the regulation of sports supplements and featuring the Australian Institute of Sport classification system.

Section 2 focuses on nutrition assessment and energy balance. Chapter 8 centers on assessment and how sports RDNs can incorporate the Nutrition Care Process, Standards of Practice, and Standards of Professional Performance into a sports nutrition practice. Chapter 9 was authored by a sports RDN and an exercise scientist, which helps to provide different approaches to the assessment of body size and composition. Both Chapters 10 (energy balance) and 11 (weight management) were written by 2 new authors, bringing a fresh perspective to these topics.

Section 3 puts these principles into practice. Chapters 12 through 19 provide practical applications of the sports nutrition basics discussed in Sections 1 and 2. We have kept the same population-specific topics included in the previous edition. It took the collaborative efforts of multiple experienced sports RDNs to complete this section, which offers you a plethora of information that you can incorporate into your practice.

Section 4 has been renamed "Activity-Specific Nutrition Guidelines" to include the exciting new chapter on tactical nutrition (Chapter 23) along with the traditional sport-specific recommendations. Chapters 20 and 21 feature updated research for sprint, power, and intermittent sports, and Chapter 22 reviews the research behind fueling endurance athletes.

Section 5 is brand new to this edition and is titled "Advancing the Future." It is led by Chapter 24, Emerging Opportunities in Sports Nutrition, which was first included in the sixth edition and explores a variety of nontraditional practice areas such as CrossFit, obstacle course races, motorsports, performance arts (eg, dancers, marching band), esports, and more. The *Sports Nutrition* textbook has always focused on being as inclusive as possible and now for the first time Chapter 24 also reviews the available evidence pertaining to transgender and gender nonconforming athletes. This chapter includes the current knowledge-base and best practices for providing evidence-based, compassionate care, recognizing that there is much that we still do not know and still have to learn about this understudied population. Section 5 also includes 2 brand new chapters. Chapter 25 introduces the term *dietary pattern* and discusses its role in health promotion and sports performance, along with a general overview of the core elements of the main US dietary patterns identified as "healthy" in the *Dietary Guidelines for Americans, 2020–2025*. The chapter also includes the metabolic impacts from each dietary pattern as they relate to athletes. Special attention is given to identifying the considerable gaps in knowledge regarding the prevalence of and adherence to the specific dietary patterns by athletes. Chapter 26 focuses on operations and management in sports nutrition. The information presented in the previous chapters collectively underscores the vital importance of performance nutrition for health and athletic performance. The RDN with advanced training in sports nutrition (often a CSSD) is the preferred provider of performance nutrition services.

Section 6 includes the At-A-Glance section, which has been expanded to include updated information on 24 sports. The book's appendixes include information on helpful sports nutrition–related position statements, position stands, consensus statements, and websites.

The role of the sports RDN has expanded tremendously over the years. Sports RDNs now play integral roles in operations, teams, and schools by focusing on individualized nutrition plans, evidence-based practice, advanced nutrition therapies, performance and recovery, cultural sensitivity, and program development. The sports RDN takes a holistic approach to athlete health and performance, reflecting the growing recognition of the critical role of nutrition in athletic success.

SECTION 1

SPORTS NUTRITION FOUNDATIONS

A thorough understanding of exercise physiology and the way nutrients support training and competition is essential for the registered dietitian nutritionist working with active people. The first section of *Sports Nutrition* seeks to enhance this understanding by examining the critical role of macronutrients and micronutrients in exercise performance.

The physiology of exercise includes more than just energy production. Athletic success depends on proper nutrition for growth and development and for effective immune system function, as discussed in Chapter 1. Our knowledge of the interrelated roles of dietary carbohydrate, protein, and fat has increased tremendously in the past 20 years, and this new information is incorporated into Chapters 2, 3, and 4. Micronutrients are covered in detail in Chapter 5, which presents the most current research on the effects of vitamin and mineral intake on sports performance. The most essential nutrient for athletes, water, is explained in both scientific and practical terms in Chapter 6, and further discusses fluid, electrolytes, and exercise. Finally, this section concludes with a comprehensive look at dietary supplements and sports foods that athletes use in the hope of improving performance in Chapter 7. Specifically, Chapter 7 discusses how the sports dietitian can critically evaluate dietary supplements and provide sound advice to athletes about using these supplements.

CHAPTER 1

Physiology of Exercise

Laura J. Kruskall, PhD, RDN, CSSD, LD, FACSM, FAND, ACSM EP-C

LEARNING OBJECTIVES

- Understand the basic principles of exercise physiology, the physiological responses to exercise, and adaptations to physical training.
- Identify the primary energy systems and substrates used to fuel the working muscle during physical activity.
- List the principles of exercise training.
- Utilize key concepts in the registered dietitian nutritionist scope of practice to discuss physical activity and exercise with clients.
- Explain the basic principles in the *Physical Activity Guidelines for Americans*, 2nd Edition.

INTRODUCTION

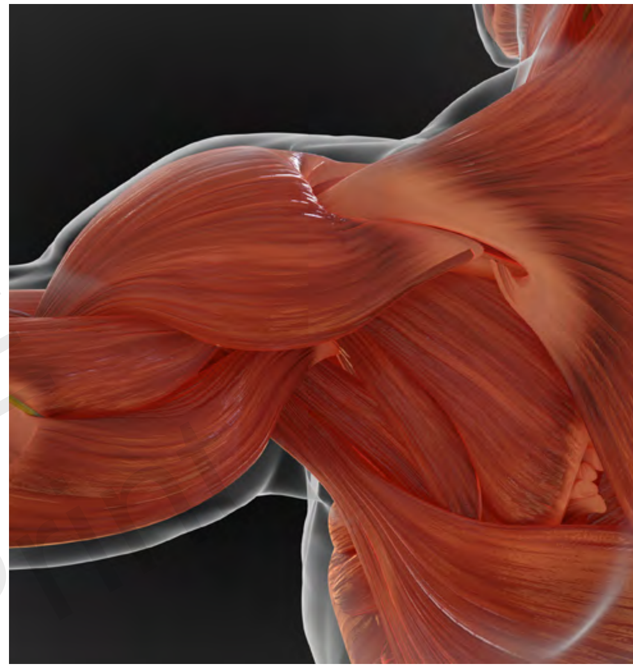
The human body is a dynamic organism composed of molecules, cells, tissues, whole organs, and systems working together to regulate the environment within itself—a process called *homeostasis*. Many factors can threaten the inner environment of the body; the body's response is always to attempt to maintain homeostasis. External extremes and challenges to the body include changes in temperature and altitude. Individuals can deliberately challenge the body by participating in physical activity and exercise. During physical activity and exercise, homeostasis in systems such as the cardiorespiratory system and musculoskeletal system is challenged, triggering a body response. With these challenges, the organ systems must coordinate and adjust to meet the increased energy and metabolic demands of the body.

Exercise physiology is the study of these adjustments. It also includes the responses to exercise that result from acute bouts of activity, as well as the chronic adaptations that occur from repeated exercise and long-term training.[1] This chapter provides a brief overview of the basics of the exercise physiology and includes a discussion of the role of the registered dietitian nutritionist (RDN)[2] or Board Certified Specialist in Sports Dietetics (CSSD)[3] and appropriate application to practice.

