6TH EDITION

SPORTS NUTRITION

A Handbook for Professionals

SPORTS, CARDIOVASCULAR, AND WELLNESS NUTRITION DIETETICS PRACTICE GROUP

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FOREWORD

The sixth edition of *Sports Nutrition: A Handbook for Professionals* is an evidence-based complete reference manual written by experienced sports dietitians and others with acclaimed expertise in their respective practice areas. The unique feature of this manual is the focus on key takeaways at the end of every chapter to guide the reader on how to apply the principles presented. Balancing the evidence-based information with practical application points will be valuable for all professionals interested in the health and performance of athletes, including sports medicine professionals, sports dietitians, athletic and fitness trainers, coaches, and educators.

This edition provides a comprehensive overview of the expected core topics, such as nutrition assessment, energy balance, macronutrient and micronutrient basics, and body composition, and it also includes emerging areas of interest. Some of these newly featured topics include detailed discussions on nine endurance events, emerging areas of opportunity for the sports registered dietitian nutritionist, the gut microbiome, and the most recent considerations in weight management.

Your understanding of sports nutrition practice will undoubtedly grow, and you will benefit from owning this sixth edition. I strongly recommend this as the best sports nutrition reference manual available and an absolute must for your professional library! This copy will replace the lovingly worn and repeatedly highlighted fifth edition in my own library. I can't wait to startreading this edition again in its published format!

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PREFACE

Effectively delivering evidence-based guidelines translated into practical information for athletes is critical for improving their health and performance. The sixth edition of *Sports Nutrition: A Handbook for Professionals* is a joint venture between the Academy of Nutrition and Dietetics and the Sports, Cardiovascular, and Wellness Nutrition (SCAN) dietetic practice group. All six editions of this manual have involved SCAN registered dietitian nutritionists, and this edition offers *even more* chapters written or reviewed by SCAN registered dietitian nutritionists. We are pleased with the changes to the sixth edition and hope that you will find this updated edition useful.

ACKNOWLEDGMENTS

The sixth edition of *Sports Nutrition: A Handbook for Professionals* builds on the previous five editions of a book that belongs on the shelf of any health and sports professional. This edition continues to provide evidence-based information, as well as practical applications, for a broad range of athletes of all ages. We would like to extend a special thanks to the following individuals:

- The SCAN executive committee, past and present chairwomen (Carol Lapin, Eve Pearson, and Karen Collins), for their support and recognition of the value of this project
- The SCAN office and our past Executive Director, Athan Barkoukis, for his persistence and attention to detail
- The returning authors and the 11 new authors who provided their time, talent, and expertise in writing such high-quality chapters
- The reviewers who played such a critical role in the process of creating the manual
- The Academy of Nutrition and Dietetics Publications, Resources, and Products Team
- The athletes, coaches, and families of all the athletes we have worked with over the years who motivate us to remain current and relevant

Note from Christine Karpinski:

I cannot thank Chris Rosenbloom, 5th edition editor-in-chief, enough for her invaluable advice, support, and context.

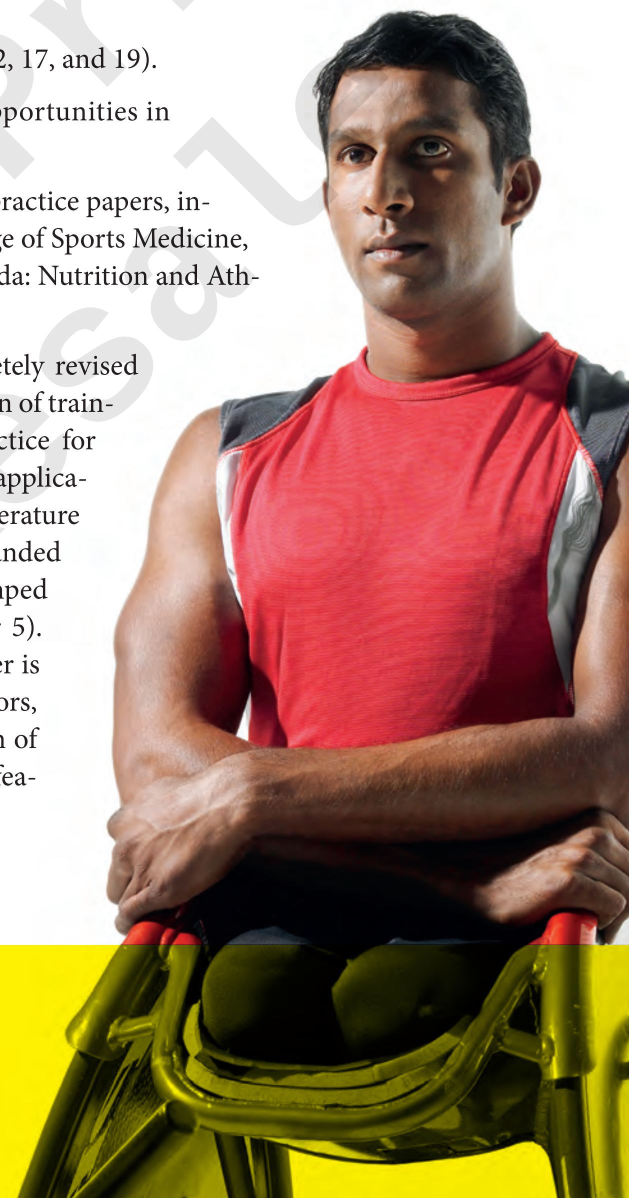
Christine A. Karpinski, PhD, RDN, CSSD, LDN, Editor-in-Chief
Christine A. Rosenbloom, PhD, RDN, CSSD, FAND, Assistant Editor

OVERVIEW OF THE SIXTH EDITION

The sixth edition of *Sports Nutrition: A Handbook for Professionals* is organized in four sections and designed to be a complete reference manual for practicing professionals that can also be used as resource for undergraduate and graduate sports nutrition classes. We think that we have made some excellent changes to this new edition:

- We have increased the number of authors who are SCAN registered dietitian nutritionists (RDNs), featuring 11 new lead authors. The manual is anchored by our esteemed returning authors who are a mix of SCAN 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 to have authors provide several takeaway points 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 sixth edition.
- We completely revised seven chapters (Chapters 1, 5, 8, 9, 12, 17, and 19).
- A brand new chapter (Chapter 23) discusses emerging opportunities in sports nutrition.
- We include guidelines from the most current position and practice papers, including the 2016 Position Statement of the American College of Sports Medicine, Academy of Nutrition and Dietetics, and Dietitians of Canada: Nutrition and Athletic Performance.

