

THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS AND CIRCULATION



chapter 16

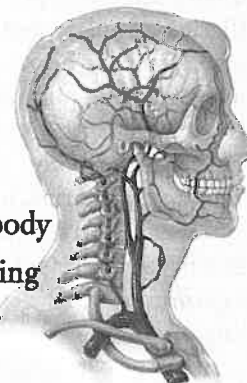
did you know?

Physical activity helps to protect the cardiovascular system in many ways. It improves blood cholesterol levels and blood sugar regulation. Regular exercise leads to increased output from the parasympathetic nervous system (not during exercise, but during the rest of the day), which leads to a lower resting heart rate and lower resting blood pressure. Physical activity burns calories, thus helping to prevent obesity. People who exercise regularly have lower rates of inflammation markers, such as C-reactive protein. Less inflammation suggests lower risk of artery disease. To maximize cardiovascular health, researchers recommend about an hour a day of brisk activity.



Focus on Wellness, page 410

www.wiley.com/college/apcentral



The cardiovascular system contributes to the homeostasis of other body systems by transporting and distributing blood throughout the body to deliver materials such as oxygen, nutrients, and hormones and to carry away wastes. This transport is accomplished by blood vessels, which form closed circulatory routes for blood to travel from the heart to body organs and back again. In Chapters 14 and 15 we discussed the composition and functions of blood and the structure and function of the heart. In this chapter, we examine the structure and functions of the different types of blood vessels that carry the blood to and from the heart, as well as factors that contribute to blood flow and regulation of blood pressure.

looking back to move ahead . . .

- Diffusion (page 47)
- Medulla Oblongata (page 250)
- Antidiuretic Hormone (page 322)
- Mineralocorticoids (page 331)
- Great Vessels of the Heart (page 369)

BLOOD VESSEL STRUCTURE AND FUNCTION

OBJECTIVES • Compare the structure and function of the different types of blood vessels.

- Describe how substances enter and leave the blood in capillaries.
- Explain how venous blood returns to the heart.

There are five types of blood vessels: arteries, arterioles, capillaries, venules, and veins. **Arteries** (AR-ter-ēz) carry blood *away from the heart* to body tissues. Two large arteries—the aorta and the pulmonary trunk—emerge from the heart and branch out into medium-sized arteries that serve various regions of the body. These medium-sized arteries then divide into small arteries, which, in turn, divide into still smaller arteries called **arterioles** (ar-TER-ē-ōls). Arterioles within a tissue or organ branch into numerous microscopic vessels called **capillaries** (KAP-i-lar'-ēz). Groups of capillaries within a tissue reunite to form small veins called **venules** (VEN-ūls). These, in turn, merge to form progressively larger vessels called veins. **Veins** (VĀNZ) are the blood vessels that convey blood from the tissues *back to the heart*.

At any one time, systemic veins and venules contain about 64% of the total volume of blood in the system, systemic arteries and arterioles about 13%, systemic capillaries about 7%, pulmonary blood vessels about 9%, and the heart chambers about 7%. Because veins contain so much of the blood, certain veins function as **blood reservoirs**. The main blood reservoirs are the veins of the abdominal organs (especially the liver and spleen) and the skin. Blood can be diverted quickly from its reservoirs to other parts of the body, for example, to skeletal muscles to support increased muscular activity.

Arteries and Arterioles

The walls of arteries have three layers of tissue surrounding a hollow space, the **lumen**, through which the blood flows (Figure 16.1a). The inner layer is composed of **endothelium**, a type of simple squamous epithelium; a basement membrane; and an elastic tissue called the internal elastic lamina. The middle layer consists of smooth muscle and elastic tissue. The outer layer is composed mainly of elastic and collagen fibers.

Sympathetic fibers of the autonomic nervous system innervate vascular smooth muscle. An increase in sympathetic stimulation typically causes the smooth muscle to contract, squeezing the vessel wall and narrowing the lumen. Such a decrease in the diameter of the lumen of a blood vessel is called **vasoconstriction**. In contrast, when sympathetic stimu-

lation decreases, or in the presence of certain chemicals (such as nitric oxide or lactic acid), smooth muscle fibers relax. The resulting increase in lumen diameter is called **vasodilation**. Additionally, when an artery or arteriole is damaged, its smooth muscle contracts, producing vascular spasm of the vessel. Such a vasospasm limits blood flow through the damaged vessel and helps reduce blood loss if the vessel is small.

The largest-diameter arteries contain a high proportion of elastic fibers in their middle layer, and their walls are relatively thin in proportion to their overall diameter. Such arteries are called **elastic arteries**. These arteries help propel blood onward while the ventricles are relaxing. As blood is ejected from the heart into elastic arteries, their highly elastic walls stretch, accommodating the surge of blood. Then, while the ventricles are relaxing, the elastic fibers in the artery walls recoil, which forces blood onward toward the smaller arteries. Examples include the aorta and the brachiocephalic, common carotid, subclavian, vertebral, pulmonary, and common iliac arteries. Medium-sized arteries, on the other hand, contain more smooth muscle and fewer elastic fibers than elastic arteries. Such arteries are called **muscular arteries** and are capable of greater vasoconstriction and vasodilation to adjust the rate of blood flow. Examples include the brachial artery (arm) and radial artery (forearm).

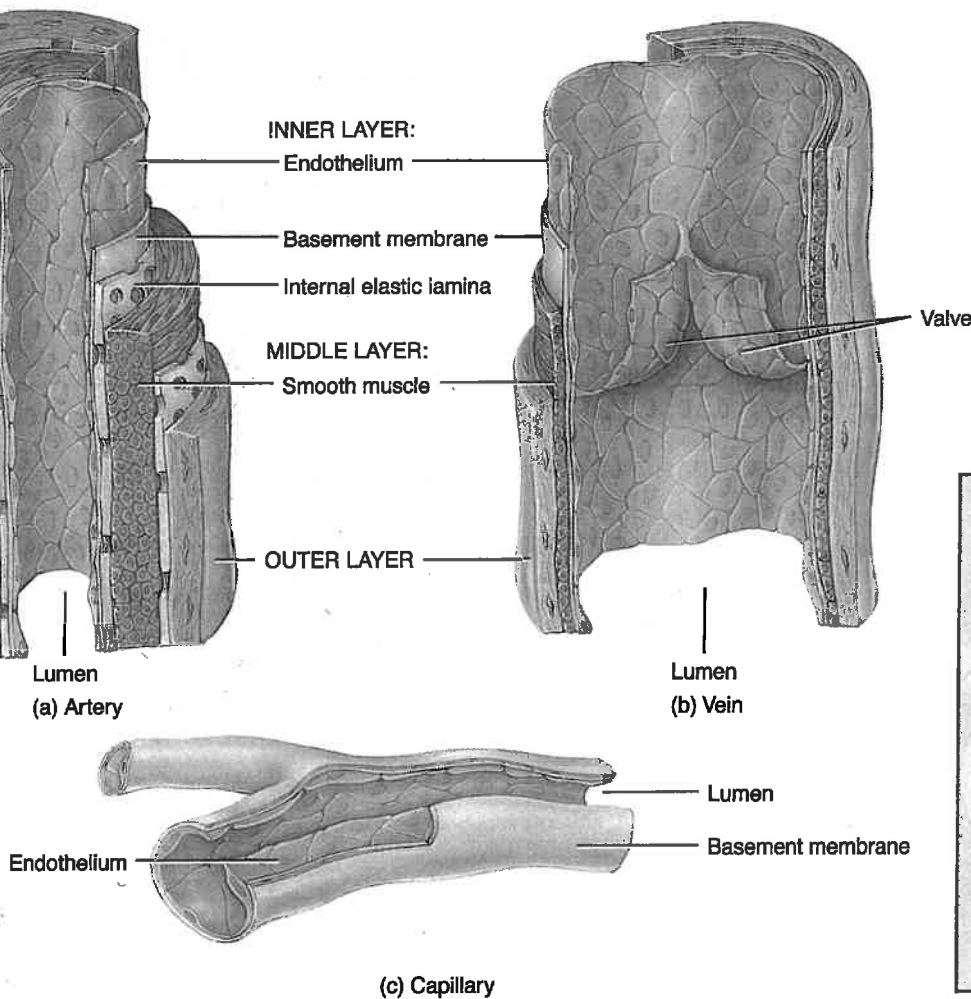
An **arteriole** (= small artery) is a very small, almost microscopic, artery that delivers blood to capillaries. The smallest arterioles consist of little more than a layer of endothelium covered by a few smooth muscle fibers (see Figure 16.2a). Arterioles play a key role in regulating blood flow from arteries into capillaries. During vasoconstriction, blood flow from the arterioles to the capillaries is restricted; during vasodilation, the flow is significantly increased. A change in diameter of arterioles can also significantly alter blood pressure; vasodilation decreases blood pressure and vasoconstriction increases blood pressure.

