



The Heart and Lungs at Work

After completing this chapter you should be able to:

- explain the function and control of the cardiovascular and respiratory systems;
- describe the relationship between the cardiorespiratory system and energy production;
- explain the measures that are used to evaluate and describe the various components of the cardiovascular and respiratory systems;
- describe the acute and chronic effects of physical activity on the body;
- analyze the effects of different environmental conditions on the body during physical activity.

During an average human life the heart will beat about three billion times, beginning at conception and continuing until death. The heart is one of the first organs to begin functioning and is often associated with life and death. This life-sustaining organ that pumps blood throughout our bodies is only one part of our circulatory system. The others – blood vessels (the passageways) and blood (the transport medium) – complete the transport system that delivers supplies to the tissues that need them for survival and growth. Oxygen is perhaps the most important supply to be delivered at rest and during exercise.

The systems of the body, however, are by no means independent of one another. Pulmonary structure and function are closely linked with the cardiovascular system; without getting oxygen into the body through breathing (ventilation), diffusion, and gas exchange in the lungs, there is no oxygen to transport to the body's tissues. Thus, the body's systems must work together in order to function most efficiently.

Because cardiovascular function is so vital to our existence, it is important to be aware of the advantages that can result from training, and their implications for health. Exercise offers numerous benefits, and enhanced cardiovascular function is one of them. Understanding the changes that occur during exercise will enable you to train more effectively for performance and will improve your cardiovascular health. How are blood flow and blood volume controlled? What is actually involved in the transport of oxygen? And what role does hemoglobin play in oxygen transport? The answers to these and other questions will be presented in this chapter; this material will provide the foundation you will need to attain and maintain optimal cardiovascular health.

Cardiovascular Anatomy

The primary role of the cardiovascular system is supplying the muscles and organs with the oxygen and nutrients that they need to function properly

and removing metabolic by-products from areas of activity. Optimal functioning of the cardiovascular system is critical for human performance. The anatomy and physiology of the heart and the blood vessels are described in this section.

The Heart

Structure

The heart is an organ made up of striated muscle that serves to pump blood through the human body. The heart pumps blood through the body by using two different pumps, called **ventricles** (Figure 7.1). The blood comes to the heart from the peripheral organs. The right ventricle receives deoxygenated blood from the body and pumps it to the lungs, and the left ventricle receives oxygenated blood from the lungs and pumps it to the rest of the body. Since the **left ventricle** has to pump blood through the entire body, it is larger and its muscle walls are stronger than that of the **right ventricle**, which has to pump blood only a short distance to the lungs. The heart has two smaller chambers called **atria** (singular = atrium). These smaller pumps receive blood from the body (**right atrium**) or the lungs (**left atrium**) and then pump the blood into the right and left ventricles, ensuring that the ventricles have a sufficient supply of blood for distribution to the lungs and other areas of the body, respectively.

Function

The heart contracts in a constant rhythm that may speed up or slow down depending on the need for blood (and oxygen) in the body. For example, if you start running, your leg muscles will need more oxygen to do the work of running. Therefore your heart will have to pump more oxygen-carrying blood to those working muscles and will have to beat more rapidly in order to supply that blood. The beating of the heart is governed by an automatic electrical impulse that is generated by the sinus node. The **sinus node** is a small bundle of nerve fibers that are found in the wall of the right atrium near the opening of the **superior vena**