Section 1 covers sports nutrition basics. It begins with a completely revised overview of exercise physiology (Chapter 1), including a description of training principles and an important discussion about scope of practice for sports RDNs. Chapters 2 through 4 cover the basics and sports applications of dietary carbohydrates, protein, and fat, with updated literature and practical advice. Chapter 4 also contains a significantly expanded discussion of high-fat diets and fat adaptation. A completely revamped vitamin and mineral chapter is featured in this edition (Chapter 5). Instead of an alphabetical review of the micronutrients, the chapter is organized into categories based on risk (due to training, risk factors, and dietary intake) and function. 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 has an increased focus on how sports RDNs can translate and incorporate the Nutrition Care Process and the Standards of Practice and Standards of Professional Performance into a sports nutrition practice. A sports RDN and an exercise scientist collaborated to provide a different approach to the assessment of body size and composition (Chapter 9). Three authors worked together to update Chapters 10, which includes a discussion of the emerging research on gut microbiome. Lastly, the seasoned authors of Chapter 11 provide new research in the area of weight management.

Section 3 has been renamed *Principles in Practice* to better reflect the approach of its chapters. Chapters 12 through 19 provide practical application of the sports nutrition basics discussed in Sections 1 and 2. To that end, we have kept the same population-specific topics as we had in the previous edition. It took the collaborative efforts of nine experienced sports RDNs to complete this section, which offers you a plethora of information that you can incorporate into your practice.

Section 4 digs deep into sport-specific recommendations. Chapters 20 and 21 feature updated research for sprint, power, and intermittent sports. Chapter 22 discusses the research behind fueling endurance athletes, and brand new to this edition is an in-depth discussion about considerations for specific endurance events, such as adventure racing, obstacle course racing, cross-country skiing, endurance cycling, endurance running, marathon rowing, triathlons, endurance mountain biking, and multiday events. This section concludes with a new chapter (Chapter 23), which explores emerging areas of opportunities for sports RDNs, such as CrossFit, obstacle course races, motorsports, performance artists (eg, dancers, marching band), first responders, and more.

SECTION 1

SPORTS NUTRITION BASICS

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. Because of the importance of this topic, the first section of *Sports Nutrition* examines 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 an effective immune system function (Chapter 1). Our knowledge of the interrelated roles of dietary carbohydrate, protein, and fat has increased tremendously in the past decade, 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 how vitamins and minerals affect sports performance. The most essential nutrient for athletes, water, is explained in both scientific and practical terms in the chapter on hydration, electrolytes, and exercise (Chapter 6). Lastly, this section concludes with a comprehensive look at dietary supplements and ergogenic aids that athletes use in the hope of improving performance (Chapter 7). This chapter 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, LDN, FACSM, FAND, ACSM EP-C

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 include changes in temperature and altitude. One deliberate challenge is participation in physical activity and exercise, when homeostasis in systems such as the cardiorespiratory and musculoskeletal are 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.

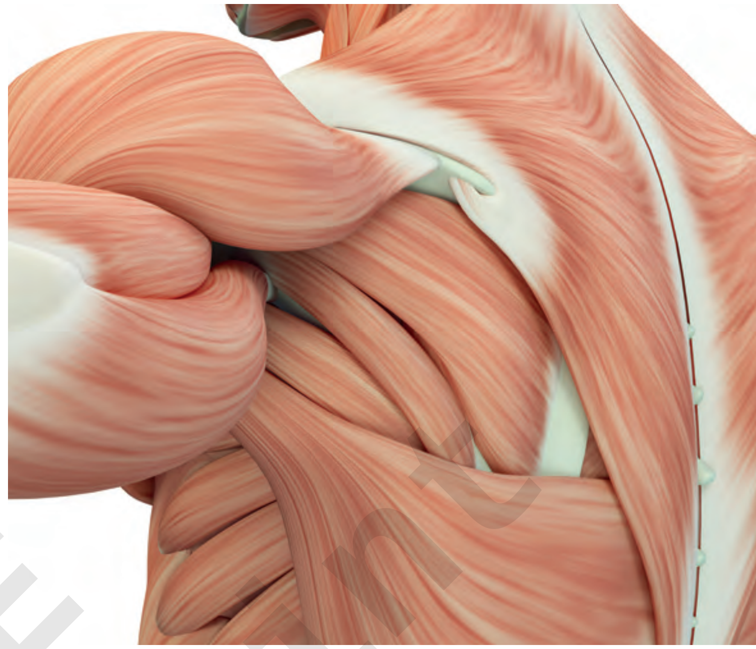
Exercise physiology is the study of these alterations and the responses to exercise that result from acute bouts of activity, as well as the chronic adaptations that occur from repeated exercise and long-term training.[1] This chapter will provide a brief overview of the basics of the physiology of exercise and will include a discussion of the role of the registered dietitian nutritionist (RDN) or certified specialist in sports dietetics and appropriate application to practice.

ACUTE RESPONSE TO EXERCISE

Even at rest, the body is in a constant state of flux, metabolically active to maintain physiological function. This requires a continual supply of energy. During exercise, the energy demands of skeletal muscle greatly increase, and the respiratory and cardiovascular systems must work harder to allow for increased respiration and blood supply to the working muscles with a concomitant reduction of blood flow to the gastrointestinal tract. This can continue for minutes to hours depending on the intensity of exercise and the condition of the individual. In some sports or events, the increased energy demand is relatively constant for an extended time (eg, a marathon), while in others it 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 increase can be 2 to 20 times that at rest. Very high-intensity activities can exceed this range but can only be sustained for seconds to minutes. Ultimately, the body systems must work together to meet the increased energy demands.[1-5]