Capillaries

Capillaries (*capillar-* = hairlike) are microscopic vessels that connect arterioles to venules (Figure 16.1c). Capillaries are present near almost every body cell, and they are known as **exchange vessels** because they permit the exchange of nutrients and wastes between the body's cells and the blood. The number of capillaries varies with the metabolic activity of the tissue they serve. Body tissues with high metabolic requirements, such as muscles, the liver, the kidneys, and the nervous system, have extensive capillary networks. Tissues with lower metabolic requirements, such as tendons and ligaments, contain fewer capillaries. A few tissues—all covering and lining epithelia, the cornea and lens of the eye, and cartilage—lack capillaries completely.

Figure 16.1 Comparative structure of blood vessels. The relative size of the capillary in (c) is enlarged for emphasis. Note the valve in the vein.

Arteries carry blood away from the heart to tissues. Veins carry blood from tissues back to the heart.



Functions of Blood Vessels

1. Blood vessels form a closed system of tubes that carries blood away from the heart (in arteries), transports it through the tissues of the body (in arterioles, capillaries, and venules), and then returns it to the heart (in veins).
2. Exchange of substances between the blood and body tissue cells occurs as blood flows through the capillaries.
3. Nutrients and oxygen diffuse from the blood through interstitial fluid into tissue cells. Waste products, including carbon dioxide, diffuse from tissue cells through interstitial fluid into the blood.

? Would you expect a femoral artery or a femoral vein to have the thicker wall? A wider lumen?

Structure of Capillaries

A capillary consists of a layer of endothelium that is surrounded by basement membrane (Figure 16.1c). Because capillary walls are very thin, many substances easily pass through them to reach tissue cells from the blood or to enter the blood from interstitial fluid. The walls of all other blood vessels are too thick to permit the exchange of substances between blood and interstitial fluid. Depending on how tightly their endothelial cells are joined, different types of capillaries have varying degrees of permeability.

In some regions, capillaries link arterioles to venules directly. In other places, they form extensive branching networks (Figure 16.2). Blood flows through only a small part of

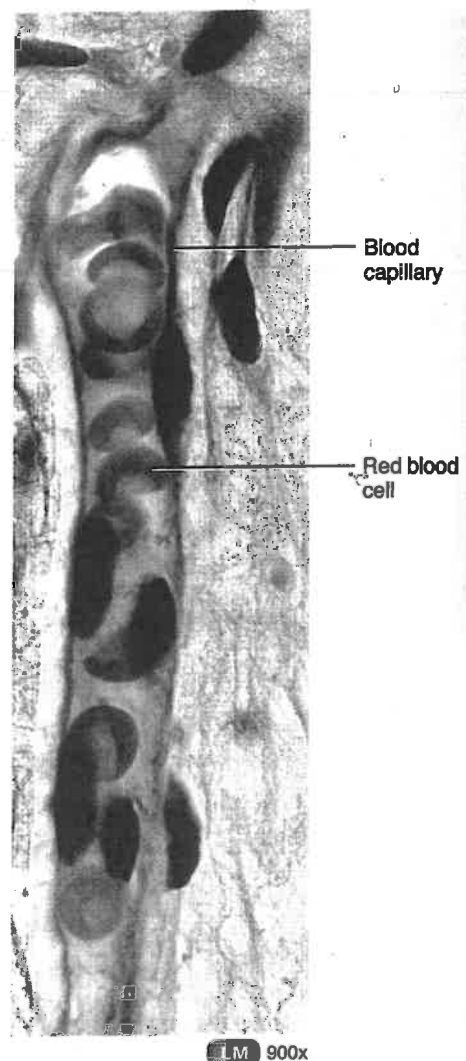
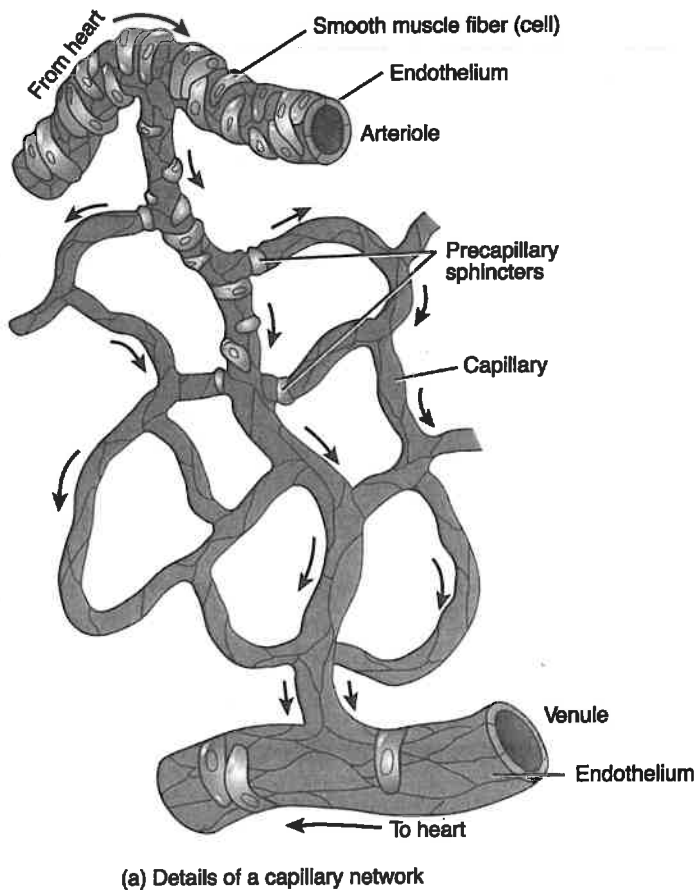
a tissue's capillary network when metabolic needs are low. But when a tissue becomes active, the entire capillary network fills with blood. The flow of blood in capillaries is regulated by smooth muscle fibers in arteriole walls and by *precapillary sphincters*, rings of smooth muscle at the point where capillaries branch from arterioles (Figure 16.2a). When precapillary sphincters relax, more blood flows into the connected capillaries; when precapillary sphincters contract, less blood flows through their capillaries.

Capillary Exchange

Because of the small diameter of capillaries, blood flows more slowly through them than through larger blood vessels. The

Figure 16.2 Capillaries. Because red blood cells and capillaries are nearly the same size, red blood cells squeeze through capillaries in single file.

Arterioles regulate blood flow into capillaries, where nutrients, gases, and wastes are exchanged between blood and interstitial fluid.