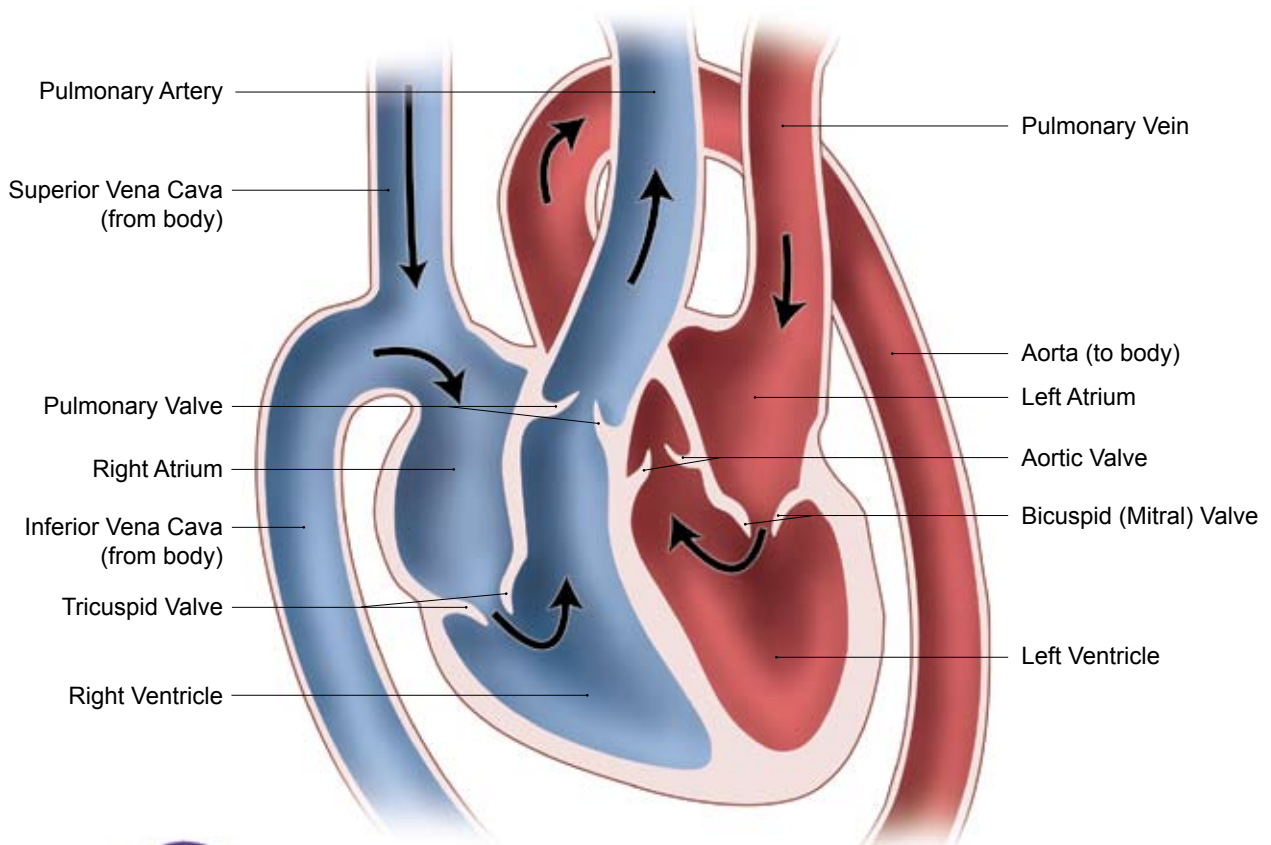


Figure 7.1 Chambers and valves of the heart.



The heart works like an efficient pump.

cava (see Figure 7.5). The sinus node generates an electrical charge called an **action potential** that causes the muscle walls of the heart to contract. The atria contract before the ventricles contract, which allows for the blood to be quickly pumped into the ventricles from the atria and then from the ventricles to the lungs and the body. The sinus node determines the rate of beating of the entire heart (Figure 7.2).

Blood Pressure

Blood pressure is an important measure of cardiac function (Figure 7.3). There are two components to the measure of blood pressure. The first component is the pressure in the ventricles when they are contracting and pushing blood out into the body. This is called **systole**. *Systolic pressure* provides an estimate of the heart's work and the strain against the arterial walls during the contraction. In healthy young adults, systolic pressure is normally around 120 mm Hg.

The second component of blood pressure, called **diastole**, describes the pressure in the heart when it is in the relaxation phase of the cardiac cycle (the ventricles are relaxed and being filled with blood). *Diastolic pressure* is used as an indicator of peripheral blood pressure (the blood pressure in the body outside the heart). It provides an indication of the ease with which the blood

