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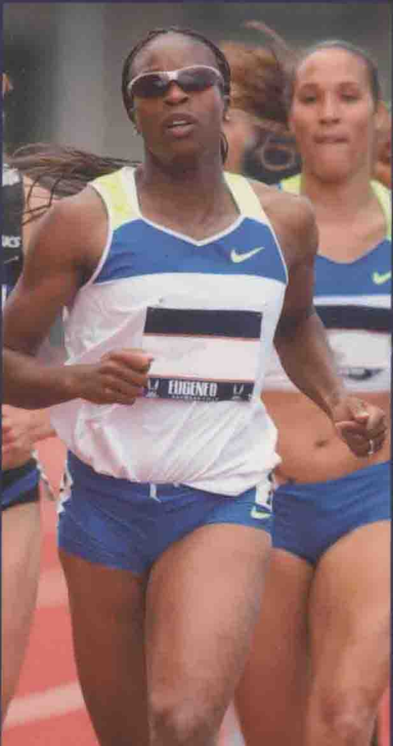
Developing Endurance



NSCA™
National Strength and Conditioning Association

Ben Reuter, Editor

DEVELOPING ENDURANCE

运动力量训练　　Developing Endurance

National Strength and Conditioning Association

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NSCA

Ben Reuter
EDITOR

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DEVELOPING ENDURANCE

Introduction

Participation in endurance sports and racing is a growing activity for people all over the world. In many countries, a popular recreational activity is participating in running races and triathlons to raise money for charitable organizations. More and more people are participating in 10K runs, marathons, and bike tours. A growing number of people are also participating in triathlon races ranging from sprint distances to Ironman. Additionally, noncompetitive bike tours, triathlons, marathons, adventure races, and other types of prolonged aerobic activity attract people from diverse backgrounds.

Knowledge of proper training programs and techniques for endurance training is still catching up with participation. A training program that is properly designed is essential for athletes to be able to enjoy endurance activities as much as possible. A properly designed program can also minimize the risk of injury and maximize performance for those individuals who are competing.

Many endurance activities involve some amount of running. According to various research studies, as many as 75 to 80 percent of runners are injured each year; an injury is defined as something that causes the runner to miss one or more days of training. Often these injuries occur because of improperly designed training and conditioning programs. The information provided in this book can be a valuable tool to help the endurance coach or self-coached athlete develop a training program that is designed to maximize performance and minimize the risk of injury.

When training for endurance events, many people do not consider the importance of overall physical fitness. Physical fitness consists of three main training components: cardiovascular (or aerobic) training, resistance training, and flexibility training. Each component has a valuable place in a properly designed program for the endurance athlete.

Endurance sports are activities that require a high level of muscle endurance. This is achieved primarily through aerobic activities—running, cycling, swimming, and so on. The muscles are trained to contract repeatedly at a submaximal level without fatiguing. Some endurance training programs focus almost exclusively on aerobic training, using a "more is better" approach. This approach often leads to the exclusion of other aspects of fitness because athletes and coaches think they don't have time to devote to other areas.

Well-trained endurance athletes do need a high level of aerobic conditioning, but long-term avoidance or minimization of the other components of overall fitness—especially resistance training—can lead to performance plateaus and chronic injuries. Most people who participate in endurance sports are recreational athletes,

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so overall physical fitness is an important part of maintaining a high quality of life. As a person ages, muscle strength (the ability to produce force) and muscle power (the ability to produce force rapidly) decrease. Endurance training maximizes the ability to produce repeated submaximal muscle contractions, but it does very little to maintain or increase muscle strength or power.

Endurance sports are a unique activity. Participants in endurance sports have a wide range of body types, age, and experience. For example, it isn't unusual for marathoners to finish in times ranging from less than 2 1/2 hours to almost 7 hours. The age of these finishers often ranges from less than 20 years old to well over 70 years of age. Some of the participants are first-time finishers, but other participants may have previously completed numerous marathon races. No matter what the body type, age, or experience, all the athletes complete the same event over the same terrain. Each participant needs to have adequate physical conditioning, skill, and mental fortitude to ensure that he or she is able to successfully complete the event. The information in this book will benefit everyone from the novice who trains for health and fitness to the experienced competitor who is trying to maximize performance.