? **Why do metabolically active tissues have extensive capillary networks?**

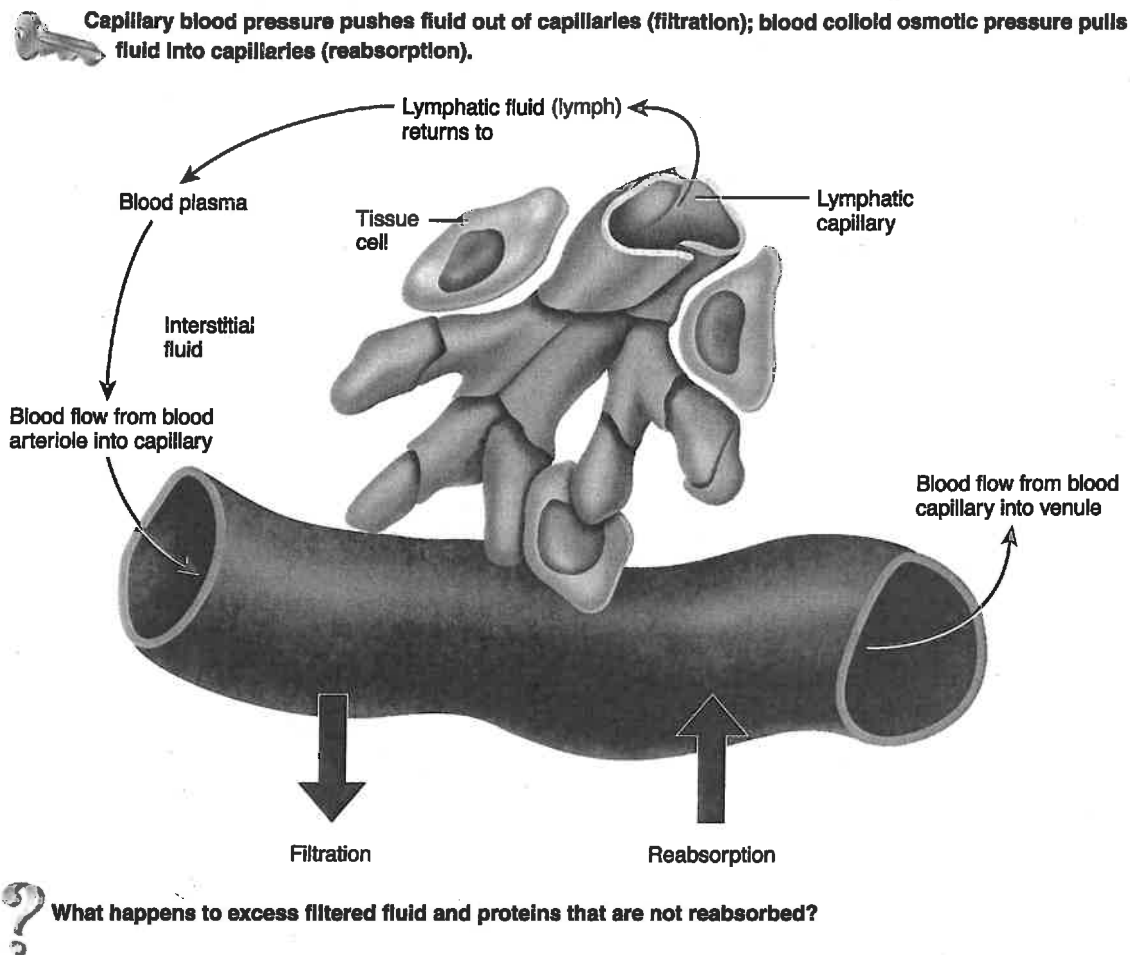
slow flow aids the prime mission of the entire cardiovascular system: to keep blood flowing through capillaries so that **capillary exchange**—the movement of substances into and out of capillaries—can occur.

Capillary blood pressure, the pressure of blood against the walls of capillaries, “pushes” fluid out of capillaries into interstitial fluid. An opposing pressure, termed **blood colloid osmotic pressure**, “pulls” fluid into capillaries. (Recall that osmotic pressure is the pressure of a fluid due to its solute concentration. The higher the solute concentration, the greater the os-

motonic pressure.) Most solutes are present in nearly equal concentrations in blood and interstitial fluid. But the presence of proteins in plasma and their virtual absence in interstitial fluid gives blood the higher osmotic pressure. Blood colloid osmotic pressure is osmotic pressure due mainly to plasma proteins.

Capillary blood pressure is higher than blood colloid osmotic pressure for about the first half of the length of a typical capillary. Thus, water and solutes flow out of the blood capillary into the surrounding interstitial fluid, a movement called **filtration** (Figure 16.3). Because capillary blood pressure de-

Figure 16.3 Capillary exchange.



creases progressively as blood flows along a capillary, at about the capillary's midpoint, blood pressure drops below blood colloid osmotic pressure. Then, water and solutes move from interstitial fluid into the blood capillary, a process termed **reabsorption**. Normally, about 85% of the filtered fluid is reabsorbed. The excess filtered fluid and the few plasma proteins that do escape enter lymphatic capillaries and eventually are returned by the lymphatic system to the cardiovascular system.

Localized changes in each capillary network can regulate vasodilation and vasoconstriction. When vasodilators are released by tissue cells, they cause dilation of nearby arterioles and relaxation of precapillary sphincters. Then, blood flow into the capillary networks increases, and O_2 delivery to the tissue rises. Vasoconstrictors have the opposite effect. The ability of a tissue to automatically adjust its blood flow to match its metabolic demands is called **autoregulation**.

Venules and Veins

When several capillaries unite, they form venules. Venules receive blood from capillaries and empty blood into veins, which return blood to the heart.

Structure of Venules and Veins

Venules (= little veins) are similar in structure to arterioles; their walls are thinner near the capillary end and thicker as they progress toward the heart. **Veins** are structurally similar to arteries, but their middle and inner layers are thinner (see Figure 16.1b). The outer layer of veins is the thickest layer. The lumen of a vein is wider than that of a corresponding artery.

In some veins, the inner layer folds inward to form **valves** that prevent the backflow of blood. In people with weak venous valves, gravity forces blood backward through the valve. This increases venous blood pressure, which pushes the vein's wall outward. After repeated overloading, the walls lose their elasticity and become stretched and flabby, a condition called **varicose veins**.

By the time blood leaves the capillaries and moves into veins, it has lost a great deal of pressure. This can be observed in the blood leaving a cut vessel: Blood flows from a cut vein slowly and evenly, whereas it gushes out of a cut artery in rapid spurts. When a blood sample is needed, it is usually collected from a vein because pressure is low in veins and many of them are close to the skin surface.

Venous Return

Venous return, the volume of blood flowing back to the heart through systemic veins, occurs due to pressure generated in three ways: (1) contractions of the heart, (2) the skeletal muscle pump, and (3) the respiratory pump. Blood pressure is generated by contraction of the heart's ventricles and is measured in millimeters of mercury, abbreviated mm Hg. The pressure difference from venules (averaging about 16 mm Hg) to the right atrium (0 mm Hg), although small, normally is sufficient to cause venous return to the heart. When you stand, the pressure pushing blood up the veins in your lower limbs is barely enough to overcome the force of gravity pushing it back down.

The **skeletal muscle pump** operates as follows (Figure 16.4):

- 1 While you are standing at rest, both the venous valve closer to the heart and the one farther from the heart in this part of the leg are open, and blood flows upward toward the heart.
- 2 Contraction of leg muscles, such as when you stand on tiptoes or take a step, compresses the vein. The compression pushes blood through the valve closer to the heart, an action called *milking*. At the same time, the valve farther from the heart in the uncompressed segment of the

vein closes as some blood is pushed against it. People who are immobilized through injury or disease lack these contractions of leg muscles. As a result, their venous return is slower and they may develop circulation problems.

- 3 Just after muscle relaxation, pressure falls in the previously compressed section of vein, which causes the valve closer to the heart to close. The valve farther from the heart now opens because blood pressure in the foot is higher than in the leg, and the vein fills with blood from the foot.

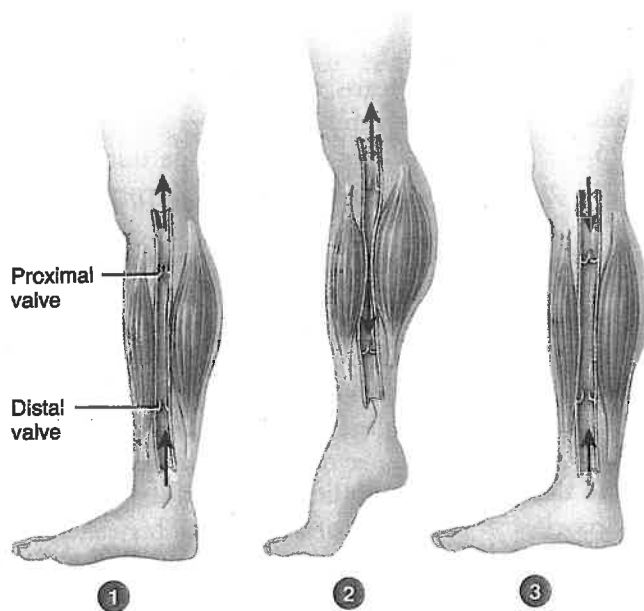
The **respiratory pump** is also based on alternating compression and decompression of veins. During inhalation (breathing in) the diaphragm moves downward, which causes a decrease in pressure in the thoracic cavity and an increase in pressure in the abdominal cavity. As a result, abdominal veins are compressed, and a greater volume of blood moves from the compressed abdominal veins into the decompressed thoracic veins and then into the right atrium. When the pressures reverse during exhalation (breathing out), the valves in the veins prevent backflow of blood from the thoracic veins to the abdominal veins.

CHECKPOINT

1. How do arteries, capillaries, and veins differ in function?
2. Distinguish between filtration and reabsorption.
3. What factors contribute to blood flow back to the heart?

Figure 16.4 Action of the skeletal muscle pump in returning blood to the heart. Steps are described in the text.

Milking refers to skeletal muscle contractions that drive venous blood toward the heart.



? What mechanisms, besides cardiac contractions, act as pumps to boost venous return?

BLOOD FLOW THROUGH BLOOD VESSELS

OBJECTIVES • Define blood pressure and describe how it varies throughout the systemic circulation.

- Identify the factors that affect blood pressure and vascular resistance.
- Describe how blood pressure and blood flow are regulated.