ACUTE RESPONSE TO EXERCISE

Even at rest, the body is in a constant state of flux—it remains metabolically active to maintain physiological function. This requires a continual supply of energy. During exercise, the energy demands of skeletal muscles greatly increase, and the respiratory and cardiovascular systems must work harder to allow for increased respiration and to supply blood to the working muscles with a concomitant reduction of blood flow to the gastrointestinal tract. This respiratory and cardiovascular response can continue for minutes to hours depending on the intensity of exercise and the physical training status of the individual. In some sports or events, the increased energy demand is relatively constant for an extended time (eg, a marathon). In others the energy demand is not constant and is often characterized by periods of high intensity followed by periods of active recovery or rest (eg, soccer, tennis). During both endurance and stop-and-go activities, the energy demand can increase by 2 to 20 times that at rest. Very high-intensity activities can exceed this range, though they can be sustained for only seconds to minutes. Ultimately, the body systems must work together to meet the increased energy demands.[1,4-7]

Skeletal Muscle and Exercise



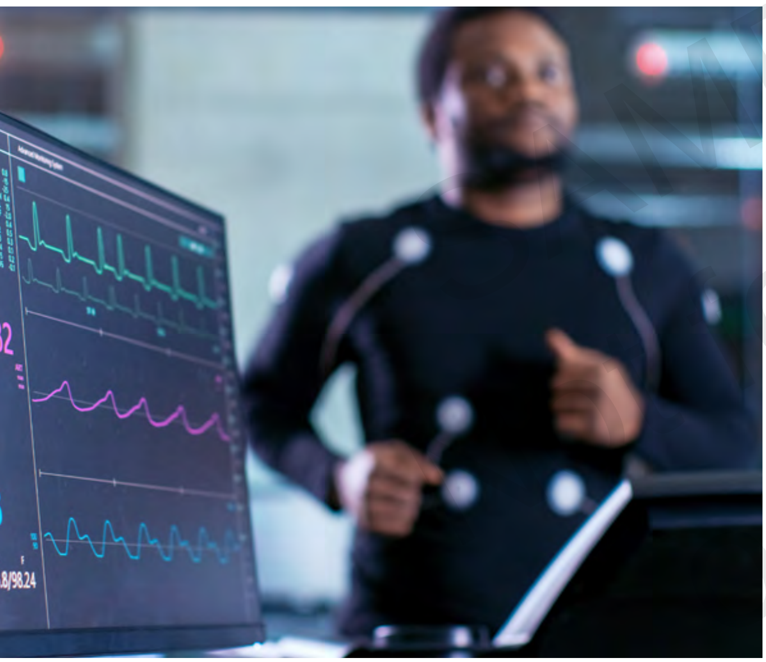
Skeletal muscles terminate where tendons attach to the skeleton. As these muscles contract and relax, they allow movement of the body. The human body has more than 600 skeletal muscles that allow for fine and gross movement. A muscle or muscle group (such as the biceps or quadriceps) is often thought of as a single unit. These units, however, are made of many complex components working together to complete a single contraction. A single nerve and the group of muscle fibers it innervates are referred to as a *motor unit*. *Muscle fiber* is the term used to describe a muscle cell. Each muscle fiber contains organelles, including mitochondria for aerobic energy production and hundreds to thousands of myofibrils. The functional units of a myofibril, *sarcomeres*, are responsible for the contractile properties of the muscle. Sarcomeres are composed of thin and thick filaments called *actin* and *myosin*, respectively. Activation of the motor unit causes these filaments to "slide" over one another, allowing the muscles to shorten, or contract. This slide, referred to as the *sliding filament theory*, is a process that requires energy. Not all available motor units are activated at once—only those needed to generate the appropriate force are used. The force and speed of movement needed determine the extent of the motor unit recruitment: the higher the force or speed of contraction required, the greater the number of individual muscle fibers that must be recruited for contraction. Muscle groups in opposition cannot contract at the same time—one contracts while the other relaxes or lengthens (eg, biceps and triceps). Nerve transmission is coordinated, so it is unlikely to stimulate the contraction of 2 antagonistic muscles at any time.[1,8-10]

Different types of muscle fibers contract at different speeds, producing varying amounts of force. *Type I fibers*, sometimes referred to as slow-twitch fibers, have a high level of aerobic endurance; they can use a continuous supply of energy from the aerobic metabolism of carbohydrate and fat. These fibers allow prolonged muscular contraction for long periods. They are primarily used during activities of daily living, such as walking, or during lower-intensity endurance events, such as bike riding or jogging. *Type II fibers*, sometimes referred to as fast-twitch fibers, have relatively poor endurance capacity and work better anaerobically. These are primarily used for activities such as a tennis serve or a weightlifting set. Although these fiber types can be further classified as type IIa, type IIx, and type IIc, experts are still researching the differences between the types.[1]

Most skeletal muscles consist of approximately 50% type I fibers and 50% type II fibers (25% type IIa fibers, 22%–24% type IIx, and 1%–3% type IIc). The precise percentages of fibers can vary greatly among individuals, and extreme variation in athletes from different sports is common. Type IIa fibers are recruited most frequently but are secondary to type I fibers. Type IIa fibers generate more force than type I fibers but fatigue more easily. Type IIa fibers also tend to be recruited during higher-intensity events of short duration, such as a half-mile run or a strength-training workout. Experts do not fully understand the importance of type IIx fibers. Research findings indicate that they are used in explosive activities such as a 50-meter dash or weightlifting. Type IIc fibers are recruited least frequently. Most muscle groups contain both type I and II fibers and recruit the appropriate type needed for an activity.[1,8-12]

There may be differences in skeletal muscle fiber types when athletes are compared to untrained individuals. Most studies show little to no difference in the proportion of type I muscle fibers between athletes and controls (although in contrast, some studies show large differences).[13-18] One study examining bodybuilders reported extremely high amounts of type IIx fibers,[13] yet other similar studies do not support this finding.[15,17,19] There do, however, appear to be proportional differences in type IIa and type IIx muscle fibers between strength and power athletes vs untrained control subjects. Some studies support the notion that strength and power athletes have a greater proportion of type IIa fibers and a smaller proportion of type IIx fibers, whereas other studies do not.[13-18] The majority of studies show a shift from type IIx to type IIa fibers with long-term resistance training.[14-19]

What is the relationship between fiber type and endurance performance success? Researchers believe that an increased number of type I fibers could benefit an athlete during long endurance activities and more type II fibers would benefit an athlete during high-intensity activities. Endurance athletes tend to possess a greater proportion of type I vs type II muscle fibers, but the difference does not appear to be caused by training. Furthermore, studies show that endurance athletes do not experience pronounced changes in their type IIa fiber profiles.[20-23] Studies examining the muscle fiber types in the gastrocnemius muscle in distance runners and sprinters support this hypothesis: endurance athletes have more type I fibers, and sprinters have more type II fibers. Health care practitioners and athletes should note that fiber type is just 1 piece of the puzzle. Other factors that affect performance include training, nutrition, and motivation.[1,8-10,24]



Cardiovascular and Respiratory Systems

The cardiovascular and respiratory systems work together to deliver oxygen and nutrients to working muscles and tissues and to remove metabolic waste products and carbon dioxide. Together, these systems are often referred to as the cardiorespiratory system, and this combined system consists of the heart, blood vessels, airways, and lungs. The cardiorespiratory system has many functions and supports all other physiological systems. Additional key functions include transporting compounds such as hormones, nutrients, oxygen, carbon dioxide, and waste such as urea; supporting thermoregulation and fluid balance; and maintaining acid-base balance.