This book is designed for the self-coached athlete, the personal trainer interested in increasing the number of clients, and the endurance coach who is looking to review or expand knowledge. The individuals using this book may be looking to improve their competition performance, or they may be involved in endurance activities simply for enjoyment, with no intention of ever competing in an official event or competition.

Traditionally, endurance coaches and athletes may not have been aware of the National Strength and Conditioning Association (NSCA) or may not have known that NSCA members could offer training knowledge relevant to endurance athletes. By the same token, many NSCA members may not have recognized that their knowledge and skills would be valuable to endurance athletes. However, this book takes advantage of each contributor's expertise. All of the contributors were selected not only for their professional knowledge but also because they practice what they preach. The About the Contributors section at the end of the book shows that the contributors are not only experts on endurance training programs but also active participants in endurance sports.

Chapter 1 provides an overview of physiology as it pertains to physical activity. It also provides information related specifically to endurance activity, which will be especially valuable for those readers without a background in endurance sports. Chapter 2 covers testing and assessment and provides a valuable source of information that athletes, coaches, and fitness professionals can use to determine if a program is optimally effective.

Chapter 3 provides a summary of endurance training principles with an emphasis on explaining proper program design through periodization, or the systematic manipulation of exercise parameters (volume, intensity, and duration). Periodized training is designed to maximize healthy physiological adaptations and minimize the negative effects of too much exercise or too little recovery. Chapter 4 includes important information about nutrition and hydration.

Chapters 5 is an excellent introduction to training program design specific to endurance sports, including running, cycling, swimming, and triathlon. This chapter is a valuable tool for the experienced and inexperienced endurance athlete or coach. Unlike many books about endurance training, which have minimal information on resistance training, this book contains details on how resistance training can enhance the endurance athlete's training and performance. Chapter 6 provides explanations of resistance training exercises, and chapter 7 explores the science behind resistance training for the endurance athlete. These two chapters provide a clear rationale for the inclusion of resistance training in an endurance program, as well as practical direction about how to integrate the resistance training with the aerobic training.

Chapters 8 through 11 address running, cycling, swimming, and triathlon individually. These chapters include sample training programs and extensive information on sport-specific program design.

Endurance sports are a growing activity worldwide, and the dissemination of knowledge to coaches and participants of those sports is essential to make the sports as safe and enjoyable as possible. This book is an excellent addition to the library of endurance athletes, participants, and coaches who recognize the importance of training information supported by science.

Contents

CHAPTER 1

Physiology of Endurance Sport Training

Randy Wilber

This chapter provides you with the basic knowledge of exercise physiology needed for coaching or participating in endurance-based sporting activities. Understanding this information is important for people who are active competitors or people who participate in endurance activities for health and recreation. A significant amount of physical energy is required when a person trains for and competes in endurance-based sporting events. Therefore, we begin this chapter with a discussion of energy production. Some basic questions will get us started:

- What exactly is energy?
- How is energy produced and used in an endurance athlete's body?

The answers to these questions rely primarily on the basic sciences of biology and biochemistry. If you're studying these subjects for the first time, you may find them to be very technical and a bit overwhelming. In that case, you should focus on the nonscientific analogies provided and should refer to the figures where indicated. These tips will help you get the most out of this chapter.

THREE ENERGY SYSTEMS

The basic unit of energy within the human body is adenosine triphosphate (ATP). To make things simple, think of a molecule of ATP as an "energy dollar bill." Each of us has millions of molecules of ATP in our body, providing us with energy. We are constantly using and replenishing ATP, even when we are not exercising. Based on this cash analogy, ATP utilization and production can be seen as similar to the daily scenario in which we spend and earn cash to maintain our lifestyle.