We saw in Chapter 15 that cardiac output (CO) depends on stroke volume and heart rate. Two other factors influencing cardiac output and the proportion of blood that flows through specific circulatory routes are blood pressure and vascular resistance.


Blood Pressure

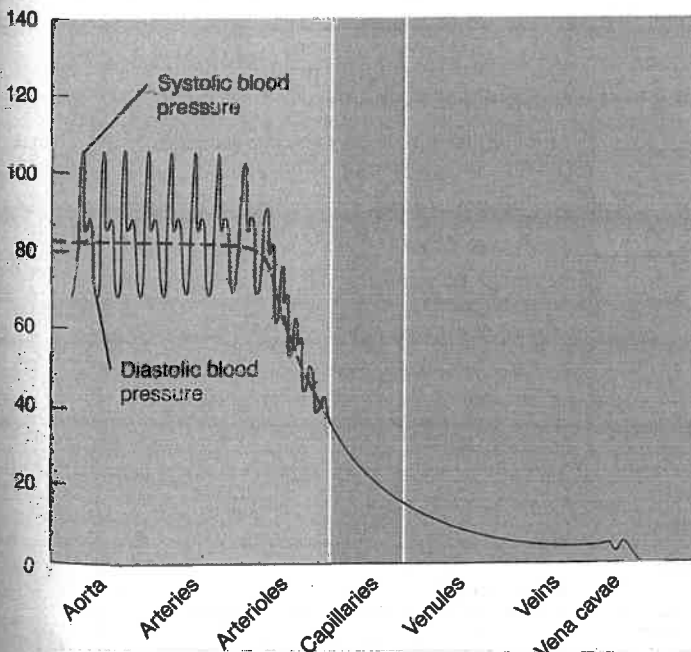
As you have just learned, blood flows from regions of higher pressure to regions of lower pressure; the greater the pressure difference, the greater the blood flow. Contraction of the ventricles generates **blood pressure (BP)**, the pressure exerted by blood on the walls of a blood vessel. BP is highest in

the aorta and large systemic arteries, where in a resting, young adult, it rises to about 110 mm Hg during systole (contraction) and drops to about 70 mm Hg during diastole (relaxation). Blood pressure falls progressively as the distance from the left ventricle increases (Figure 16.5), to about 35 mm Hg as blood passes into systemic capillaries. At the venous end of capillaries, blood pressure drops to about 16 mm Hg. Blood pressure continues to drop as blood enters systemic venules and then veins, and it reaches 0 mm Hg as blood returns to the right atrium.

Blood pressure depends in part on the total volume of blood in the cardiovascular system. The normal volume of blood in an adult is about 5 liters (5.3 qt). Any decrease in this volume, as from hemorrhage, decreases the amount of blood that is circulated through the arteries. A modest decrease can be compensated by homeostatic mechanisms that help maintain blood pressure, but if the decrease in blood volume is greater than 10% of total blood volume, blood pressure drops, with potentially life-threatening results. Conversely, anything that increases blood volume, such as water retention in the body, tends to increase blood pressure.

Figure 16.5 Blood pressure changes as blood flows through the systemic circulation. The dashed line is the mean (average) pressure in the aorta, arteries, and arterioles.

 Blood pressure falls progressively as blood flows from systemic arteries through capillaries and back to the right atrium. The greatest drop in blood pressure occurs in the arterioles.



 What is the relationship between blood pressure and blood flow?

Resistance

Vascular resistance is the opposition to blood flow due to friction between blood and the walls of blood vessels. An increase in vascular resistance increases blood pressure; a decrease in vascular resistance has the opposite effect. Vascular resistance depends on (1) size of the blood vessel lumen, (2) blood viscosity, and (3) total blood vessel length.

1. **Size of the lumen.** The smaller the lumen of a blood vessel, the greater its resistance to blood flow. Vasoconstriction narrows the lumen, and vasodilation widens it. Normally, moment-to-moment fluctuations in blood flow through a given tissue are due to vasoconstriction and vasodilation of the tissue's arterioles. As arterioles dilate, resistance decreases, and blood pressure falls. As arterioles constrict, resistance increases, and blood pressure rises.
2. **Blood viscosity.** The viscosity (thickness) of blood depends mostly on the ratio of red blood cells to plasma (fluid) volume, and to a smaller extent on the concentration of proteins in plasma. The higher the blood's viscosity, the higher the resistance. Any condition that increases the viscosity of blood, such as dehydration or polycythemia (an unusually high number of red blood cells), thus increases blood pressure. A depletion of plasma proteins or red blood cells, as a result of anemia or hemorrhage, decreases viscosity and thus decreases blood pressure.
3. **Total blood vessel length.** Resistance to blood flow increases when the total length of all blood vessels in the body increases. The longer the blood vessel, the greater the contact between the vessel wall and the blood. The greater the contact between the vessel wall and the blood, the greater the friction. An estimated 400 miles of additional blood vessels develop for each extra pound of fat, one reason why overweight individuals may have higher blood pressure.

Regulation of Blood Pressure and Blood Flow

Several interconnected negative feedback systems control blood pressure and blood flow by adjusting heart rate, stroke volume, vascular resistance, and blood volume. Some systems allow rapid adjustments to cope with sudden changes, such as the drop in blood pressure in the brain that occurs when you stand up; others provide long-term regulation. The body may also require adjustments to the distribution of blood flow. During exercise, for example, a greater percentage of blood flow is diverted to skeletal muscles.

Role of the Cardiovascular Center

In Chapter 15 we noted how the *cardiovascular (CV) center* in the medulla oblongata helps regulate heart rate and stroke

volume. The CV center also controls the neural and hormonal negative feedback systems that regulate blood pressure and blood flow to specific tissues.

INPUT The cardiovascular center receives input from higher brain regions: the cerebral cortex, limbic system, and hypothalamus (Figure 16.6). For example, even before you start to run a race, your heart rate may increase due to nerve impulses conveyed from the limbic system to the CV center. If your body temperature rises during a race, the hypothalamus sends nerve impulses to the CV center. The resulting vasodilation of skin blood vessels allows heat to dissipate more rapidly from the surface of the skin.

The CV center also receives input from three main types of sensory receptors: proprioceptors, baroreceptors, and chemoreceptors. *Proprioceptors*, which monitor movements of joints and muscles, provide input to the cardiovascular center during physical activity, such as playing tennis, and cause the rapid increase in heart rate at the beginning of exercise.

Baroreceptors (pressure receptors) are located in the aorta, internal carotid arteries (arteries in the neck that supply blood to the brain), and other large arteries in the neck and chest. They send impulses continuously to the cardiovascular center to help regulate blood pressure. If blood pressure falls, the baroreceptors are stretched less, and they send nerve impulses at a slower rate to the cardiovascular center

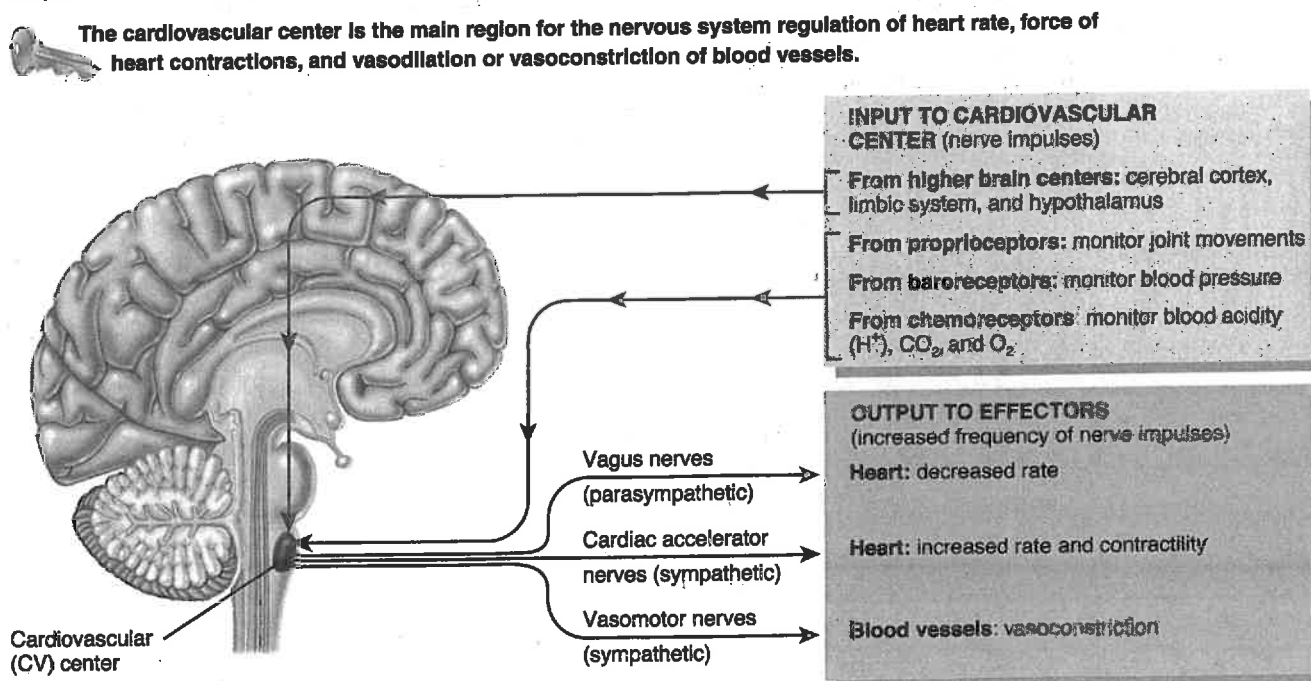
(Figure 16.7). In response, the cardiovascular center decreases parasympathetic stimulation of the heart and increases sympathetic stimulation of the heart. As the heart beats faster and more forcefully, and as vascular resistance increases, blood pressure increases to the normal level.

