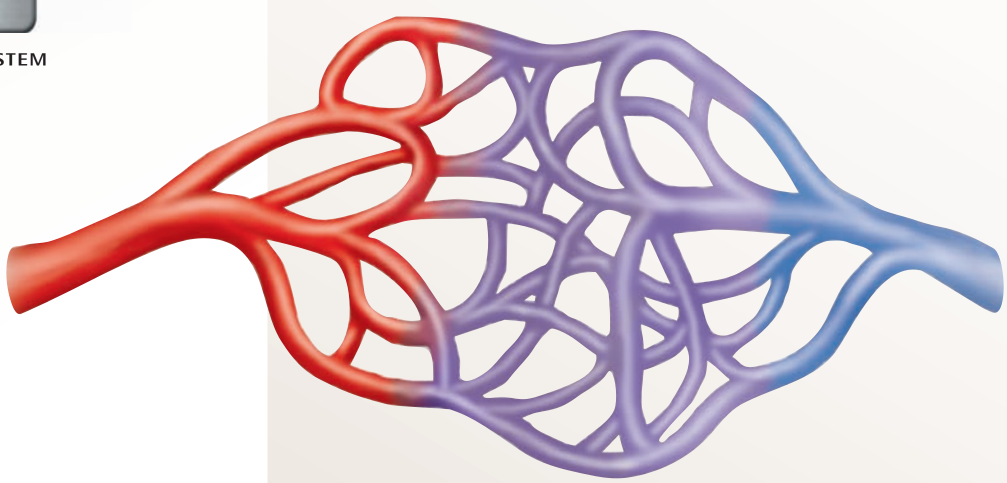
23

Vessels and Circulation

OUTLINE

MODULE 9: CARDIOVASCULAR SYSTEM



Blood vessels are analogous to highways—they are an efficient mode of transport for oxygen, carbon dioxide, nutrients, hormones, and waste products to and from body tissues. The heart is the mechanical pump that propels the blood through the vessels. Together, the heart and blood vessels form a closed-loop system, whereby blood is continuously pumped to and from all areas of the body.

Blood vessels are not rigid and immobile; rather, they can pulsate and change shape in accordance with the body's needs. This chapter examines the basic histologic structure common to all blood vessels and traces the flow of blood through all of the different body regions.

Study Tip!

Here are some tips to help you remember the names and kinds of blood vessels:

1. Blood vessels often share names with either the body region they traverse or the bone next to them. For example, the radial artery travels near the radius, and the axillary artery is in the axillary region.
2. Some blood vessels are named for the structure they supply. For example, the renal arteries supply the kidneys, the gonadal arteries supply the gonads, and the facial arteries supply the face.
3. Arteries and veins that travel together (called companion vessels) sometimes share the same name. For example, the femoral artery is accompanied by the femoral vein.
4. Writing out your own simplified flowchart of blood vessels for each body region will help you better understand and remember the pattern of blood flow in that region.

23.1 Anatomy of Blood Vessels

Learning Objectives:

1. **Compare and contrast the structure of arteries, capillaries, and veins.**
2. **Describe how the different types of vessels interconnect to transport blood.**

The **systemic circulation** consists of the blood vessels that extend to all body regions. The **pulmonary circulation** consists of the vessels that take the blood to and from the lungs for the purpose of gas exchange. Both circulations work continuously and in tandem with each other.

The three classes of blood vessels are arteries, capillaries, and veins. In the systemic circulation, as the ventricles of the heart contract, arteries convey blood away from the heart to the body. Arteries branch into smaller and smaller vessels until they feed into the capillaries, where gas and nutrient exchange occurs. From the capillaries, veins return blood to the heart.

Arteries become progressively smaller as they branch and extend farther from the heart, while veins become progressively larger as they merge and come closer to the heart. The site where two or more arteries (or two or more veins) converge to supply the same body region is called an **anastomosis** (ă-nas′tō-mō′sis; pl., *anastomoses*). Arterial anastomoses provide alternate blood supply routes to body tissues or organs. (For an example, see figure 23.12, which shows anastomoses among the superior and inferior epigastric arteries.) Some arteries do not form anastomoses; these so-called **end arteries** provide only one pathway through which blood can reach an organ. Examples of end arteries include the renal artery of the kidney and the splenic artery of the spleen. Other arteries (such as the coronary arteries in the heart wall) are called **functional end arteries,** meaning that their anastomoses are so tiny that the arteries may almost be considered end arteries. Veins tend to form many more anastomoses than do arteries.

Often, an artery travels with a corresponding vein. These vessels are called **companion vessels** because they supply the same body region and tend to lie next to one another.

23.1a Blood Vessel Tunics

Both artery and vein walls have three layers, called **tunics** (too′nik; *tunica* = coat). The tunics surround the **lumen** (loo′men), or inside space, of the vessel through which blood flows. These tunics are the tunica intima, tunica media, and tunica externa **(figure 23.1)**.

The innermost layer of a blood vessel wall is the **tunica intima** (too′ni-kă in-ti′mă; *intimus* = inmost), or *tunica interna*. It is composed of an **endothelium** (a simple squamous epithelium lining the blood vessel lumen) and a subendothelial layer made up of a thin layer of areolar connective tissue.

The **tunica media** (mē′dē-ă; *medius* = middle) is the middle layer of the vessel wall. It is composed of circularly arranged layers of smooth muscle cells. Sympathetic innervation causes the smooth muscle to contract, resulting in **vasoconstriction** (vā′sō-kon-strik′shŭn), or narrowing of the blood vessel lumen. When the fibers relax, **vasodilation** (vā′sō-dī-lā′shŭn), or widening of the blood vessel lumen, results.

The **tunica externa** (eks-ter′nă; *externe* = outside), or *tunica adventitia,* is the outermost layer of the blood vessel wall. It is composed of areolar connective tissue that contains elastic and collagen fibers. The tunica externa helps anchor the vessel to other structures. Very large blood vessels require their own blood supply to the tunica externa in the form of a network of small arteries called the **vasa vasorum** (vā-să vā-sŏr′ŭm; vessels of vessels). The vasa vasorum extend through the tunica externa.

In arteries, the thickest layer is the tunica media, while veins have a thicker tunica externa. The lumen in an artery is narrower than in its companion vein of the same size **(figure 23.2)**. Further, arteries tend to have more elastic and collagen fibers in all their tunics, which means that artery walls remain open (patent), can spring back to shape, and can withstand changes in blood pressure. In contrast, vein walls tend to collapse if there is no blood in them. **Table 23.1** compares the characteristics of arteries and veins.

