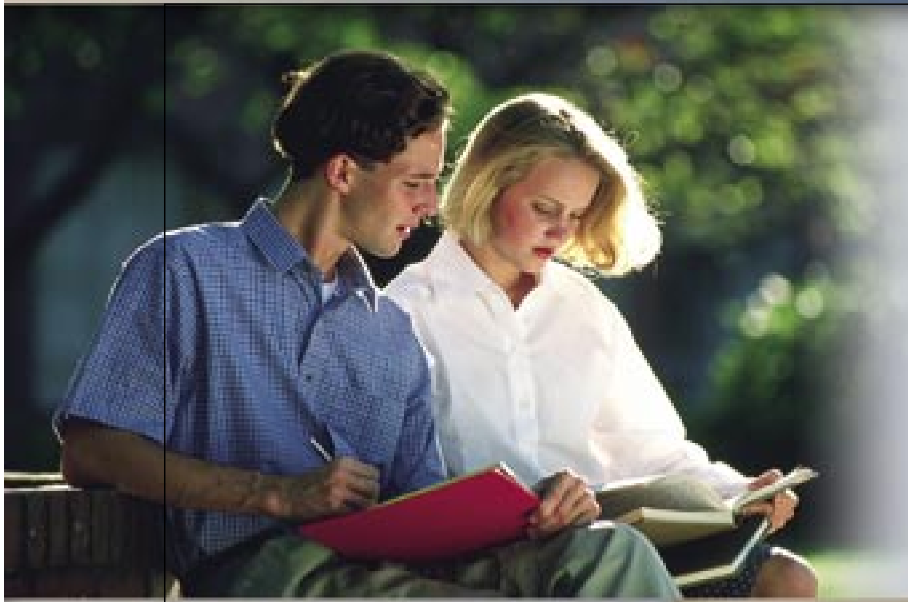
PART II Maintenance of the Human Body



CHAPTER 5

Cardiovascular System: Heart and Blood Vessels

Sharon was studying for an anatomy and physiology exam. "There is SO much to remember," she groaned. "How am I ever going to remember all of this for the test next week?" she wondered. Allen, her study partner, said the concept of structure suits function might help. You were introduced to this concept in Chapter 3 when you learned that cells have organelles enabling them to carry out their specific function. If you know the function of a cell or organ, you can often describe the structure of it, and vice versa. Allen suggested that Sharon use this technique when studying the organs of the cardiovascular system. For example, if Sharon learns that the aorta, the major artery in the body, receives blood under high pressure from the heart, she should be able to remember that the aorta is thick walled and stretchy.

Allen also suggested that Sharon think of analogies to help her remember the functions of various organs. He told her that arteries remind him of interstates because they carry a large volume of blood, just as interstates accommodate a large number of cars. As you study the organs of this system, you too might think of everyday examples to help you remember the functions of cardiovascular organs for the exam, when your knowledge will be assessed.

CHAPTER CONCEPTS

5.1 Overview of the Cardiovascular System
In the cardiovascular system, the heart pumps the blood, and the blood vessels transport blood about the body. Exchanges at the capillaries refresh the blood and then tissue fluid.

5.2 The Types of Blood Vessels
Arteries, which branch into arterioles, take blood away from the heart to capillaries, which empty into venules. Venules join to form veins that take blood back to the heart.

5.3 The Heart Is a Double Pump
The right side of the heart pumps blood to the lungs, and the left side of the heart pumps blood to the rest of the body.

5.4 Features of the Cardiovascular System
Blood pressure which moves blood in the arteries drops off in the capillaries where exchange takes place. Skeletal muscle contraction largely accounts for the movement of blood in the veins.

5.5 Two Cardiovascular Pathways
One cardiovascular pathway takes blood from the heart to the lungs and back to the heart. The other pathway takes blood from the heart to all the other organs in the body and back to the heart.

5.6 Exchange at the Capillaries
At the systemic capillaries, nutrients and oxygen are exchanged for carbon dioxide and other wastes. In this way, tissue fluid and the body's cells remain alive and healthy

5.7 Cardiovascular Disorders
Hypertension and atherosclerosis are two cardiovascular disorders that can lead to stroke, heart attack, and aneurysm. Ways to prevent and treat cardiovascular disease are constantly being improved.

5.1 Overview of the Cardiovascular System

The cardiovascular system consists of (1) the heart, which pumps blood, and (2) the blood vessels, through which the blood flows.

Circulation Performs Exchanges

Even though circulation of blood depends on the beating of the heart, the actual purpose of circulation is to service the cells. Blood brings cells the oxygen and nutrients they need to continue to exist, and it also removes their waste products. This is symbolized by the arrows in Figure 5.1 that point to and away from **tissue fluid,** which bathes the cells. Blood would not be able to continue to perform this function if it did not become refreshed in the lungs, at the intestines, and at the kidneys. At the lungs, carbon dioxide leaves blood, and oxygen enters it, as indicated by the two arrows in and out of the lungs in Figure 5.1. Blood is purified of its wastes at the kidneys, while water and salts are retained as needed. This exchange is represented by arrows that go into and out of the kidneys in Figure 5.1. Finally, nutrients enter blood at the intestines. The liver, the largest organ of the body, is very important because it can take up amino acids from the blood and return to it blood proteins that help transport substances, such as fats, in the blood. The liver removes any poisons that have entered blood at the intestines. Therefore, a double arrow is shown to and from blood at the liver in Figure 5.1. Following up on Allen's suggestion in the opening story, we can liken the blood vessels to streets that allow cars to move about. Just imagine that you are moving about town to exchange birthday gifts that are not useful for items you would find useful. Just like blood, at each stop you give up the useless item (wastes) and receive, in turn, something of use (nutrients and oxygen).

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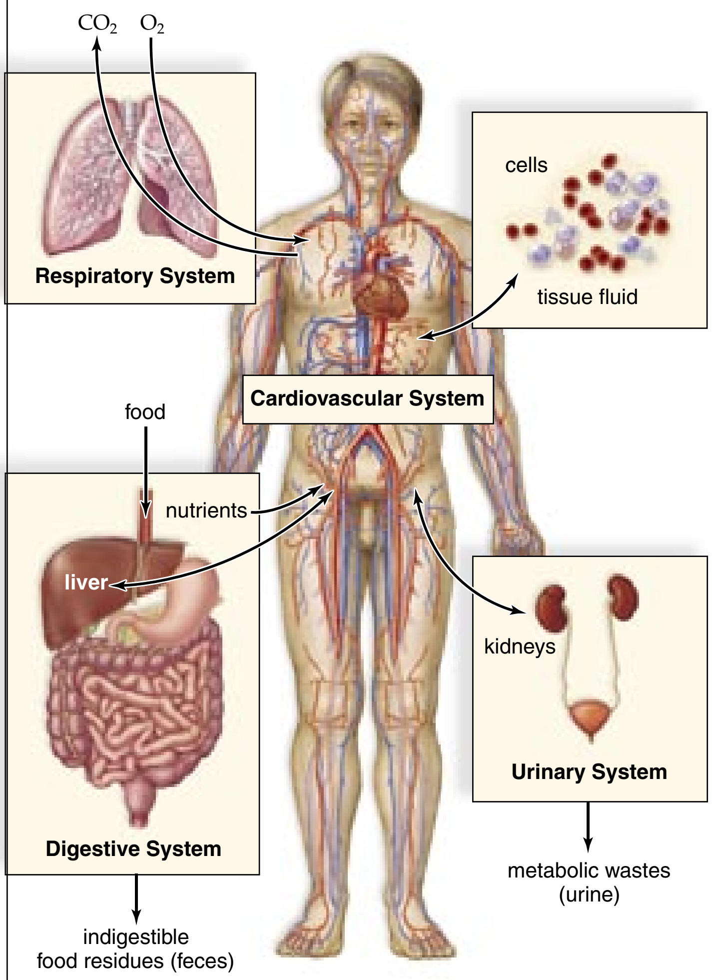


Figure 5.1 The cardiovascular system.
The cardiovascular system transports blood about the body and, with the help of other systems in the body, it maintains favorable conditions for the cells of the body.

Functions of the Cardiovascular System

In this chapter, we will see that

1. contractions of the heart generate blood pressure, which moves blood through blood vessels.
2. blood vessels transport the blood, which moves from the heart into arteries, capillaries, and veins, before returning to the heart.
3. exchanges at the capillaries (the smallest of the blood vessels) refreshes blood and then tissue fluid, sometimes called interstitial fluid.
4. The heart and blood vessels regulate blood flow, according to the needs of the body.

Lymphatic System

The **lymphatic system** is of assistance to the cardiovascular system because lymphatic vessels collect excess tissue fluid and return it to the cardiovascular system. When exchanges occur in the tissues between blood and tissue fluid, water collects in the tissues. This water enters lymphatic vessels, which start in the tissues and end at cardiovascular veins in the shoulders. As soon as fluid enters lymphatic vessels, it is called lymph. Lymph, you will recall, is a fluid tissue, as is blood (see page 64).

Check Your Progress 5.1

1. What are the two parts of the cardiovascular system?
2. What are the functions of the cardiovascular system?
3. How does the lymphatic system help the cardiovascular system?

5.2 The Types of Blood Vessels

As Allen advised Sharon on page 85, the structure of the three types of blood vessels (arteries, capillaries, and veins) is appropriate to their function (Fig.-5.2).

The Arteries: From the Heart

The arterial wall has three layers. The innermost layer is a thin layer of cells called endothelium, the middle layer is a relatively thick layer of smooth muscle and elastic tissue, while the outer layer is connective tissue. The strong walls of an artery give it support when blood enters under pressure; the elastic tissue allows an artery to expand to absorb the pressure. **Arterioles** are small arteries just visible to the naked eye. The middle layer of arterioles has some elastic tissue but is composed mostly of smooth muscle, whose fibers encircle the arteriole. When these muscle fibers contract, the vessel constricts; when these muscle fibers relax, the vessel dilates. Whether arterioles are constricted or dilated regulates blood pressure. The greater the number of vessels dilated, the lower the blood pressure.

The Capillaries: Exchange

Arterioles branch into capillaries. Each capillary is an extremely narrow, microscopic tube with a wall composed only of endothelium (a single layer of epithelial cells) with a basement membrane. Although each capillary is small, their total surface area in humans is about 6,300 square meters. Capillary beds (networks of many capillaries) are present in all regions of the body, so no cell is far from a capillary. In the tissues, only certain capillaries are open at any given time. For example, after eating, the capillaries that serve the digestive system are open, and those that serve the muscles are closed. When a capillary bed is closed, the precapillary sphincters contract, and the blood moves from arteriole to venule by way of an arteriovenous shunt.

The Veins: To the Heart

Venules are small veins that drain blood from the capillaries and then join to form a vein. The walls of venules (and veins) have the same three layers as arteries, but there is less smooth muscle in the middle layer and less connective tissue in the outer layer. Therefore, the wall of a vein is thinner than that of an artery.

Veins often have **valves,** which allow blood to flow only toward the heart when open and prevent the backward flow of blood when closed. Valves are found in the veins that carry blood against the force of gravity, especially the veins of the lower extremities.

Since the walls of veins are thinner, they can expand to a greater extent. At any one time, about 70% of the blood is in the veins. In this way, the veins act as a blood reservoir. If blood is lost due to hemorrhaging, nervous stimulation causes the veins to constrict, providing more blood to the rest of the body.