By contrast, when an increase in pressure is detected, the baroreceptors send impulses at a faster rate. The cardiovascular center responds by increasing parasympathetic stimulation and decreasing sympathetic stimulation. The resulting decreases in heart rate and force of contraction lower cardiac output, and vasodilation lowers vascular resistance. Decreased cardiac output and decreased vascular resistance both lower blood pressure.

Moving from a prone (lying down) to an erect position decreases blood pressure and blood flow in the head and upper part of the body. The drop in pressure, however, is quickly counteracted by the baroreceptor reflexes. Sometimes these reflexes operate more slowly than normal, especially in older people. As a result, a person can faint due to reduced brain blood flow upon standing up too quickly.

CHEMORECEPTOR REFLEXES *Chemoreceptors* (chemical receptors) that monitor blood levels of O_2 , CO_2 , and H^+ are located in the two *carotid bodies* in the common carotid ar-

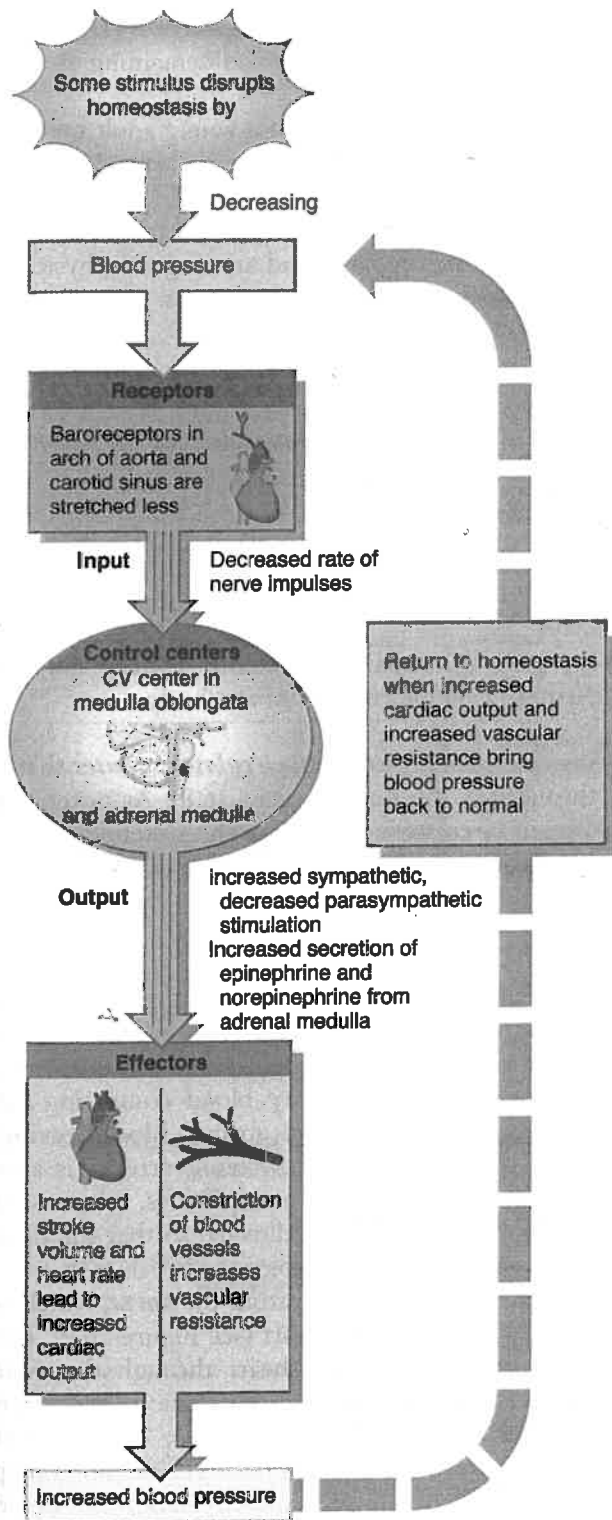
Figure 16.6 The cardiovascular (CV) center. Located in the medulla oblongata, the CV center receives input from higher brain centers, proprioceptors, baroreceptors, and chemoreceptors. It provides output to both the sympathetic and parasympathetic divisions of the autonomic nervous system.



How does vasoconstriction affect vascular resistance and blood flow?

Figure 16.7 Negative feedback regulation of blood pressure via baroreceptor reflexes.

The baroreceptor reflex is a neural mechanism for rapid regulation of blood pressure.



? Does this negative feedback cycle happen when you lie down or when you stand up?

teries and in the *aortic body* in the arch of the aorta. *Hypoxia* (lowered O_2 availability), *acidosis* (an increase in H^+ concentration), or *hypercapnia* (excess CO_2) stimulates the chemoreceptors to send impulses to the cardiovascular center. In response, the CV center increases sympathetic stimulation of arterioles and veins, producing vasoconstriction and an increase in blood pressure.

OUTPUT Output from the cardiovascular center flows along sympathetic and parasympathetic fibers of the ANS (see Figure 16.6). An increase in sympathetic stimulation increases heart rate and the forcefulness of contraction, whereas a decrease in sympathetic stimulation decreases heart rate and contraction force. The vasomotor region of the cardiovascular center also sends impulses to arterioles throughout the body. The result is a moderate state of vasoconstriction, called *vasomotor tone*, that sets the resting level of vascular resistance. Sympathetic stimulation of most veins results in movement of blood out of venous blood reservoirs, which increases blood pressure.

Hormonal Regulation of Blood Pressure and Blood Flow

Several hormones help regulate blood pressure and blood flow by altering cardiac output, changing vascular resistance, or adjusting the total blood volume.

1. **Renin–angiotensin–aldosterone (RAA) system.** When blood volume falls or blood flow to the kidneys decreases, certain cells in the kidneys secrete the enzyme *renin* into the bloodstream (see Figure 13.14 on page 331). Together, renin and angiotensin converting enzyme (ACE) produce the active hormone *angiotensin II*, which raises blood pressure by causing vasoconstriction. Angiotensin II also stimulates secretion of *aldosterone*, which increases reabsorption of sodium ions (Na^+) and water by the kidneys. The water reabsorption increases total blood volume, which increases blood pressure.
2. **Epinephrine and norepinephrine.** In response to sympathetic stimulation, the adrenal medulla releases epinephrine and norepinephrine. These hormones increase cardiac output by increasing the rate and force of heart contractions; they also cause vasoconstriction of arterioles and veins in the skin and abdominal organs.
3. **Antidiuretic hormone (ADH).** ADH is produced by the hypothalamus and released from the posterior pituitary in response to dehydration or decreased blood volume. Among other actions, ADH causes vasoconstriction, which increases blood pressure. For this reason ADH is also called *vasopressin*.
4. **Atrial natriuretic peptide (ANP).** Released by cells in the atria of the heart, ANP lowers blood pressure by causing vasodilation and by promoting the loss of salt and water in the urine, which reduces blood volume.

■ CHECKPOINT

4. What two factors influence cardiac output?
5. Describe how blood pressure decreases as distance from the left ventricle increases.
6. What factors determine vascular resistance?
7. Explain the role of the cardiovascular center, reflexes, and hormones in regulating blood pressure.

CHECKING CIRCULATION

OBJECTIVE • Explain how pulse and blood pressure are measured.