The molecular structure of ATP is shown in figure 1.1. ATP is made up of three unique subunits: (1) adenine, (2) ribose, and (3) the phosphate groups. Rather than memorize the structure of ATP, focus your attention on the wavy lines that connect the three phosphate groups. Each of these wavy lines represents a high-energy bond.

Figure 1.2 shows the basic biochemical reaction whereby ATP produces energy. A single molecule of ATP is represented on the left side of the reaction. When ATP comes in contact with water and the enzyme ATPase, one of its high-energy bonds is broken or cleaved, which releases a burst of chemical energy. This burst of chemical energy can be used for all of the important physiological functions, including nerve transmission, blood circulation, tissue synthesis, glandular secretion, digestion, and skeletal muscle contraction (which we will focus on later in this chapter). When this reaction breaks the bond in ATP, it creates a molecule of adenosine diphosphate (ADP) and a phosphate molecule (P_i).

Now that you understand what energy is, let's take a look at how it is produced. The body has three energy-producing systems (see figure 1.3): the immediate (ATP-CP),

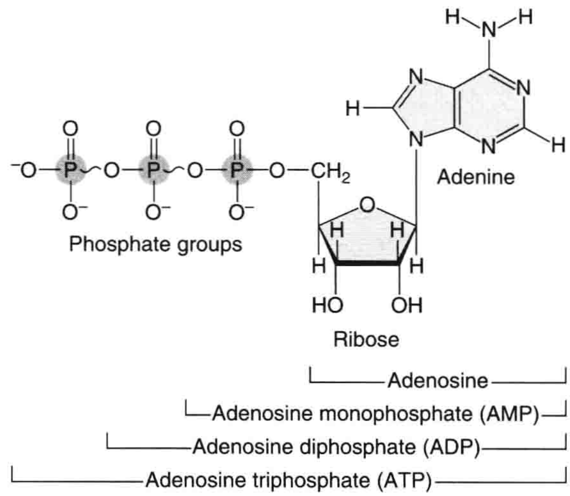

Figure 1.1 Structure of adenosine triphosphate (ATP).

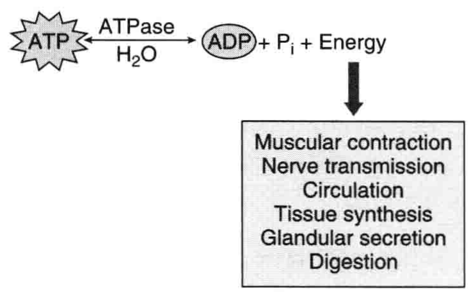

Figure 1.2 Biochemical conversion of ATP to ADP + P_i + energy.

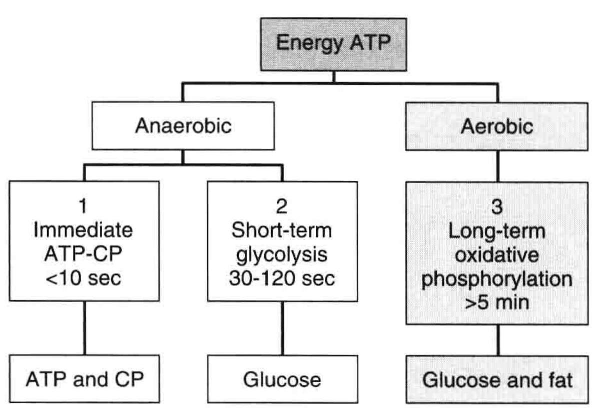

Figure 1.3 The three energy systems.

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short-term (glycolysis), and long-term (oxidative phosphorylation) systems. The three energy systems are similar in that they all produce ATP, but they differ in how quickly they produce ATP and in the amount of ATP produced. Two of the three energy systems—the immediate and short-term systems—are anaerobic energy systems. In other words, these two energy systems do not require oxygen to produce ATP. In contrast, the long-term energy system is aerobic and requires oxygen to produce ATP.