Pulmonary ventilation describes breathing, or air moving in and out of the lungs. Ventilation happens in 2 phases: inspiration and expiration. *Inspiration* is an active process involving the activation of the diaphragm and external intercostal muscles, whereas *expiration* is usually a passive process as muscles relax and air is expelled from the lungs. Most of the oxygen in the blood is bound to hemoglobin and delivered to the working muscle. Once inside the muscle, oxygen is transported to the mitochondria by myoglobin and is then available for aerobic energy production in the muscle cells.[1]

The cardiac cycle occurs during each heartbeat and includes both electrical and mechanical events.[1] *Heart rate* describes the number of heartbeats, or the number of contractions of the ventricles (the lower chambers of the heart), per unit of time. Heart rate is usually measured and expressed as beats per minute (bpm). The normal heart rate range for untrained individuals is 60 to 100 bpm. *Tachycardia* refers to a heart rate that is faster than normal; *bradycardia* refers to a heart rate this is slower than normal. *Stroke volume* is the volume of blood pumped during 1 heartbeat. *Cardiac output* is the total volume of blood pumped from 1 heartbeat and is the product of heart rate multiplied by stroke volume. Resting cardiac output averages 5 L/min, but this number can vary with body size. Cardiac output increases with exercise and can range from less than 20 L/min in an untrained sedentary person to 40 L/min or more for individuals with elite endurance training. *Athlete heart* refers to anatomical alterations in which unique muscle thickness, electrical signals, and anatomical function develop as a result of physical training. This is usually seen in individuals who train at least 1 hour per day most days of the week.[1,25]

The volume of blood distributed throughout the body depends on the metabolic demands of the tissues, with the most active tissues receiving the greatest amount of blood. When the body is at rest, many organs require more blood than skeletal muscles. The muscle receives approximately 15% of the cardiac output at rest, but this can increase to as much as 80% during intense exercise to meet oxygen and nutrient demands of active muscle.[1,26]

Cardiovascular and Respiratory Responses to Acute Exercise

The initiation of exercise requires increased muscle oxygen and nutrient demand and the removal of more metabolic waste products. When exercise begins, pulmonary ventilation increases to meet the oxygen demand of the muscles. During lower-intensity activities, this demand can be met by simply moving more air in and out of the lungs. However, as exercise intensity increases, respiration rate also increases. During most common forms of endurance exercise, pulmonary ventilation typically does not reach maximum capacity and is not the limiting factor in performance; very high–intensity exercise may be the exception. During prolonged endurance exercise, respiratory muscles can withstand fatigue. However, there is a point at which athletes cannot take in a higher volume of air and the respiration rate cannot be any higher. At this point, athletes are at their aerobic capacity, and the energy required for continued activity must be supplied by anaerobic metabolism. The term used to describe this sequence is *maximal oxygen uptake*, also known as *VO_2 max*.

An athlete's VO_2 max is an important consideration for performance lasting more than a few minutes and can be measured in an exercise physiology laboratory. It is considered the best measurement of cardiovascular or aerobic fitness.[1,27-29] VO_2 max is usually expressed in units of milliliters per kilogram per minute ($mL \times kg^{-1} \times min^{-1}$). A sedentary individual may see a 10-fold increase in VO_2 max while exercising, whereas an endurance athlete may see a 23-fold increase. Studies show that a sedentary male has an average VO_2 max of 35 $mL \times kg^{-1} \times min^{-1}$, whereas a world-class male endurance athlete can have a VO_2 max as high as 80 $mL \times kg^{-1} \times min^{-1}$.[30,31]

Gas exchange in the lungs is not considered a limiting factor in endurance exercise performance. In endurance athletes, maximum cardiac output is closely related to VO_2 max and endurance performance. Heart rate increases linearly with exercise intensity and plateaus when maximum heart rate is achieved. Maximum heart rate (estimated as 220 – age in years) differs little between trained and untrained individuals, although the intensity level at which these individuals will reach their maximum heart rates will vary. For example, both a trained and an untrained person may have the same maximum heart rate of 170 bpm, but the trained person can work at a higher training workload before reaching that maximum heart rate.

Stroke volume is another key factor for determining cardiovascular endurance capacity. In an untrained person, stroke volume increases proportionally with exercise intensity but does not increase further once a person reaches 40% to 60% of their VO_2 max. In trained individuals, stroke volume can continue to increase past this threshold as exercise intensity increases. Because both heart rate and stroke volume increase with exercise, total increased cardiac output parallels the intensity of the exercise to meet the increased blood flow demands of the working muscle. Individuals do not usually exercise at maximum heart rate; instead, they perform submaximal exercise for an extended time. The point where the cardiovascular system is delivering the optimal amount of oxygen and nutrients to the muscle is called *steady-state heart rate*.[1,27,30-33]

FUEL FOR EXERCISE

The biologically usable form of energy in the human body is adenosine triphosphate (ATP). ATP is required for skeletal muscle contraction and relaxation. Skeletal muscles require increased energy during all movements, including intentional exercise. As exercise intensity or duration increases, the body may have difficulty keeping up with this increased energy demand, and a person will feel fatigue. If energy cannot be supplied to the muscles in a timely manner and in adequate amounts, movement will cease. Once energy from endogenous carbohydrate stores is exhausted, ATP production is limited by the availability of exogenous fuel from carbohydrates, fats, and proteins.[1,7,32]

Energy Substrates

Plants rely on photosynthesis to convert sunlight into chemical energy, and animals consume these plants. Human beings obtain energy by consuming plants and animals, thereby taking in energy nutrients. Energy nutrients consist of carbohydrate, fat, and protein. All cells in the body have the ability to break down these nutrients for energy, and each cell has a substrate preference in its resting state. The cells have metabolic pathways to process these energy substrates and generate ATP. For example, in muscle cells, ATP is hydrolyzed to release a phosphate group, adenosine diphosphate (ADP), and energy.[1,5-7]

The human body can acquire energy through the intake of foods and beverages (exogenous sources) or from the breakdown of substrates stored for later use (endogenous sources). Under normal circumstances, the primary nutrients for energy production come from carbohydrate and fat. Typically, protein contributes less than 5% to 10% of the body's energy needs because it is utilized for other important functions, such as acting as enzymes, hormones, and immune proteins and performing tissue maintenance, growth, and repair. The exception to this occurs during the later stages of prolonged endurance exercise when protein can contribute up to 15% of the energy needs if exogenous carbohydrate is not consumed and glycogen stores become depleted.

As previously noted, the primary nutrients for energy production come from carbohydrate and fat. The storage form of carbohydrate in human beings is glycogen, which consists of glucose and is found in both skeletal muscle and liver tissue. These organs can store a maximum capacity of glycogen. Liver tissue can store 75 to 110 g (300–440 kcal) of glycogen, whereas skeletal muscle can hold 300 to 400 g (1,200–1,600 kcal). Circulating glucose in the plasma provides only a small source of carbohydrate, approximately 5 g (20 kcal). Glycogen storage generally cannot be relied on as the only source of energy during exercise because the brain and central nervous system require glucose for energy and take priority. Fat is stored as triglycerides within adipose tissue and skeletal muscle. Unlike glycogen, adipose tissue triglyceride is limitless and can provide 70,000 kcal or more of energy.[1,5,34,35]

Energy Systems

ATP is stored in cells in very limited quantities, so the body must constantly generate ATP to meet the demands of cellular metabolism and muscle contraction during exercise. During rest, most of the cells and organs use a constant supply of ATP. With increased activity, the demand by skeletal muscle for ATP can increase greatly, depending on the intensity and duration of exercise. Each muscle contraction uses ATP, which is hydrolyzed to ADP and a single phosphate group. The ADP and phosphate group must then be rephosphorylized to ATP. There are 3 basic metabolic pathways to accomplish this: those that rely on the large amount of creatine found in muscle cells (phosphocreatine system), those that generate ATP without the use of oxygen (anaerobic), and those that require oxygen involvement (aerobic).[1,5,34,35]