Finally, capillaries contain only the tunica intima, but this layer consists of a basement membrane and endothelium only. Intercellular clefts are the thin spaces between adjacent cells in

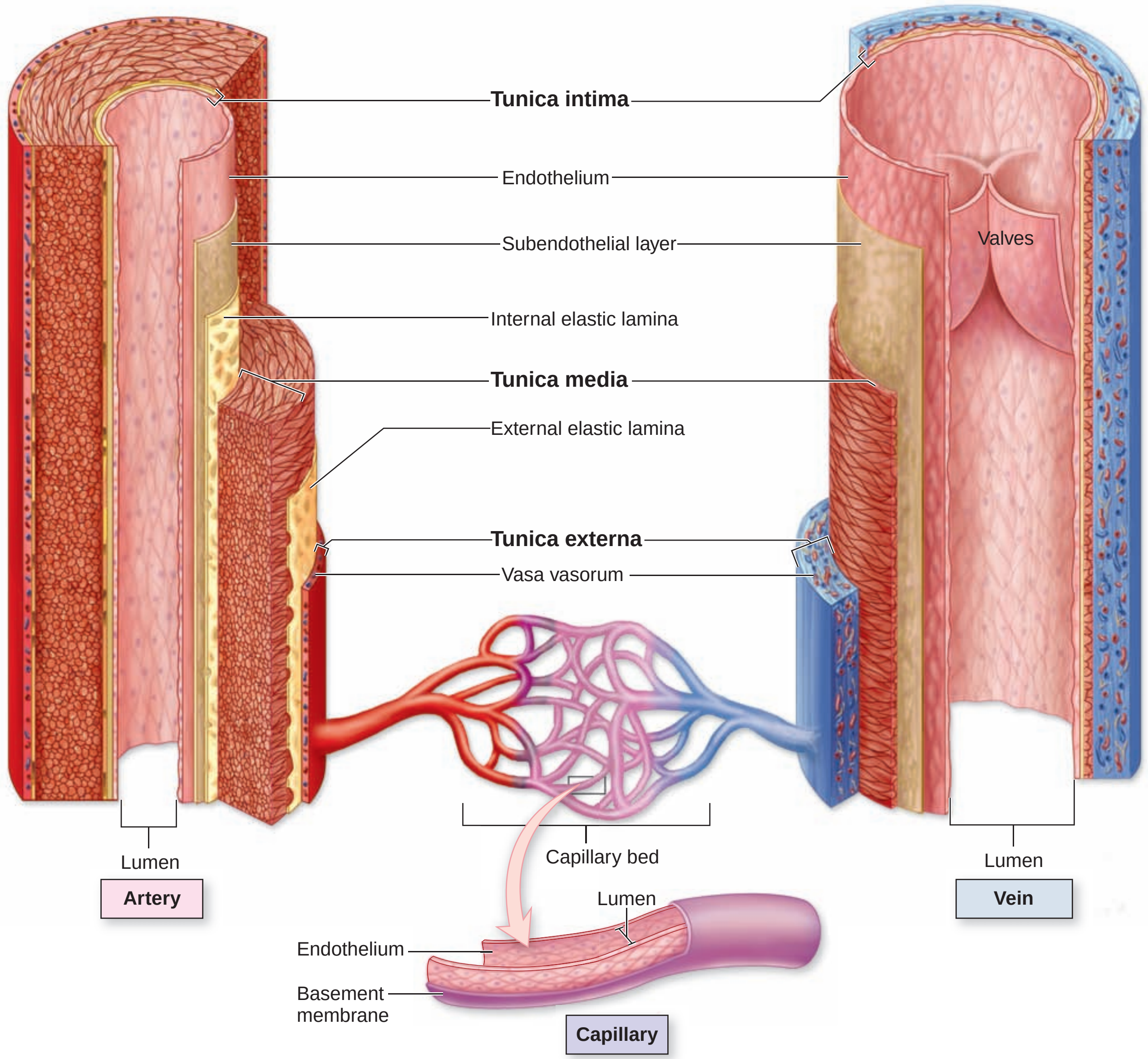


Figure 23.1

Walls of an Artery, a Capillary, and a Vein. Both arteries and veins have a tunica intima, tunica media, and tunica externa. However, an artery has a thicker tunica media and a relatively smaller lumen, whereas a vein's thickest layer is the tunica externa, and it has a larger lumen. Some veins also have valves. Capillaries typically have only a tunica intima, but they do not have a subendothelial layer—just the endothelium and a basement membrane.

the capillary wall. Having only the tunica intima, without connective tissue and muscle layers, allows for rapid gas and nutrient exchange between the blood and the tissues.

23.1b Arteries

Arteries (ar′ter-ē) transport blood away from the heart. The arteries in the systemic circulation carry oxygenated blood to the body tissues. In contrast, the pulmonary arteries (part of the pulmonary circulation) carry deoxygenated blood to the lungs.

The three basic types of arteries are elastic arteries, muscular arteries, and arterioles (**figure 23.3**, *right*). In general, as an artery's diameter decreases, there is a corresponding decrease in the amount of elastic fibers and a relative increase in the amount of smooth muscle.

Elastic Arteries

Elastic arteries are the largest arteries, with diameters ranging from 2.5 to 1 centimeter. They are also called *conducting arteries* because they conduct blood away from the heart to the smaller