Check Your Progress 5.2

1. What are the types of blood vessels?
2. What is the structure and function of these vessels?

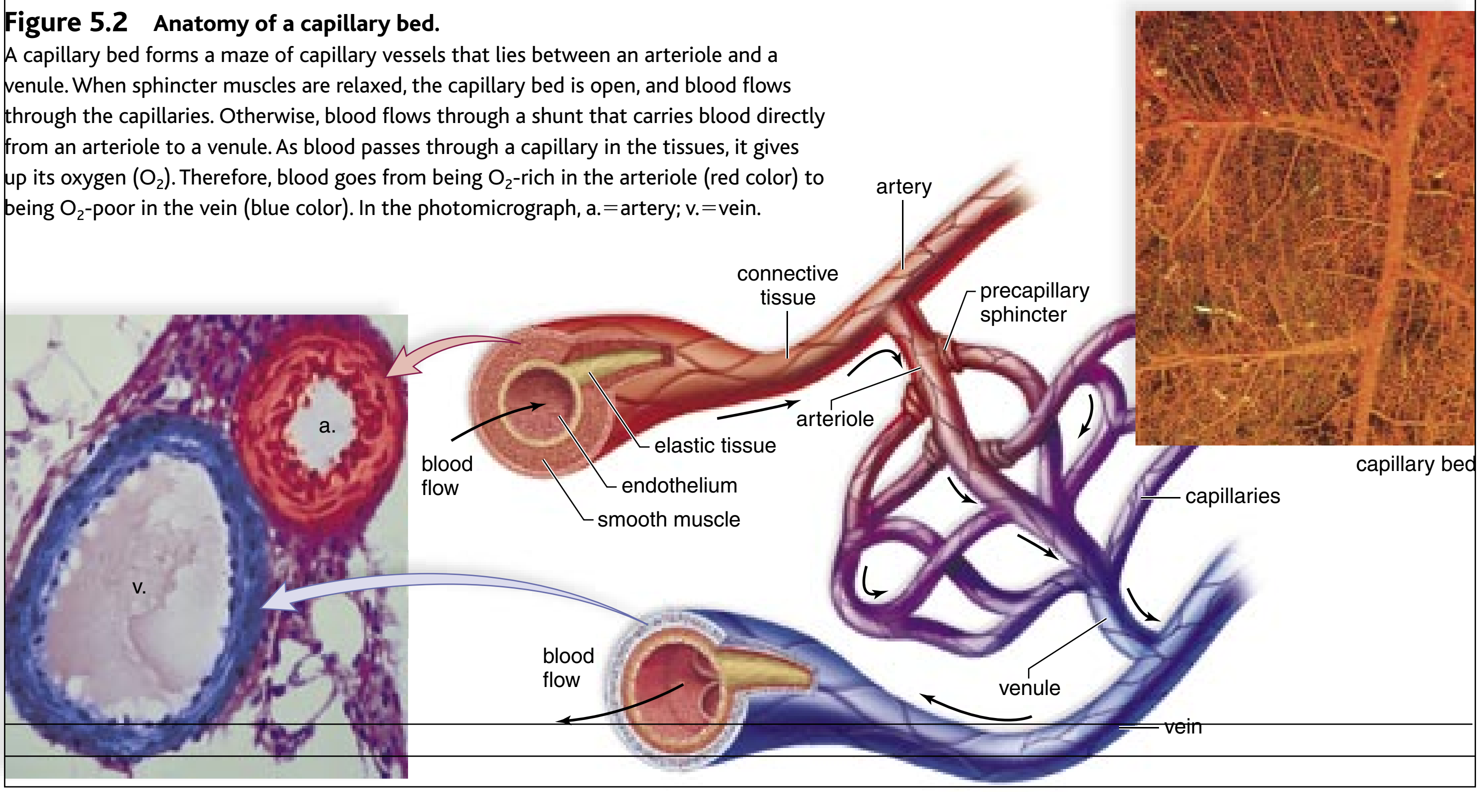


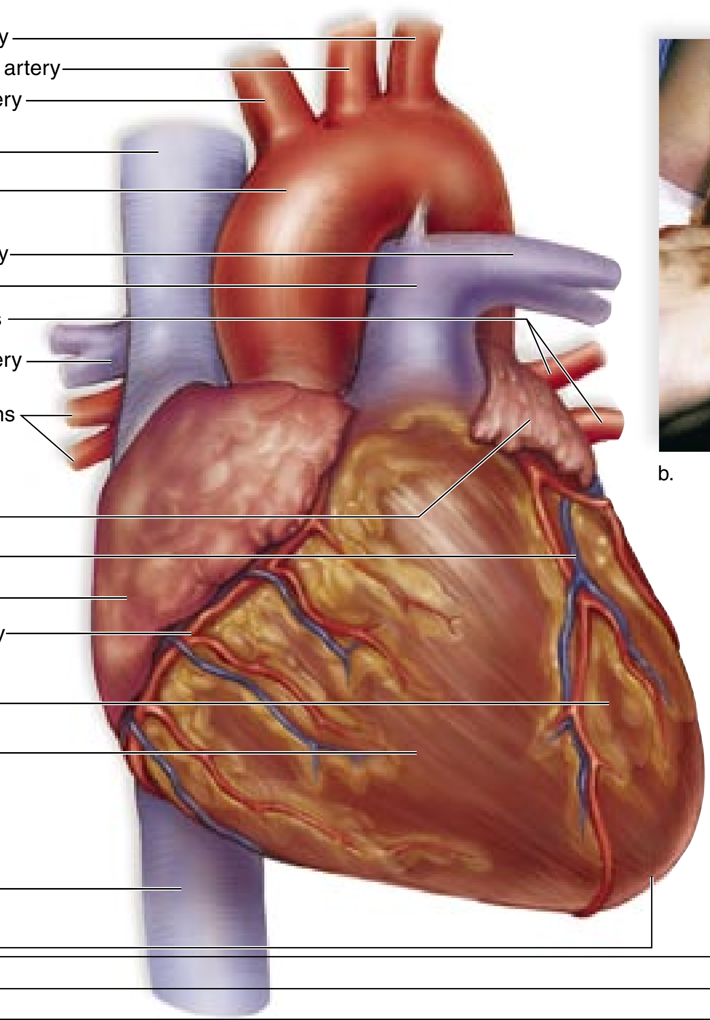
Figure 5.2 **Anatomy of a capillary bed.**
A capillary bed forms a maze of capillary vessels that lies between an arteriole and a venule. When sphincter muscles are relaxed, the capillary bed is open, and blood flows through the capillaries. Otherwise, blood flows through a shunt that carries blood directly from an arteriole to a venule. As blood passes through a capillary in the tissues, it gives up its oxygen (O_2). Therefore, blood goes from being O_2-rich in the arteriole (red color) to being O_2-poor in the vein (blue color). In the photomicrograph, a.=artery; v.=vein.

5.3 The Heart Is a Double Pump

The **heart** is a cone-shaped, muscular organ located between the lungs, directly behind the sternum (breastbone). The heart is tilted so that the apex (the pointed end) is oriented to the left (Fig. 5.3). To approximate the size of your heart, make a fist, then clasp the fist with your opposite hand. The major portion of the heart, called the **myocardium,** consists largely of cardiac muscle tissue. This tissue is serviced by the coronary artery and cardiac vein and not by the blood it pumps. The muscle fibers of the myocardium are branched and tightly joined to one another at intercalated disks. The heart is surrounded by the **pericardium,** a thick, membranous sac that supports and protects the heart. The inside of the pericardium secretes a lubrication fluid, and the pericardium slides smoothly over the surface as the heart pumps the blood.

Internally, a wall called the **septum** separates the heart into a right side and a left side (Fig. 5.4*a*). The heart has four chambers. The two upper, thin-walled atria (sing., **atrium**) are called the right atrium and the left atrium. Each atrium has a wrinkled, protruding appendage called an auricle. The two lower chambers are the thick-walled **ventricles,** called the right ventricle and the left ventricle (Fig. 5.4).

Heart valves keep blood flowing in the right direction and prevent its backward movement. The two valves that lie between the atria and the ventricles are called the **atrioventricular valves (AV valves).** These valves are supported by strong fibrous strings called **chordae tendineae.** The chordae, which are attached to muscular projections of the ventricular walls, called papillary muscles, support the valves and prevent them from inverting when the heart contracts. The atrioventricular valve on the right side is called the tricuspid valve because it has three flaps, or cusps. The atrioventricular valve on the left side is called the bicuspid valve because it has two flaps. The bicuspid valve is commonly referred to as the mitral valve, because it has a shape like a bishop's hat, or mitre. The remaining two valves are the **semilunar valves,** with flaps shaped like half-moons, that lie between the ventricles and their attached vessels. The semilunar valves are named for their attached vessels: The pulmonary semilunar valve lies between the right ventricle and the pulmonary trunk. The aortic semilunar valve lies between the left ventricle and the aorta.



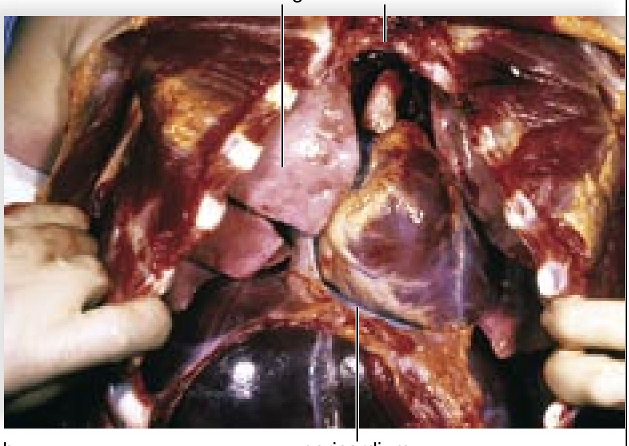


Figure 5.3 External heart anatomy. **a.** The venae cavae and the pulmonary trunk are attached to the right side of the heart. The aorta and pulmonary veins are attached to the left side of the heart. **b.** Photograph of a heart in its natural position in the chest.

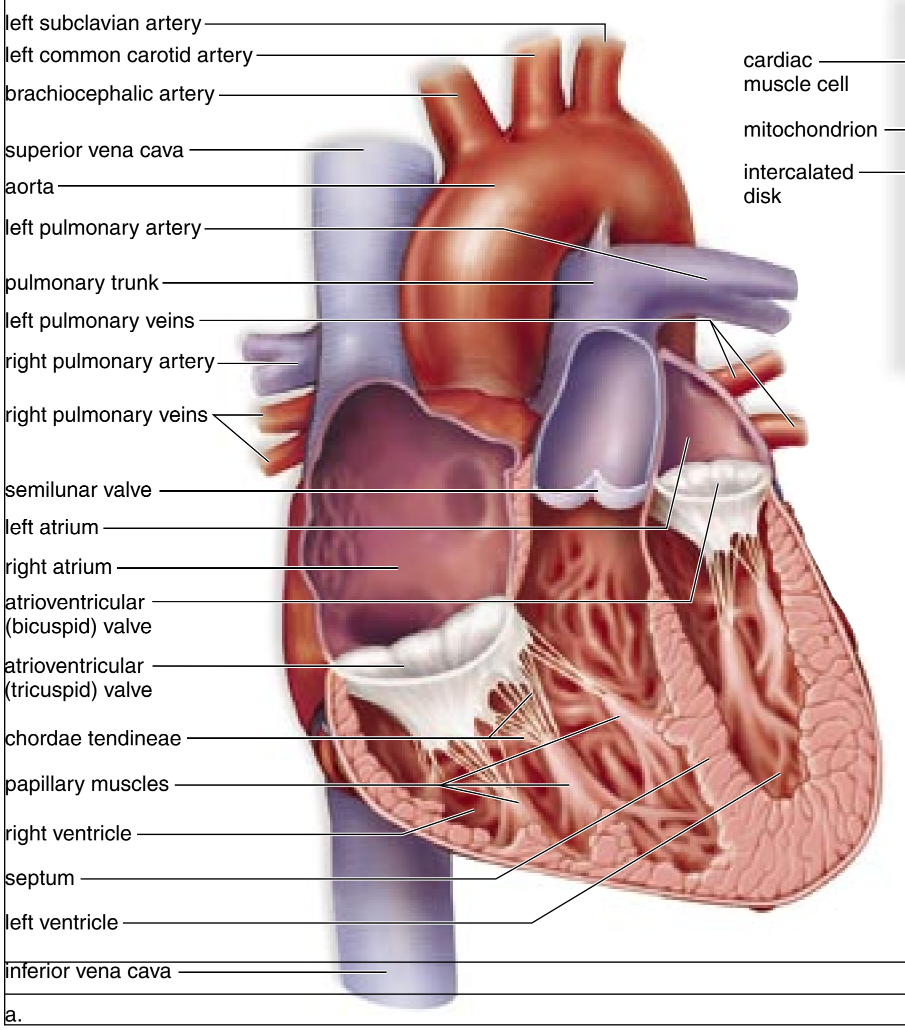
Passage of Blood Through the Heart

Even though the presence of intercalated disks (Fig. 5.4*b*) between cardiac muscle cells allows both atria and then both ventricles to contract simultaneously, we can trace the path of blood through the heart in the following manner:

- The superior vena cava and the inferior vena cava, which carry O_2-poor blood, enter the right atrium.
- The right atrium sends blood through an atrioventricular valve (the tricuspid valve) to the right-ventricle.
- The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk. The pulmonary trunk divides into two **pulmonary arteries,** which go to the lungs.
- Four **pulmonary veins,** which carry O2-rich blood, enter the left atrium.
- The left atrium sends blood through an atrioventricular-valve (the bicuspid, or mitral, valve) to the left ventricle.
- The left ventricle sends blood through the aortic semilunar valve into the aorta to the body proper.

From this description, you can see that O_2-poor blood never mixes with O_2-rich blood and that blood must go through the lungs in order to pass from the right side to the left side of the heart. The heart is a double pump because the right ventricle of the heart sends blood through the lungs, and the left ventricle sends blood throughout the body. Sharon had no trouble deciding that the left ventricle must have the harder job of pumping blood. She showed Allen that the atria have thin walls, and each pumps blood into the ventricle right below it. The ventricles are thicker, and they pump blood into blood vessels that travel to other parts of the body. The thinner myocardium of the right ventricle pumps blood to the lungs, which are nearby in the thoracic cavity. The left ventricle, has a thicker wall than the right ventricle, and this enables it to pump blood to all the other parts of the body.

The pumping of the heart sends blood out under pressure into the arteries. Because the left side of the heart is the stronger pump, blood pressure is greatest in the aorta. Blood pressure then decreases as the total cross-sectional area of arteries and then arterioles increases (see Fig. 5.8). A different mechanism, aside from blood pressure, is used to move blood in the veins.