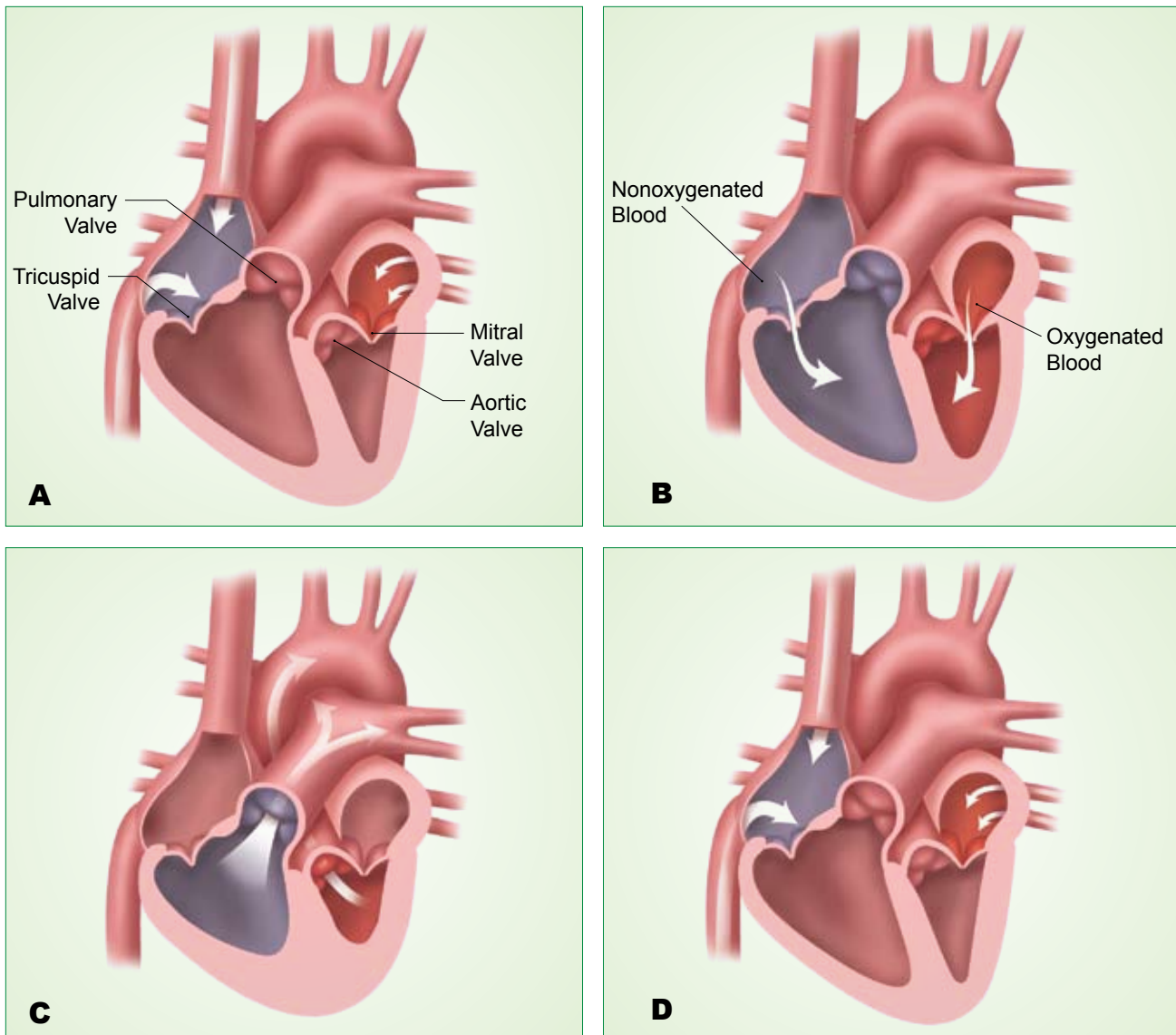


Figure 7.2 The finely tuned cardiac cycle. **A.** As the heart relaxes in diastole, both atria and ventricles simultaneously fill with blood. **B.** The atria, squeezing into systole, force blood into the ventricles. **C.** As the ventricle compartments fill with blood, they contract, thereby ejecting blood to the lungs and body. **D.** The atria and ventricles relax as the cycle begins anew.

flows from the arterioles into the capillaries. The normal diastolic pressure in healthy young adults is about 70 to 80 mm Hg.

Cardiac Output

The amount of blood that is pumped into the aorta each minute by the heart is known as the **cardiac output** (measured in liters per minute). Cardiac output is the product of stroke volume

(measured in liters per minute) and heart rate (measured in beats per minute) and is therefore representative of the quantity of blood that flows to the peripheral circulation. Cardiac output can be described by the simple equation presented below:

$$\text{Cardiac Output} = \text{Stroke Volume} \times \text{Heart Rate}$$



Figure 7.3 Measuring blood pressure.