Skeletal Muscle and Exercise

Skeletal muscles are attached to the skeleton. These muscles allow movement of the body as they contract and relax. The human body has over 600 skeletal muscles that allow fine and gross movement. We often think of a muscle or muscle group (like the biceps or quadriceps) as a single unit. These units, however, are made of many complex components working together to complete a single contraction. Muscle fiber is the term to describe a muscle cell. A single nerve and the group of muscle fibers it innervates are referred to as a motor unit. Each muscle cell contains organelles, including mitochondria for aerobic energy production, and hundreds to thousands of myofibrils. Sarcomeres, the functional unit of a myofibril, are responsible for the contractile properties of the muscle. Sarcomeres are comprised 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 an energy-requiring process. Not all available motor units are activated at once—only those needed to generate the appropriate force will be used. The force and speed of movement needed will 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 two antagonistic muscles at any time.[1,6-9]

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 with activities of daily living, like walking, or during lower-intensity endurance events, like bike riding or jogging. Type II fibers, sometimes referred to as fast-twitch, have relatively poor endurance capacity and work better anaerobically. While these fiber types can be further classified as type IIa, type IIx, and type IIc, the differences between the types are not fully understood and are a subject of research.

Most skeletal muscles comprise approximately 50% type I fibers, 25% type IIa fibers, 22% to 24% type IIx, and only 1% to 3% type IIc. The precise percentages of fibers can vary greatly among individuals, even within the specific muscle, and we often see extreme variation in athletes from different sports. Type IIa fibers are recruited most frequently but are secondary to type I fibers, and type IIc are recruited least frequently. Type IIa fibers generate more force than type I but fatigue more easily. They tend to be recruited during higher-intensity events of short duration, such as a half-mile run or a strength-training workout. The significance of type IIx fibers is poorly understood. It appears they are used with explosive activities such as a 50-meter dash or weightlifting. Most muscle groups contain both types of fibers and recruit the type needed for the activity.[1,6-11]

It is plausible to suspect a difference in skeletal muscle fiber types between different types of athletes and untrained individuals. Most studies show little to no difference in the proportion of type I muscle fibers between athletes and controls (but, in contrast, some studies show large differences).[12-18] One study examining bodybuilders reported extremely high values of type IIx fibers,[18] yet other similar studies do not support this finding.[14,16,19] There does, however, appear to be proportional differences in type IIa and type IIx muscle fibers between strength and power athletes and untrained control subjects. Studies support the notion that strength and power athletes have a greater proportion of type IIa and a smaller proportion of type IIx fibers, while others do not.[12-18] The majority of studies show a shift from type IIx to type IIa fibers with long-term resistance training.[12-17,19]

Endurance athletes tend to possess a greater proportion of type I muscle fibers, but the difference does not appear to be caused by training for shifts between type II and type I. Furthermore, it seems that endurance athletes do not have significant changes in their type IIa fiber profile.[20-23] Lack of concrete evidence leads many to scientists ask: Is there a relationship between fiber type and endurance performance success? We would expect that more type I fibers would enhance long-endurance performance activities and more type II fibers would benefit high-intensity activities. Studies reporting on muscle fiber types in the gastrocnemius muscle in distance runners and sprinters support this concept: Endurance athletes have more type I fibers and sprinters have more type II fibers. It is important to keep in mind that fiber type is just one piece of the puzzle. Other factors, such as training, nutrition, and motivation, also affect performance.[1,6-9,24]

Cardiovascular and Respiratory Systems

The cardiovascular and respiratory systems work together seamlessly to deliver oxygen and nutrients to the working muscle and all tissues and to remove metabolic waste products and carbon dioxide from these tissues. These systems working together, often called the cardiorespiratory system, consist of the heart, blood vessels, airways, and lungs. Pulmonary ventilation is the term to describe breathing (air moving in and out of the lungs). Ventilation happens in two phases: inspiration and expiration. Inspiration is an active process involving the activation of the diaphragm and external intercostal muscles, while 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 cell.[1,9]

The cardiorespiratory system has many functions and supports all other physiological systems. In addition to those already identified, key functions include transportating hormones and other compounds, assisting thermoregulation and fluid balance, and maintaining acid-base balance. The cardiac cycle occurs during each heartbeat and includes both electrical and mechanical events.[1,9]

Heart rate is the number of heartbeats per unit of time, usually measured and expressed as beats per minute (bpm). Heart rate is based on the number of contractions of the ventricles (the lower chambers of the heart). Normal range for heart rate is 60 to 100 bpm. A heart rate that is faster than normal is called tachycardia; a heart rate this is slower than normal is called bradycardia. Volume of blood pumped during one heartbeat is called stroke volume. Cardiac output is the total volume of blood pumped from one heartbeat, a product of the heart rate and the stroke volume. Resting cardiac output averages 5 L/min but 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 those with elite endurance training.[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. At rest, many organs require more blood than skeletal muscles. At rest, the muscle receives approximately 15% of the cardiac output, but this can increase to as much as 80% during intense exercise to deliver oxygen and nutrients to the 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. Almost immediately upon beginning exercise, ventilation increases to meet the oxygen demand of the muscle. During lower-intensity activities, this can be accomplished by simply moving more air in and out of the lungs. As exercise intensity increases, respiration rate increases. During most common forms of endurance exercise, pulmonary ventilation is usually not at its maximum capacity and therefore not the limiting factor in performance. The exception may occur during very high-intensity exercise. Usually the respiratory muscles can withstand fatigue during prolonged endurance exercise. There is a point where athletes cannot take in any higher volume of air and respiration rate cannot be any faster. At this point, they are at aerobic capacity, and the energy required for any activity in excess of this must come entirely from anaerobic metabolism. The term to describe this is maximal oxygen uptake (VO_2 max). VO_2 max, an important consideration for performance lasting more than a few minutes, 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 as $mL \times kg^{-1} \times min^{-1}$. A sedentary person may see a 10-fold increase in maximal oxygen transport with exercise, while an endurance athlete may see a 23-fold increase. A sedentary man has an average VO_2 max of 35 $mL \times kg^{-1} \times min^{-1}$, while a world-class endurance athlete can have one as high as 80 $mL \times kg^{-1} \times min^{-1}$.[30,31]

The lungs–gas exchange is not considered a limiting factor in exercise performance. Instead, with longer-term endurance exercise, glycogen availability, or its utilization by the working skeletal muscles, is the more important factor. The key element seems to be the maximum cardiac output (heart rate multiplied by stroke volume) that can be achieved, as this is closely related to both VO_2 max and endurance performance. Heart rate increases linearly as exercise intensity increases, but ultimately a maximum rate is achieved, and the heart rate plateaus. Maximum heart rate differs little between trained and untrained individuals, although the intensity level at which these individuals will reach maximum heart rate will vary. For example, both a trained and untrained person may have a maximum heart rate of 170 bpm, but the trained person can work at a higher oxygen uptake before reaching that maximum heart rate.