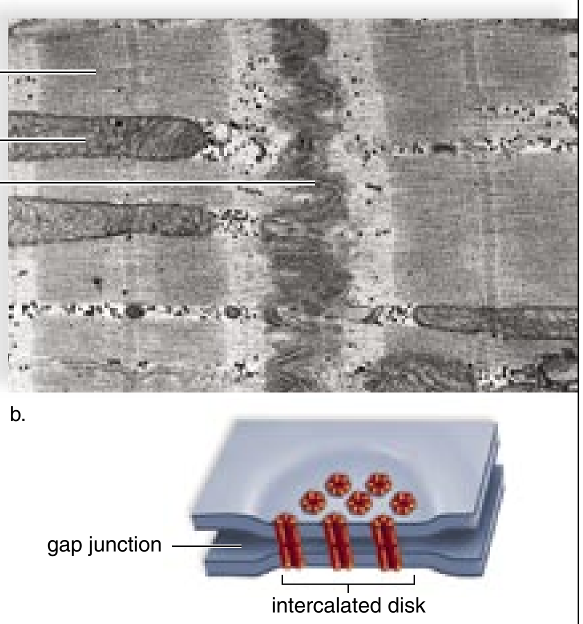


Figure 5.4 **Internal view of the heart.**
a. The heart has four chambers, the two chambers on the right are separated from the two chambers on the left by a septum. The right side pumps the blood to the lungs and the left side pumps blood to the rest of the body. **b.** Cardiac muscle cells contract simultaneously because gap junctions are present at folded plasma membranes called intercalated disks. Desmosomes at the same location allow the cells to bend and stretch.

The Heartbeat Is Controlled

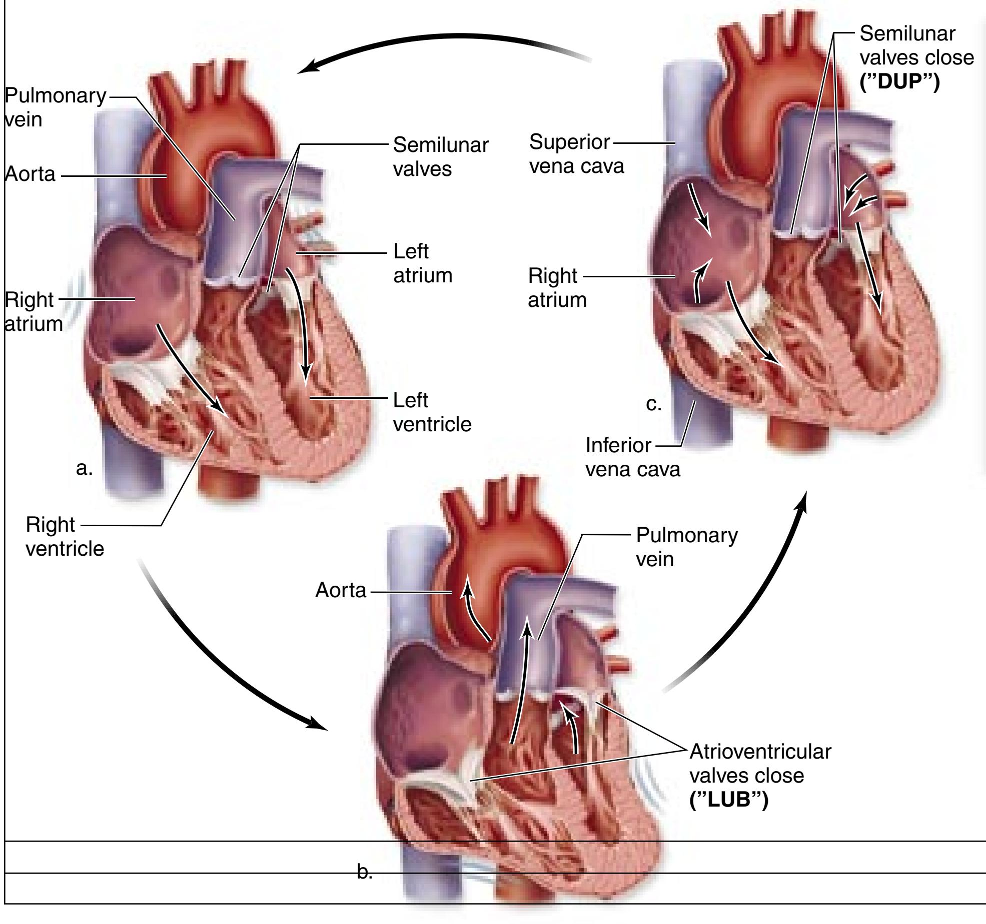
Each heartbeat is called a **cardiac cycle** (Fig. 5.5). When the heart beats, first the two atria contract at the same time; next, the two ventricles contract at the same time. Then, all chambers relax. **Systole,** the working phase, refers to contraction of the chambers, and the word **diastole,** the resting phase, refers to relaxation of the chambers. The heart contracts, or beats, about 70 times a minute, and each heartbeat lasts about 0.85 second. A normal adult rate at rest can vary from 60 to 80 beats per minute.

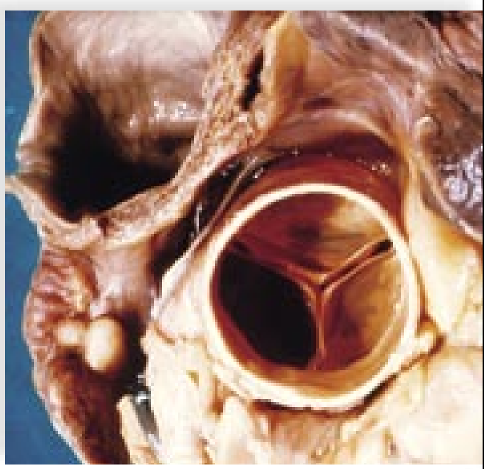
Allen told Sharon, in order to understand the "LUB-DUP" sounds of a heartbeat, concentrate on the ventricles. The first sound, "lub," occurs when increasing pressure of blood inside a ventricle forces the cusps of the AV valve to slam shut. The force of the blood is just like a strong wind that blows a door (the valve cusps) shut, Allen thought. In contrast, the pressure of blood inside a ventricle causes the semilunar valves (pulmonary and aortic) to open. The "dup" occurs when the ventricles relax, and blood in the arteries pushes back, causing the semilunar valves to close. A heart murmur, or a slight swishing sound after the "lub," is often due to ineffective valves, which allow blood to pass back into the atria after the AV valves have closed. Rheumatic fever resulting from a bacterial infection is one possible cause of a faulty valve, particularly the bicuspid valve. Faulty valves can be surgically corrected.

Internal Control of Heartbeat

The rhythmical contraction of the atria and ventricles is due to the internal (intrinsic) conduction system of the heart. Nodal tissue, which has both muscular and nervous characteristics, is a unique type of cardiac muscle located in two regions of the heart. The **SA (sinoatrial) node** is located in the upper dorsal wall of the right atrium; the **AV (atrioventricular) node** is located in the base of the right atrium very near the septum (Fig. 5.6*a*). The SA node initiates the heartbeat and automatically sends out an excitation impulse every 0.85 second; this causes the atria to contract. When impulses reach the AV node, there is a slight delay that allows the atria to finish their contraction before the ventricles begin their contraction. The signal for the ventricles to contract travels from the AV node through the two branches of the **atrioventricular bundle** (AV bundle) before reaching the numerous and smaller **Purkinje fibers.** The AV bundle, its branches, and the Purkinje fibers work efficiently because gap junctions at intercalated disks allow electrical current to flow from cell to cell (see Fig. 5.4*b*).

The SA node is called the **pacemaker** because it usually keeps the heartbeat regular. If the SA node fails to work properly, the heart still beats due to impulses generated by the AV node. But the beat is slower (40 to 60 beats per minute). To correct this condition, it is possible to implant an artificial pacemaker, which automatically gives an electrical stimulus to the heart every 0.85 second.





d.

Figure 5.5 Stages in the cardiac cycle.
a. When the atria contract, the ventricles are relaxed and filling with blood. The atrioventricular valves are open, and the semilunar valves are closed.
b. When the ventricles contract, the atrioventricular valves are closed, the semilunar valves are open, and the blood is pumped into the pulmonary trunk and aorta. **c.** When the heart is relaxed, both the atria and the ventricles are filling with blood. The atrioventricular valves are open, and the semilunar valves are closed. **d.** Aortic semilunar valve.

External Control of Heartbeat

The body has an external (extrinsic) way to regulate the heartbeat. A cardiac control center in the medulla oblongata, a portion of the brain that controls internal organs, can alter the beat of the heart by way of the parasympathetic and sympathetic portions of the nervous system. Allen reminded Sharon that, as studied in Chapter 1, the parasympathetic division promotes those functions associated with a resting state, and the sympathetic division brings about those responses associated with fight or flight. It makes sense, then, said Allen, that the parasympathetic division decreases SA and AV nodal activity when we are inactive, and the sympathetic division increases SA and AV nodal activity when we are active or excited.

The hormones epinephrine and norepinephrine, which are released by the adrenal medulla, also stimulate the heart. During exercise, for example, the heart pumps faster and stronger due to sympathetic stimulation and due to the release of epinephrine and norepinephrine.

The Electrocardiogram Is a Record of the Heartbeat

An **electrocardiogram (ECG)** is a recording of the electrical changes that occur in myocardium during a cardiac cycle. Body fluids contain ions that conduct electric currents, and therefore, the electrical changes in myocardium can be detected on the skin's surface. When an ECG is being taken, electrodes placed on the skin are connected by wires to an instrument that detects the myocardium's electrical changes. Thereafter, a pen rises or falls on a moving strip of paper. Figure 5.6*b* depicts the pen's movements during a normal cardiac cycle.

When the SA node triggers an impulse, the atrial fibers produce an electrical change called the P wave. The P wave indicates the atria are about to contract. After that, the QRS complex signals that the ventricles are about to contract. The electrical changes that occur as the ventricular muscle fibers recover produce the T wave.

Various types of abnormalities can be detected by an ECG. One of these, called ventricular fibrillation, is an uncoordinated contraction of the ventricles (Fig. 5.6*c*). Ventricular fibrillation is of special interest because it can be caused by an injury or drug overdose. It is the most common cause of sudden cardiac death in a seemingly healthy person over age 35. Once the ventricles are fibrillating, they have to be defibrillated by applying a strong electric current for a short period of time. Then the SA node may be able to reestablish a coordinated beat.

Check Your Progress 5.3

1. Why is the heart a double pump?
2. What causes the "lub" and the "dup" of the heart sounds?
3. What keeps the heartbeat regular?

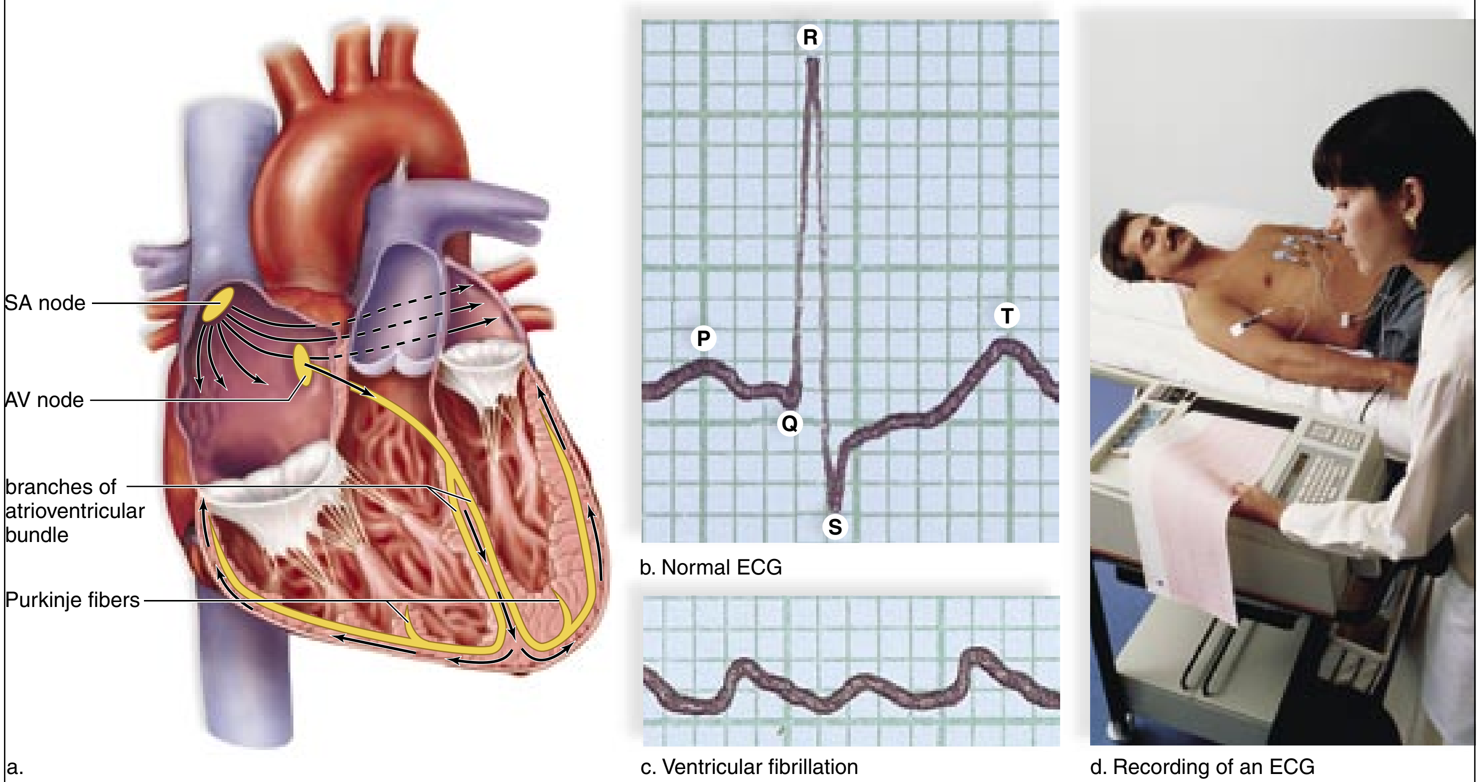


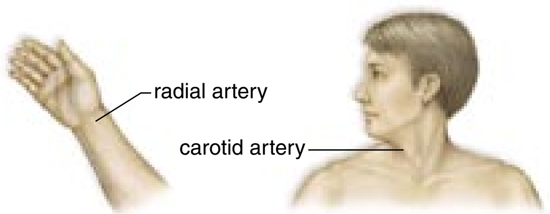
Figure 5.6 Conduction system of the heart.
a. The SA node sends out a stimulus (black arrows), which causes the atria to contract. When this stimulus reaches the AV node, it signals the ventricles to contract. Impulses pass down the two branches of the atrioventricular bundle to the Purkinje fibers, and thereafter, the ventricles contract. **b.** A normal ECG indicates that the heart is functioning properly. The P wave occurs just prior to atrial contraction; the QRS complex occurs just prior to ventricular contraction; and the T wave occurs when the ventricles are recovering from contraction. **c.** Ventricular fibrillation produces an irregular electrocardiogram due to irregular stimulation of the ventricles. **d.** The recording of an ECG.