ADENOSINE TRIPHOSPHATE-PHOSPHOCREATINE SYSTEM

The adenosine triphosphate–phosphocreatine (ATP-PCr) system is the quickest way for the body to produce ATP. This anaerobic system is used during intensive, explosive movements, such as a tennis serve or a power lift. The ATP-PCr system generates ATP rapidly; however, it is very limited and only supplies ATP for up to 10 seconds. A key component in the ATP-PCr system is phosphocreatine (PCr), which is stored in skeletal muscle and consists of a molecule of creatine attached to a single molecule of phosphate. To generate ATP, a creatine kinase enzyme breaks the creatine and phosphate molecules apart, and the free phosphate then combines with ADP, forming new ATP. The ATP-PCr system is limited because the amount of PCr stored in the skeletal muscle is small. Once all PCr molecules have donated their phosphate groups to ADP, the system can no longer facilitate further ATP production until PCr is replenished. A combination of rest and dietary intake is the main way to replenish PCr.[1,5] Approximately 95% of the body's creatine is found in skeletal muscle and can easily be replenished by the diet. Athletes who include meat in their diet obtain plenty of creatine, but creatine can also be synthesized from the amino acids methionine, arginine, and glycine, which are obtained from other dietary sources.[1,5,34,35]

ANAEROBIC GLYCOLYSIS

The anaerobic glycolysis (AG) system oxidizes 1 glucose molecule (6 carbons) to form 2 pyruvic acid molecules (3 carbons each). Glucose can come from dietary intake (circulating blood glucose) or from glycogen stored in the muscles or liver. During AG, energy is generated in 2 ways. The first generates ATP directly from the breakdown of glucose to pyruvate. The second generates ATP through the oxidation of glucose, during which hydrogen molecules are removed from the carbon skeleton of glucose. Nicotinamide adenine dinucleotide (NAD) is a coenzyme that carries electrons and receives these hydrogen molecules to form NADH. NADH transports hydrogen to the electron transport chain (ETC) in the mitochondria where it undergoes oxidative phosphorylation so the body can generate ATP aerobically. Although this AG pathway does not produce large amounts of ATP, it does generate ATP fairly rapidly. AG and the ATP-PCr system are the predominant energy systems for the first few minutes of intense, continuous activity.[1,5,36] AG also provides energy during the first few moments of moderate, longer-duration activity as the aerobic system begins to generate ATP.[5,37,38]

AG is limited by the production and accumulation of lactate during high-intensity situations when the demand for ATP by skeletal muscle is high. Production of pyruvate from the AG process is not problematic when oxygen is present to be the final acceptor of these hydrogen molecules to form metabolic water. However, when oxygen is limited, such as during very high–intensity activity, the pyruvate is converted to lactic acid. Lactic acid is relatively unstable at normal body pH and loses a hydrogen ion or dissociates into lactate. As hydrogen molecules accumulate, the pH of the muscle cell drops, and glycolytic enzymatic activity is hampered, resulting in skeletal muscle fatigue. The body must slow down to recover before intense activity can continue. Lactate is constantly being produced, but it is easily cleared with time by several mechanisms, as follows[5,37,38]:

- Lactate is taken up and oxidized by the mitochondria in the same muscle cell. This occurs primarily in type I muscle fibers.
- Higher amounts of lactate are produced in type II muscle fibers and then transported to the type I fibers or to other cells in the body for oxidation.
- Lactate travels from the muscle to the liver, is converted to glucose via gluconeogenesis, and is sent back to the working muscle for fuel (the Cori cycle). Once lactate is cleared, activity can continue.

AEROBIC METABOLISM

Through aerobic metabolism, the body can break down carbohydrates, fats, and proteins with the involvement of oxygen through the Krebs cycle and the ETC. Unlike the ATP-PCr system and AG, aerobic metabolism can supply ATP on a fairly limitless basis as long as macronutrients and oxygen are available. Acetyl coenzyme A (CoA) is a metabolic intermediate of both glucose and fat oxidation and is ultimately oxidized through aerobic metabolism. Acetyl CoA combines with oxaloacetate to begin the Krebs cycle. Many hydrogen molecules produced during the Krebs cycle are shuttled by NAD and flavin adenine dinucleotide (FAD) to the ETC. As the hydrogen molecules are passed along the chain, ATP is generated. Oxygen, the final hydrogen acceptor, combines with these molecules to form water. The ETC is the most efficient way that the body produces ATP because there are no metabolic byproducts that lead to fatigue.[1,5,34]

CROSSOVER CONCEPT

All metabolic systems work concurrently. The relative contribution of each system depends on the physiological need for ATP. The oxidation of fatty acids produces more ATP per gram than that of carbohydrates, but at a lower rate and with a greater oxygen requirement. A 16-carbon fatty acid can produce 106 molecules of ATP, whereas oxidation of a 6-carbon glucose molecule nets approximately 32 molecules of ATP. More ATP can be produced from fatty acid because of its longer carbon chain, but ATP can only be generated from fat aerobically. A glucose molecule does not yield as much ATP, but it can be oxidized rapidly and without oxygen when necessary.[5,39]

During rest or low-intensity activity, ATP demand is low, and oxygen is plentiful. As a result, fat is the preferred fuel source during these times. With increased exercise intensity, skeletal muscle requires increased ATP, and oxygen delivery becomes more limited. In this scenario, the body relies more on carbohydrate than fat for fuel because glucose is oxidized more rapidly and is more oxygen efficient (more ATP is generated per oxygen molecule used). The point at which the body shifts from using predominantly fat to predominantly carbohydrate is known as the *crossover point*. Both carbohydrate and fat are always being used, but the ATP demand and oxygen availability determine which substrate and metabolic system is predominant in ATP generation.[1,34,36,39]

FATIGUE

Muscular fatigue refers to the impairment or inability of the muscle to produce force. At rest and during lower-intensity exercise, human beings are capable of producing enough ATP to fuel activity without muscular fatigue, as long as sufficient energy substrates (primarily carbohydrate and fat) are readily available in the body. At low exercise intensity, carbon-containing pyruvate is consistently oxidized to acetyl CoA. At the same time, hydrogen molecules are shuttled smoothly within cells to the ETC by the compounds NAD and FAD. At such low exercise intensities, ATP is readily produced in required amounts, and there are no metabolic byproducts that contribute to fatigue.[1,40-42]

Short-Term Fatigue

Short-term fatigue occurs when exercise intensity rises to levels that disturb the body's ability to derive energy from the primary exercise fuel substrates: carbohydrate and fat. Possible causes of short-term fatigue include the accumulation of metabolic products such as inorganic phosphate and lactate, the depletion of phosphocreatine, and changes in cellular calcium. However, the primary cause of short-term fatigue is the limited ability to inspire and transport oxygen to working muscles at a rate sufficient to keep up with increased ATP demand as exercise intensity rises. The process of short-term fatigue consists of the following steps[1,40-42]:

1) When oxygen levels at the working muscle are insufficient, hydrogen molecules that normally bind with oxygen to form water start to accumulate and eventually overwhelm the capacity for NAD and FAD to accept and transport all of the hydrogen molecules.
2) The normal metabolism of pyruvate to acetyl CoA diminishes, and instead pyruvate accepts these hydrogen molecules and forms lactic acid, which rapidly dissociates into lactate.
3) Lactate is formed faster than it can be cleared, and the acidic environment in the cell disrupts glycolytic enzymatic activity.
4) At this point, ATP production is hindered, and skeletal muscle contraction is impaired.
5) The only way to restore homeostasis is to reduce exercise intensity to enhance oxygen uptake and clear metabolic byproducts. Lactate is not just a waste product of metabolism; it is a fuel source for resting tissues and contracting cardiac and skeletal muscles. Endurance-trained individuals can

better utilize lactate for energy. Once the lactate is cleared (which is a rapid process), the fatigue dissipates, and the skeletal muscle can once again contract.