Stroke volume is also a determining factor for cardiovascular endurance capacity. In untrained persons, stroke volume increases proportionally as exercise intensity increases but usually does not further increase once a person is exercising at 40% to 60% of his or her VO_2 max. In trained individuals, stroke volume can increase even further as exercise intensity increases. Since 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.[1,27,30-32]

FUEL FOR EXERCISE

The biologically usable form of energy in the human body is adenosine triphosphate (ATP). Each time skeletal muscles contract or relax, ATP is required. All movement, including intentional exercise, requires an increased energy demand on skeletal muscles. If energy cannot be supplied in a timely manner and in adequate amounts, movement will cease. As the intensity or duration of exercise increases, the body may have difficulty keeping up with this increased energy demand, and ultimately fatigue ensues. One of the limiting factors in ATP production is exogenous fuel from the energy nutrients once endogenous carbohydrate stores are exhausted.[1,5,33]

Energy Substrates

Plants rely on the process of photosynthesis to convert light from the sun into chemical energy. Humans obtain energy from consuming plants and animals, thereby taking in energy nutrients. Energy nutrients come in the form of carbohydrate, fat, or protein. All cells in the body have the ability to oxidize these nutrients, causing a breakdown and release of stored energy. The cells also have metabolic pathways to process these energy substrates, resulting in the generation of ATP. In muscle cells, ATP is hydrolyzed, releasing a phosphate group, adenosine diphosphate (ADP), and energy.[1,3,5,33]

In addition to gaining energy from the ingestion of nutrients from foods and beverages (exogenous sources), the human body has the ability to store and utilize substrates for later use (endogenous sources). Under normal circumstances, the primary nutrients for energy production come from carbohydrate and fat. Usually, protein contributes less than 5% to 10% to the body's energy needs because it has so many other important functions, such as acting as enzymes, hormones, and immune proteins and performing functions such as tissue maintenance, growth, and repair. The exception to this is during the later stages of prolonged endurance exercise where proteins can contribute up to 15% of the energy needs if exogenous carbohydrate is not consumed and glycogen stores become depleted. In this chapter, we will focus on carbohydrate and fat being the fuel sources for working muscle during exercise.

The storage form of carbohydrate in humans, glycogen, is found in both skeletal muscle and liver. Glycogen storage has a maximum capacity, and, on average, these organs can store approximately 1,600 to 2,500 kcal of energy. The liver can store up to 75 to 100 g (300 to 400 kcal) of glycogen, while skeletal muscle can hold up to 300 to 400 g (1,200 to 1,600 kcal). Plasma glucose is a small source of carbohydrate, containing approximately 5 to 25 g (20 to 100 kcal). Under normal circumstances, we cannot fully depend on any of these stores to fuel exercise because the brain and central nervous system require glucose and take priority. Fat (adipose tissue) is stored as triglycerides within adipose tissue and skeletal muscle. Unlike glycogen, adipose tissue triglyceride is limitless and can provide 70,000 kcal of energy or more.[3,34,35]

Energy Systems

ATP is stored in body cells in very limited quantities, so the body must constantly have the ability to generate ATP to meet the demands of cellular metabolism and especially muscle contraction during exercise. During rest, most of the cells and organs use a constant supply of ATP. With increased activity, skeletal muscle ATP demand can increase greatly, depending on the intensity and duration of exercise. As ATP is used—with each muscle contraction generating ADP and a single phosphate group—the ADP and phosphate group must be rephosphorylized to ATP. There are three basic metabolic pathways to accomplish this: those that generate ATP without the use of oxygen, called anaerobic; those that require oxygen involvement, called aerobic; and those that rely on the large amount of creatine found in muscle cells, called the phosphocreatine (PC) system. 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.[1,3,34,35]

ADENOSINE TRIPHOSPHATE–PHOSPHOCREATINE SYSTEM

The most rapid method that the body uses to produce ATP is the ATP-PC system. This anaerobic system is used during intensive, explosive movements, such as a tennis serve or a power lift. This system generates ATP rapidly; however, it is very limited and only supplies ATP for up to 10 seconds. A key component in the ATP-PC system is PC, which is stored in skeletal muscle. PC is simply a molecule of creatine attached to a single molecule of phosphate. A creatine kinase enzyme breaks the two molecules apart, and the free phosphate molecule then combines with ADP, forming new ATP. The ATP-PC system is limited because there is a very small pool of PC stored in the skeletal muscle. Once all PC molecules have donated their phosphate group to ADP, the system can no longer facilitate further ATP production until PC is replenished, which normally happens during recovery with rest and dietary intake.[1,3]

ANAEROBIC GLYCOLYSIS

This system oxidizes one glucose molecule (six carbons) to form two pyruvic acid molecules (three carbons). Glucose can come from dietary intake (circulating blood glucose) or from glycogen stored in the muscle or liver. In the process, potential energy is generated in two ways. First, ATP is directly generated from the breakdown process of glucose to pyruvate. Second, while glucose is being oxidized, hydrogen molecules are being removed. Nicotinamide adenine dinucleotide (NAD) is a coenzyme that carries electrons. NAD receives these molecules, accepts an electron (hydrogen molecule [H]), and forms NADH, transporting hydrogen to a mitochondrial location, called the electron transport chain (ETC), where the body can generate ATP aerobically. This pathway does not produce large amounts of ATP but does generate it fairly rapidly. This system and the ATP-PC system are the predominant energy systems for the first few minutes of intense, continuous activity.[1,3,36] Anaerobic glycolysis also provides energy during the first few moments of moderate, longer-duration activity as the aerobic system begins to generate ATP.[3,37,38]