Pulse

The alternate expansion and elastic recoil of an artery after each contraction and relaxation of the left ventricle is called a **pulse**. The pulse is strongest in the arteries closest to the heart. It becomes weaker as it passes through the arterioles, and it disappears altogether in the capillaries. The radial artery at the wrist is most commonly used to feel the pulse. Other sites where the pulse may be felt include the brachial artery along the medial side of the biceps brachii muscle; the common carotid artery, next to the voice box, which is usually monitored during cardiopulmonary resuscitation; the popliteal artery behind the knee; and the dorsal artery of the foot above the instep of the foot.

The pulse rate normally is the same as the heart rate, about 75 beats per minute at rest. **Tachycardia** (tak'-i-KAR-dē-a; *tachy-* = fast) is a rapid resting heart or pulse rate over 100 beats/min. **Bradycardia** (brād'-i-KAR-dē-a; *brady-* = slow) indicates a slow resting heart or pulse rate under 50 beats/min.

Measurement of Blood Pressure

In clinical use, the term **blood pressure** usually refers to the pressure in arteries generated by the left ventricle during systole and the pressure remaining in the arteries when the ventricle is in diastole. Blood pressure is usually measured in the brachial artery in the left arm (see Figure 16.10a). The device used to measure blood pressure is a **sphygmomanometer** (sfīg'-mō-ma-NOM-e-ter; *sphygmo-* = pulse; *manometer* = instrument used to measure pressure). When the pressure cuff is inflated above the blood pressure attained during systole, the artery is compressed so that blood flow stops. The technician places a stethoscope below the cuff over the brachial artery and then slowly deflates the cuff. When the cuff is deflated enough to allow the artery to open, a spurt of

blood passes through, resulting in the first sound heard through the stethoscope. This sound corresponds to **systolic blood pressure (SBP)**—the force with which blood is pushing against arterial walls during ventricular contraction. As the cuff is deflated further, the sounds suddenly become faint. This level, called the **diastolic blood pressure (DBP)**, represents the force exerted by the blood remaining in arteries during ventricular relaxation.

The normal blood pressure of a young adult male is less than 120 mm Hg systolic and less than 80 mm Hg diastolic, reported, for example, as “110 over 70” and written as 110/70. In young adult females, the pressures are 8 to 10 mm Hg less. People who exercise regularly and are in good physical condition may have even lower blood pressures.

■ CHECKPOINT

8. What causes pulse?
9. Distinguish between systolic and diastolic blood pressure.

CIRCULATORY ROUTES

OBJECTIVE • Compare the major routes that blood takes through various regions of the body.

Blood vessels are organized into **circulatory routes** that carry blood throughout the body (Figure 16.8). As noted earlier, the two main circulatory routes are the systemic circulation and the pulmonary circulation.

Systemic Circulation

The **systemic circulation** includes the arteries and arterioles that carry blood containing oxygen and nutrients from the left ventricle to systemic capillaries throughout the body, plus the veins and venules that carry blood containing carbon dioxide and wastes to the right atrium. Blood leaving the aorta and traveling through the systemic arteries is a bright red color. As it moves through the capillaries, it loses some of its oxygen and takes on carbon dioxide, so that the blood in the systemic veins is a dark red color.

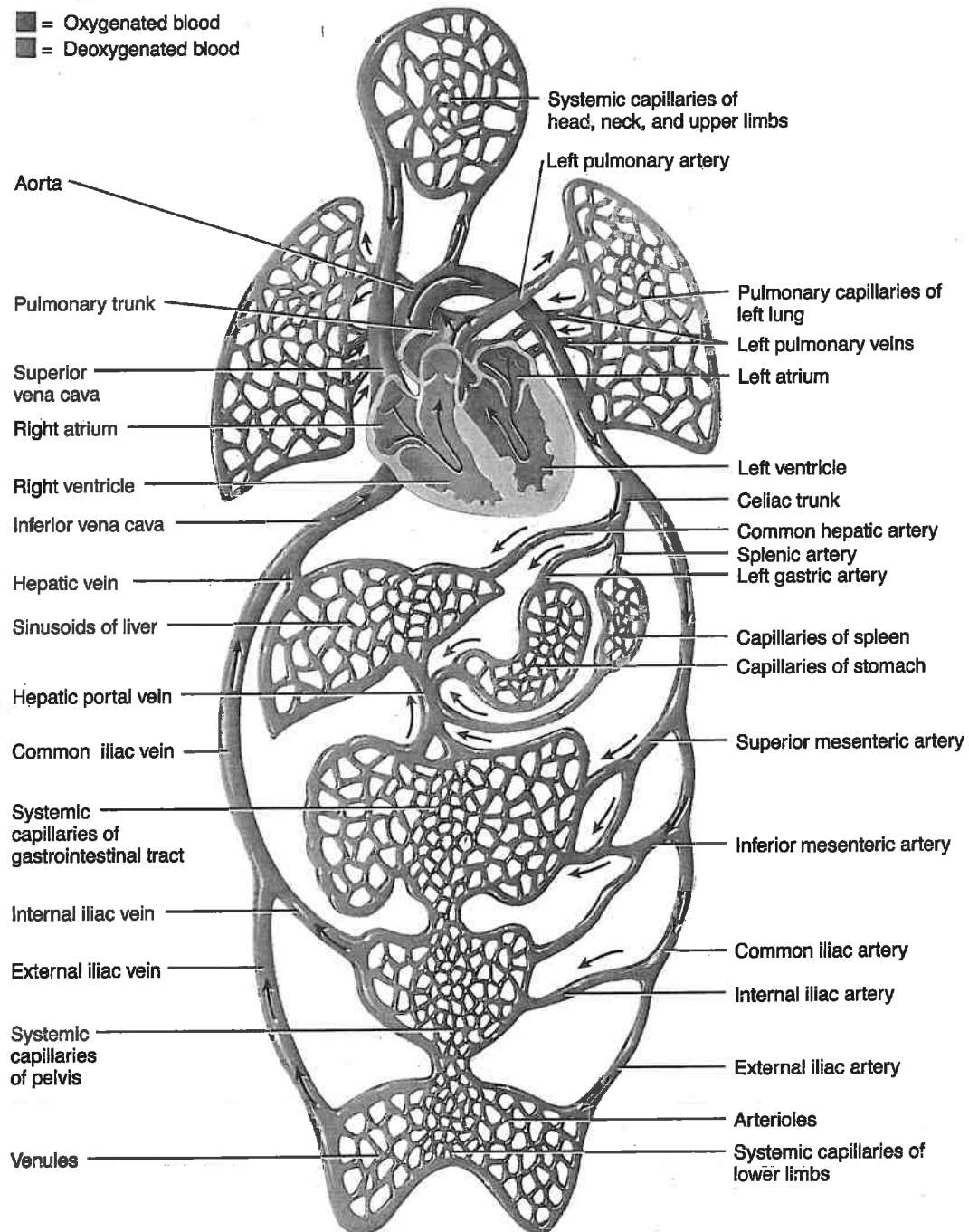
All systemic arteries branch from the **aorta**, which arises from the left ventricle of the heart (see Figure 16.9). Deoxygenated blood returns to the heart through the systemic veins. All the veins of the systemic circulation empty into the **superior vena cava**, **inferior vena cava**, or the **coronary sinus**, which, in turn, empty into the right atrium. The principal blood vessels of the systemic circulation are described and illustrated in Exhibits 16.1 through 16.7 and Figures 16.9 through 16.15 starting on page 396.

Figure 16.8 Circulatory routes. Red arrows indicate hepatic portal circulation. The details of the pulmonary circulation are shown here, and the details of the hepatic portal circulation are shown in Figure 16.16.



Blood vessels are organized into routes that deliver blood to various tissues of the body.

- = Oxygenated blood
- = Deoxygenated blood



What are the two principal circulatory routes?

Exhibit 16.1 The Aorta and Its Branches (Figure 16.9)

OBJECTIVE • Identify the four principal divisions of the aorta and locate the major arterial branches arising from each.

• The **aorta** (*aortae* = to lift up), the largest artery of the body, is 2 to 3 cm (about 1 in.) in diameter. Its four principal divisions are the ascending aorta, arch of the aorta, thoracic aorta, and abdominal aorta. The **ascending aorta** emerges from the left ventricle posterior to the pulmonary trunk. It gives off two coronary artery branches that supply the myocardium of the heart. Then it turns to the

left, forming the **arch of the aorta**. Branches of the arch of the aorta are described in Exhibit 16.2. The part of the aorta between the arch of the aorta and the diaphragm, the **thoracic aorta**, is about 20 cm (8 in.) long. The part of the aorta between the diaphragm and the common iliac arteries is the **abdominal aorta** (ab-DOM-i-nal). The main branches of the abdominal aorta are the

celiac trunk, the **superior mesenteric artery**, and the **inferior mesenteric artery**. The abdominal aorta divides at the level of the fourth lumbar vertebra into two **common iliac arteries**, which carry blood to the lower limbs.