The technical name for the immediate energy system is the ATP-CP system (ATP stands for adenosine triphosphate, and CP stands for creatine phosphate). The biochemical reactions involved in the immediate energy system are shown in figure 1.4. Notice that the first reaction is the same one that was described earlier for the conversion of ATP to chemical energy. Again, one of the high-energy bonds is cleaved (broken) in that reaction. As a result, ATP, which contains three phosphate groups, is converted to adenosine diphosphate (ADP), which contains two phosphate groups. As shown in figure 1.4, ADP is not simply thrown away after the initial reaction. Rather, it goes through a recycling process with CP (which has one phosphate group). The CP donates its phosphate group to ADP (two phosphate groups) to produce a new molecule of ATP (three phosphate groups), leaving a molecule of creatine (CR), which will later bond with another molecule of phosphate.

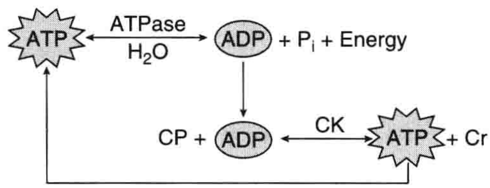

Figure 1.4 The two basic biochemical reactions of the immediate energy system (ATP-CP): (1) the synthesis of ATP from ADP and a phosphate and (2) the release of energy by the breakdown of ATP to ADP.

Using our cash analogy, the immediate energy system is similar to the cash in a person's wallet:

- ▶ The person can access and use the cash immediately.
- ▶ However, the person has a very limited amount of cash.

Similarly, the immediate energy system has the advantage of producing ATP very quickly, but it has the disadvantage of producing a very limited supply of ATP. In terms of athletic performance, the immediate energy system is the dominant energy system during very high-intensity, short-duration exercise lasting approximately 10 seconds or less. Examples of athletic events in which the immediate energy system is dominant would include the 100-meter sprint in track, a 10-meter diving event, and weightlifting events.

Like the immediate energy system, the short-term energy system is anaerobic. The technical name for the short-term energy system is glycolysis because the first of several biochemical reactions in this energy system involves the conversion of glycogen (stored glucose) to free glucose. A simplified version of the short-term energy system is shown in figure 1.5. One molecule of glucose is converted to two molecules of pyruvic acid; then, in the absence of oxygen, the two molecules of pyruvic acid are converted to two molecules of lactic acid. Most important, notice that two molecules of ATP are also produced.

Using our cash analogy, the short-term energy system is similar to the money that a person has in a checking account:

- The person has a larger amount of money available (compared to the cash in the person's wallet).
- However, accessing this money in order to transfer it into cash form takes a little longer.

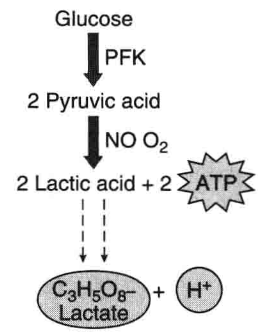

Figure 1.5 A simplified version of the biochemical reactions involving the short-term energy system (glycolysis). (PFK stands for phosphofructokinase.)

Similarly, the short-term energy system has the advantage of producing more ATP than the immediate energy system, but it has the disadvantage of taking a little more time to do so. Another disadvantage is that the short-term energy system produces lactic acid, which is quickly converted to lactate and positively charged hydrogen ions (H^+) (refer to figure 1.5). High concentrations of H^+ create the acidic burning sensation in exercising skeletal muscle and contribute (along with other biochemical, neural, and biomechanical factors) to premature fatigue. In terms of athletic performance, the short-term energy system is the dominant energy system during high-intensity, moderate-duration exercise lasting approximately 30 to 120 seconds. Examples include the 400-meter sprint in track, the 100-meter sprint in swimming, and the 1,000-meter track event in cycling.

The long-term energy system is aerobic in nature and requires oxygen to produce ATP. The technical name for this energy system is oxidative phosphorylation. A simplified version of this relatively complex energy system is shown in figure 1.6. Notice that the long-term energy system starts out the same way as the short-term energy system—that is, a single molecule of glucose is converted to two molecules of pyruvic acid. However, because oxygen is available, pyruvic acid is not converted to lactic acid as in the short-term energy system. Rather, pyruvic acid enters several mitochondria in the cell (see figure 1.7) and is converted to acetyl coenzyme A (acetyl CoA); it then goes through a series of biochemical reactions (Krebs cycle and electron transport system [ETS]) that ultimately produce 32 molecules of ATP.