5.4 Features of the Cardiovascular System

When the left ventricle contracts, blood is sent out into the aorta under pressure. A progressive decrease in pressure occurs as blood moves through the arteries, arterioles, capillaries, venules, and finally the veins. Blood pressure is highest in the aorta and lowest in the venae cavae, which enter the right atrium.

Pulse Rate Equals Heart Rate

The surge of blood entering the arteries causes their elastic walls to stretch, but then they almost immediately recoil. This rhythmic expansion and recoil of an arterial wall can be felt as a **pulse** in any artery that runs close to the body's surface. It is customary to feel the pulse by placing several fingers on the radial artery, which lies near the outer border of the palm side of a wrist. A carotid artery, on either side of the trachea in the neck, is another accessible location for feeling the pulse.



Normally, the pulse rate indicates the heart rate because the arterial walls pulse whenever the left ventricle contracts. The pulse rate is usually 70 beats per minute but can vary between 60 and 80 beats per minute.

Blood Flow Is Regulated

The beating of the heart is necessary to homeostasis because it creates the pressure that propels blood in the arteries and the arterioles. Arterioles lead to the capillaries where exchange with tissue fluid takes place.

Blood Pressure Moves Blood in Arteries

Blood pressure is the pressure of blood against the wall of a blood vessel. A sphygmomanometer (blood pressure instrument) can be used to measure blood pressure, usually in the brachial artery of the arm (Fig. 5.7). The highest arterial pressure, called the **systolic pressure,** is reached during ejection of blood from the heart. The lowest arterial pressure, called the **diastolic pressure,** occurs while the heart ventricles are relaxing. Normal resting blood pressure for a young adult is said to be 120 mm mercury (Hg) over 80 mm Hg, or simply 120/80, but these values can vary somewhat and still be within the range of normal blood pressure (Table 5.1). The higher number is the systolic pressure, and the lower number is the diastolic pressure. Actually, as stated, blood pressure is highest in the aorta and lowest in the venae cavae. It is customary, however, to take the blood pressure in the brachial artery of the arm, where it is usually 120/80. Low blood pressure is called hypotension, and high blood pressure is called hypertension.

Table 5.1 Normal Values for Adult Blood Pressure (mm)

	Systolic Pressure	Diastolic Pressure
Normal	95–135	50–90
Hypotension	Less than 95	Less than 50
Hypertension	Greater than 135	Greater than 9

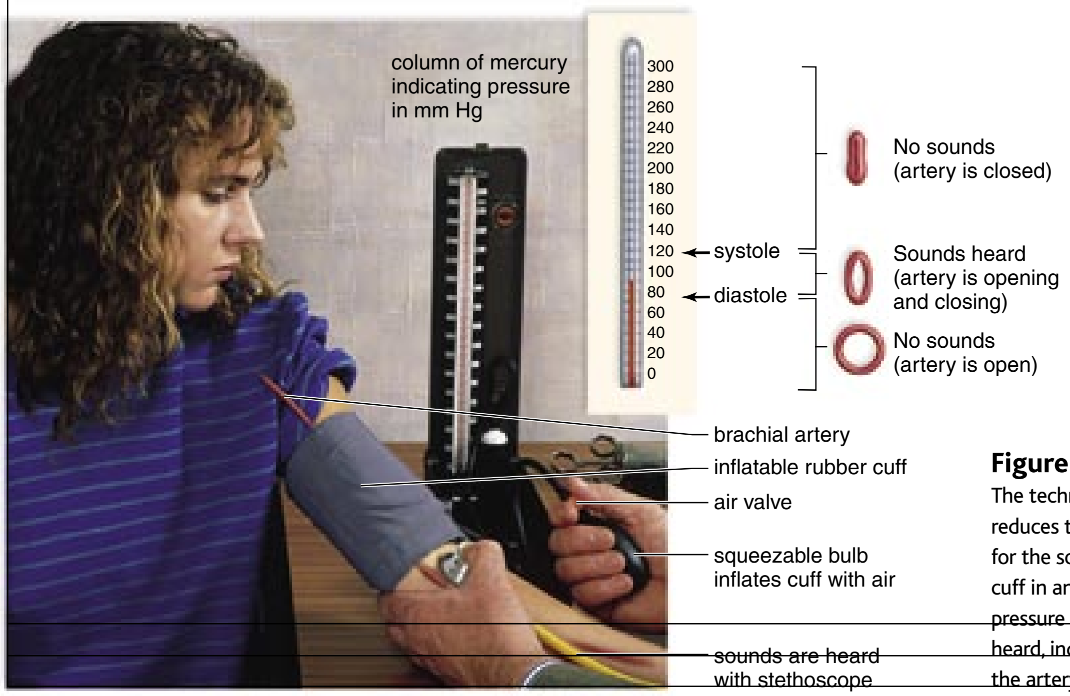


Figure 5.7 Use of a sphygmomanometer. The technician inflates the cuff with air, gradually reduces the pressure, and listens with a stethoscope for the sounds that indicate blood is moving past the cuff in an artery. This is systolic blood pressure. The pressure in the cuff is further reduced until no sound is heard, indicating that blood is flowing freely through the artery. This is diastolic pressure.

Both systolic and diastolic blood pressure decrease with distance from the left ventricle because the total cross-sectional area of the blood vessels increases—there are more arterioles than arteries. The decrease in blood pressure causes the blood velocity to gradually decrease as it flows toward the capillaries.

Blood Flow Is Slow in the Capillaries

There are many more capillaries than arterioles, and blood moves slowly through the capillaries (Fig. 5.8). This is important because the slow progress allows time for the exchange of substances between the blood in the capillaries and the surrounding tissues.

Blood Flow in Veins Returns Blood to Heart

While they were studying, Sharon pointed to Figure 5.8 and showed Allen that blood pressure is minimal in venules and veins. Even so, velocity of flow increases in veins. “There must be some influence rather than blood pressure that causes blood to flow in the veins” said Sharon. Indeed, venous return is dependent upon three factors:

1. the **skeletal muscle pump,** which is dependent on skeletal muscle contraction;
2. the **respiratory pump,** which is dependent on breathing;
3. valves in veins.

The skeletal muscle pump works like this: When skeletal muscles contract, they compress the weak walls of the veins. This causes the blood to move past a valve (Fig. 5.9). Once past the valve, blood cannot flow backward. The importance of the skeletal muscle pump in moving blood in the veins can be demonstrated by forcing a person to stand rigidly still for an hour or so. Fainting may occur because blood collects in the limbs, depriving the brain of needed oxygen. In this case, fainting is beneficial because the resulting horizontal position aids in getting blood to the head.

The respiratory pump works like this: When we inhale, the chest expands, and this reduces pressure in the thoracic cavity. Blood will flow from higher pressure (in the abdominal cavity) to lower pressure (in the thoracic cavity). When we exhale, the pressure reverses, but again the valves in the veins prevent backward flow. “Another example of structure suits function” said Allen, “because the function of the veins is to return blood to the heart.”

Check Your Progress 5.4

1. What does the pulse rate of a person indicate?
2. What accounts for the flow of blood in the arteries?
3. What accounts for the flow of blood in the veins?

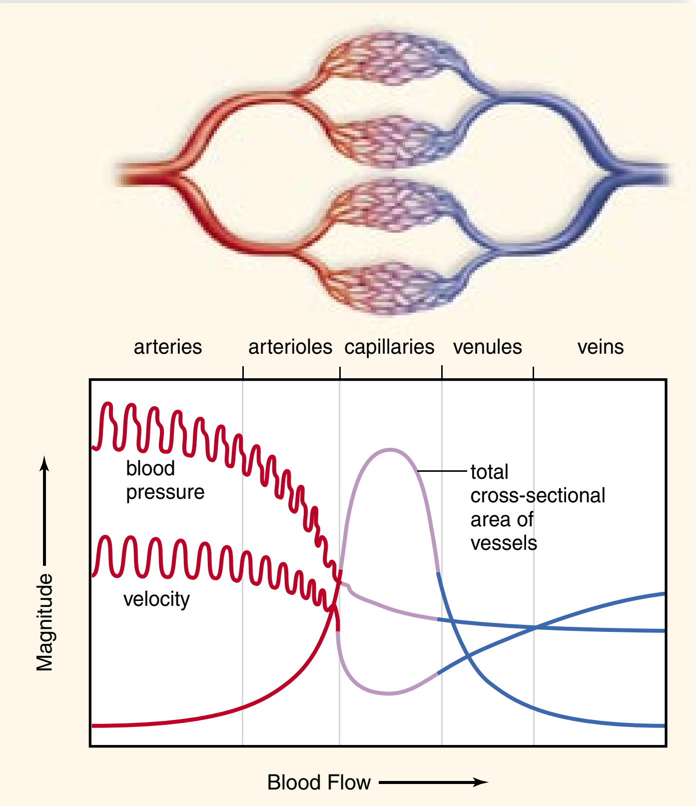


Figure 5.8 **Velocity and blood pressure related to vascular cross-sectional area.**
In capillaries, blood is under minimal pressure and has the least velocity. Blood pressure and blood velocity drop off because capillaries have a greater total cross-sectional area than arterioles.

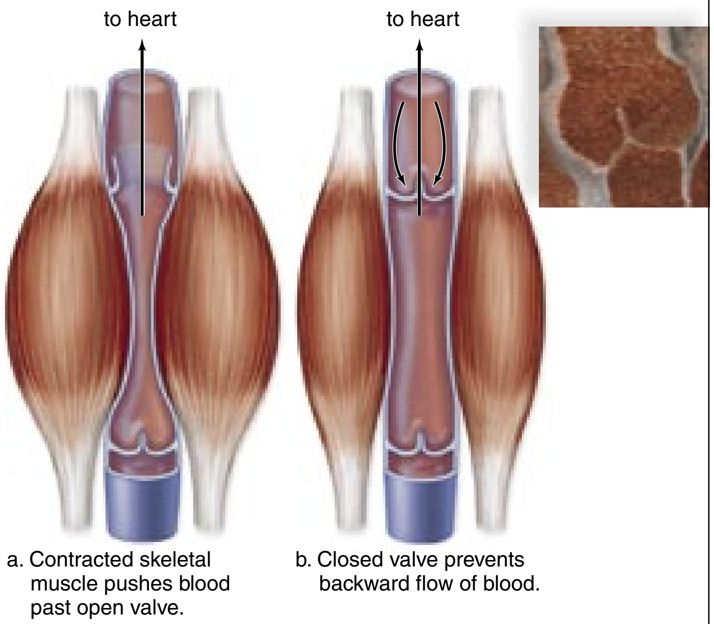


Figure 5.9 **Cross section of a valve in a vein.**
a. Pressure on the walls of a vein, exerted by skeletal muscles, increases blood pressure within the vein and forces a valve open. **b.** When external pressure is no longer applied to the vein, blood pressure decreases, and back pressure forces the valve closed. Closure of the valves prevents the blood from flowing backward, and therefore, veins return blood to the heart. **c.** Micrograph of valve in vein.

5.5 Two Cardiovascular Pathways

As mentioned, the blood flows in two circuits: the **pulmonary circuit,** which circulates blood through the lungs, and the **systemic circuit,** which serves the needs of body tissues (Fig. 5.10). Both circuits, as we shall see, are necessary to homeostasis.