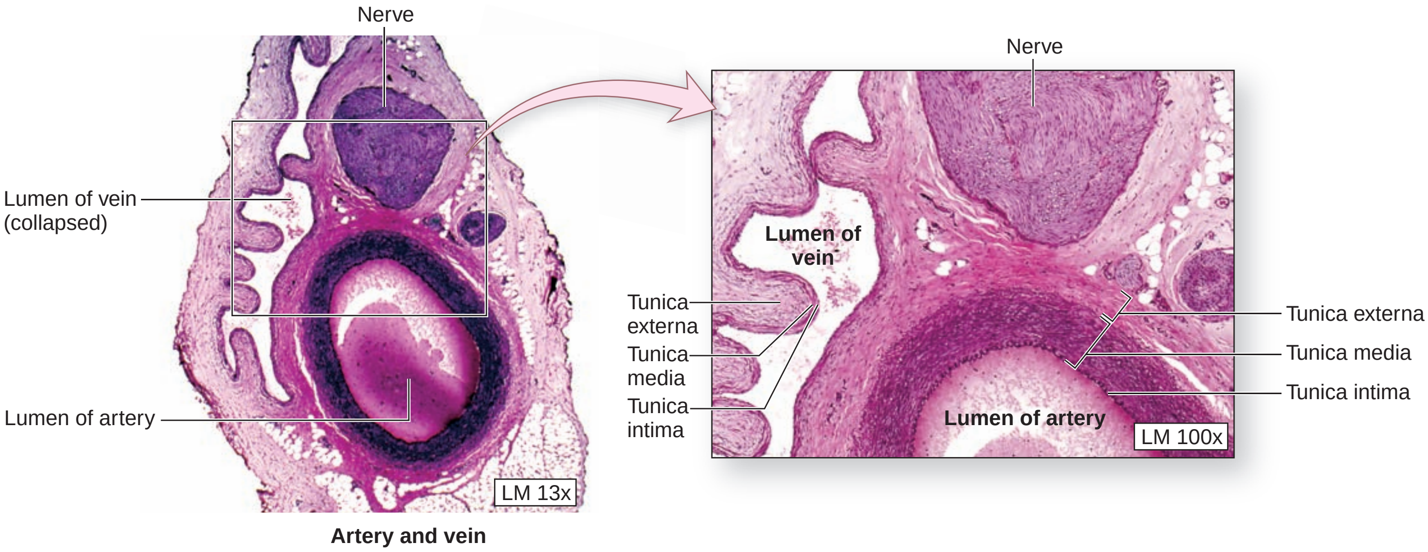


Figure 23.2

Microscopic Comparison of Arteries and Veins. Arteries generally maintain their shape in tissues as a result of the thicker tunica media layer and more elastic fibers in their walls. The walls of neighboring veins often collapse when they are not filled with blood.

Table 23.1 Comparison of Arteries and Veins

Characteristic	Artery	Vein
Lumen Diameter	Narrower than vein lumen	Wider than artery lumen; often appears collapsed when cut in cross section
General Wall Thickness	Thicker than companion vein	Thinner than companion artery
Cross-Sectional Shape	Retains its circular cross-sectional shape	Cross section tends to flatten out (collapse) if no blood is in the vein
Thickest Tunic	Tunica media	Tunica externa
Elastic and Collagen Fibers in Tunics	More than in vein	Less than in artery
Valves	None	Present in most veins
Blood Pressure	Higher than in veins (larger arteries typically > 90 mm Hg)	Lower than in arteries (approximately 2 mm Hg)
Blood Flow	Transports blood away from heart	Transports blood to heart
Blood Oxygen Levels	Systemic arteries carry blood high in O_2 Pulmonary arteries carry blood low in O_2	Systemic veins carry blood low in O_2 Pulmonary veins carry blood high in O_2

muscular arteries. As their name suggests, these arteries have a large proportion of elastic fibers throughout all three tunics, especially in the tunica media **(figure 23.4*a*)**. The abundant elastic fibers allow the elastic artery to stretch when a heart ventricle ejects blood into it. In this manner, the elastic arteries are able to withstand the strong pulsations of the ejected blood as well as reduce the force of the pulsations somewhat, so that the pressure of the arterial blood equalizes slightly as it reaches the smaller arteries and eventually the capillaries. Examples of elastic arteries include the aorta and the pulmonary, brachiocephalic, common carotid, subclavian, and common iliac arteries. Elastic arteries branch into muscular arteries.

Muscular Arteries

Muscular arteries typically have diameters ranging from 1 centimeter to 3 millimeters. These medium-sized arteries are also called *distributing arteries* because they distribute blood to body organs and tissues. Unlike elastic arteries, the elastic fibers in muscular arteries are confined to two circumscribed rings: The **internal elastic lamina** (lam′i-nă) separates the tunica intima from the tunica media, and the **external elastic lamina** separates the tunica media from the tunica externa (figure 23.4*b*).

Muscular arteries have a proportionately thicker tunica media, with multiple layers of smooth muscle fibers. The greater amount of