Stroke Volume The amount of blood that is pumped out of the left ventricle with each heartbeat is the **stroke volume**. The stroke volume of the heart is measured in milliliters (1 liter = 1,000 ml). A typical stroke volume for a normal heart is about 70 ml of blood. Regular exercise and sports training can serve to increase stroke volume.

Heart Rate The rhythmical contraction of the walls of the heart is commonly known as a **heartbeat**. **Heart rate** is the number of times the heart beats in one minute and is measured in beats per minute (bpm). At rest the normal heart rate of an adult can range from 40 bpm in a highly trained athlete to 70 bpm in a normal, healthy person. During intense exercise, the heart rate may increase to up to 200 bpm and occasionally even higher. The maximum expected heart rate for most people can be estimated by using the following equation:

$$\text{Maximum Heart Rate} = 220 - \text{Age (in years)}$$

Intensity of Work The intensity of aerobic exercise can be estimated by measuring heart rate as the two are highly related. The higher the intensity of exercise, the higher the heart rate per minute. Since heart rate is a measure that is easily



Figure 7.4 A. Measuring the carotid pulse. B. Measuring the radial pulse.

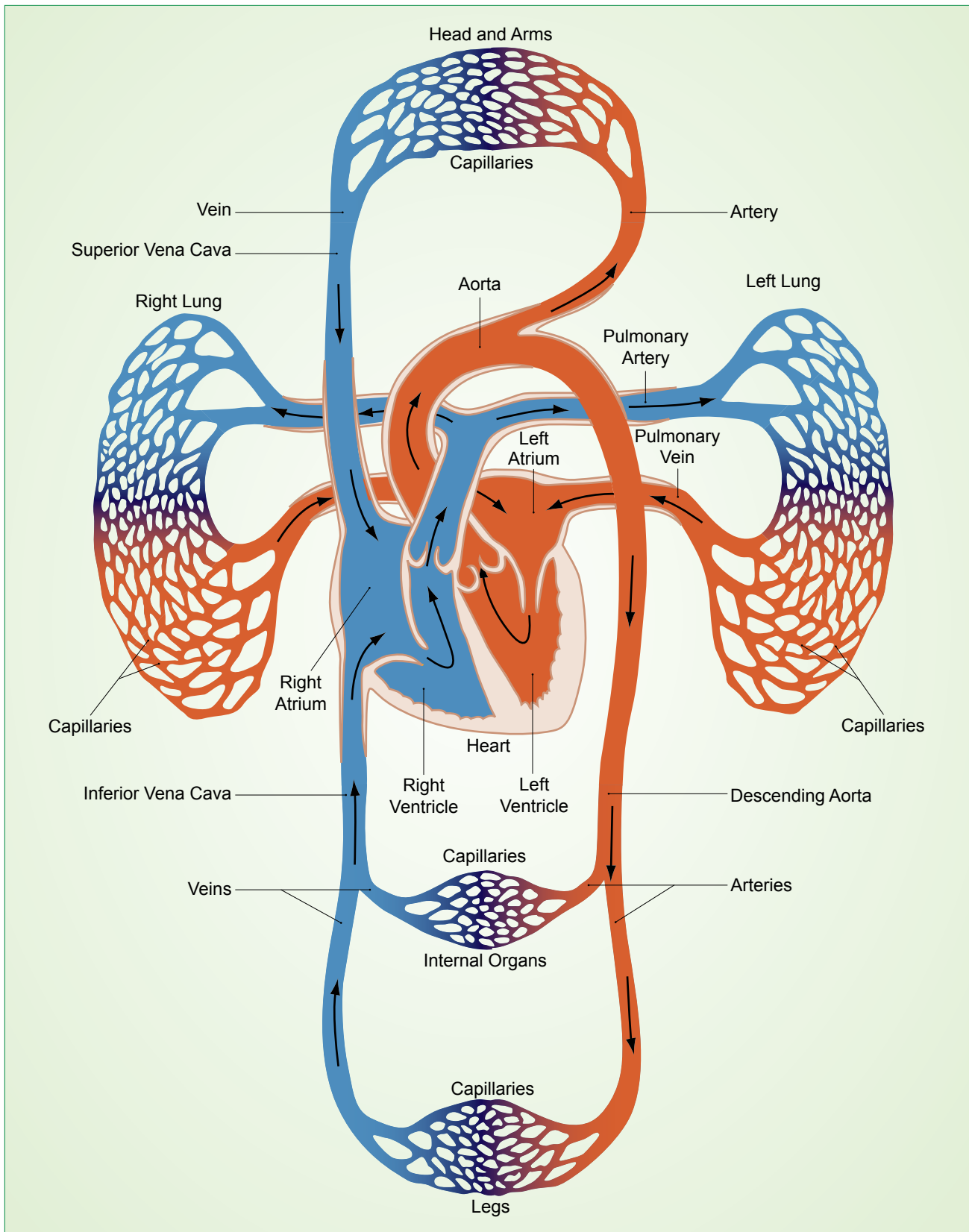


Figure 7.5 Circuitry of the heart and cardiovascular system. Oxygenated blood is shown in red, deoxygenated blood in blue.



obtained, it becomes very practical for estimation of intensity of work and/or exercise. The heart rate can easily be measured by feeling the carotid or radial pulses with the middle three fingers as in Figure 7.4. By placing two or three fingers and applying light pressure between the trachea and the sternocleidomastoid muscle in the neck, you can feel the carotid pulse. Then count the number of beats in 10 seconds and multiply the figure by 6 to get the number of beats per minute.