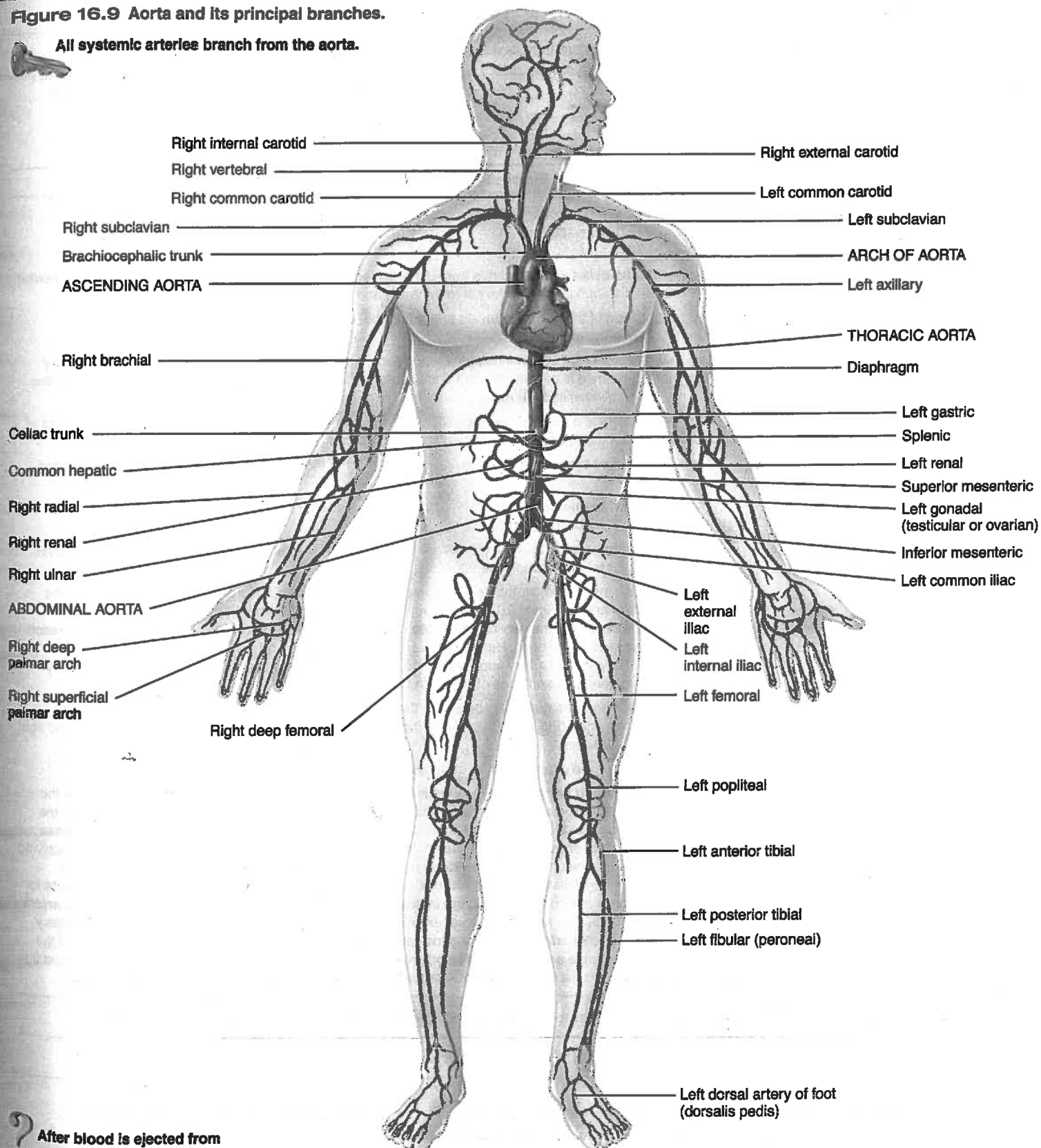
■ **CHECKPOINT**

What general regions do each of the four principal divisions of the aorta supply?

Division and Branches	Region Supplied
Ascending Aorta	
Right and left coronary arteries	Heart.
Arch of the Aorta (see Exhibit 16.2)	
Brachiocephalic trunk (brā'-kē-ō-se-FAL-ik)	
Right common carotid artery (ka-ROT-id)	Right side of head and neck.
Right subclavian artery (sub-KLĀ-vē-an)	Right upper limb.
Left common carotid artery	Left side of head and neck.
Left subclavian artery	Left upper limb.
Thoracic Aorta (<i>thorac</i> = chest)	
Bronchial arteries (BRONG-kē-al)	Bronchi of lungs.
Esophageal arteries (e-sof'-a-JĒ-al)	Esophagus.
Posterior intercostal arteries (in'-ter-KOS-tal)	Intercostal and chest muscles.
Superior phrenic arteries (FREN-ik)	Superior and posterior surfaces of diaphragm.
Abdominal Aorta	
Inferior phrenic arteries (FREN-ik)	Inferior surface of diaphragm.
Celiac trunk (SĒ-lē-ak)	
Common hepatic artery (he-PAT-ik)	Liver.
Left gastric artery (GAS-trik)	Stomach and esophagus.
Splenic artery (SPLĒN-ik)	Spleen, pancreas, and stomach.
Superior mesenteric artery (MES-en-ter'-ik)	Small intestine, cecum, ascending and transverse colons, and pancreas.
Suprarenal arteries (soo'-pra-RĒ-nal)	Adrenal (suprarenal) glands.
Renal arteries (RĒ-nal)	Kidneys.
Gonadal arteries (gō-NAD-al)	
Testicular arteries (tes-TIK-ū-lar)	Testes (male).
Ovarian arteries (ō-VAR-ē-an)	Ovaries (female).
Inferior mesenteric artery	Transverse, descending, and sigmoid colons; rectum.
Common iliac arteries (IL-ē-ak)	
External iliac arteries	Lower limbs.
Internal iliac arteries	Uterus (female), prostate (male), muscles of buttocks, and urinary bladder.

Figure 16.9 Aorta and its principal branches.

All systemic arteries branch from the aorta.



Overall anterior view of the principal branches of the aorta

After blood is ejected from the heart, what are the names of the four divisions of the aorta that it passes through?

Exhibit 16.2 The Arch of the Aorta (Figure 16.10)

OBJECTIVE • Identify the three arteries that branch from the arch of the aorta.

• The **arch of the aorta**, the continuation of the ascending aorta, is 4 to 5 cm (almost 2 in.) in length. It has three branches. In order, as they emerge from the arch of the aorta, the

three branches are the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery.