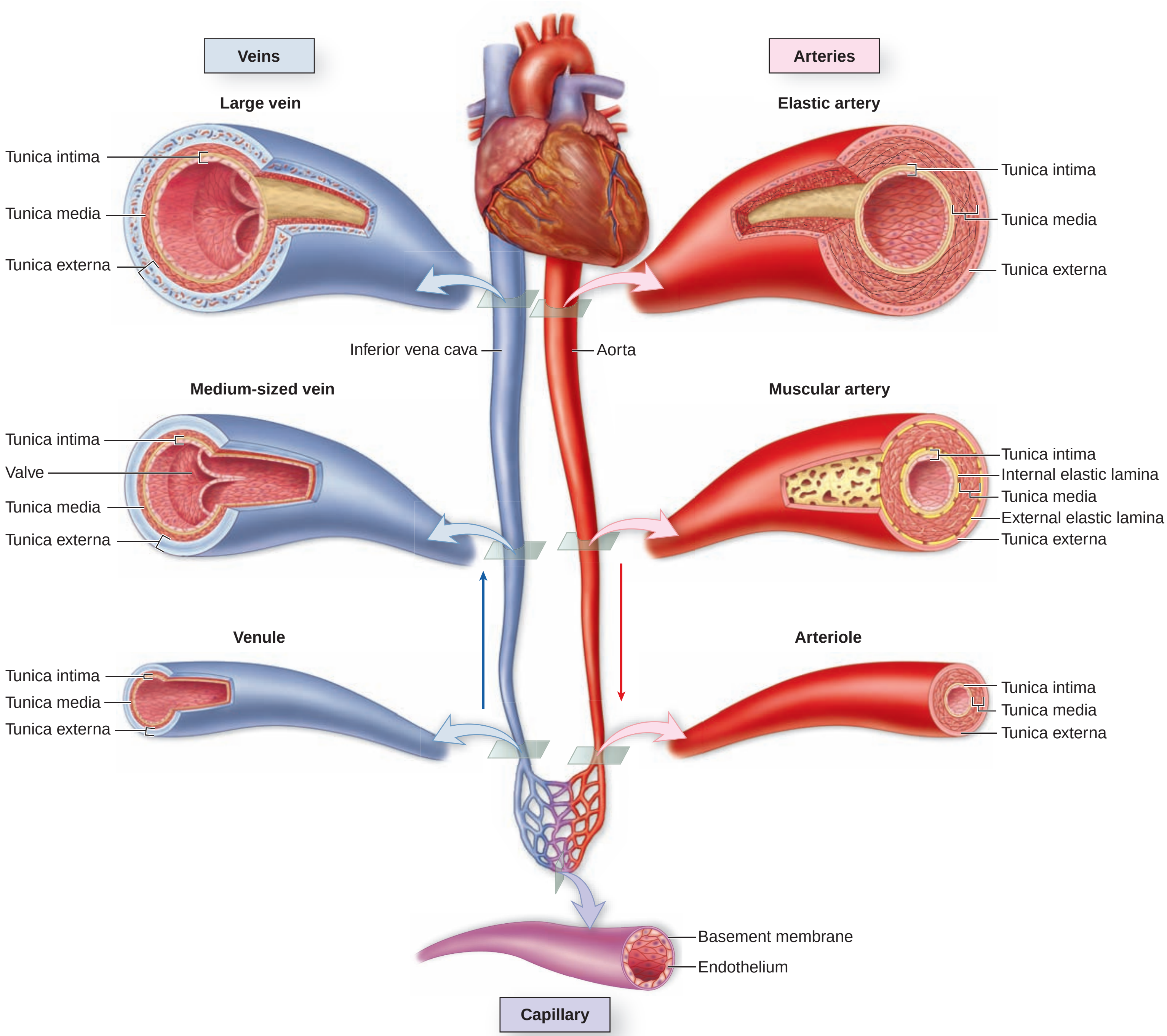
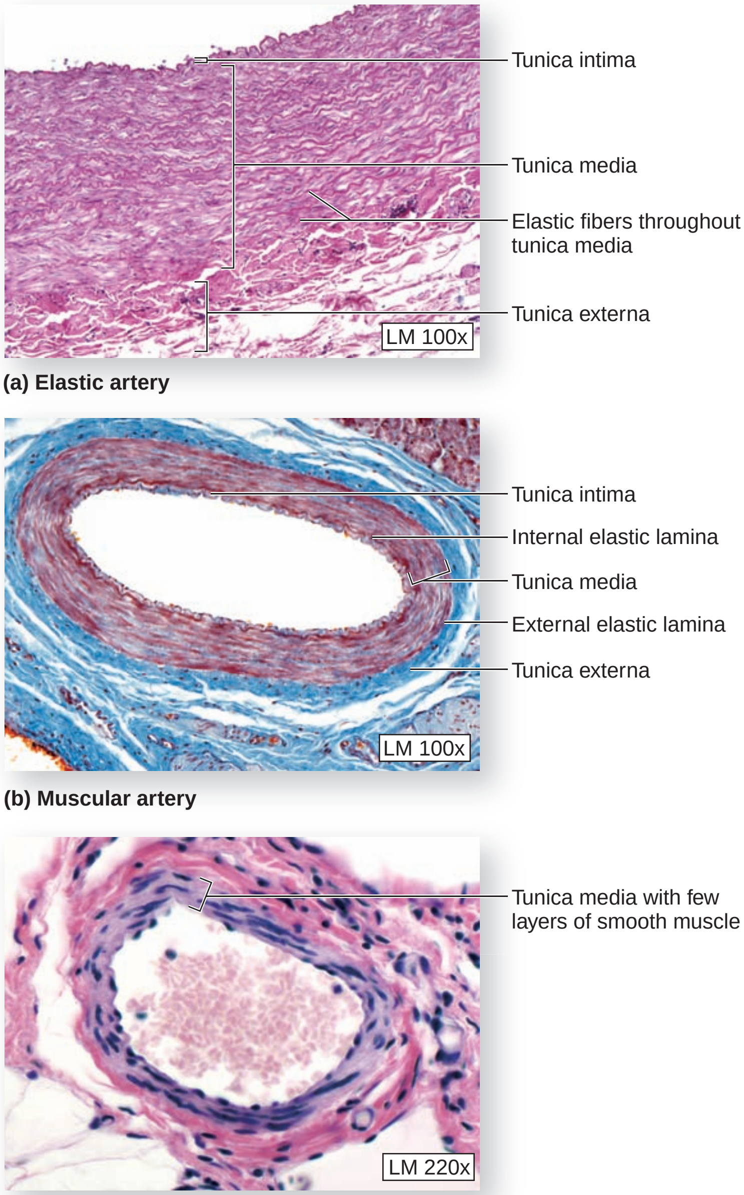


Figure 23.3

Comparison of Companion Vessels. Arteries and veins supplying the same region are called companion vessels. The thickness of the tunics differs, depending on the size of the vessels.



(c) Arteriole

Figure 23.4

Types of Arteries. (*a*) Elastic arteries have vast arrays of elastic fibers in their tunica media. (*b*) Muscular arteries have a tunica media composed of numerous layers of smooth muscle flanked by elastic laminae. (*c*) Arterioles typically have a tunica media composed of six or fewer layers of smooth muscle cells.

muscle and lesser amount of elastic fibers result in less distensibility but better ability to vasoconstrict and vasodilate. Most of the named blood vessels (such as the brachial, anterior tibial, coronary, and inferior mesenteric arteries) are examples of muscular arteries. Muscular arteries branch into arterioles.

Arterioles

Arterioles (ar-tēr′ē-ōl) are the smallest arteries, with diameters ranging from 3 millimeters to 10 micrometers. In general, arterioles have less than six layers of smooth muscle in their tunica media (figure 23.4*c*). Larger arterioles have all three tunics, whereas the smallest arterioles may have an endothelium surrounded by a single layer of smooth muscle fibers. Sympathetic innervation causes contraction in the smooth muscle of the arteriole wall and results in vasoconstriction of the arteriole, which raises blood pressure. Arteriole vasoconstriction decreases blood flow into the capillaries, whereas arteriole vasodilation increases blood flow into the capillaries.

Study Tip!

Is that a muscular artery or an arteriole you are examining under the microscope? One easy way to figure this out is to count the smooth muscle layers in the tunica media:

- Arterioles have six or fewer layers of smooth muscle in their tunica media.
- Muscular arteries usually have many more layers of smooth muscle in their tunica media.

23.1c Capillaries

Capillaries (kap′-i-lar-ē; *capillaris* = relating to hair), the smallest blood vessels, connect arterioles to venules (see figure 23.3). The average capillary diameter is 8 to 10 micrometers, just slightly larger than the diameter of a single erythrocyte. The narrow vessel diameter means erythrocytes must travel in single file (called a rouleau; see chapter 21) through each capillary. Most capillaries consist solely of a tunica intima composed of a very thin, single layer of endothelium and a basement membrane; there is no subendothelial layer. The thin wall and the narrow vessel diameter are optimal for diffusion of gases and nutrients between blood in the capillaries and body tissues. Oxygen and nutrients from the blood can pass through the endothelial lining to the tissues, while carbon dioxide and waste products may be removed from the tissues and enter the cardiovascular system for removal. Some capillaries have additional functions; for example, the capillaries in the small intestine mucosa are also responsible for receiving digested nutrients. Thus, capillaries are called the **functional units** of the cardiovascular system.