Long-Term Fatigue

Lactate accumulation is not significantly related to fatigue in prolonged endurance activities. Long-term or substrate fatigue, sometimes referred to as "hitting the wall" or "bonking," is thought to be a consequence of glycogen depletion. Because glycogen storage capacity is limited in skeletal muscles and liver tissue, depletion can occur fairly rapidly. Once glycogen stores are depleted, dietary carbohydrate absorption and gluconeogenesis cannot keep up with the ATP demand of the skeletal muscles, and movement must stop. The body cannot continue to perform until more carbohydrate (glucose) becomes available for ATP production. For endurance athletes, any strategy to maximize glycogen stores and provide a continuous supply of glucose during exercise will help delay the onset of substrate depletion.[1,40-42]

PRINCIPLES OF EXERCISE TRAINING

Exercise training refers to the body's response to physical activity repeated over time, resulting in positive physiological adaptations. Appropriate training coupled with proper fueling and adequate rest and recovery generally results in improved performance. Overtraining or undertraining will not result in a desirable effect. The principles of exercise training apply to the novice beginning an exercise program to improve health, as well as to the elite athlete wishing to compete. Appropriate exercise training depends on factors such as the individual's body composition, the specificity of training, the ability to incorporate progressive overload and periodization, and the avoidance of detraining.

Individual Body Composition

An individual's body composition depends on both genetic and environmental factors. Although genetics creates a starting point and boundaries that determine fat patterning and muscularity, this does not mean that one's ultimate body shape and size are completely outside individual control. The ability to alter physique can be influenced to an extent with nutrition and training. It is, however, important to be realistic about genetic potential. People have different body shapes and can respond differently to the same training. For example, a very tall and lean person may never be able to achieve the physique of a professional bodybuilder through resistance training. On the other hand, a stout, muscular person may never be light or fast enough to compete as an elite marathon runner. Furthermore, some people are considered "higher responders" to training and seem to achieve desired results more easily than "lower responders." It is important for individuals to be realistic in terms of body type and athletic potential.[43,44]

Specificity of Training

Specificity dictates that physiological adaptations and performance enhancements are specific to the mode, intensity, and duration of the exercise training. A training regimen must induce a physical stress specific to the system needed for performance gains. For example, a distance runner must perform endurance activities of long enough duration to promote cellular training adaptations, such as increases in mitochondrial density. Anaerobic sprints or weightlifting promote increased muscle strength and hypertrophy, which are not beneficial to an endurance athlete. Similarly, cardiovascular training will not result in the increased muscular strength and hypertrophy desired for the high-intensity activity needed by athletes specializing in stop-and-go sports. The training program must mimic the desired activity.[1,45,46]

Progressive Overload

To see improvements, athletes need to overload the system being trained (eg, cardiovascular, muscular), resulting in continuous demands on that system. For example, if a person wants to gain strength, they may initially bench press 100 lb for 8 repetitions, and over time, they will be able to do 12 to 15 repetitions at that weight before reaching fatigue. As training continues, the athlete will need to add weight until again reaching fatigue at 8 repetitions. In addition to the weight and number of repetitions performed, muscles can reach fatigue in other ways. For example, one can increase the number of sets of the exercise, decrease the rest period between sets, or emphasize the eccentric contraction by decreasing the speed of the lowering motion. With endurance performance, the athlete must increase the total training volume with intensity, duration, or both, to see an improvement.[1,45,46]

Periodization or Variation

The principle of periodization involves breaking exercise training for a particular sport or event into smaller periods based on desired outcomes. Proper periodization allows for the intensity of training to be adjusted as needed to produce the desired performance outcome while working in adequate rest and recovery to prevent overtraining. Traditional (linear) periodization typically occurs over a longer time frame, such as 1 to 4 years. Within that time, there are various cycles of months (macrocycles), weeks (mesocycles), days (microcycles), and individual training sessions. Appropriately planned periodization programming should consider the athlete's goals and the demands of their sport. Well-rounded athletes require many systems and skills that make use of a combination of aerobic, anaerobic, and strength training.

Block periodization is a newer area of training that incorporates training blocks that can be individualized based on the desired sport or event. These blocks can be specific and focus on a minimum number of performance outcomes. Training consists of performing a small number of blocks at 1 time (eg, 3 or 4) over the span of a few weeks. The sequence can be customized for the sport or event. In 1 example, top-performing canoe and kayak paddlers utilized block periodization. Block 1 focused on accumulating the skills needed for the sport, with general conditioning for aerobic endurance and muscular strength and endurance. Block 2 focused on specialized movements and proper technique, combining anaerobic and aerobic conditioning along with continued muscular strength and endurance. Block 3 emphasized modeling a specific race and obtaining optimal speed and recovery between sessions. This regimen resulted in outstanding performance outcomes.[1,45-47]

Detraining

Detraining is defined as a partial or full reduction in training-induced physiological adaptations as a result of inactivity or lower training load. As both resistance and aerobic training result in increased strength and cardiovascular endurance, stopping this training (detraining) results in the opposite. Continued training is necessary to prevent this detraining effect. Systematically increasing the physical demands on the body with training will be necessary for further improvements, whereas maintenance-level training regimens prevent physiological decline from the trained state. It appears that there is a larger substantial loss of cardiorespiratory endurance gains than loss of muscular endurance, strength, and power. Fortunately, 3 training sessions per week at approximately 70% VO_2 max can maintain cardiorespiratory fitness levels and provide adequate skeletal muscle stimulatory load to retain any gains made with strength training. Formal rehabilitation is recommended for the retention of skeletal muscle mass in an injured person.[1,45,46]

PHYSIOLOGICAL ADAPTATIONS TO ENDURANCE TRAINING

Cardiorespiratory fitness is the ability to perform prolonged endurance exercise using large muscle groups. VO_2 max is one of the best measures of cardiorespiratory endurance. As discussed previously, both the respiratory and cardiovascular systems play important roles in facilitating endurance activity in acute responses to exercise. Training has minimal effect on lung structure and function, but maximal effort does increase pulmonary ventilation, pulmonary diffusion, the distribution of arterial blood away from inactive tissue and toward active skeletal muscle, and the ability of the muscle to take up delivered oxygen.[1,29]

The cardiovascular system undergoes numerous adaptations to regular endurance training. All of these changes result in a greater delivery of oxygen and nutrients to the working skeletal muscle, including the following[1,29]:

» Increases in left ventricular internal space, wall thickness, and mass allow for a stronger contraction and ultimately greater stroke volume. Increased stroke volume in trained individuals is seen both at rest and during exercise.
» Resting heart rate decreases with endurance training; the rate can be 40 bpm or lower (compared with the 60 to 80 bpm rate of a typical sedentary person).
» Exercise heart rate is also lower at a given training load (eg, 60% VO_2 max) with endurance training, but maximum heart rate does not change markedly.
» Cardiac output does not change much during rest and submaximal exercise, but it does increase considerably during maximal effort and is an important contributor to the increased VO_2 max achieved with training.
» Resting blood pressure is reduced.
» Increased capillarization, blood volume, plasma volume, and red blood cell volume improve tissue perfusion and oxygen delivery.
» Increases occur in the percentage and cross-sectional area of type I muscle fibers (those primarily used in endurance activities).
» Increases occur in mitochondria, oxidative enzymes, and myoglobin content (more machinery for ATP production).