Another limitation of this system is the production and accumulation of lactate during high-intensity situations, when skeletal muscle ATP demand is high. Production of pyruvic acid is not problematic when oxygen is present and metabolism continues. When oxygen is limited, such as during very high-intensity activity, the pyruvic acid gets converted to lactic acid. Lactic acid is relatively unstable at normal body pH: it loses a hydrogen ion or dissociates to lactate. As hydrogen molecules accumulate, the pH of the muscle cell drops, glycolytic enzymatic activity is hampered, and skeletal muscle fatigue results. The body must slow down to recover before intense activity can continue. Lactate is constantly being produced, but, fortunately, it is easily cleared with time by a few mechanisms. First, lactate is taken up and oxidized by the mitochondria in the same muscle cell. This occurs primarily in type I muscle fibers. Second, much more lactate is produced in the type II muscle fibers, but that lactate is transported to the type I fibers or to other cells in the body for oxidation. Third, via the Cori cycle, lactate travels from the muscle to the liver, gets converted to glucose via gluconeogenesis, and then is sent back to the working muscle for fuel. Once lactate is cleared, activity can continue.[3,37,38]

AEROBIC METABOLISM

The system described in the preceding section is also known as oxidative phosphorylation. Oxidative phosphorylation can break down carbohydrate, fats, or proteins with the involvement of oxygen. It uses the Krebs cycle and the ETC. Unlike the other two energy systems, oxidative phosphorylation can supply ATP on a fairly limitless basis as long as macronutrients and oxygen are available. Acetyl coenzyme A (CoA), a metabolic intermediate from both glucose and fat oxidation, is ultimately oxidized via aerobic metabolism. This compound 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 to form water. The ETC is the most efficient way that our bodies produce ATP because there are no metabolic by-products that produce fatigue.[1,3,34]

CROSSOVER CONCEPT

All metabolic systems work concurrently. One system does not shut off as another turns on; rather, all the systems are working at any given time. The relative contribution of each system will depend on the physiological need for ATP. Fatty acid oxidation produces more ATP per gram than carbohydrate oxidation, but it is a much slower process and requires more oxygen to complete. Oxidation of a 6-carbon glucose molecule nets approximately 32 molecules of ATP, but a 16-carbon fatty acid can produce 106 ATP molecules. More ATP can be produced with increased carbon length of the fatty acid. 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.[3,39]

During rest or low-intensity activity, ATP demand is low, and oxygen is plentiful. As a result, fat is the preferred fuel source at this time. As exercise intensity increases, skeletal muscle ATP demand increases and oxygen delivery becomes more limited. In this case, there is more reliance on carbohydrate for fuel because glucose is oxidized more rapidly and is more oxygen efficient (more ATP is generated per oxygen molecule used) than fat. Remember, both carbohydrate and fat are always being used, but the ATP demand and oxygen availability will determine which substrate and metabolic system is predominant in ATP generation.[34,36]

FATIGUE

Muscular fatigue refers to the impairment or inability to produce force at the level of the muscle. At rest and lower-intensity exercise, humans are capable of producing enough ATP to fuel activity without muscular fatigue, as long as there are sufficient energy substrates (primarily carbohydrate and fat) readily available in our bodies. 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 by-products that contribute to fatigue.[1,40-42]

Short-Term Fatigue

Short-term fatigue occurs when exercise intensity rises to levels that disturb our body's ability to derive energy from our primary exercise fuel substrates: carbohydrate and fat. Possible causes include the accumulation of metabolic products such as inorganic phosphate and lactate, depletion of creatine phosphate, and changes in cellular calcium. The primary culprit in metabolic 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. 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 the hydrogen molecules. Pyruvate's normal metabolism to acetyl CoA diminishes, and instead, pyruvate accepts these hydrogen molecules and forms lactic acid, which rapidly dissociates to lactate. Lactate is formed faster than it can be cleared, and the acidic environment in the cell disrupts glycolysis enzymatic activity. At this point, ATP production is hindered, and skeletal muscle contraction is impaired. The only way to restore homeostasis is to reduce exercise intensity to enhance oxygen uptake and clear metabolic by-products. Lactate is not just a waste product of metabolism; it is a fuel source for resting tissues and contracting cardiac and skeletal muscles, and endurance-trained individuals can better utilize lactate for energy. Once the lactate is cleared—and this is a rapid process—the fatigue dissipates and the skeletal muscle can once again contract.[1,40-42]

Long-Term Fatigue

Lactate accumulation is not significantly related to fatigue in prolonged endurance activities. Long-term fatigue or substrate fatigue, sometimes referred to as "hitting the wall" or "bonking," is thought to be a consequence of glycogen depletion. Because liver and muscle glycogen storage capacity is limited, depletion can occur fairly rapidly. Once glycogen stores are depleted, dietary carbohydrate absorption and gluconeogenesis cannot keep up with the skeletal muscle ATP demand, 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 desired 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.

Individuality

Both genetic and environmental factors contribute to body composition. While genetics creates starting points and boundaries that determine our fat patterning and muscularity, this does not mean that our ultimate body shape and size are completely outside our control. We have the ability to alter our physique, to an extent, with nutrition and training. It is, however, important to understand that we must be realistic about our genetic potential. People have different body shapes, separated into three categories: the ectomorph is generally tall and lean; the endomorph is rounder; and the mesomorph is somewhere in between. People from different categories can respond differently to the same training. For example, a very tall and lean person may never be able to participate in a resistance training regimen resulting in the physique of a professional bodybuilder. 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 than lower responders. Being realistic in terms of body type and accomplishments for specific types is an important consideration.[43,44]

Specificity

This principle 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 long enough in duration to promote cellular training adaptations, such as increases in mitochondrial density. Anaerobic sprints or weight lifting promote increased muscle strength and hypertrophy, which are detrimental to an endurance athlete. Similarly, cardiovascular training will not result in the increased muscular strength and hypertrophy desired for high-intensity activity and stop-and-go sport athletes. The training program must mimic the desired activity.[1,45]

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, he or she may initially bench press 100 lbs for 8 repetitions, and, over time, he or she will be able to do 12 to 15 repetitions before fatigue. As training continues, he or she needs to add weight until again reaching fatigue at 8 repetitions. In addition to the weight and number of repetitions performed, muscle 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 slowing the speed of the lowering motion. With endurance performance, one must increase the total training volume with intensity, duration, or both to see an improvement.[1,45]

Variation/Periodization

The principle of periodization involves exercise training for a particular sport or event in smaller periods based on the desired outcome. Proper periodization allows for the intensity of training needed for the desired performance outcome while working in adequate rest and recovery to prevent overtraining. Traditional periodization usually consisted of a long time frame, such as 1 to 4 years. Within that time, there were various cycles of months (macrocycles), weeks (mesocycles), days (microcycles), and individual training sessions. This plan may work well for individuals training for a specific, single competition like a marathon. The focus here is on the cardiovascular system. This is not as effective for well-rounded athletes who wish to compete in multiple types of events across seasons. Well-rounded athletes require many systems and skills that make use of a combination of aerobic, anaerobic, and strength training.