The extensive capillaries in a capillary bed create an increase in the total surface area of these blood vessels (especially when compared to a single arteriole or venule). The increase in total surface area results in slower blood flow through the capillaries, thus allowing sufficient time for nutrient, gas, and waste exchange between the tissues and the blood. The capillary bed architecture, along with this slower blood flow, results in a change from a pulsatile flow to a steady flow of blood.

Capillaries do not function independently; rather, a group of capillaries (10–100) functions together and forms a **capillary bed** **(figure 23.5)**. A capillary bed is fed by a **metarteriole** (met′ar-tēr′ē-ōl; *meta* = after), which is a vessel branch of an arteriole. The proximal part of the metarteriole is encircled by scattered smooth muscle fibers, whereas the distal part of the metarteriole (called the **thoroughfare channel**) has no smooth muscle fibers. The thoroughfare channel connects to a **postcapillary venule** (ven′ool, vē′nool), which drains the capillary bed. Vessels called **true capillaries** branch from the metarteriole and make up the bulk of the capillary bed. At the origin of each true capillary, a smooth muscle ring called the **precapillary sphincter** controls blood flow into the true capillaries. Sphincter relaxation permits blood to flow into the true capillaries, whereas sphincter contraction causes blood to flow directly from the metarteriole into the postcapillary venule

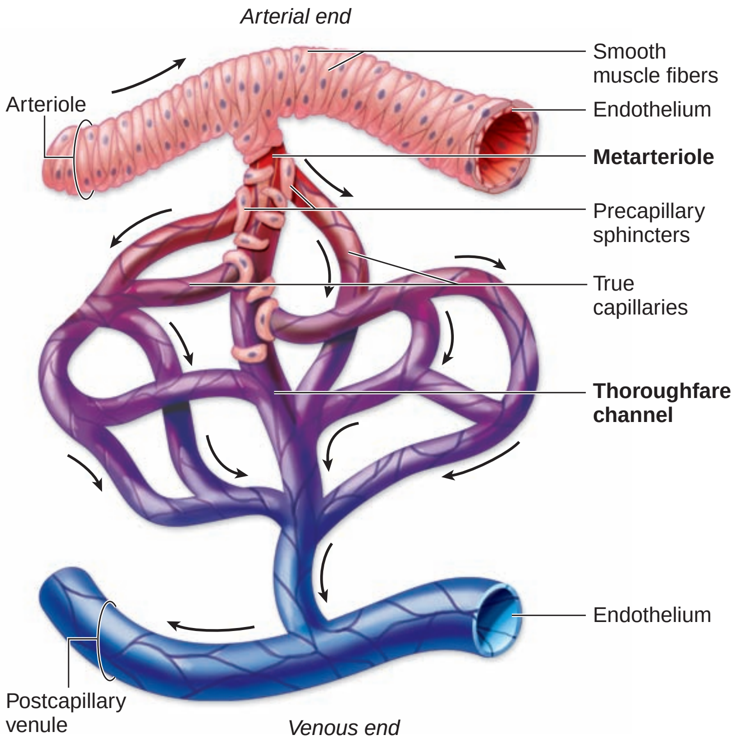


Figure 23.5

Capillary Bed Structure. A capillary bed originates from a metarteriole. The distal part of the metarteriole is called the thoroughfare channel, and it merges with the postcapillary venule. True capillaries branch from the metarteriole, and blood flow into these true capillaries is regulated by the precapillary sphincters.

via the thoroughfare channel. The precapillary sphincters open when the tissue needs nutrients, and they close when the tissue's needs have been met. These precapillary sphincters go through cycles of contracting and relaxing at a rate of about 5–10 cycles per minute. This cyclical process is called **vasomotion.**

The three basic kinds of capillaries are continuous capillaries, fenestrated capillaries, and sinusoids **(figure 23.6)**. In **continuous capillaries,** the most common type, endothelial cells form a complete, continuous lining and are connected by tight junctions (see chapter 4). Materials can pass through the endothelial cells or the intercellular clefts via either simple diffusion or pinocytosis (a type of endocytosis whereby droplets of fluid are packaged in pinocytotic vesicles, see chapter 2). Continuous capillaries are found in muscle, skin, the thymus, the lungs, and the CNS.

Fenestrated (fen′es-trā′ted; *fenestra* = window) **capillaries** have **fenestrations** (or pores) within each endothelial cell. These fenestrations measure 10 to 100 nanometers in diameter. The basement membrane remains continuous. Fenestrated capillaries are seen where a great deal of fluid transport between the blood and interstitial tissue occurs, such as in the small intestine (intestinal villi), the ciliary process of the eye, most of the endocrine glands, and the kidney.

Sinusoids (si′nŭ-soyd; *sinus* = cavity, *eidos* = appearance), or *discontinuous capillaries,* have larger gaps than fenestrated capillaries, and their basement membrane is either discontinuous or absent. Sinusoids tend to be wider, larger vessels with openings that allow for transport of larger materials, such as proteins or cells (e.g., blood cells). Sinusoids are found in bone marrow, the anterior pituitary, the parathyroid glands, the adrenal glands, the spleen, and the liver.

23.1d Veins

Veins (vān) drain capillaries and return the blood to the heart. Compared with a corresponding artery, vein walls are relatively thin, and the vein lumen is larger (see figure 23.3, *left*). Systemic veins carry deoxygenated blood to the right atrium of the heart, while pulmonary veins carry oxygenated blood to the left atrium of the heart. Because blood pressure gradually decreases as blood travels through smaller arteries and into capillaries, the pressure has been substantially reduced by the time blood reaches the veins. At rest, the body's veins hold about 60% of the body's blood. Thus, veins function as **blood reservoirs.**

Venules

Venules are the smallest veins, measuring from 8 to 100 micrometers in diameter. Venules are companion vessels with arterioles since both supply the same areas and generally are of similar size. The smallest ones, called **postcapillary venules,** drain capillaries (see figure 23.5). Postcapillary venules resemble continuous capillaries in structure, except that they have a slightly wider lumen. The mechanism of **diapedesis** (dī′ă-pē-dē′sis), by which