For example, a count of 17 beats in 10 seconds multiplied by 6 would result in a heart rate of 102 beats per minute. This elementary procedure allows you to quickly determine how hard you are working without any specialized equipment.

The Peripheral Circulatory System

All of the larger blood vessels of the body are made up of tubes composed of layers of tissue. Smooth muscle cells that allow them to contract or relax also surround the fibrous tubes of the arteries, arterioles, venules, and veins. This enables the vessels of the peripheral circulatory system to regulate blood flow and alter the pattern of circulation throughout the body.

The peripheral circulatory system is made up of the vessels that carry blood away from the heart to the muscles and organs (lungs, brain, stomach, intestines) and then return the blood to the heart. The vessels that carry blood away from the heart are called arteries, and the vessels that return blood to the heart are called veins (Figure 7.5).

Arteries

As the **arteries** carry blood away from the heart, they branch into smaller and smaller vessels called **arterioles**. The arterioles also branch into smaller and smaller vessels until they are composed of vessels that are about the width of one red blood cell. At this point, they are called **capillaries** (Figures 7.5 and 7.11). The capillaries are small vessels composed of only endothelial cells that allow for the exchange of oxygen and nutrients

from the blood to muscles and organs and also allow blood to pick up the waste products and carbon dioxide from metabolism.

Veins

As the blood begins to return to the heart, the capillaries connect to form larger and larger vessels called **venules**. The venules then merge into even larger vessels called **veins**. Veins have an additional feature that facilitates the return of blood to the heart, sometimes against the pull of gravity. In comparison to arteries, veins have **valves** that open with the flow of blood in the direction of return to the heart (e.g., from the

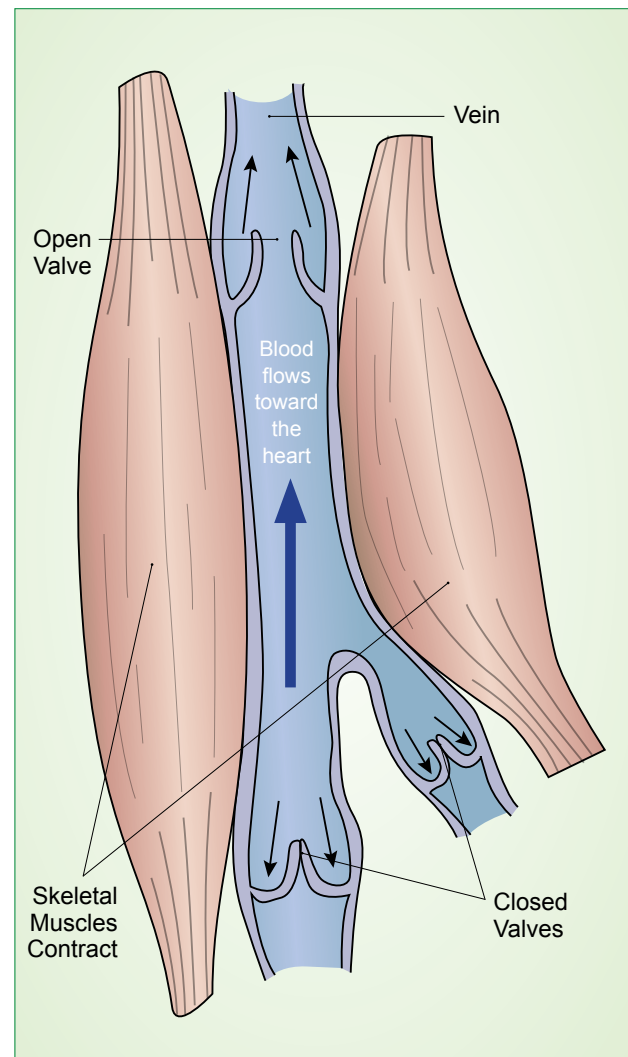


Figure 7.6 The skeletal muscle pump.