The Pulmonary Circuit Exchange of Gases

The path of blood through the lungs can be traced as follows: Blood from all regions of the body first collects in the right atrium and then passes into the right ventricle, which pumps it into the pulmonary trunk. The pulmonary trunk divides into the right and left pulmonary arteries, which branch as they approach the lungs. The arterioles take blood to the pulmonary capillaries, where carbon dioxide is given off and oxygen is picked up. Blood then passes through the pulmonary venules, which lead to the four pulmonary veins that enter the left atrium. Since blood in the pulmonary arteries is O_2-poor but blood in the pulmonary veins is O_2-rich, it is not correct to say that all arteries carry blood that is high in oxygen and all veins carry blood that is low in oxygen (as people tend to believe). Just the reverse is true in the pulmonary circuit.

The Systemic Circuit: Exchanges with Tissue Fluid

The systemic circuit includes all of the arteries and veins shown in Figure 5.10. The heart pumps blood through 60,000 miles of blood vessels in order to deliver nutrients and oxygen and remove wastes from all body cells.

The largest artery in the systemic circuit, the **aorta,** receives blood from the heart, and the largest veins, the **superior** and **inferior venae cavae,** return blood to the heart. The superior vena cava collects blood from the head, the chest, and the arms, and the inferior vena cava collects blood from the lower body regions. Both enter the right atrium.

Tracing the Path of Blood

Allen told Sharon that it's easy to trace the path of blood in the systemic circuit because you always begin with the left ventricle, which pumps blood into the aorta. Branches from the aorta go to the organs and major body regions. For example, this is the path of blood to and from the lower legs:

left ventricle—aorta—common
iliac artery—femoral artery—lower leg
capillaries—femoral vein—
common iliac vein—inferior vena cava—right atrium

"So," said Allen "when tracing blood, you need only mention the aorta, the proper branch of the aorta, the region, and the vein returning blood to the vena cava." In most instances, the artery and the vein that serve the same region are given the same name (Fig. 5.11). What happens in between the artery and the vein? Arterioles from the artery branch into capillaries, where exchange takes place, and then venules join into the vein that enters a vena cava.

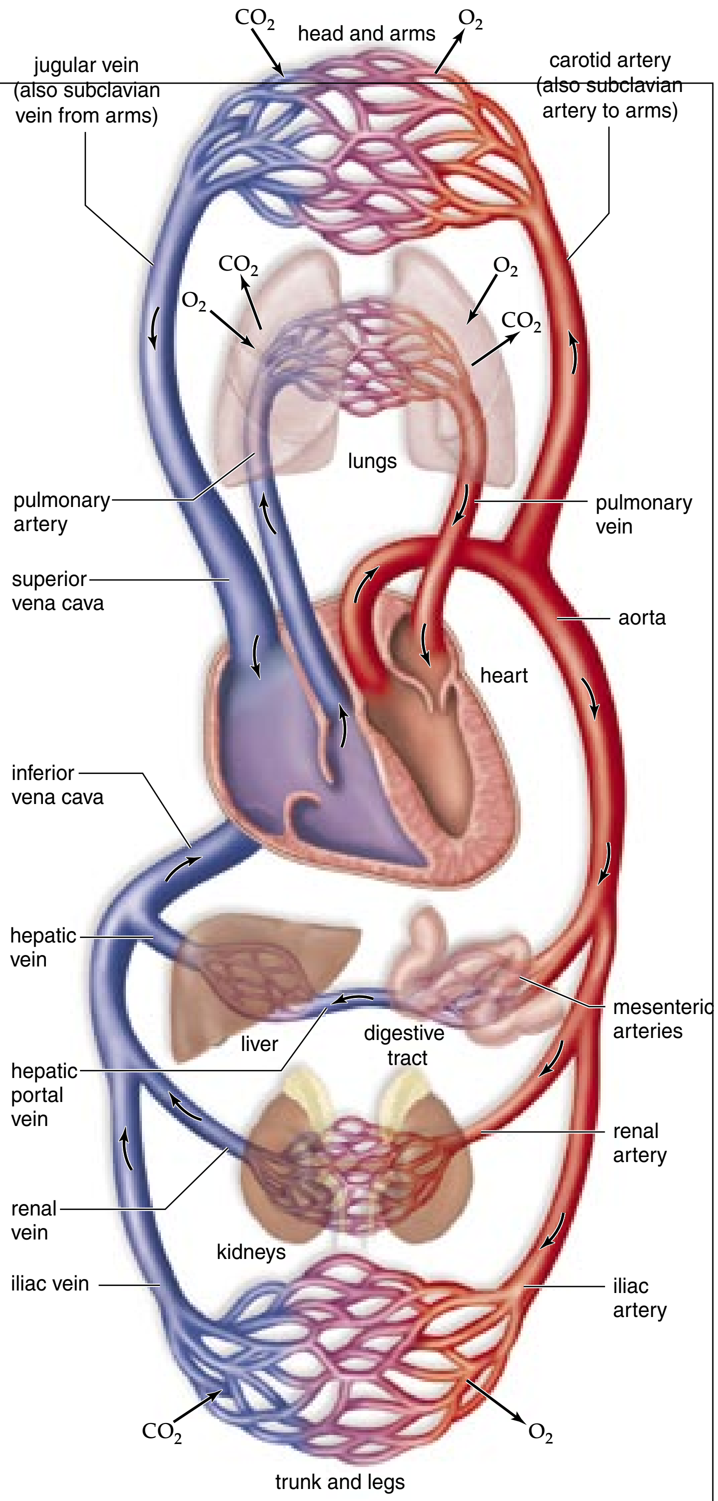


Figure 5.10 **Cardiovascular system diagram.**
The blue-colored vessels carry blood high in carbon dioxide, and the red-colored vessels carry blood high in oxygen; the arrows indicate the flow of blood. Compare this diagram, useful for learning to trace the path of blood, with Figure 5.11 to realize that arteries and veins go to all parts of the body. Also, there are capillaries in all parts of the body. No cell is located far from a capillary.

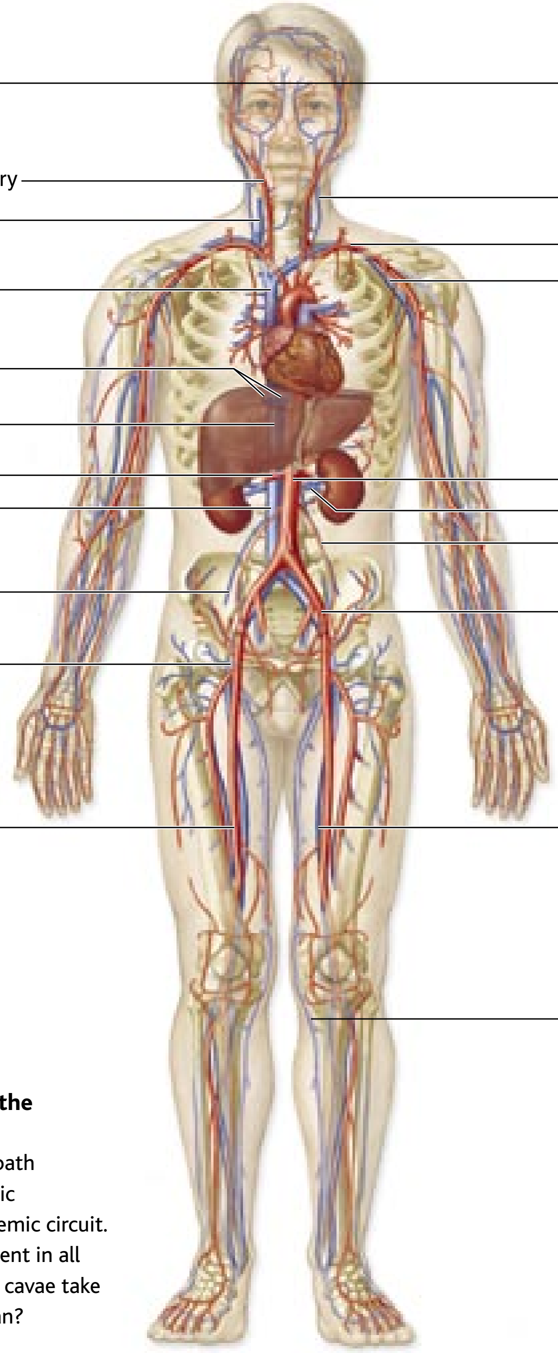


Figure 5.11 Major arteries and veins of the systemic circuit.
Figure 5.10 is helpful when learning to trace the path of blood, but this illustration offers a more realistic representation of major blood vessels of the systemic circuit. It shows that systemic arteries and veins are present in all parts of the body. The superior and inferior venae cavae take their names from their relationship to which organ?

Coronary Circulation

X-ref The **coronary arteries** (see Fig. 5.3) serve the heart muscle itself. (The heart is not nourished by the blood in its chambers.) The coronary arteries are the first branches off the aorta. They originate just above the aortic semilunar valve, and they lie on the exterior surface of the heart, where they divide into diverse arterioles. Because they have a very small diameter, the coronary arteries may become clogged, as discussed in the Health Focus on page 98. The coronary capillary beds join to form venules. The venules converge to form the cardiac veins, which empty into the right atrium.

Hepatic Portal System

The **hepatic portal vein** takes blood from the capillary bed of the digestive tract to a capillary bed in the liver. A so-called portal system always lies between capillary beds. The blood in the hepatic portal vein is O_2 poor but rich in glucose and amino acids. The liver stores glucose as glycogen, and it synthesizes blood proteins from the amino acids or else stores them. The liver also purifies the blood of pathogens that have entered the body by way of the intestinal capillaries. The **hepatic vein** leaves the liver and enters the inferior vena cava.

Check Your Progress 5.5

1. What is the relative oxygen content of the blood flowing in the pulmonary artery compared with that in the pulmonary vein? Explain.
2. What is the pathway of blood in the pulmonary circuit?
3. Trace the path of blood from the heart to the digestive tract and back to the heart by way of the hepatic portal vein.

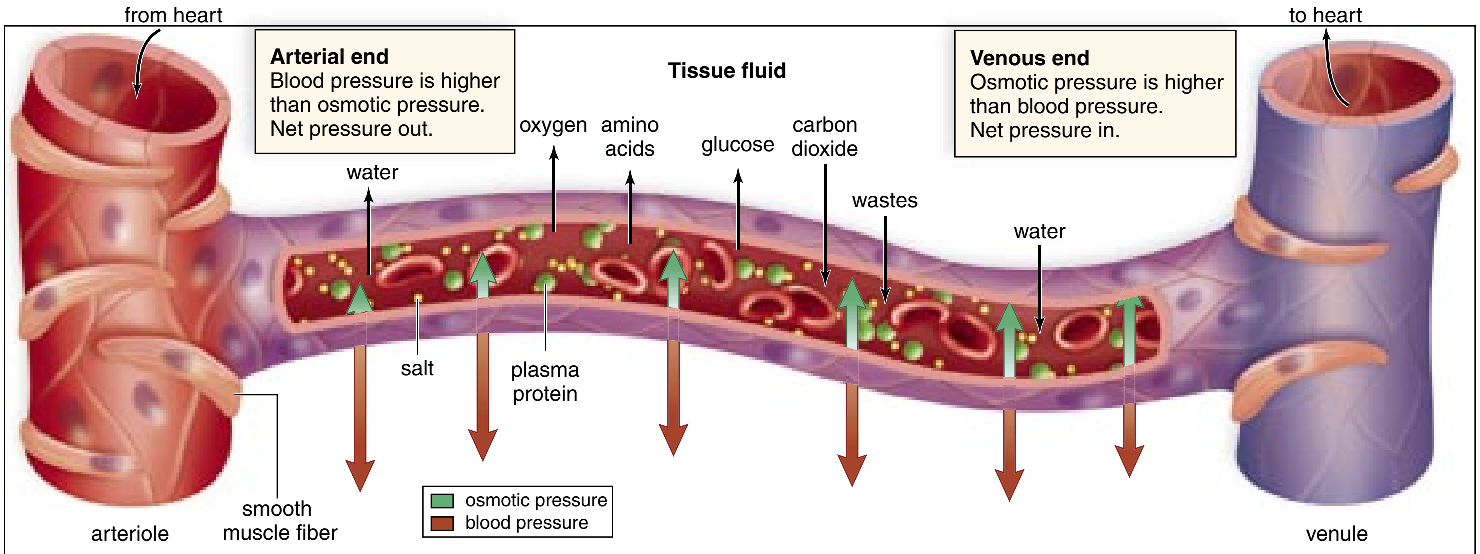


Figure 5.12 **Capillary exchange.**
A capillary, illustrating the exchanges that take place and the forces that aid the process. At the arterial end of a capillary, the blood pressure is higher than the osmotic pressure; therefore, water (H_2O) tends to leave the bloodstream. In the midsection, molecules, including oxygen (O_2) and carbon dioxide (CO_2), follow their concentration gradients. At the venous end of a capillary, the osmotic pressure is higher than the blood pressure; therefore, water tends to enter the bloodstream. Notice that the red blood cells and the plasma proteins are too large to exit a capillary.

5.6 Exchange at the Capillaries

Two forces primarily control movement of fluid through the capillary wall: osmotic pressure, which tends to cause water to move from tissue fluid to blood, and blood pressure, which tends to cause water to move in the opposite direction. At the arterial end of a capillary, blood pressure (30 mm Hg) is higher than the osmotic pressure of blood (21 mm Hg) (Fig. 5.12). Osmotic pressure is created by the presence of salts and the plasma proteins. Because blood pressure is higher than osmotic pressure at the arterial end of a capillary, water exits a capillary at this end.