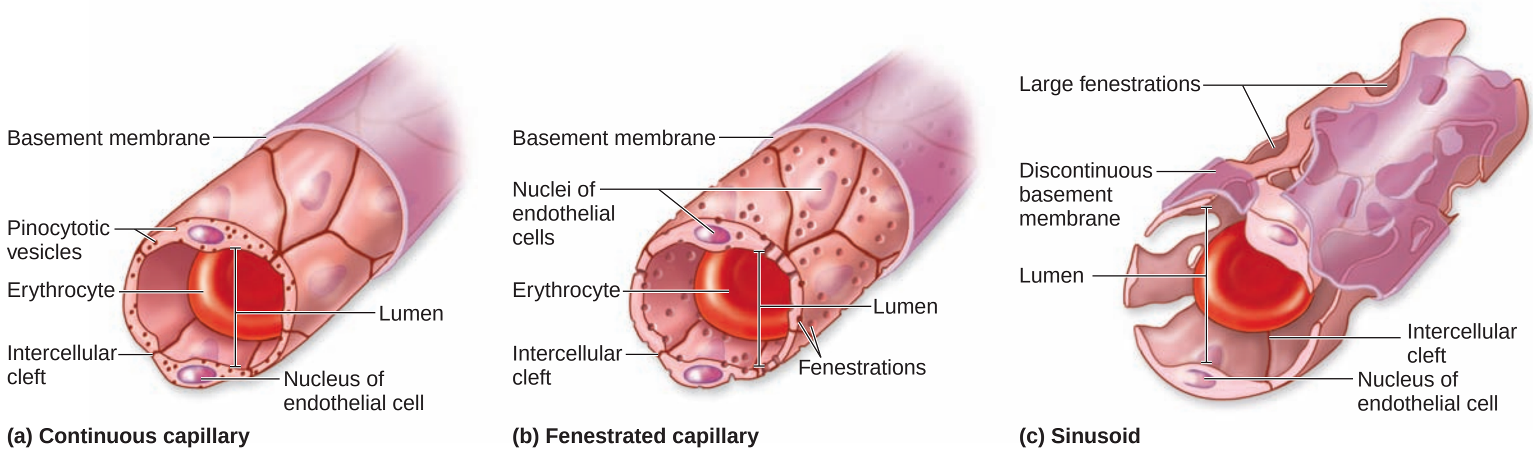


Figure 23.6

Types of Capillaries. (*a*) Continuous capillaries have tight junctions between the endothelial cells that permit minimal fluid leakage. (*b*) Fenestrated capillaries have fenestrations (pores) in the endothelial cells to permit small molecules to move out of the vessel. (*c*) Sinusoids have big gaps between the endothelial cells and a discontinuous basement membrane that promotes transport of larger molecules.

Study Tip!

Arteries always transport blood *away* from the heart, while veins always transport blood back *to* the heart, regardless of whether the blood is oxygenated or deoxygenated.

leukocytes migrate from blood vessels into interstitial fluid, occurs primarily in the postcapillary venules. Smaller venules merge to form larger venules. The largest venules have all three tunics. Venules merge to form veins.

Veins

A venule becomes a vein when its diameter is greater than 100 micrometers. Smaller and medium-sized veins typically travel with muscular arteries, while the largest veins travel with (correspond to) elastic arteries (see figure 23.3). Blood pressure in veins is too low to overcome the forces of gravity. To prevent blood from pooling in the limbs and assist blood moving back to the heart, most veins contain numerous **valves** formed primarily of tunica intima and strengthened by elastic and collagen fibers. Thus, as blood flows superiorly in the limbs, these one-way valves close to prevent backflow **(figure 23.7)**.

In addition to valves, many deep veins pass between skeletal muscle groups. As the skeletal muscles contract, veins are squeezed to help pump the blood toward the heart. This process is called the **skeletal muscle pump.** When skeletal muscles are more active—for example, when a person is walking—blood is pumped more quickly and efficiently toward the heart. Conversely, inactivity (as when a person has been sitting for a long time or is bedridden) leads to blood pooling in the leg veins.

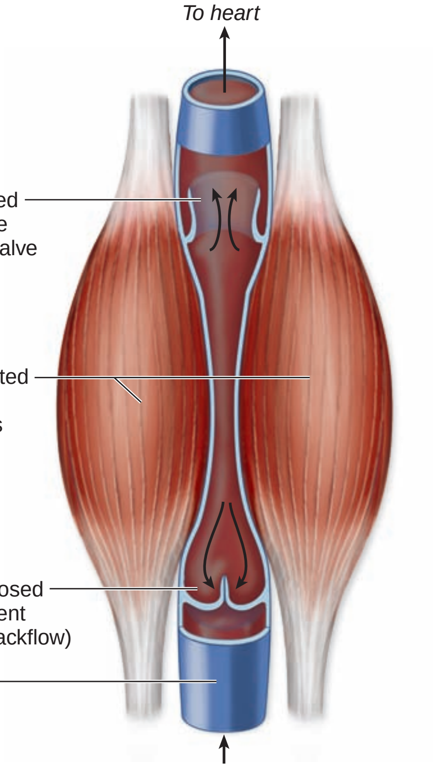


Figure 23.7

Valves in Veins. Valves are one-way flaps that prevent pooling and backflow of venous blood to ensure that blood flows toward the heart. Particularly in the lower limbs, the contraction of skeletal muscles squeezes the veins passing between muscles and forces blood toward the heart.

CLINICAL VIEW

Varicose Veins

Varicose (var′i-kōs; *varix* = dilated vein) **veins** are dilated, tortuous (having many curves or twists) veins. The valves in these veins have become nonfunctional, causing blood to pool in one area and the vein to swell and bulge. Varicose veins are most common in the superficial veins of the lower limbs. They may be a result of genetic predisposition, aging, or some form of stress on the venous system that inhibits venous return (such as standing for long periods of time, obesity, or pregnancy). Varicose veins may become inflamed and painful, especially if fluid leaks from them into the tissues.

Symptoms of varicose veins may be alleviated by elevating the affected body part or wearing compression stockings (to promote blood movement in the lower limbs). In a procedure called *sclerotherapy,* an irritant is injected into small varicose veins to make them scar and seal off. Typically, a patient needs multiple sclerotherapy sessions before optimal results are seen. For larger varicose veins, an outpatient surgical procedure called stripping or vein removal (*phlebectomy*) is necessary. These veins can be removed without affecting the circulation, since the blood may be shunted to other veins that are not varicose. Even after treatment, it is possible for varicose veins to recur.

Varicose veins in the anorectal region are called **hemorrhoids** (hem′ŏ-royd). Hemorrhoids occur due to increased intra-abdominal pressure, as when a person strains to have a bowel movement or is in labor during childbirth. Hemorrhoids may need to be surgically excised if they become too painful or bleed excessively.