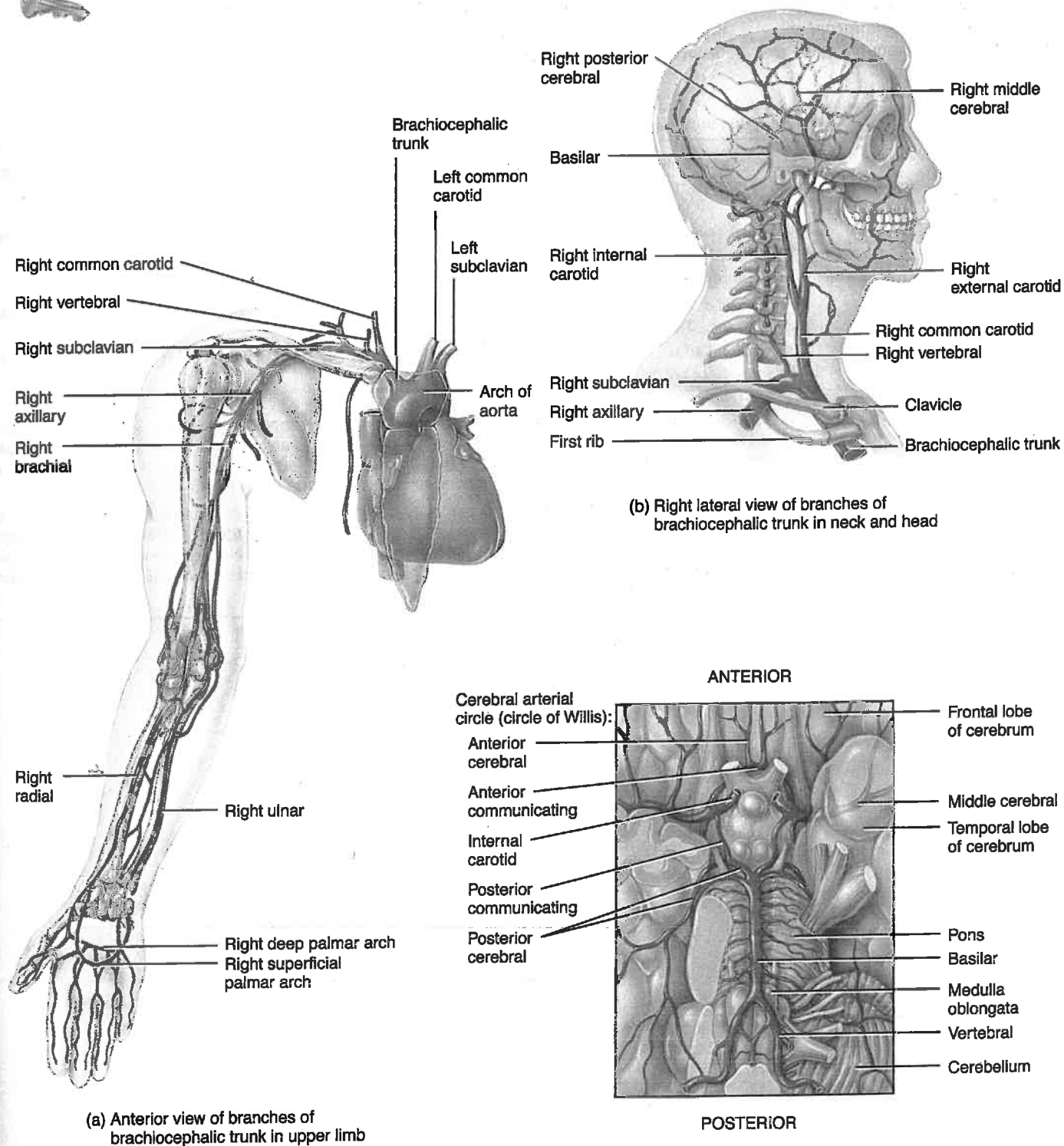
■ CHECKPOINT

What general regions do the arteries that arise from the arch of the aorta supply?

Artery	Description and Region Supplied
Brachiocephalic Trunk (brā'-kē-ō-se-FAL-ik; <i>brachio-</i> = arm; <i>-cephalic</i> = head)	The brachiocephalic trunk divides to form the right subclavian artery and right common carotid artery (Figure 16.10a).
Right subclavian artery (sub-KLĀ-vē-an)	The right subclavian artery extends from the brachiocephalic trunk and then passes into the armpit (axilla). The general distribution of the artery is to the brain and spinal cord, neck, shoulder, and chest.
Axillary artery (AK-sī-lēr-ē = armpit)	The continuation of the right subclavian artery into the axilla is called the axillary artery . Its general distribution is to the shoulder.
Brachial artery (BRĀ-kē-al = arm)	The brachial artery , which provides the main blood supply to the arm, is the continuation of the axillary artery into the arm. It is commonly used to measure blood pressure. Just below the bend in the elbow, the brachial artery divides into the radial artery and ulnar artery.
Radial artery (RĀ-dē-al = radius)	The radial artery is a direct continuation of the brachial artery. It passes along the lateral (radial) aspect of the forearm and then through the wrist and hand; it is a common site for measuring radial pulse.
Ulnar artery (UL-nar = ulna)	The ulnar artery passes along the medial (ulnar) aspect of the forearm and then into the wrist and hand.
Superficial palmar arch (palma = palm)	The superficial palmar arch is formed mainly by the ulnar artery and extends across the palm. It gives rise to blood vessels that supply the palm and the fingers.
Deep palmar arch	The deep palmar arch is formed mainly by the radial artery. The arch extends across the palm and gives rise to blood vessels that supply the palm.
Vertebral artery (VER-te-bral)	Before passing into the axilla, the right subclavian artery gives off a major branch to the brain called the right vertebral artery (Figure 16.10b). The right vertebral artery passes through the foramina of the transverse processes of the cervical vertebrae and enters the skull through the foramen magnum to reach the inferior surface of the brain. Here it unites with the left vertebral artery to form the basilar artery (BAS-lar). The vertebral artery supplies the posterior portion of the brain with blood. The basilar artery supplies the cerebellum and pons of the brain and the internal ear.
Right common carotid artery (ka-ROT-id)	The right common carotid artery begins at the branching of the brachiocephalic trunk and supplies structures in the head (Figure 16.10b). Near the larynx (voice box), it divides into the right external and right internal carotid arteries.
External carotid artery	The external carotid artery supplies structures <i>external</i> to the skull.
Internal carotid artery	The internal carotid artery supplies structures <i>internal</i> to the skull such as the eyeball, ear, most of the cerebrum of the brain, and pituitary gland. Inside the cranium, the internal carotid arteries along with the basilar artery form an arrangement of blood vessels at the base of the brain near the hypophyseal fossa called the cerebral arterial circle (circle of Willis) . From this circle (Figure 16.10c) arise arteries supplying most of the brain. The cerebral arterial circle is formed by the union of the anterior cerebral arteries (branches of internal carotids) and posterior cerebral arteries (branches of basilar artery). The posterior cerebral arteries are connected with the internal carotid arteries by the posterior communicating arteries (ko-MŪ-nī-kā'-ting). The anterior cerebral arteries are connected by the anterior communicating artery . The internal carotid arteries are also considered part of the cerebral arterial circle. The functions of the cerebral arterial circle are to equalize blood pressure to the brain and provide alternate routes for blood flow to the brain, should the arteries become damaged.
Left Common Carotid Artery	Divides into basically the same branches with the same names as the right common carotid artery.
Left Subclavian Artery	Divides into basically the same branches with the same names as the right subclavian artery.

Figure 16.10 Arch of the aorta and its branches.

The arch of the aorta is the continuation of the ascending aorta.



What are the three major branches of the arch of the aorta, in order of their origination?

Exhibit 16.3 Arteries of the Pelvis and Lower Limbs (Figure 16.11)

OBJECTIVE • Identify the two major branches of the common iliac arteries.

• The abdominal aorta ends by dividing into the right and left **common iliac arteries**. These, in turn, divide into the **internal** and **external iliac arteries**. In sequence, the ex-

ternal iliacs become the **femoral arteries** in the thighs, the **popliteal arteries** posterior to the knee, and the **anterior** and **posterior tibial arteries** in the legs.

■ CHECKPOINT

What general regions do the internal and external iliac arteries supply?

Artery	Description and Region Supplied
Common iliac arteries (IL-ē-ak = ilium)	At about the level of the fourth lumbar vertebra, the abdominal aorta divides into the right and left common iliac arteries . Each gives rise to two branches: internal iliac and external iliac arteries. The general distribution of the common iliac arteries is to the pelvis, external genitals, and lower limbs.
Internal iliac arteries	The internal iliac arteries are the primary arteries of the pelvis. They supply the pelvis, buttocks, external genitals, and thigh.
External iliac arteries	The external iliac arteries supply the lower limbs.
Femoral arteries (FEM-o-ral = thigh)	The femoral arteries , continuations of the external iliacs, supply the lower abdominal wall, groin, external genitals, and muscles of the thigh.
Popliteal arteries (pop'-li-TĒ-al = posterior surface of the knee)	The popliteal arteries , continuations of the femoral arteries, supply muscles and the skin on the posterior of the legs; muscles of the calf; knee joint; femur; patella; and fibula.
Anterior tibial arteries (TIB-ē-al = shin bone)	The anterior tibial arteries , which branch from the popliteal arteries, supply the knee joints, anterior muscles of the legs, skin on the anterior of the legs, and ankle joints. At the ankles, the anterior tibial arteries become the dorsal arteries of the foot (dorsalis pedis arteries) , which supply the muscles, skin, and joints on the dorsal aspects of the feet. The dorsal arteries of the foot give off branches that supply the feet and toes.
Posterior tibial arteries	The posterior tibial arteries , the direct continuations of the popliteal arteries, distribute to the muscles, bones, and joints of the leg and foot. Major branches of the posterior tibial arteries are the fibular (peroneal) arteries , which supply the leg and ankle. Branching of the posterior tibial arteries gives rise to the medial and lateral plantar arteries. The medial plantar arteries (PLAN-tar = sole) supply the muscles and skin of the feet and toes. The lateral plantar arteries supply the feet and toes.