X-ref

Midway along the capillary, where blood pressure is lower, the two forces essentially cancel each other, and there is no net movement of water. Solutes now diffuse according to their concentration gradient: Oxygen and nutrients (glucose and amino acids) diffuse out of the capillary; carbon dioxide and wastes diffuse into the capillary. Red blood cells and almost all plasma proteins remain in the capillaries. The substances that leave a capillary contribute to tissue fluid, the fluid between the body's cells. Since plasma proteins are too large to readily pass out of the capillary, tissue fluid tends to contain all components of plasma, except much lesser amounts of protein.

At the venule end of a capillary, where blood pressure has fallen even more, osmotic pressure is greater than blood pressure, and water tends to move into the capillary. Almost the same amount of fluid that left the capillary returns to it, although some excess tissue fluid is always collected by the lymphatic capillaries (Fig. 5.13). Tissue fluid contained within lymphatic vessels is called **lymph.** Lymph is returned to the systemic venous blood when the major lymphatic vessels enter the subclavian veins in the shoulder region.

X-ref

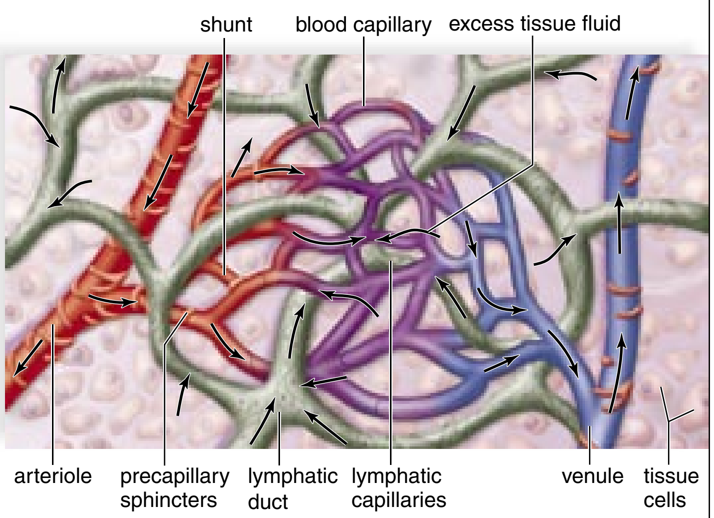


Figure 5.13 **Capillary bed.**
A lymphatic capillary bed, near a blood capillary bed. When lymphatic capillaries take up excess tissue fluid, it becomes lymph. Precapillary sphincters can shut down a blood capillary, and blood then flows through the shunt.

Check Your Progress 5.6

1. How does the exchange of materials take place across a capillary wall in the tissues?
2. What happens to excess tissue fluid created by capillary exchange?

5.7 Cardiovascular Disorders

Cardiovascular disease (CVD) is the leading cause of untimely death in the Western countries. Modern research efforts have resulted in improved diagnosis, treatment, and prevention. This section discusses the range of advances that have been made, first in correcting vascular disorders, and then in correcting heart disorders. The Health Focus on page 98 emphasizes how to prevent CVD from developing in the first place.

Disorders of the Blood Vessels

Hypertension and atherosclerosis lead, most often, to stroke due to an artery blocked by a blood clot, or a heart attack due to a coronary artery clogged by plaque. Treatment involves doing away with the blood clot or prying open the coronary artery. Another possible outcome is an aneurysm, in which a burst blood vessel must be replaced.

High Blood Pressure

Hypertension occurs when blood moves through the arteries at a higher pressure than normal. Also called high blood pressure, hypertension is sometimes called a silent killer because it may not be detected until it has caused a heart attack, stroke, or even kidney failure. Hypertension is present when the systolic blood pressure is 140 or greater or the diastolic blood pressure is 90 or greater. While both systolic and diastolic pressures are considered important, it is the diastolic pressure that is emphasized when medical treatment is being considered.

The best safeguard against developing hypertension is regular blood pressure checks and a lifestyle that lowers the risk of CVD. If already present, a physician can prescribe various drugs that help lower blood pressure. Diuretics cause the kidneys to excrete water; beta blockers and angiotensin-converting enzyme (ACE) inhibitors counteract hormones that tend to raise the blood pressure.

Hypertension is often seen in individuals who have **atherosclerosis,** an accumulation of soft masses of fatty materials, including cholesterol, beneath the inner linings of arteries. Such deposits are called **plaque.** As it develops, plaque tends to protrude into the lumen of the vessel and X-ref interfere with the flow of blood (Fig. 5.14). In most instances, atherosclerosis begins in early adulthood and develops progressively through middle age, but symptoms may not appear until an individual is 50 or older. To prevent the onset and development of plaque, the American Heart Association and other organizations recommend a diet low in saturated fat and cholesterol but rich in omega-3 polyunsaturated fatty acids, as discussed in the Health Focus on page 98.

Plaque can cause a clot to form on the irregular arterial wall. As long as the clot remains stationary, it is called a **thrombus,** but when and if it dislodges and moves along with the blood, it is called an **embolus.** If **thromboembolism** (a clot that has been carried in the bloodstream but is now stationary) is not treated, complications can arise, as mentioned in the following section.

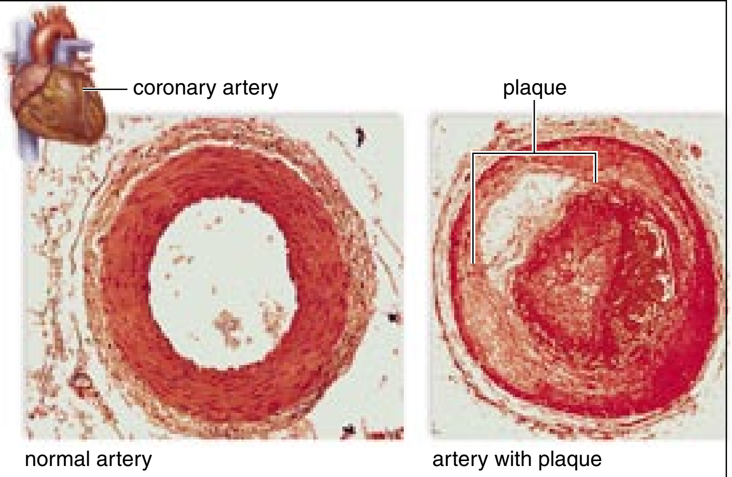


Figure 5.14 **Coronary arteries and plaque.**
When plaque is present in a coronary artery, a heart attack is more apt to occur because of restricted blood flow.

Research has suggested several possible causes for atherosclerosis aside from hypertension. Chief among these, as discussed in the Focus reading on page 98, are smoking and a diet rich in lipids and cholesterol. Research also indicates that a low-level bacterial or viral infection that spreads to the blood may cause an injury that starts the process of atherosclerosis. This infection may surprisingly originate with gum diseases or be due to *Helicobacter pylori* (the bacterium that causes ulcers.) People who have high levels of C-reactive protein, a protein that occurs in the blood following a cold or injury, are more likely to have a heart attack.

Stroke, Heart Attack, and Aneurysm

Stroke, heart attack, and aneurysm are associated with hypertension and atherosclerosis. A cerebrovascular accident (CVA), also called a **stroke,** often results when a small cranial arteriole bursts or is blocked by an embolus. A lack of oxygen causes a portion of the brain to die, and paralysis or death can result. A person is sometimes forewarned of a stroke by a feeling of numbness in the hands or the face, difficulty in speaking, or temporary blindness in one eye.

A myocardial infarction (MI), also called a **heart attack,** occurs when a portion of the heart muscle dies due to a lack of oxygen. If a coronary artery becomes partially blocked, the individual may then suffer from **angina pectoris,** characterized by a radiating pain in the left arm. Nitroglycerin or related drugs dilate blood vessels and help relieve the pain. When a coronary artery is completely blocked, perhaps because of thromboembolism, a heart attack occurs.

Health Focus

Prevention of Cardiovascular Disease

Certain genetic factors predispose an individual to cardiovascular disease, such as family history of heart attack under age 55, male gender, and ethnicity (African Americans are at greater risk). Those with one or more of these risk factors need not despair, however. It means only that they should pay particular attention to the following guidelines for a heart-healthy lifestyle.

The Don'ts

Smoking

When a person smokes, the drug nicotine, present in cigarette smoke, enters the bloodstream. Nicotine causes the arterioles to constrict and the blood pressure to rise. Restricted blood flow and cold hands are associated with smoking in most people. More serious is the need for the heart to pump harder to propel the blood through the lungs at a time when the blood's oxygen-carrying capacity is reduced.

Drug Abuse

Stimulants, such as cocaine and amphetamines, can cause an irregular heartbeat and lead to heart attacks in people who are using drugs even for the first time. Intravenous drug use may also result in a cerebral blood clot and stroke.

Too much alcohol can destroy just about every organ in the body, the heart included. But investigators have discovered that people who take an occasional drink have a 20% lower risk of heart disease than do teetotalers. Two to four drinks a week is the recommended limit for men, one to three drinks for women.

Weight Gain

Hypertension (high blood pressure) is prevalent in persons who are more than 20% above the recommended weight for their height. More tissues require servicing, and the heart sends the blood out under greater pressure in those who are overweight. It may be harder to lose weight once it is gained, and therefore, it is recommended that weight control be a lifelong endeavor. Even a slight decrease in weight can bring with it a reduction in hypertension.

Being overweight increases the risk of diabetes type 2 in which glucose damages blood vessels and makes them prone to the development of plaque. Diabetics especially need to follow the diet discussed next.

The Do's

Healthy Diet

A diet low in saturated fats and cholesterol is protective against cardiovascular disease. Cholesterol is ferried in the blood by two types of plasma proteins, called LDL (low-density lipoprotein) and HDL (high-density lipoprotein). LDL (called "bad" lipoprotein) takes cholesterol from the liver to the tissues, and HDL (called "good" lipoprotein) transports cholesterol out of the tissues to the liver. When the LDL level in blood is abnormally high or the HDL level is abnormally low, cholesterol accumulates in the cells. When cholesterol-laden cells line the arteries, plaque develops, which interferes with circulation.

Figure 5A **Exercising and good health.**
Regular exercise helps prevent and control cardiovascular disease.

It is recommended that everyone know his or her blood cholesterol level. Individuals with a high blood cholesterol level (200 mg/100 mL) should be further tested to determine their LDL-cholesterol level. The LDL-cholesterol level, together with other risk factors such as age, family history, presence of diabetes, and whether the patient smokes, will determine who needs dietary therapy to lower their LDL. Eating foods high in saturated fat (red meat, cream, and butter) and foods containing so-called trans fats (margarine, commercially baked goods, and deep-fried foods) raises the LDL-cholesterol level. Unsaturated fatty acids in olive and canola oils, most nuts, and cold-water fish tend to lower LDL-cholesterol levels. Cold-water fish (e.g., halibut, sardines, tuna, and salmon) contain polyunsaturated fatty acids and especially omega-3 polyunsaturated fatty acids that can reduce plaque. If dietary changes are not sufficient, drugs called statins can be used to lower the LDL level.

Exercise

People who exercise are less apt to have cardiovascular disease (Fig. 5A). One study found that moderately active men who spent an average of 48 minutes a day on a leisure-time activity, such as gardening, bowling, or dancing, had one-third fewer heart attacks than peers who spent an average of only 16 minutes each day on such activities. Exercise, which helps keep weight under control, may also help minimize stress and reduce hypertension. X-ref

An **aneurysm** is a ballooning of a blood vessel, most often the abdominal artery or the arteries leading to the brain. Atherosclerosis and hypertension can weaken the wall of an artery to the point that an aneurysm develops. If a major vessel such as the aorta should burst, death is likely. It is possible to replace a damaged or diseased portion of a vessel, such as an artery, with a plastic tube. Cardiovascular function is preserved, because exchange with tissue cells can still take place at the capillaries. In the future, it may be possible to use vessels made by injecting a patient's cells inside an inert mold.

Dissolving Blood Clots

Medical treatment for thromboembolism includes the use of t-PA, a biotechnology drug. This drug converts plasminogen, a molecule found in blood, into plasmin, an enzyme that dissolves blood clots. In fact, t-PA, which stands for tissue plasminogen activator, is the body's own way of converting plasminogen to plasmin. t-PA is also being used for thrombolytic stroke patients, but with limited success because some patients experience life-threatening bleeding in the brain. A better treatment might be new biotechnology drugs that act on the plasma membrane to prevent brain cells from releasing and/or receiving toxic chemicals caused by the stroke.

If a person has symptoms of angina or a stroke, aspirin may be prescribed. Aspirin reduces the stickiness of platelets and thereby lowers the probability that a clot will form. There is evidence that aspirin protects against first heart attacks, but there is no clear support for taking aspirin every day to prevent strokes in symptom-free people. Physicians warn that long-term use of aspirin might have harmful effects, including bleeding in the brain.