A newer area of training uses training blocks (or block periodization) that can be individualized based on the desired sport or event. These blocks can focus on a minimum number of performance outcomes. Training consists of performing a small number of blocks at one time (eg, three or four), and the blocks may last a few weeks. The sequence can be customized for the sport or event. One example comes from top-performing canoe and kayak paddlers. The first block of their training focused on accumulating the skills needed for the sport with general conditioning for aerobic endurance and muscular strength and endurance. Block two focused on specialized movements and proper technique, combining anaerobic and aerobic conditioning along with continued muscular strength and endurance. Block three emphasized specific race modeling and obtaining optimal speed and recovery between sessions. This regimen resulted in outstanding performance outcomes.[1,46]

Detraining

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, while maintenance-level training regimens prevent physiological decline from the trained state. Detraining can be defined as partial or full reductions in training-induced physiological adaptations in response to a lower training load or inactivity. It appears there is a more significant loss of cardiorespiratory endurance gains than loss of muscular endurance, strength, and power. While these data are not concrete, some research shows that athletes can lose approximately 25% of cardiorespiratory gains in about 10 to 20 days of inactivity. Data vary regarding muscle strength, power, and endurance, but 2 weeks of inactivity often results in declines in muscular endurance and strength. Fortunately, three training session 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.[1,45]

PHYSIOLOGICAL ADAPTATIONS TO ENDURANCE TRAINING

Cardiorespiratory fitness is the term for 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, with acute responses to exercise, both the respiratory and cardiovascular systems play an important role in facilitating endurance activity. Training has minimal effect on lung structure and function, but maximal effort does increase pulmonary ventilation, pulmonary diffusion, distribution of arterial blood away from inactive tissue toward active skeletal muscle, and the ability of the muscle to take up delivered oxygen.[1,29]

The cardiovascular system has numerous adaptations to regular endurance training, summarized below. All changes result in greater delivery of oxygen and nutrients to the working skeletal muscle.[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 at rest and exercise.
- Resting heart rate decreases with endurance training; the rate and can be 40 bpm or lower (compared with the 60 to 80 bpm in the 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 drastically change.
- Cardiac output does not change much during rest and submaximal exercise but does increase considerably during maximal effort and is a significant contributor to the increased VO_2 max with training.
- Resting blood pressure is reduced.
- Increased capillarization, blood volume, plasma volume, and red blood cell volume, improve tissue perfusion and oxygen delivery.
- There are increases in percentage and cross-sectional area of type I muscle fibers (those primarily used in endurance activities).
- There are increases in mitochondria, oxidative enzymes, and myoglobin content (more machinery for ATP production).

PHYSIOLOGICAL ADAPTATIONS TO RESISTANCE TRAINING

Individuals undergo regular resistance training to improve muscular strength and power. Strength can be defined as the maximum force generated by the muscle, whereas power is a product of muscle force × velocity and, therefore, is an indicator of the rate at which the work 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 can be seen within months. Skeletal muscle is very dynamic. Training can improve size (hypertrophy) and strength, while disuse or immobility can result in decreased size (atrophy) and strength. Muscle size and strength are somewhat related: Training causes an increase in both and detraining causes a decrease in both. The primary neuromuscular adaptations to regular resistance training include:

- improved neural adaptations (increased motor unit recruitment, decreasing 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 myofibrils and actin and myosin filaments from hypertrophy.

Muscles can be trained to improve strength and size, but there is a limit beyond which further adaptation is not possible. Genetic potential plays a large role in body type. For example, it may be impossible for a tall, slender person to look like a professional bodybuilder, and likewise it may be impossible for a large muscular person to become a lean, slim runner.[43,44]

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 not a ceiling for performance enhancement. Excessive training usually results in a performance decrement, which the athlete often follows with even more effort to compensate. The American College of Sports Medicine (ACSM) and the European College of Sports Science issued a Joint Consensus Statement on this topic.[47] The two terms to describe this condition are overreaching and overtraining. Overreaching describes excessive training that results in short-term performance decrements that can be reversed in several days to several weeks with proper training and rest. In addition, adequate fluid to restore hydration, adequate carbohydrate to replenish glycogen stores, and adequate protein to optimize protein synthesis and healing are critical. 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. This is characteristic during periods of competition training. Overtraining results in a series of symptoms referred to as the overtraining syndrome (OTS). OTS is more serious because long-term decrements in performance can take several weeks or months to recover from. OTS includes both physiological maladaptations and often psychological factors stemming from stress of competition, family and social relationships, and other life demands. There are no set diagnostic criteria for OTS because symptoms vary from person to person and are highly individualized. 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.[47,48] See Box 1.1 for a list of some symptoms.

Box 1.1 Signs and Symptoms of Overtraining Syndrome[47,48]

These are some of the common signs and symptoms of overtraining syndrome:

- 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. States that license the various health professions have a very specific defined scope of practice for each profession. 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 Didactic Programs in Nutrition and Dietetics do not require courses in exercise science, and student learning outcomes do not have a knowledge requirement for this area. As a result, many RDNs graduating from traditional dietetics programs are not qualified to discuss detailed issues regarding fitness assessment and exercise prescription.

It is critical for the practitioner to understand the laws of the state or states where they live and practice. 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 you live in a state that 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. They should, at a minimum, be familiar with the current federal Physical Activity Guidelines for Americans[45] and the overall health benefits of exercise. From a general standpoint, RDNs should 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 or client's current level of physical activity and stage of readiness to change as a basis for physical activity plans and goals. When should an RDN refer a client to a qualified exercise professional? 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.