CLINICAL VIEW

Deep Vein Thrombosis

Deep vein thrombosis (throm-bō′sis; a clotting) **(DVT)** refers to a **thrombus,** which is a blood clot in a vein. The most common site for the thrombus is a vein in the calf (sural) region; the femoral region is another common site. The blood clot partially or completely blocks the flow of blood in the vein. DVT typically occurs in individuals with heart disease or those who are inactive or immobile for a long period of time, such as bedridden patients or those who have been immobilized in a cast. Even healthy individuals who have been on a long airline trip may develop DVT. In fact, DVT is sometimes called "economy class syndrome" in reference to the reduced amount of leg room in economy class seating on airlines. DVT may also be a complication in pregnancy, where fluid accumulation in the legs and impingement of the fetus on the inferior vena cava may prevent efficient blood flow back to the heart. For inactive individuals, the leg muscles (e.g., gastrocnemius and soleus) do not contract as often and can't help propel blood through the deep veins, thus allowing the blood to pool and potentially to clot.

Initial signs of DVT include fever, tenderness and redness in the affected area, severe pain and swelling in the areas drained by the affected vein, and rapid heartbeat. A person experiencing these symptoms should seek immediate medical attention. The most serious complication of DVT is a **pulmonary embolus** (em′bō-lŭs; a plug), in which a blood clot breaks free within the vein and travels through vessels to the lung, eventually blocking a branch of the pulmonary artery and potentially causing respiratory failure and death. If a DVT is diagnosed, the patient is given anticoagulation medication (such as low-molecular-weight heparin) to help prevent further clotting and break up the existing clot.

To reduce the risk for DVT, a person should maintain a healthy weight, stay active, and treat medical conditions that may increase the risk for DVT. On a long airline flight or car trip, stretching the legs and moving the feet frequently assist venous circulation in the legs. Bedridden individuals may wear full-length compression stockings to assist circulation in the lower limbs.

WHAT DID YOU LEARN?

1. What is the structure and function of an anastomosis?
2. Describe the capillary types. List a location for each in the body.
3. Explain how valves and muscular pumps help veins propel blood back to the heart.

23.2 Blood Pressure

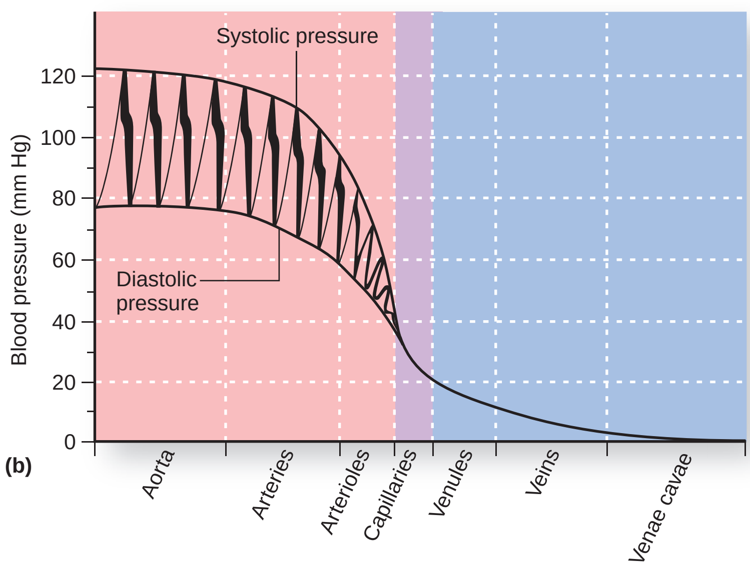
Learning Objectives:

1. Describe the factors that influence blood pressure and its measurement.
2. Compare and contrast diastolic and systolic blood pressure.
3. Explain how blood pressure changes as blood travels through arteries, capillaries, and veins.

The rhythmic pumping of blood through the heart produces a rhythmic pulsation of blood through the arteries. When you check your **pulse** (pŭls; *pulsus* = a stroke), you are feeling these pulsations of blood. Arterial walls contain elastic connective tissue, which allows them to expand and recoil in response to the pulsating blood. Due to this pulsating blood, larger arteries tend to exhibit high pressure, which gradually decreases as blood travels into smaller and smaller arteries.

Blood pressure is the force per unit area that blood places on the inside wall of a blood vessel and is measured in millimeters of mercury (mm Hg). Arterial blood pressure is measured with a **sphygmomanometer** (sfig′mō-mă-nom′ĕ-ter; *sphygmos* = pulse, *manos* = thin, *metron* = measure) **(figure 23.8*a*)**. A cuff

(a)



(b)

Figure 23.8

Blood Pressure. (*a*) A sphygmomanometer is used to measure blood pressure in the brachial artery. (*b*) A tracing compares the blood pressure changes as blood flows through the different vessels in the cardiovascular system.

CLINICAL VIEW

Hypertension: The "Silent Killer"

Hypertension is chronically elevated blood pressure, defined as a systolic pressure greater than 140 mm Hg and/or a diastolic pressure greater than 90 mm Hg. About 90–95% of all hypertension cases are **essential hypertension,** in which the cause is idiopathic (unknown). **Secondary hypertension** accounts for the other 5–10% of cases, meaning that the high blood pressure is caused by another condition, usually renal disease or an adrenal gland tumor.

Hypertension has many serious effects on the body. It causes changes in the blood vessel walls, making them prone to further injury. Increased damage makes the blood vessels more likely to develop atherosclerosis (see Clinical View: In Depth on page 708). In addition, hypertension causes undue stress on arterioles, resulting in thickening of the arteriole walls and reduction in luminal diameter, a condition called **arteriolosclerosis.** Furthermore, hypertension causes thickening of the renal arteries, leading to renal failure, and it can greatly damage the cerebral arteries, making them prone to rupture, which results in a fatal brain hemorrhage or stroke. Finally, hypertension is a major cause of heart failure owing to the extra workload placed on the heart.

Since hypertension is initially asymptomatic (meaning no noticeable symptoms are present), it has been dubbed the "silent killer." Everyone is encouraged to have their blood pressure checked early in life, and regularly, to make sure they are not suffering from hypertension. Mild hypertension may be controlled by losing weight, eating a healthy diet, exercising regularly, and not smoking. Stress is also associated with hypertension; thus, reducing stress, or learning to manage it, is important in treatment. In many instances, however, medication may be needed to control hypertension. Diuretics increase urine output, thereby reducing salt and water retention and consequently lowering blood volume. Beta-blockers slow the heart rate and lower heart output, while ACE (angiotensin-converting enzyme) inhibitors block angiotensin II (a protein that constricts arterioles), thereby increasing vasodilation.

is wrapped around the arm such that when inflated it completely compresses the brachial artery, temporarily stopping the flow of blood. Then air is gradually released from the cuff while a health-care practitioner places a stethoscope just distal to the compressed artery and listens for the sound of blood flow. Once the first pulsation is heard through the stethoscope, the sphygmomanometer is read. The reading on the dial at this time is the **systolic blood pressure,** the pressure in the vessel during ventricular systole (ventricular contraction). The health-care practitioner continues to listen to artery pulsations, and when the pulsations stop (because blood is flowing evenly through the blood vessel), the sphygmomanometer is read again for a measurement of **diastolic blood pressure,** the pressure during ventricular diastole (ventricular relaxation).