Using our cash analogy, the long-term energy system is similar to the money that a person has placed in long-term investments such as mutual funds, stocks, bonds, or IRAs:

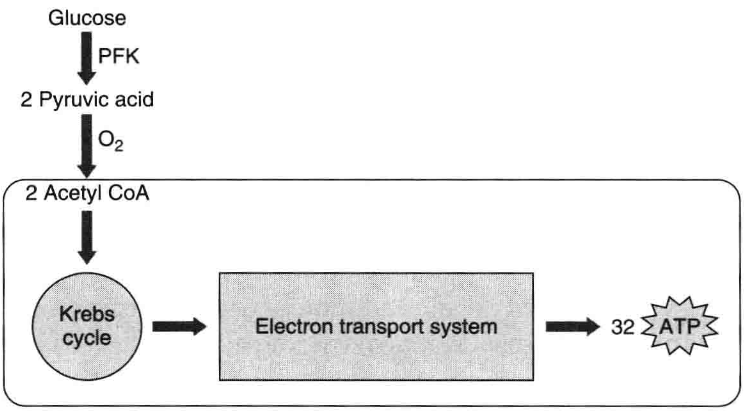

Figure 1.6 A simplified version of the biochemical reactions involved in the long-term energy system (oxidative phosphorylation). (PFK stands for phosphofructokinase.)

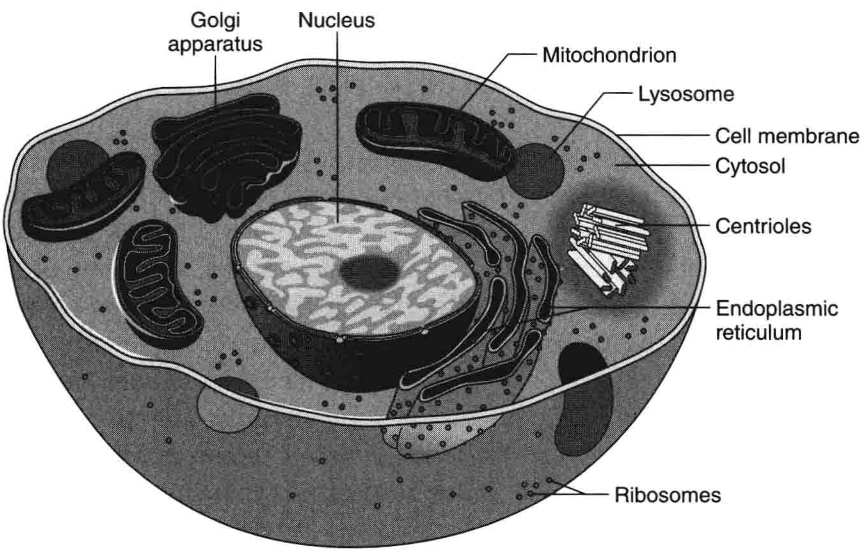

Figure 1.7 Cell structure showing several mitochondria.

- The person has a significantly larger amount of money compared to the money in a checking account or the cash in a wallet.
- However, the person must go through several more steps and must wait longer to access the funds, liquefy them, and turn them into cash.

Similarly, the long-term energy system has the advantage of producing very large amounts of ATP compared with the other energy systems; however, this system has the disadvantage of taking more time than the other energy systems to produce that large amount of ATP. The long-term energy system takes longer because it uses oxygen to produce ATP. The only place in the cell where oxygen can be used to produce ATP is in the mitochondrion, which is essentially a very large ATP factory with several "stops on the assembly line." This ultimately increases the time needed for the final production of ATP.