PHYSIOLOGICAL ADAPTATIONS TO RESISTANCE TRAINING

Individuals can undertake regular resistance training to improve muscular strength and power. *Strength* is the maximum force generated by the muscle, whereas *power* is a product of muscle force and velocity. Power is an indicator of the rate at which the work of the muscle is performed. Changes in strength and power require numerous adaptations in the neuromuscular system depending on the type of resistance training. The neuromuscular system is highly responsive to training, and improvements in strength and/or power can be seen within months. Skeletal muscle is very dynamic. Training can improve muscle size (hypertrophy) and strength, whereas disuse or immobility can result in decreased size (atrophy) and strength. The primary neuromuscular adaptations to regular resistance training include:

» improved neural adaptations (increased motor unit recruitment, decreased neurologic inhibition) with strength gains, with or without hypertrophy, especially in the early stages of training;
» strength gains related to muscle hypertrophy in later stages of training; and
» increased size of the individual skeletal muscle fibers and increased numbers of myofibrils and actin and myosin filaments from hypertrophy.

Genetic potential plays a large role in body type. Muscles can be trained to improve strength and size, but there is a limit beyond which further adaptation is not possible.[43,44]

OVERREACHING AND OVERTRAINING

It is clear that proper training and adequate recovery result in increased performance, but many athletes develop the belief that "more is better" and that there is no ceiling for performance enhancement. Excessive training usually results in a performance decrement, for which the athlete often compensates with even more effort. The different stages of training-induced fatigue and subsequent restoration are known as functional overreaching and nonfunctional overreaching, also referred to as overtraining syndrome.[48] The American College of Sports Medicine and the European College of Sports Science[49] issued a joint consensus statement on this topic. *Functional overreaching* refers to a short-term training-induced decrement in performance thought to be necessary for optimal physiological adaptations. *Nonfunctional overreaching* describes excessive training that results in short-term performance decrements that may take several weeks to months to reverse with proper training and rest. During this time, it is critical that the athlete take in adequate amounts of fluid to restore hydration, carbohydrate to replenish glycogen stores, and protein to optimize protein synthesis and healing.

The symptoms leading to performance decrements include overall fatigue, muscular fatigue, chronic muscle tenderness and soreness, lack of concentration, and disrupted eating habits or loss of interest in eating. Persistent training with lack of physiological and psychological recovery can result in long-term and potentially permanent incomplete recovery, referred to as overtraining syndrome (OTS). OTS is more serious because long-term decrements in performance can take months to recover from. OTS includes both physiological maladaptation and psychological dysfunction stemming from increased physical and psychological stress. Because of a lack of standardization and because symptoms vary from person to person, experts have not reached a consensus on diagnostic criteria for OTS. It is important for an athlete with suspected OTS to seek medical care to rule out other confounding diseases or conditions and to develop a sound recovery plan, which consists of deloaded activity, rest, and functional treatment based on symptoms. Box 1.1 provides a list of some symptoms of overtraining syndrome.[1,49,50]

BOX 1.1 Signs and Symptoms of Overtraining Syndrome[1,49,50]

Decline in performance despite continued training

Fatigue, with loss of skeletal muscle strength, endurance capacity, and overall coordination

Decrease in appetite

Weight or fat loss

Anxiousness, restlessness, and sleep disruption

Inability to concentrate, loss of motivation, and even depression

SCOPE OF PRACTICE FOR REGISTERED DIETITIAN NUTRITIONISTS

Scope of practice is an important issue for all health professionals.[51] States that license various health professions have a defined scope of practice for each profession.[52] For RDNs interested in sports dietetics, there is a natural desire to discuss exercise with patients and clients, regardless of whether the RDN has the appropriate educational training or certification to do so. Current nutrition and dietetics educational programs accredited by the Accreditation Council for Education in Nutrition and Dietetics do not require courses, certain knowledge, or competencies specific to exercise science.[53] As a result, many RDNs graduating from traditional nutrition and dietetics programs are not qualified to discuss detailed issues regarding fitness assessment and exercise prescription. RDNs seeking to obtain more knowledge and skill related to nutrition and physical activity, exercise performance, or both should review the *Revised 2021 Standards of Practice and Standards of Professional Performance for Registered Dietitian Nutritionists*

(Competent, Proficient, and Expert) in Sports and Human Performance Nutrition to see if this is an area of specialty in which to seek additional credentialing.[54]

It is critical for the practitioner to understand the laws of the state(s) where they practice.[52] The exercise profession relies largely on self-regulated certification. Many states regulate the profession of dietetics, yet most states (except Louisiana) do not regulate the practice of exercise professionals. If a state licenses any health profession, licensure supersedes any registration or certification.

Physical Activity Guidance

RDNs with an interest in sports dietetics should be comfortable discussing some aspects of exercise and physical activity with their patients and clients. At a minimum, they should be familiar with the current federal *Physical Activity Guidelines for Americans*[45,46] and the overall health benefits of exercise. In general, RDNs can assist medically cleared patients and clients with planning and implementing ways to increase their physical activity levels to match these guidelines. RDNs should use the patient's or client's current level of physical activity and stage of readiness to change as a basis for planning physical activity goals. It is critical for the RDN to fully assess their current knowledge and scope of practice in the area of exercise science. Most RDNs who specialize in sports dietetics should be able to discuss the health benefits of exercise and the principles of exercise training discussed earlier in this chapter. Conducting a fitness assessment and prescribing exercise require specialized knowledge and skills and, ideally, an appropriate certification, both of which can be obtained by RDNs. If a patient or client needs physical activity information, a fitness assessment, or an exercise prescription that is outside of the RDN's scope of practice, the RDN must then provide a referral to a qualified exercise professional.

Fitness Assessment and Exercise Prescription

A fitness assessment measures cardiorespiratory fitness, musculoskeletal strength and endurance, flexibility, balance, and body composition. This information is used to develop a detailed exercise plan, known as an *exercise prescription*, tailored to the individual's current fitness level and health goals. The exercise prescription should be created by a qualified exercise professional. Conducting fitness assessments and writing exercise prescriptions may be outside the scope of practice for some RDNs, depending on whether they hold additional training and certification.

The American College of Sports Medicine (ACSM) ProFinder (www.acsm.org/certification/about/profinder) and the US Registry of Exercise Professionals (USREPS, https://usreps.org) are reputable websites that list qualified exercise professionals.[55,56] ACSM has certified more than 34,000 health professionals worldwide. USREPS is a nationally recognized registry of exercise professionals and an advocate for the exercise professionals who hold accredited exercise certifications from the National Commission of Certifying Agencies (NCCA).[57]

Reputable Exercise and Fitness Certifications

Unlike in nutrition and dietetics, no single accrediting body for college-level programs in kinesiology or exercise science results in a nationally recognized credential in either specialty. Academic programs in these fields may voluntarily become accredited through the Commission on Accreditation of Allied Health Education Programs (CAAHEP)[58] with the goal of achieving some consistency among all exercise science programs. Many CAAHEP-accredited programs provide a track for students to prepare for and earn an exercise-based certification.