knee to the hip) and close to prevent blood flow in the opposite direction (Figure 7.6). Blood can be pushed through veins by smooth muscle that surrounds the veins, by contraction of the various skeletal muscles (or muscle groups), or to a minor extent by the pumping action of the heart.

Red Blood Cells

Red blood cells, or **erythrocytes** (Figure 7.7), are specialized cells (approximately 8 μm in diameter) that are present in the blood. Other components of blood include **white blood cells** and a clear fluid called **plasma**. The percentage of the blood that is made up of red blood cells is called the **hematocrit**, which normally is about 45 percent. The primary function of the red blood cells is to transport oxygen from the lungs to the tissues and carbon dioxide from the body back to the lungs. Red blood cells are able to perform this function because they contain an oxygen-binding substance called **hemoglobin**.

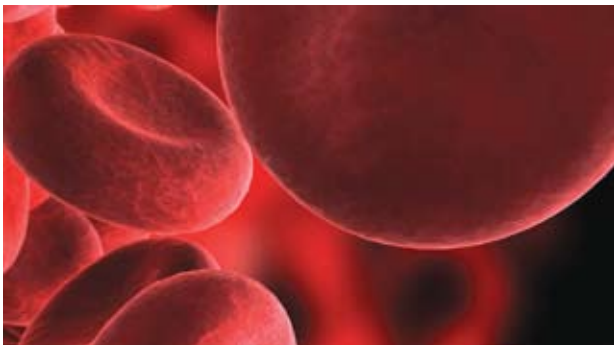


Figure 7.7 Red blood cells.

Hemoglobin

Hemoglobin is a molecule made up of proteins and iron. Each hemoglobin molecule can bond to and transport four oxygen molecules. The amount of oxygen that is carried by the blood depends on the **partial pressure of oxygen (PO_2)**. Thus, in the lungs where the partial pressure of oxygen is high because of the fresh air that is present, hemoglobin binds easily to oxygen, and the red blood cells

become saturated with oxygen. However, once the blood has reached the tissues, the partial pressure of oxygen is usually much lower because the metabolism of the body uses up the oxygen that is present. When the partial pressure of oxygen is lower, oxygen unbinds (dissociates) from hemoglobin and is diffused to the tissues, where it is used to produce energy. The difference in the amount of oxygen that is present in the blood as it leaves the lungs and the amount of oxygen that is present in the blood when it returns to the lungs is called the **arterial–venous oxygen difference (a–v O_2 difference)** and is measured in milliliters of oxygen per deciliter of blood (i.e., $\text{ml O}_2/100 \text{ ml blood}$). This is an important physiological measure of the amount of oxygen that is being used by the body. If the a–v O_2 difference increases, it means that the body is using more oxygen. A typical a–v O_2 difference at rest is about 4 to 5 $\text{ml O}_2/\text{dl}$ of blood, while at exercise the a–v O_2 difference may increase to 15 $\text{ml O}_2/\text{dl}$ of blood.

The total mass of red blood cells in the circulatory system is regulated within very narrow limits. New red blood cells (**reticulocytes**) are produced in the bone marrow. The principal factor that stimulates red blood cell formation is the circulating hormone **erythropoietin (EPO)**. EPO is secreted in response to low oxygen levels (when one is at high altitude; Figure 7.8) and also in response to exercise. Thus, exercise can increase the percentage of new red blood cells in the body. New red blood cells contain more hemoglobin than older red blood cells and thus can carry greater amounts of oxygen.

Cardiovascular Physiology

The Transport of Carbon Dioxide

Carbon dioxide (CO_2) is produced in the body as a by-product of metabolism. Once formed, carbon dioxide diffuses from the cells to the blood where it is transported to the lungs via one of three mechanisms: (1) a small percentage of the