Fitness Assessment and Exercise Prescription

Fitness assessments and exercise prescriptions may be out of the scope of practice for RDNs, depending on whether or not they hold additional training and certification. 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. This should be created by qualified exercise professionals. There are two reputable places to find qualified exercise professionals: The ACSM ProFinder (http://certification.acsm.org/pro-finder) and the US Registry of Exercise Professionals (USREPS) website (www.usreps.org/Pages/default.aspx).[49,50] ACSM has certified over 32,000 health professionals in 44 countries. The 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).

Reputable Exercise and Fitness Certifications

Unlike nutrition and dietetics, no single accrediting body for programs in kinesiology or exercise science results in a nationally recognized credential. These academic programs may voluntarily become accredited through the Commission on Accreditation of Allied Health Education Programs (CAAHEP)[51] with the goal to have 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.

It is important for the RDN who is not qualified to conduct fitness assessments and provide exercise prescriptions to have a network of qualified exercise professionals for patient/client referral, and this should be documented when using the Nutrition Care Process. There are numerous exercise-related certifications available, so it is important to research the qualifications for certification and the knowledge and skills assessed in the process. The NCCA governs many of the exercise certifications. A few reputable organizations and their certifications are listed in Table 1.1.

Table 1.1 Examples of Reputable Organizations that Certify Exercise Professionals[a]

Name of Organization	Name of Certification	Qualifications	Purpose
American College of Sports Medicine	Certified Personal Trainer	18 years old High school diploma or equivalent Adult CPR[b]/AED[c] certification	Plan and implement exercise programs for healthy individuals
American College of Sports Medicine	Certified Group Exercise Instructor	18 years old High school diploma CPR/AED	Supervise participants or lead instructional sessions for healthy individuals
American College of Sports Medicine	Certified Exercise Physiologist	Bachelor of science degree in exercise science, exercise physiology, or kinesiology CPR/AED	Fitness assessments, exercise plans, personal training for those with medically controlled diseases

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Table 1.1 Examples of Reputable Organizations that Certify Exercise Professionals[a] (Continued)

Name of Organization	Name of Certification	Qualifications	Purpose
American College of Sports Medicine	Certified Clinical Exercise Physiologist	Bachelor of science degree in exercise science, exercise physiology, or kinesiology 400–500 hours of supervised experience Basic Life Support certification	Fitness assessments, exercise plans, personal training for those with medically controlled diseases and those with cardiovascular, pulmonary, and metabolic diseases
American College of Sports Medicine	Registered Clinical Exercise Physiologist	Master of Science degree in exercise science, exercise physiology, or kinesiology 600 hours of supervised experience Basic Life Support certification	Fitness assessments, exercise plans, personal training for those with medically controlled diseases and those with cardiovascular, pulmonary, and metabolic diseases Rehabilitative strategies
American College of Sports Medicine	Specialty Certifications Exercise Is Medicine Credential Certified Cancer Exercise Trainer Certified Inclusive Fitness Trainer Certified Physical Activity in Public Health Specialist	Bachelor of Science degree in exercise science, exercise physiology, or kinesiology Another American College of Sports Medicine certification or National Commission of Certifying Agencies–accredited health and fitness certification CPR/AED	See American College of Sports Medicine website for specifics (www.acsm.org)
National Strength and Conditioning Association	Certified Personal Trainer	18 years old High school diploma CPR/AED	Work with healthy clients in one-on-one situations
National Strength and Conditioning Association	Certified Special Population Specialist	Current National Strength and Conditioning Association certification or RDN[d] credential CPR/AED Supervised practice experience	Use an individualized approach to assess, motivate, educate, and train special population clients
National Strength and Conditioning Association	Certified Strength and Conditioning Specialist	Bachelor of science from an accredited institution CPR/AED	Implement strength and conditioning programs for athletes in a team setting
American Council on Exercise	Personal Trainer Certification	18 years old High school diploma CPR/AED	One-on-one or small-group training for healthy individuals

Continued on next page

Table 1.1 Examples of Reputable Organizations that Certify Exercise Professionals[a] (Continued)

Name of Organization	Name of Certification	Qualifications	Purpose
American Council on Exercise	Group Fitness Instructor Certification	18 years old High school diploma CPR/AED	Lead fitness classes for healthy individuals
American Council on Exercise	Health Coach Certification	18 years old CPR/AED Current National Strength and Conditioning Association–accredited certification or license in nutrition (RDNs may qualify) or associates of science degree or higher in nutrition 2 years of work experience	Lead healthy clients to sustainable, healthy change by applying knowledge in behavior change, physical activity, and nutrition
American Council on Exercise	Specialty Certifications Mind Body Fitness Nutrition Weight Management	National Strength and Conditioning Association–accredited certification or equivalent professional credentials, including NDTR[e] and RDN	See American Council on Exercise website for specifics (www.nsca.org)

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

[b] CPR = cardiopulmonary resuscitation

[c] AED = automated external defibrillator

[d] RDN = registered dietitian nutritionist.

[e] NDTR = nutrition dietetic technician, registered;

Physical Activity Guidance and the Nutrition Care Process

The first step in the Nutrition Care Process is assessment. During this step, the RDN should refer to the current Nutrition Terminology Reference Manual (eNCPT) website (http:\\ncpt.webaturhor.com).[52] The RDN may assess readiness to change, weight and body composition, and physical activity history and current level of physical activity. During the diagnosis step, the RDN can document any problems and create a diagnostic statement. Usually the diagnosis refers to level of physical activity or inactivity, readiness to change, or something in the behavioral domain. For the intervention step, the RDN can choose to provide education if it is within his or her scope, can refer to a qualified exercise professional, or can do a combination of both. For most RDNs, education can include the health benefits of exercise, how to start an exercise program, the key concepts presented in the Physical Activity Guidelines for Americans, and provision of additional resources (eg, handouts, names of community centers, list of professionals). Monitoring and evaluation should include follow-up on the physical activity–related goals set for the patient or client.

Federal Physical Activity Guidelines

RDNs with an interest in sports dietetics should be familiar with the federal Physical Activity Guidelines for Americans and be comfortable discussing these guidelines with their patients or clients.[45] The guidelines may be downloaded for free at the Health.gov website (http://health.gov/paguidelines). Some key concepts from this document are discussed in this section. Principles of training were discussed previously and are again presented in these guidelines. Box 1.2 provides definitions of the levels, components, and intensity of physical activity.