If an RDN is not qualified to conduct fitness assessments and provide exercise prescriptions, it is important that they have a network of qualified exercise professionals for patient or client referral, and this should be documented when using the Nutrition Care Process.[59] Both physicians and exercise professionals can be a valuable resource for patients and clients. Fellowship-trained or board-certified sports medicine physicians can guide the client and may have a network of qualified exercise professionals for collaboration. Numerous exercise-related certifications are available; therefore, it is important to research the qualifications for certification and the knowledge and skills assessed in the process. The NCCA[57] governs many of the exercise certifications. Several reputable organizations and their certifications are listed in Box 1.2 on page 14.[60-62]

BOX 1.2 Example Certifications for Exercise Professionals[a,60-62]

Certification	Qualifications	Purpose
American College of Sports Medicine (ACSM) (www. acsm.org)		
Certified Personal Trainer	At least 18 years of age High school diploma or the equivalent Adult CPR/AED certification Must also pass examination	Plan and implement exercise programs for healthy individuals
Certified Group Exercise Instructor	At least 18 years of age High school diploma or the equivalent Adult CPR/AED certification Must also pass examination	Supervise participants or lead instructional sessions for healthy individuals
Certified Exercise Physiologist	Minimum of a bachelor's degree in exercise science, exercise physiology, or kinesiology Adult CPR/AED certification Must also pass examination	Conduct fitness assessments, create exercise plans, conduct personal training for those with medically controlled diseases
Certified Clinical Exercise Physiologist	Master's degree in clinical exercise physiology or the equivalent and 600 hours of hands-on clinical experience **OR** Bachelor's degree in exercise science, exercise physiology, or the equivalent and 1,200 hours of hands-on clinical experience Basic Life Support or CPR for the Professional Rescuer certification	Conduct fitness assessments; create exercise plans; conduct personal training for those with medically controlled diseases and those with cardiovascular, pulmonary, and metabolic diseases

Certification	Qualifications	Purpose
Exercise is Medicine Credential	Minimum of a bachelor's degree in exercise science, exercise physiology, or kinesiology ACSM certification or other National Commission for Certifying Agencies (NCCA)–accredited or International Organization for Standardization/International Electrotechnical Commission 17024 fitness certification Must complete all modules of the Exercise is Medicine online course and pass all online exams with a score of 80% or higher	Help individuals with common chronic diseases lead healthier, more active lives Credential holders are also more likely to be seen as trusted referral resource by health care providers
Autism Exercise Specialist Certificate	Available to exercise professionals, physical education or adapted physical education teachers, physical therapists, recreational therapists, or special education professionals Must complete online course and pass virtual or in-person examination	Incorporate specialized strategies to implement individual or group exercise programs for those with autism in a gym, home, or classroom setting
ACSM in Collaboration with the American Cancer Society (ACS) (www.acsm.org)		
ACSM/ACS Certified Cancer Exercise Trainer	ACSM- or NCCA-accredited health or fitness certification Adult CPR/AED certification Bachelor's degree (in any field) with 500 hours of experience training older adults or individuals with chronic conditions **OR** 10,000 hours of experience training older adults or individuals with chronic conditions Must also pass examination	Work with clients who have been cleared by their physician for independent exercise and physical activity

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BOX 1.2 *Example Certifications for Exercise Professionals*[a,60–62] **(CONTINUED)**

Certification	Qualifications	Purpose
ACSM in collaboration with the National Center on Health, Physical Activity and Disability (NCHPAD) (www.acsm.org)		
ACSM/NCHPAD Certified Inclusive Fitness Trainer	Complete online preparation course and pass examination	Empower those who are challenged by physical, sensory, or cognitive disabilities to engage in physical activity
ACSM in Collaboration with the National Physical Activity Society (NPAS) (www.acsm.org)		
ACSM/NPAS Certified Physical Activity in Public Health Specialist	Bachelor's degree in a health-related field from a regionally accredited college or university **OR** Bachelor's degree in any subject with 1,200 hours of experience in settings promoting physical activity, healthy lifestyle management, or other health promotion Must also pass examination	Promote physical activity with a focus on the public health setting; develop key partnerships to establish legislation, policies, and programs that promote physical activity for people throughout the country
National Strength and Conditioning Association (NSCA) (www.nsca.org)		
Certified Strength and Conditioning Specialist (CSCS)	Minimum of a bachelor's degree or currently enrolled as a college senior Current CPR/AED certification Must pass an exam that tests knowledge, skills, and abilities in 2 areas of professional practice: scientific foundations and practical/applied	Apply scientific knowledge to train athletes for the primary goal of improving athletic performance; conduct sport-specific testing sessions, design and implement safe and effective strength-training and conditioning programs, and provide guidance regarding nutrition and injury prevention
NSCA-Certified Personal Trainer (CPT)	At least 18 years of age High school diploma or an equivalent Current CPR/AED certification Must pass an exam that tests knowledge, skills, and abilities in 4 domains: client consultation/fitness assessment, program planning, exercise techniques, and safety/emergency issues	Assess, motivate, educate and train clients regarding their personal health and fitness needs; design safe and effective exercise programs, provide guidance to help clients achieve their personal health and fitness goals, and respond appropriately in emergency situations

Certification	Qualifications	Purpose
Certified Special Population Specialist (CSPS)	Minimum of a bachelor's degree **OR** A license in 1 of a number of occupations Current CPR/AED certification Must pass an exam that tests knowledge, skills, and abilities in 4 domains: basic pathophysiology and science of health status, condition, disorder or disease; client consultation; program planning; and safety, emergency procedures, and legal issues	Assess, motivate, educate, and train special population clients of all ages regarding their health and fitness needs, preventively and in collaboration with health care professionals
American Council on Exercise (ACE) (www.acefitness.org)		
Personal Trainer Certification	At least 18 years of age High school diploma or the equivalent Adult CPR/AED certification Must also pass examination	May work as a virtual coach or online trainer, athletic coach, gym owner, self-employed corrective exercise and injury prevention specialist
Group Fitness Instructor Certification	At least 18 years of age High school diploma or the equivalent Adult CPR/AED certification Must also pass examination	Lead various fitness classes for healthy individuals
Medical Exercise Specialist Certification	At least 18 years of age Adult CPR/AED certification Bachelor's degree in exercise science or a related field Proof of 500 hours of work experience designing and implementing exercise programs for apparently healthy individuals and/or high-risk individuals	Work as part of a client's health care team, helping them prevent or effectively manage chronic disease

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BOX 1.2 *Example Certifications for Exercise Professionals*[a,60-62] *(CONTINUED)*

Certification	Qualifications	Purpose
American Council on Exercise (ACE) (www.acefitness.org) (continued)		
Health Coach Certification	At least 18 years of age Adult CPR/AED certification Must also submit proof of at least 1 of the following: • Current NCCA-accredited certification in fitness, nutrition, health care, wellness, human resources, or a related field • Associate's degree or higher from an accredited college or university in fitness, exercise science, nutrition, health care, wellness, or a related field • Minimum of 2 years of documented work experience in coaching, leading, designing, implementing, or facilitating 1 or more of the areas behavior or lifestyle change, exercise, wellness, nutrition, or physical activity • Completed health coach training and education program approved by the National Board for Health and Wellness Coaches (NBHWC)	Recognize unique dietary, emotional, and physical needs of individuals and help people reach their goals and implement lifestyle changes that improve their overall health and wellness with exercise, nutrition, and psychology; can work in a variety of settings from health clubs to corporations, virtual coaching to health care

[a] This is not an all-inclusive list. Please see the organization websites for updated information.

Physical Activity Guidance and the Nutrition Care Process

The Nutrition Care Process consists of nutrition assessment, diagnosis, intervention, monitoring, and evaluation.[63] These steps as they relate to physical activity guidance are detailed further below.

Assessment The RDN may assess an individual's readiness to change, weight and body composition, physical activity history, and current level of physical activity.

Diagnosis The RDN can document any problems and create a diagnosis (problem, etiology, signs and symptoms) statement. The diagnosis often references the individual's level of physical activity or inactivity, readiness to change, or something in the behavioral domain.