In terms of athletic performance, the long-term energy system is the dominant energy system in low- to moderate-intensity, long-duration exercise lasting longer than 5 minutes. Examples of this type of activity include the marathon, the 800-meter swim, and road events in cycling. So the long-term energy system is the dominant energy system used during endurance-based sporting events. However, athletes need to understand that the long-term system is not the only energy system used in endurance sports.

ENERGY DYNAMICS DURING EXERCISE

As described previously, ATP (energy) can be produced via three energy systems. Although we looked at each of the energy systems separately, this does not mean that only one energy system can function at a time. To understand this concept better, we can use the analogy of a symphony orchestra: The orchestra includes several instrument groups, and each group plays softly, moderately, or loudly depending on the musical score.

At the beginning of the symphony, the string group may be loud, the woodwind group may be moderate, and the percussion group may be soft. These musical emphases may be reversed by the end of the symphony to reflect soft music by the string group and loud music by the percussion group. The same is true for energy production during exercise. Each of the three energy systems is in a state of dynamic flux. Like the instrument groups, each of the energy systems is operating constantly during exercise, but the systems operate at different levels of ATP production depending on the intensity and duration of the exercise.

An example of the "symphony orchestra" effect is shown in figure 1.8, which shows energy dynamics during a cycling road race, a sporting event that is classified as an endurance event. During pack riding, the exercise intensity is moderate, and the duration is relatively long. As discussed earlier, the dominant energy system during moderate-intensity, long-duration exercise is the long-term (oxidative phosphorylation) energy system. Although the long-term system is dominant, it is not the only energy system that is active during pack riding. The other two energy systems are active, but they are "playing softly."

During a hill climb, the intensity picks up, but the duration is shorter compared with pack riding. This type of high-intensity, moderate-duration exercise requires the short-term (glycolysis) energy system to play the loudest, the immediate (ATP-CP) energy system to play louder, and the long-term system to play softer. Finally, the energy dynamics are reversed during the final sprint to the finish, which involves exercise at a very high intensity but for a short duration. In this phase, the immediate system is clearly the loudest, and the short-term and long-term systems are relatively quiet.

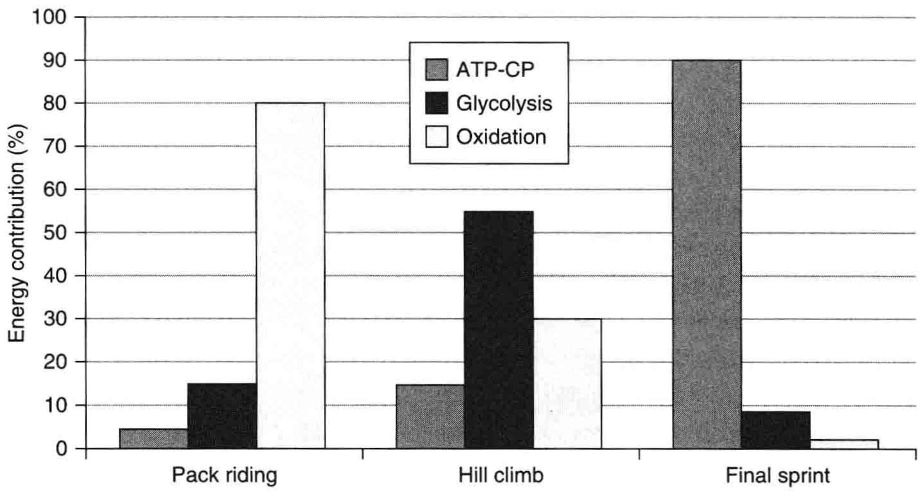

Figure 1.8 Energy dynamics during a cycling road race.

In endurance sport, the dominant energy system is the oxidative phosphorylation energy system. However, keeping in mind our symphony orchestra analogy, athletes must remember the role that the ATP-CP and glycolysis energy systems play in the performance of endurance activities. Knowing when to train and how much time to devote to training each of the three energy systems is an important ingredient of success in endurance sport. This knowledge is also reflected in a well-designed and scientifically based training plan. (Chapter 3 addresses this concept in more detail.)