Another way of defining exercise intensity is the use of metabolic equivalents (METs). MET is the ratio of rate of energy expended during exercise to the rate of energy expended at rest. One MET is equivalent to a VO_2 of 3.5 mL × kg^{-1} × min^{-1}. Multiples of this value can be used to quantify energy expenditure and will be discussed in detail in Chapter 10. METs are a simple concept: 1 MET is the work at rest, while 5 METs would be work at 5 times rest. The Physical Activity Guidelines also use MET-minutes for guidance. MET-minutes take into account both physical activity intensity and duration. For example, a 4-MET activity for 30 minutes equals 120 MET-minutes, and an 8-MET activity for 15 minutes also equals 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. Keep in mind, these physical activity guidelines are for 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/week, with potential greater health benefits found at greater than 1,000 MET-min/week. The relationship between intensity and METs is summarized here:

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

Box 1.2 Definitions of Levels, Components, and Intensity of Physical Activity [45]

Levels of Physical Activity	
Inactive	No activity beyond baseline (This is considered unhealthy.)
Low	Beyond baseline but fewer than 150 min/w (Better for health than inactive.)
Medium	150–300 min/wk (Additional and possible extensive health benefits.)
High	>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 in one session or how many repetitions
Intensity of Physical Activity	
Light	1.1–2.9 METs (1.1–2.9 times rest)
Moderate	3.0–5.9 METs
Vigorous	≥6.0 METs

KEY GUIDELINES FOR HEALTH

- Physical activity reduces the risk of many adverse health outcomes.
- Some physical activity is better than none.
- 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 equals 1 minute of vigorous physical activity.

SUMMARY

Exercise physiology is the study of the alterations and responses to acute and chronic exercise. Exercise disrupts homeostasis resulting in increased energy needs to meet 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 demand. At low- or moderate-intensity exercise, the body can use carbohydrate and fat via aerobic metabolism, meeting the energy demands with ease. As exercise intensity increases, the body's reliance on carbohydrate for 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, while 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 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 federal Physical Activity Guidelines for Americans. Beyond this, if the RDN cannot complete a fitness assessment and exercise prescription, then the RDN should refer to a qualified exercise professional.

KEY TAKEAWAYS

An understanding of exercise physiology basics is necessary for all RDNs interested in sports nutrition 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 via 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 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 federal Physical Activity Guidelines for Americans.

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

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AT A GLANCE ROWING (CREW)

A typical crew race is 2,000 meters lasting 5½ to 8 minutes and requiring strength, power, and endurance. The crew season begins in the fall with preseason training. Winter is a time of intense training and muscle building, whereas the spring racing season is known for its long daily practices leading up to a rest day and weekend competition. Summer is the off-season. There are lightweight and open (heavy) weight categories. Learn more about the sport at the US Rowing website (www.usrowing.org).

GENERAL NUTRITION GUIDELINES

Energy:	Rowing is considered a relatively high–energy-expenditure sport.
Carbohydrate:	Recommended intake is between 5 and 7 g/kg/d.
Protein:	Recommended intake is between 1.2 and 1.7 g/kg/d.
Fat:	Recommended intake is approximately 1.0 g/kg/d. Fat, in the form of heart-healthy fats, may be increased to meet high energy needs while training and decreased during the off-season.

COMMON NUTRITIONAL CONCERNS

Energy Intake

Fatigue and lack of appetite may result in involuntary underconsumption of energy. Lightweight rowers may voluntarily restrict energy to make weight.

Making Weight

Lightweight rowers who are genetically lean and biologically small can comfortably meet the requirements for lightweight rowing. Problems with disordered eating and eating disorders occur when extraordinary efforts must be made to attain and maintain a low body weight. Voluntary dehydration may also be an issue. Learning to manage weight in the off-season is preferred to cutting weight in season. Dangerous weight-cutting practices and disordered eating are found in both male and female rowers.

Consumption of Foods with Low Nutrient Density

Rowers have high energy needs, and both male and female heavyweight rowers quickly discover that they must eat a lot of food to maintain energy balance. High-fat, high-sugar snack foods and beverages can provide the energy needed but not the nutrients.

Balancing Fluid Intake with Fluid Losses

Dehydration is a daily concern. Rowers have water bottles in the boat during training, but they do not have access to them during long training pieces (approximately 30 to 45 minutes each). It is unlikely that rowers can maintain fluid balance during training. Therefore, they should pay special attention to drinking sufficiently before and after training.

APPENDIX A

Selected Sports Nutrition–Related Position Papers, Practice Papers, and Consensus Statements

Academy of Nutrition and Dietetics Positions

The following are available at www.eatright.org/positions:

- Nutrition and Athletic Performance (joint position statement of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine.)
- Functional Foods
- Nutrient Supplementation
- Nutrition Intervention in the Treatment of Eating Disorders
- Total Diet Approach to Healthy Eating
- Vegetarian Diets
- Interventions for the Treatment of Overweight and Obesity in Adults

American College of Sports Medicine Positions

The following are available at http://journals.lww.com/acsm-msse/pages/collectiondetails.aspx?TopicalCollectionId=1:

- Exercise and Type 2 Diabetes
- Exercise and Physical Activity for Older Adults
- The Female Athlete Triad
- Appropriate Physical Activity Intervention Strategies for Weight Loss and Prevention of Weight Regain for Adults
- Exertional Heat Illness during Training and Competition
- Exercise and Fluid Replacement
- Physical Activity and Bone Health
- Exercise and Hypertension

National Athletic Trainers' Association Positions

The following are available at www.nata.org/position-statements:

- Preventing, Detecting, and Managing Disordered Eating in Athletes
- Management of the Athlete with Type 1 Diabetes Mellitus
- Safe Weight Loss and Maintenance Practices in Sport and Exercise

International Olympic Committee Consensus Statements

The following are available at www.olympic.org/medical-and-scientific-commission:

- The IOC Consensus Statement: Beyond the Female Athlete Triad—Relative Energy Deficiency in Sport (RED-S)
- IOC Consensus Statement on Sports Nutrition 2010
- Consensus Statement on Body Composition Health and Performance in Sport

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