Intervention The RDN can choose to provide education if it is within their scope of practice, provide a referral to a qualified exercise professional, or do a combination of the 2. For most RDNs, education can include a discussion of topics such as the health benefits of exercise, the way to start an exercise program, and the key concepts presented in the *Physical Activity Guidelines for Americans*,[45,46] as well as providing additional resources (eg, handouts, names of community centers, list of professionals).

Monitoring and evaluation The RDN should include follow-up on the physical activity–related goals set for the patient or client.

For more information on how to discuss physical activity guidance using the Nutrition Care Process, refer to the Academy of Nutrition and Dietetics publication *A Physical Activity Toolkit for RDNs: Exercise is Medicine*.[64] This tool kit contains extensive links to usable resources and handouts on the topic of discussing physical activity with patients.

Physical Activity Guidelines for Americans

RDNs with an interest in sports dietetics should be familiar with the *Physical Activity Guidelines for Americans* and be comfortable discussing these guidelines with their patients or clients.[45,46] The guidelines can be downloaded free of charge at the Health.gov website (https://health.gov/our-work/nutrition-physical-activity/physical-activity-guidelines). In addition to the document itself, a ready-made PowerPoint presentation that covers key concepts in the guidelines is available. Box 1.3 on page 20 provides definitions of the levels, components, and intensity of physical activity found in the guidelines.

BOX 1.3 Definitions of Levels, Components, and Intensity of Physical Activity in the Physical Activity Guidelines for Americans[45,46]

Levels of physical activity	
Inactive	No activity beyond baseline (this is considered unhealthy)
Low	Beyond baseline but fewer than 150 min/wk (better for health than inactive)
Medium	150 to 300 min/wk (additional and possible extensive health benefits)
High	More than 300 min/wk (additional and possible extensive health benefits)
Components of physical activity	
Intensity	How hard a person works
Frequency	How often an activity is performed
Duration	How long an activity lasts in 1 session or how many repetitions are performed
Intensity of physical activity	
Light	1.1 to 2.9 METs[a] (1.1–2.9 times rest)
Moderate	3.0 to 5.9 METs
Vigorous	6.0 METs or higher

[a] MET = metabolic equivalent. 1 MET represents the work at rest and is equivalent to an oxygen consumption (VO_2) of 3.5 mL × kg^{-1} × min^{-1}.

Metabolic equivalents (METs) are another way of defining exercise intensity. MET is the ratio of the rate of energy expended during exercise to the rate of energy expended at rest. One MET is equivalent to an oxygen consumption (VO_2) of 3.5 mL × kg^{-1} × min^{-1}. Multiples of this value can be used to quantify energy expenditure, as discussed in detail in Chapter 10. One MET is the work at rest, whereas 5 METs equals 5 times the energy expenditure at rest. The *Physical Activity Guidelines* also use MET-minutes for guidance. MET-minutes consider both physical activity intensity and duration. For example, a 4-MET activity done for 30 minutes is equivalent to 120 MET-minutes, and an 8-MET activity done for 15 minutes is also equivalent to 120 MET-minutes. For health benefits, one can exercise at a lower intensity for longer periods of time or at a higher intensity for shorter periods of time. Practitioners should note that these physical activity guidelines are for general health and are not exercise training guidelines for optimal performance. The goal for health is to achieve a minimum of 500 to 1,000 MET-min/wk, with potential greater health benefits found at greater than 1,000 MET-min/wk. The relationship between intensity and METs is summarized as follows:

- Light intensity = 1.1 to 2.9 METs
- Moderate intensity = 3.0 to 5.9 METs
  - For example, walking at a rate of 3 mph requires 3.3 METs of energy expenditure.
- Vigorous intensity = 6.0 METs or greater
  - For example, running a 10-minute mile (6 mph) is a 10-MET activity.

Key guidelines for health from the *Physical Activity Guidelines for Americans* are summarized in Box 1.4.[45,46]

BOX 1.4 Summary of Key Guidelines for Health from the *Physical Activity Guidelines for Americans*[45-46]

It is important to get people to sit less and move more.

Physical activity reduces the risk of many adverse health outcomes.

Some physical activity is better than none.

Physical activity has immediate health benefits.

Consistently meeting the recommendations in these guidelines can lead to even more long-term health benefits.

There is new evidence for many additional health benefits related to physical and mental health.

Additional benefits occur with increases in intensity, frequency, and duration.

Both cardiorespiratory and resistance exercise are beneficial.

Health benefits occur at all ages.

Benefits far outweigh the possibility of adverse outcomes.

Substantial health benefits are seen with 150 min/wk of moderate-intensity physical activity or 75 min/wk of vigorous physical activity or a combination.

Additional health benefits are seen with 300 min/wk of moderate-intensity physical activity or 150 min/wk of vigorous physical activity or a combination.

Resistance training—moderate or high in intensity—involving all major muscle groups is recommended 2 d/wk or more.

For health, 2 minutes of moderate physical activity is equivalent to 1 minute of vigorous physical activity.

SUMMARY

Exercise physiology is the study of the body alterations and responses to acute and chronic exercise. Exercise disrupts homeostasis, resulting in increased energy needs to meet the metabolic demands of active muscles. The respiratory and cardiovascular systems work in a coordinated fashion to supply oxygen and nutrients to working muscles in an attempt to meet this demand. At lower moderate-intensity exercise, the body can use carbohydrate and fat in aerobic metabolism, meeting the energy demands with ease. As exercise intensity increases, the body's reliance on carbohydrate as a fuel source with some ATP being generated through anaerobic glycolysis increases. Short-term or metabolic fatigue is a result of reliance on anaerobic metabolism, whereas long-term or substrate fatigue is a result of glycogen depletion. Exercise training results in positive physiological adaptations that improve performance. Several principles of exercise training are key for determining the performance outcome.

RDNs should be comfortable discussing exercise with their patients or clients while staying within their scope of practice. The extent of this discussion will depend on individual comfort level and any additional education and certification. All RDNs should be able to discuss the health benefits of exercise and the general principles in the *Physical Activity Guidelines for Americans*. Beyond this, if the RDN cannot complete a fitness assessment and exercise prescription, then the RDN should provide a referral to a qualified exercise professional.

KEY TAKEAWAYS

An understanding of exercise physiology basics is necessary for all RDNs interested in sports nutrition in order to understand the sports nutrition-specific guidelines and their effects on performance.

Exercise results in increased skeletal muscle ATP demand, and the cardiovascular and respiratory systems work in a coordinated fashion to deliver oxygen and nutrients to the working skeletal muscle.

The key nutrients providing energy during exercise are carbohydrate and fat. Carbohydrate can provide ATP through both anaerobic and aerobic metabolism, but fat can only be fully oxidized aerobically.

At all times, the body is using a mixture of carbohydrate and fat. As exercise intensity increases, there is an increased reliance on carbohydrate for fuel (crossover concept). Carbohydrate is a more oxygen-efficient fuel and can produce ATP quickly.

Short-term or metabolic fatigue is a result of a reliance on anaerobic metabolism under high exercise intensities. Long-term or substrate fatigue is a result of glycogen depletion.

Sound training results in physiological adaptations that improve performance. There are several principles of training that should be considered.

RDNs should include physical activity in their use of the Nutrition Care Process.

All RDNs interested in sports nutrition should be comfortable discussing the health benefits of exercise and the key principles presented in the *Physical Activity Guidelines for Americans*, 2020-2025.

An RDN may or may not have the education and training to conduct fitness assessments and develop exercise prescriptions. If not, the RDN must provide a referral to a qualified exercise professional.

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