Treating Clogged Arteries

Cardiovascular disease used to require open-heart surgery and, therefore, a long recuperation time and a long unsightly scar that could occasionally ache. Now, bypass surgery can be accomplished by using robotic technology (Fig. 5.15*a*). A video camera and instruments are inserted through small cuts, while the surgeon sits at a console and manipulates interchangeable grippers, cutters, and other tools attached to movable arms above the operating table. Looking through two eyepieces, the surgeon gets a 3-D view of the operating field. Robotic surgery also has been used in many valve repairs and other heart procedures.

One way to treat an artery clogged with plaque is a **coronary bypass operation,** during which a surgeon takes a blood vessel—usually a vein from the leg—and stitches one end to the aorta and the other end to a coronary artery past the point of obstruction. Figure 5.15*b* shows a triple bypass in which three blood vessel segments have been used to allow blood to flow freely from the aorta to cardiac muscle by way of the coronary artery. Instead of coronary bypass, gene therapy has been used since 1997 to grow new blood vessels that will carry blood to cardiac muscle. The surgeon need only make a small incision and inject many copies of the gene that codes for VEGF (vascular endothelial growth

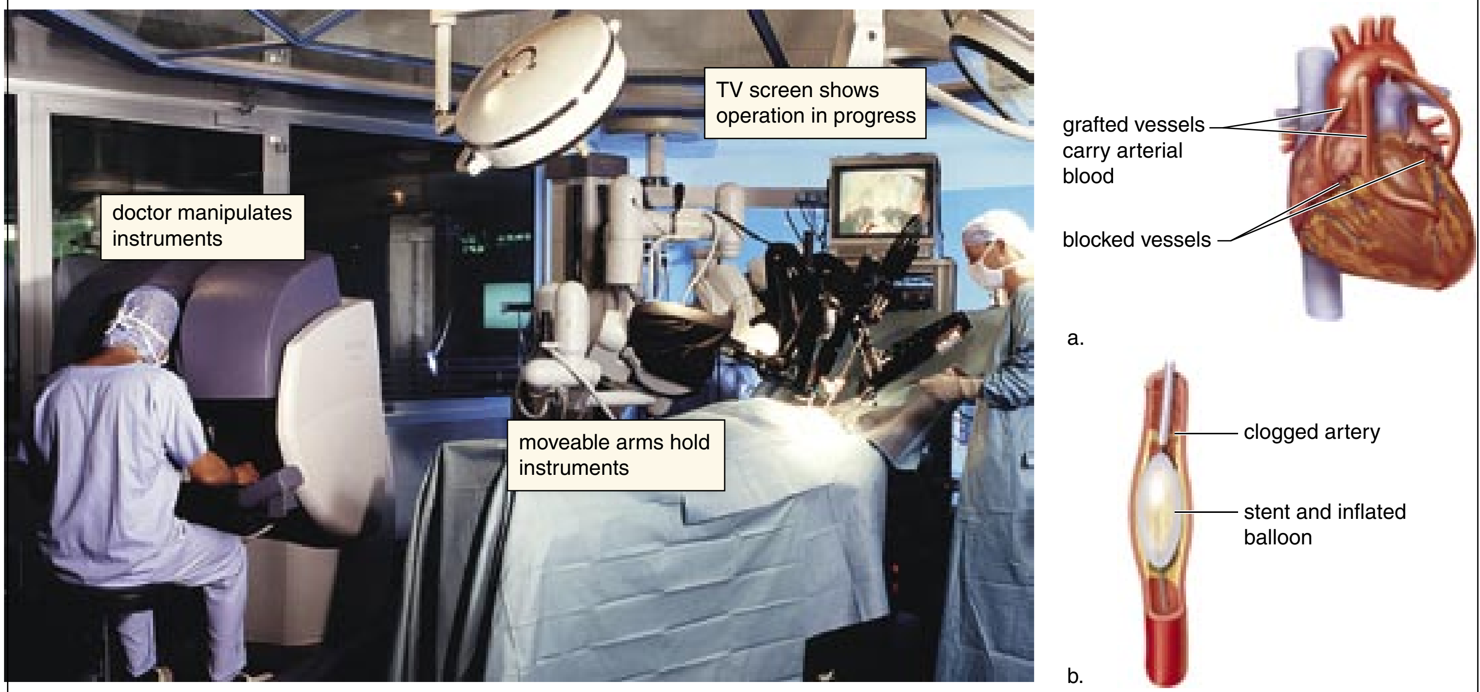


Figure 5.15 **Treatment for clogged coronary arteries.**
a. Many heart procedures, such as coronary bypass and stent insertion, can be performed using robotic surgery techniques. **b.** During a coronary bypass operation, blood vessels (usually veins from the leg) are stitched to the heart, taking blood past the region of obstruction. **c.** During stenting, a cylinder of expandable metal mesh is positioned inside the coronary artery by using a catheter. Then, a balloon is inflated so that the stent expands and opens the artery.

factor) between the ribs directly into the area of the heart that most needs improved blood flow. VEGF encourages new blood vessels to sprout out of an artery. If collateral blood vessels do form, they transport blood past clogged arteries, making bypass surgery unnecessary. About 60% of all patients who undergo the procedure do show signs of vessel growth within two to four weeks.

Another alternative to bypass surgery is available; namely, the stent (Fig. 5.15*c*). A stent is a small metal mesh cylinder that holds a coronary artery open after a blockage has been cleared. Until a couple of years ago, stenting was a second step following angioplasty. During **angioplasty,** a plastic tube is inserted into an artery of an arm or a leg and then guided through a major blood vessel toward the heart. When the tube reaches the region of plaque in an artery, a balloon attached to the end of the tube is inflated, forcing the vessel open. Now, instead of the long balloon, a stent plus an inner balloon is pushed into the blocked area. When the balloon inside the stent is inflated, it expands, locking itself in place. Some patients go home the same day; at most, after an overnight stay. The stent is more successful when it is coated with a drug that seeps into the artery lining and discourages cell growth. Uncoated stents can close back up in a few months but not ones coated with a drug that discourages closure. Because blood clotting might occur, recipients have to take anticlotting medications.

Disorders of the Heart

When a person has **heart failure,** the heart no longer pumps as it should. Heart failure is a growing problem because people who used to die from heart attacks now survive, but are left with damaged hearts. Often, the heart is oversized not because the cardiac wall is stronger but because it is sagging and swollen. One idea is to wrap the heart in a fabric sheath to prevent it from getting too big and to allow better pumping, similar to the way a weight lifter's belt restricts and reinforces stomach muscles. But a failing heart can have other problems, such as an abnormal heart rhythm. To counter that condition, it's possible to implant a cardioverter-defibrillator (ICD) just beneath the skin of the chest. These devices can sense both an abnormally slow and an abnormally fast heartbeat. If the former, they generate the missing beat like a pacemaker does. If the latter, they send the heart a sharp jolt of electricity to slow it down. If the heart rhythm should become erratic, it sends an even stronger shock like a defibrillator does.

Heart Transplants

Although heart transplants are now generally successful, many more people are waiting for new hearts than there are organs available. Today, only about 2,200 heart transplants are done annually, while many more thousands could use one. Because of the shortage of human hearts, genetically altered pigs may one day be used as a source of hearts. Also, bone marrow stem cells have been injected into the heart, and researchers report that they apparently become cardiac muscle!

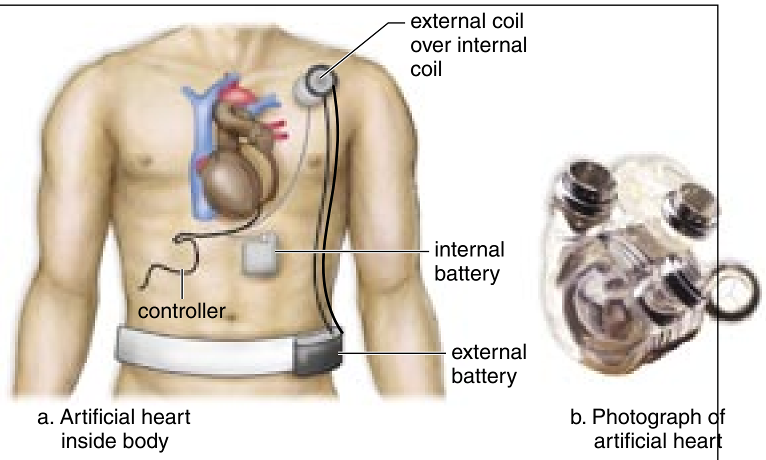


Figure 5.16 Total artificial heart.
The AbioCor is a quiet, pulsatile device that moves the blood in the same manner as a natural heart. It is powered by an external battery pack that is small and portable so the recipient can be fairly active.

Today, a left ventricular assist device (LVAD), implanted in the abdomen, is an alternative to a heart transplant. A tube passes blood from the left ventricle to the device, which pumps it on to the aorta. A cable passes from the device through the skin to an external battery the patient must tote around. Soon, as many as 20,000 people a year may be outfitted with an LVAD. Instead of an LVAD, a few pioneers have volunteered to receive a Jarvik 2000, a pump that is inserted inside the left ventricle. The Jarvik is powered by an external battery no larger than a C-size battery.

Fewer patients still have received a so-called **total artificial heart (TAH).** The only model now available to patients is the AbioCor model (Fig. 5.16), which has no wires or tubes protruding from the chest. An internal battery and controller regulate the pumping speed, and an external battery powers the device by passing electricity through the skin via external and internal coils. A rotating centrifugal pump moves silicon hydraulic fluid between left and right sacs to force blood out of the heart into the pulmonary trunk and the aorta. All recipients, thus far, have been near death and most have lived for only a short time. It's possible that once healthier patients receive an AbioCor, survival rate will improve. Different types of TAHs are being investigated in animals, however.

Check Your Progress 5.7

1. What cardiovascular disorders are common in humans and what treatments are available?

Bioethical Focus

Paying for an Unhealthy Lifestyle

Cardiovascular disease is not only the number one killer in the United States today, it is also one of the most expensive. This disorder now accounts for more than $360 billion annually in spending on treatment and research, according to the American Heart Association and the National Heart, Lung, and Blood Institute (NHLBI). However, most cases of cardiovascular disease are preventable. Many well-known risk factors put an individual at high risk for developing cardiovascular disease. Among these are a sedentary lifestyle, obesity, smoking, and poor dietary habits. With few exceptions, these risk factors are largely a matter of choice.

Who Pays for Treatment?

As treatment costs and insurance premiums continue to climb at an unprecedented rate, public debate has raged: Should individuals suffering from cardiovascular disease receive the benefits of treatment at public expense? As the cost of health care soars, patients now rely much more on third-party payers to cover the cost of treatment than in the past. With much of the population covered by some type of health insurance, the risk is spread out over most of the population. This has created a system under which everyone, healthy or not, pays in part for treatment of the unhealthy. Under this system, everyone who pays into this system has a vested interest in ensuring that others avoid risky behaviors that contribute to rising health- care costs (Fig. 5B).

To an extent, people who practice risky behaviors already pay more for their habits. For example, unhealthy individuals often pay more for life or health insurance than healthy individuals. Taxes on risky behaviors, such as smoking and drinking alcohol, used to help defray health-care costs, are commonplace. Despite these policies, most studies show that ultimately, we all pay for the treatment of cardiovascular disease. For example, insurance companies may refuse to cover preexisting conditions, including cardiovascular disease. Furthermore, more than 40 million people in the United States, many of them elderly and at risk for developing cardiovascular disease, do not have health insurance. In both cases, treatment costs are usually borne by the government. This creates an incentive, both within government and within the general public, to either ensure that such individuals adopt healthy lifestyle practices or bear more of the cost for their own treatment if they refuse to do so.

Is Legislation Needed?

Since obesity is a major cardiovascular disease risk factor, several organizations, including the Center for Science in the Public Interest (CSPI) and the World Health Organization (WHO), have pushed for the adoption of a "fat tax." This tax would be levied on foods with high fat content and/or poor nutritional value to pay, in part, for treatment of obesity-related diseases, including heart disease. Although taxing unhealthy behaviors to help defray treatment costs are generally popular with the public, the "fat tax" has proved surprisingly unpopular with voters. Thus, this measure seems unlikely to ever become public policy in the United States.

Figure 5B Unhealthy lifestyle. An unhealthy lifestyle contributes to the development of cardiovascular disease.

An alternative approach being employed is prevention. Senator Tom Harkin recently introduced the Help America Act, which emphasizes healthy lifestyles and prevention. Smoking, one of the largest risk factors for cardiovascular disease, would be taxed to help pay for the program. Many studies show that every dollar invested in cardiovascular disease prevention results in a three-dollar savings in long-term health-care costs. With this in mind, many medical associations have endorsed this bill or other similar approaches to health care.

Keep the Status Quo?

However, not everyone agrees that cardiovascular disease is as rampant as reports indicate or that the current public policy initiatives are the proper approach. One such critic points out that throughout the 1990s, despite large increases in obesity and marginal declines in risky behaviors, such as smoking, the incidence of cardiovascular disease has declined nearly 25%. Other critics insist that such intervention programs, while well intentioned, infringe on individual freedom and that rewarding healthy behaviors and penalizing risky behaviors are beyond the scope of government and public policy.

Regardless of whether or not you agree with shifting more of the cost of treatment to the unhealthy, it is up to individuals to adopt healthy practices that minimize the risk of cardiovascular disease. The ultimate human cost greatly outweighs the financial costs.