CARDIOPULMONARY PHYSIOLOGY

Because endurance-based sport relies heavily on the oxidative phosphorylation energy system, endurance athletes need to understand the basic concepts of cardiopulmonary physiology. The term *cardiopulmonary* refers to the heart and lungs and how those vital organs work in synchrony to ensure that the blood is carrying oxygen and nutrients to the working skeletal muscles during exercise.

Cardiopulmonary Anatomy

The primary anatomical structures of the cardiopulmonary system are the lungs, heart, and skeletal muscles. We begin our anatomical "tour" in the lungs. Blood passes through the capillary beds of the lungs, where it unloads carbon dioxide (CO_2) and picks up oxygen (O_2). This oxygen-enriched blood travels from the lungs to the heart via the pulmonary vein. Oxygen-enriched blood initially enters the heart in the left atrium and then flows into the left ventricle. When the heart contracts, or beats, oxygen-enriched blood is ejected from the left ventricle and exits the heart via the aorta. The aorta ultimately branches into several smaller arteries that carry oxygen-enriched blood to the entire body.

Once the oxygen-enriched blood reaches, for example, the leg muscles during running, it unloads oxygen and picks up carbon dioxide. Blood exiting the exercising muscles is "oxygen reduced" and returns to the heart via the venous system. Oxygen-reduced blood is ultimately delivered to the heart via two large veins, the superior and inferior vena cava. The venae cavae deliver oxygen-reduced blood to the right atrium of the heart; the blood then flows into the right ventricle. When the heart contracts, oxygen-reduced blood is ejected by the right ventricle and travels via the pulmonary artery to the lungs.

We have now arrived back at the starting point of our tour of cardiopulmonary anatomy—that is, as the oxygen-reduced blood enters the capillary beds of the lungs, it will unload carbon dioxide and pick up oxygen and then exit the lungs as oxygen-enriched blood. This synchrony between the lungs, heart, and tissues is taking place constantly, whether the person is awake or asleep. The entire cardiopulmonary system works overtime during any endurance-based sporting activity, such as a triathlon.

Oxygen Transport

As mentioned earlier, endurance-based sports are heavily dependent on the oxidative phosphorylation energy system for ATP. In the previous section, we referred to oxygen transport in very general terms: oxygen-enriched and oxygen-reduced blood. In this section, we examine oxygen transport in more detail, focusing on the gas physics and physiology of oxygen transport.

The first thing to consider when learning about oxygen transport is how oxygen is carried around in the body. Though a very small percentage of oxygen travels through the body dissolved in the fluid portion of the blood, the primary way by which oxygen is transported through the body is via the red blood cells, also called erythrocytes. Figure 1.9 shows the shape of a typical red blood cell. Blood contains trillions of red blood cells. The portion of the blood containing red blood cells is referred to as the hematocrit (Hct) and is expressed as a percentage of volume of red blood cells relative to the total blood volume. Hematocrits for healthy individuals residing at low elevation range from 35 to 45 percent for women and 40 to 50 percent for men.

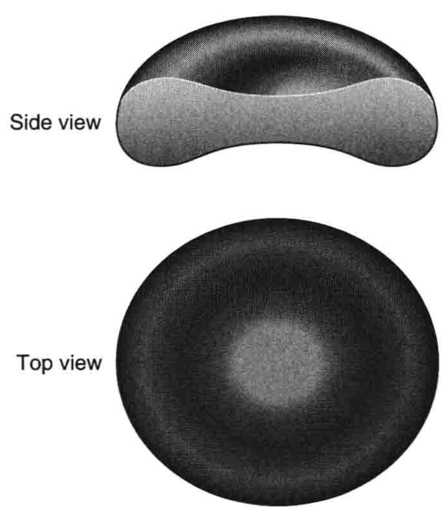

Figure 1.9 The structure of a red blood cell.

If we "broke open" a single red blood cell, we would find that it contains about 250 million molecules of hemoglobin (Hb). The hemoglobin molecule is what actually transports oxygen throughout the body. A single molecule of hemoglobin can transport 4 molecules of oxygen. Thus, a single red

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