Decide Your Opinion

1. Would you support charging higher insurance premiums or taxes on people who do not practice a healthy lifestyle?
2. Do you support the use of public money for prevention programs targeted toward unhealthy people if there is the possibility of saving money in the future?
3. Since the public does subsidize health care that disproportionately benefits the less healthy, do you believe that financial interests trump personal freedom in this matter? Why or why not?

Summarizing the Concepts

5.1 Overview of the Cardiovascular System

The cardiovascular system consists of the heart and blood vessels. The heart pumps blood into the pulmonary circuit (through the lungs) and the systemic circuit (through the rest of the body). Exchanges occur at the capillaries. Gas exchange occurs in the lungs. Tissue fluid is refreshed at the tissue capillaries.

5.2 The Types of Blood Vessels


capillary bed

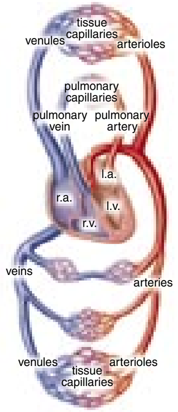
Arteries Arteries (and arterioles) take blood away from the heart. Arteries have the thickest walls, which allows them to withstand blood pressure.

Capillaries Capillaries are where exchange of substances occurs.

Veins Veins (and venules) take blood to the heart. Veins have relatively weak walls with valves that keep the blood flowing in one direction.

5.3 The Heart Is a Double Pump

The heart has a right and left side. Each side has an atrium and a ventricle. Valves keep the blood moving in the correct direction.



Right Side of the Heart The atrium receives O2-poor blood from the body, and the ventricle pumps it into the pulmonary circuit (to the lungs).

Left Side of the Heart The atrium receives O_2-rich blood from the lungs, and a ventricle pumps it into the systemic circuit.

Heartbeat During the cardiac cycle, the SA node (pacemaker) initiates the heartbeat by causing the atria to contract. The AV node conveys the stimulus to the ventricles, causing them to contract. The heart sounds, "lub-dup," are due to the closing of the atrioventricular valves, followed by the closing of the semilunar valves.

5.4 Features of the Cardiovascular System

Pulse The pulse rate indicates the heartbeat rate.

Blood Pressure Moves Blood in Arteries Blood pressure caused by the beating of the heart accounts for the flow of blood in the arteries.

Blood Flow is Slow in the Capillaries The reduced velocity of blood flow in capillaries facilitates exchange of nutrients and wastes in the tissues.

Blood Flow in Veins Returns Blood to the Heart Blood flow in veins is caused by skeletal muscle contraction, the presence of valves, and respiratory movements.

5.5 Two Cardiovascular Pathways

The cardiovascular system is divided into the pulmonary circuit and the systemic circuit.

The Pulmonary Circuit: Exchange of Gases

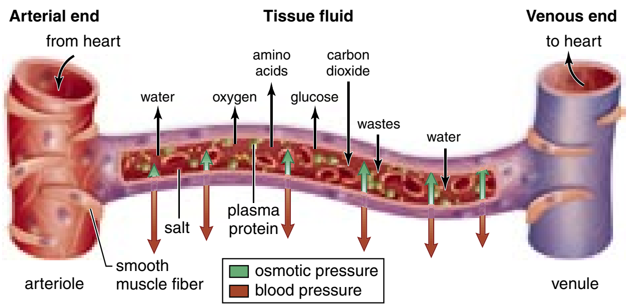
In the pulmonary circuit, blood travels to and from the lungs.

The Systemic Circuit: Exchanges with Tissue Fluid

In the systemic circuit, the aorta divides into blood vessels that serve the body's cells. Venae cavae return O2-poor blood to the heart.

5.6 Exchange at the Capillaries

This diagram pertains to capillary exchange in tissues of body parts—not including the gas-exchanging surfaces of the lungs.



- At the arterial end of a cardiovascular capillary, blood pressure is greater than osmotic pressure; therefore, water leaves the capillary.
- In the midsection, oxygen and nutrients diffuse out of the capillary, while carbon dioxide and other wastes diffuse into the capillary.
- At the venous end, osmotic pressure created by the presence of proteins exceeds blood pressure, causing water to enter the capillary.

  The fluid that is not picked up at the venous end of the cardiovascular capillary is excess tissue fluid. It enters the lymphatic capillaries.
- Lymph is tissue fluid contained within lymphatic vessels.
- The lymphatic system is a one-way system, and lymph is returned to blood by way of a cardiovascular vein.

5.7 Cardiovascular Disorders

Cardiovascular disease is the leading cause of death in the Western countries.

- Hypertension and atherosclerosis can lead to stroke, heart attack, or an aneurysm.

  Prevention Following a heart-healthy diet, getting regular exercise, maintaining a proper weight, and not smoking are protective against cardiovascular disease.

Understanding Key Terms

aneurysm 97
angina pectoris 97
angioplasty 100
aorta 94
arteriole 87
atherosclerosis 97
atrioventricular AV bundle 90
atrioventricular (AV) node 90
atrioventricular (AV) valve 88
atrium 88
blood pressure 92
cardiac cycle 90
chordae tendineae 88
coronary artery 95
coronary bypass operation 99
diastole 90
diastolic pressure 92
electrocardiogram (ECG) 91

embolus 97
heart 88
heart attack 97
heart failure 100
hepatic portal vein 95
hepatic vein 95
hypertension 97
inferior vena cava 94
lymph 96
lymphatic system 86
myocardium 88
pacemaker 90
pericardium 88
plaque 97
pulmonary artery 89
pulmonary circuit 94
pulmonary vein 89
pulse 92
Purkinje fibers 90
respiratory pump 93
SA (sinoatrial) node 90
semilunar valve 88
septum 88
skeletal muscle pump 93
stroke 97
superior vena cava 94
systemic circuit 94
systole 90
systolic pressure 92
thromboembolism 97
thrombus 97
tissue fluid 86
total artificial heart (TAH) 100
valve 87
ventricle 88
venule 87

Match the key terms to these definitions.

a. ________ Relaxation of a heart chamber.

b. ________ Large systemic vein that returns blood from body areas below the diaphragm.

c. ________ Rhythmic expansion and recoil of arteries resulting from heart contraction; can be felt from outside the body.

d. ________ Vessel that takes blood from capillaries to a vein.

e. ________ That part of the cardiovascular system that serves body parts and does not include the gas-exchanging surfaces in the lungs.

Testing Your Knowledge of the Concepts

1. What are the two parts of the cardiovascular system, and what are the functions of each part. (page 86)
2. Explain where exchanges occur in the body and the importance of those exchanges. (page 86)
3. Which of the three types of blood vessels are most numerous? Explain. (page 87)
4. Describe the structure of the heart, including the chambers and valves. (page 88)
5. Trace the path of blood through the heart, including chambers, valves, and vessels the blood travels through. (page 89)
6. What is the function of the septum in the heart? What would happen if the heart had no septum? (pages 88–89)
7. Describe the cardiac cycle, using the terms systole and diastole. What is the role of the SA node and the AV node in the cardiac cycle? (page 90)
8. Distinguish between the internal and external controls of the heartbeat. Explain how an ECG relates to the cardiac cycle. (pages 90–91)
9. In what vessel is the blood pressure the highest? The lowest? In what vessel is blood flow rate the fastest? The slowest? Why is the pressure and rate in the capillaries important to capillary function? (pages 92–93)
10. Explain why skeletal muscle contraction has an affect on venous flow but not arterial flow. (page 93)
11. Distinguish between the two cardiovascular pathways. (page 94)
12. Trace the pathway of blood to and from the brain in the systemic circuit. (page 94–95)
13. Describe the process by which nutrients are exchanged for wastes across a capillary, using glucose and carbon dioxide as examples (page 96)
14. What is the most probable association between high blood pressure and a heart attack? With this association in mind, what type of diet might help prevent a heart attack? (page 97)

In questions 15–18, match the descriptions to the circuit in the key. Answers may be used more than once.

Key:
a. pulmonary circuit
b. systemic circuit
c. both pulmonary and systemic

15. Arteries carry O2-rich blood.
16. Carbon dioxide leaves the capillaries, and oxygen enters the-capillaries.
17. Arteries carry blood away from the heart, and veins carry blood toward the heart.
18. This contains the hepatic portal system.

In questions 19–24, match the descriptions to the blood vessel in the key. Answers may be used more than once.

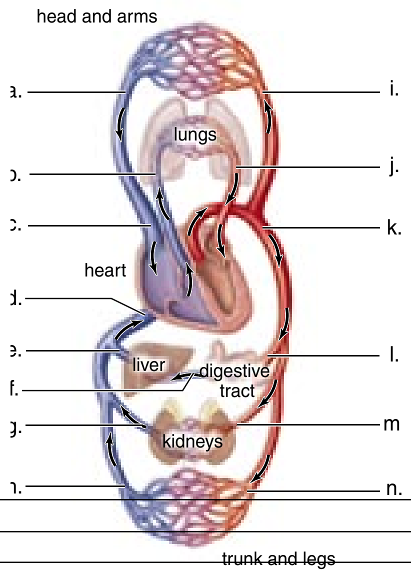
Key:
a. venules
b. veins
c. capillaries
d. arteries
e. arterioles

19. Drain blood from capillaries
20. Empty into capillaries
21. May contain valves
22. Take blood away from the heart
23. Sites for exchange of substances between blood and tissue-fluid
24. Rate of blood flow is the slowest
25. During ventricular diastole,
    a. blood flows into the aorta.
    b. the ventricles contract.
    c. the semilunar valves are closed.
    d. Both a and b are correct.
26. When the atria contract, the blood flows
    a. into the attached blood vessels.
    b. into the ventricles.
    c. through the atrioventricular valves.
    d. to the lungs.
    e. Both b and c are correct.

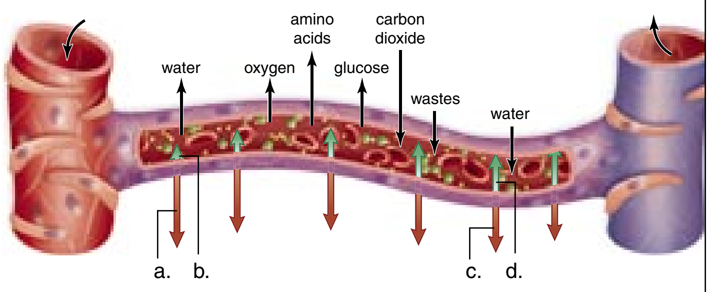
27. Heart valves located at the bases of the pulmonary trunk and aorta are called
    a. atrioventricular valves.
    b. semilunar valves.
    c. mitral valves.
    d. chordae tendineae.
28. Which of these associations is mismatched?
    a. left ventricle—aorta
    b. right ventricle—pulmonary trunk
    c. right atrium—vena cava
    d. left atrium—pulmonary artery
    e. Both b and c are incorrectly matched.
29. Which statement is not correct concerning the heartbeat?
    a. The atria contract at the same time.
    b. The ventricles relax at the same time.
    c. The AV valves open at the same time
    d. The semilunar valves open at the same time.
    e. First the right side contracts; then the left side contracts.
30. If a person's blood pressure is 115 mm Hg over 75 mm Hg, the 75 represents
    a. systolic pressure.
    b. diastolic pressure.
    c. pressure during ventricular relaxation.
    d. Both b and c are correct.
31. Accumulation of plaque in an artery wall is
    a. an aneurysm.
    b. angina pectoris.
    c. atherosclerosis.
    d. hypertension.
    e. a thromboembolism.

32.Label the following diagram of the cardiovascular system using this alphabetized list:

aorta	jugular vein
carotid artery	mesenteric arteries
hepatic portal vein	pulmonary artery
hepatic vein	pulmonary vein
iliac artery	renal artery
iliac vein	renal vein
inferior vena cava	superior vena cava



33. Label the following diagram showing the forces involved with capillary exchange. Use either blood pressure or osmotic pressure to label arrows a–d.



Thinking Critically About the Concepts

You should have noticed several examples illustrating the underlying concept of structure supports function in this chapter. There were different kinds of blood vessels that each have a specific job to do and physical characteristics that enable them to do that job. The muscle walls of the right and left ventricle vary in thickness depending on where they pump the blood. When the structure of an organ is damaged or changed as arteries are in atherosclerosis, the ability of the organ to perform its function may be compromised as well. When organs' structures are damages or changed, homeostatic conditions such as blood pressure may be affected. Dietary and lifestyle choices can either prevent damage or harm the cardiovascular system's organs.

1. The author and composer of the musical Rent died from an aortic aneurysm.
    a. Why don't aneurysms of arteries occur more frequently?
    b. Why do aortic aneurysms typically result in death?

2a. What happens to the ventriclular walls of someone who has hypertrophic cardiomyopathy (consider what you know about the word hyperactive)?
 b. How would the ability of the heart to efficiently pump blood be affected?

3. Lymphatic vessels transport tissue fluid back to the cardiovascular system. The pressure in the lymphatic vessels is low. Do you expect lymphatic vessels to have valves? Why?
4. What dietary and lifestyle choices adversely impact the structure of arteries and their ability to transport blood?
5. Think of an analogy for capillaries. Remember they are small blood vessels with very thin walls and this facilitates their ability to perform exchanges with body cells. What are the similarities between capillaries and the object you have chosen to compare them to?