Systolic pressure is greater than diastolic pressure due to the greater force from ventricular contraction. Blood pressure is expressed as a ratio, in which the numerator (upper number) is the systolic pressure and the denominator (lower number) is the diastolic pressure. The average adult has a blood pressure of 120/80 mm Hg.

Blood pressure is produced in the ventricles of the heart, so pressure is highest in the arteries closest to the heart, such as the aorta. As the arteries branch into smaller vessels and travel greater distances from the ventricles, blood pressure decreases (figure 23.8*b*). By the time the blood reaches the capillaries, fluctuations between systolic and diastolic blood pressure disappear. Blood pressure at this point is about 40 mm Hg, and once blood leaves the capillaries, pressure is below 20 mm Hg. Blood pressure drops from 20 mm Hg in the venules to almost 0 mm Hg by the time blood travels through the venae cavae to the right atrium of the heart.

Several factors can influence arterial blood pressure. Increased blood volume and increased cardiac output (the amount of blood pumped out of a ventricle in 1 minute) both can increase blood pressure. Vasoconstriction raises blood pressure, while vasodilation reduces blood pressure. Some medicines and drugs can either increase or decrease pressure as well. People who are overweight or less healthy tend to have increased blood pressure.

WHAT DO YOU THINK?

1. Nicotine stimulates the heart and raises cardiac output. It also causes arteriole vasoconstriction. Given this information, would you expect the blood pressure of a smoker to be high or relatively low?

WHAT DID YOU LEARN?

4. What is blood pressure? What are the similarities and differences between systolic pressure and diastolic pressure?

23.3 Systemic Circulation

Learning Objective:

1. **List and describe the major blood vessels involved in blood flow to and from all the body tissues.**

The systemic circulation consists of blood vessels that extend to all body regions. In this section, we discuss arterial and venous systemic blood flow according to body region. As you read these descriptions, it may help you to refer to **figure 23.9**, which shows the locations of the major arteries and veins.

23.3a General Arterial Flow Out of the Heart

Oxygenated blood is pumped out of the left ventricle of the heart and enters the **ascending aorta.** The **left** and **right coronary arteries** emerge immediately from the wall of the ascending aorta and supply the heart. The ascending aorta curves toward the left side of the body and becomes the **aortic arch** (*arch of the aorta*). Three main arterial branches emerge from the aortic arch: (1) the **brachiocephalic** (brā′kē-ō-se-fal′ik) **trunk,** which bifurcates into the **right common carotid** (ka-rot′id) **artery** supplying arterial blood to the right side of the head and neck, and the **right subclavian** (sŭb-klā′vē-an; *sub* = beneath; clavicle) **artery** supplying the right upper limb and some thoracic structures; (2) the **left common carotid artery** supplying the left side of the head and neck; and (3) the **left subclavian artery** supplying the left upper limb and some thoracic structures.

The aortic arch curves and projects inferiorly as the **descending thoracic aorta** that extends several branches to supply the thoracic wall. When this artery extends inferiorly through the aortic opening (hiatus) in the diaphragm, it is renamed the **descending abdominal aorta.** In the abdomen, arterial branches originate from the aorta wall to supply the abdominal wall and organs.

At the level of the fourth lumbar vertebra, the descending abdominal aorta bifurcates into **left** and **right common iliac** (il′ē-ak; *ileum* = groin) **arteries.** Each of these arteries further divides into an **internal iliac artery** (to supply pelvic and perineal structures) and an **external iliac artery** (to supply the lower limb).

23.3b General Venous Return to the Heart

Once oxygenated blood is distributed throughout the body, it returns to the heart through veins that often share the same names as their corresponding arteries (figure 23.9). The veins that drain the head, neck, and upper limbs merge to form the **left** and **right brachiocephalic veins,** which in turn merge to form the **superior vena cava.** The superior vena cava drains directly into the right atrium. The veins inferior to the diaphragm merge to collectively form the **inferior vena cava.** The inferior vena cava lies to the right side of the descending abdominal aorta, and is responsible for carrying venous blood toward the heart from the lower limbs, pelvis and perineum, and abdominal structures. The inferior vena cava extends through the caval opening in the diaphragm and also drains blood directly into the right atrium.

23.3c Blood Flow Through the Head and Neck

The left and right common carotid arteries supply most of the blood to the head and neck. They travel parallel immediately lateral to either side of the trachea **(figure 23.10*a*)**. At the superior border of the thyroid cartilage, each artery divides into an **external carotid artery** that supplies structures external to the skull, and an **internal carotid artery** that supplies internal skull structures. Prior to this bifurcation, the common carotid artery contains a structure called the carotid sinus, which is a receptor that detects changes in blood pressure.

Blood Flow Through the Neck and Superficial Head Structures

The external carotid artery supplies blood to several branches: (1) the **superior thyroid artery** supplies the thyroid gland, larynx, and some anterior neck muscles; (2) the **ascending pharyngeal** (fă-rin′jē-ăl; *pharynx* = throat) **artery** supplies the pharynx; (3) the **lingual** (ling′gwăl) **artery** supplies the tongue; (4) the **facial artery** supplies most of the facial region; (5) the **occipital artery** supplies the posterior portion of the scalp; and (6) the **posterior auricular artery** supplies the ear and the scalp around the ear. Thereafter, the external carotid artery divides into the **maxillary artery,** which supplies the teeth, gums, nasal cavity, and meninges, and the **superficial temporal artery,** which supplies the side of the head and the parotid gland.

Venous return is through smaller veins that merge to form the **facial, superficial temporal,** and **maxillary** (mak′si-lār-ē) **veins** (figure 23.10*b*). Some of these veins merge and drain into either the **internal jugular vein** or the **external jugular vein** that drains into the subclavian vein and then into the brachiocephalic vein. Figure 23.10*c* shows the major arteries and veins of the head and neck.

Blood Flow Through the Cranium

The internal carotid artery branches only after it enters the skull through the carotid canal. Once inside the skull, it forms multiple branches, including the **anterior** and **middle cerebral arteries,** which supply the brain, and the **ophthalmic** (op′thal′mik; *ophthalmos* = eye) **arteries**, which supply the eyes **(figure 23.11)**.

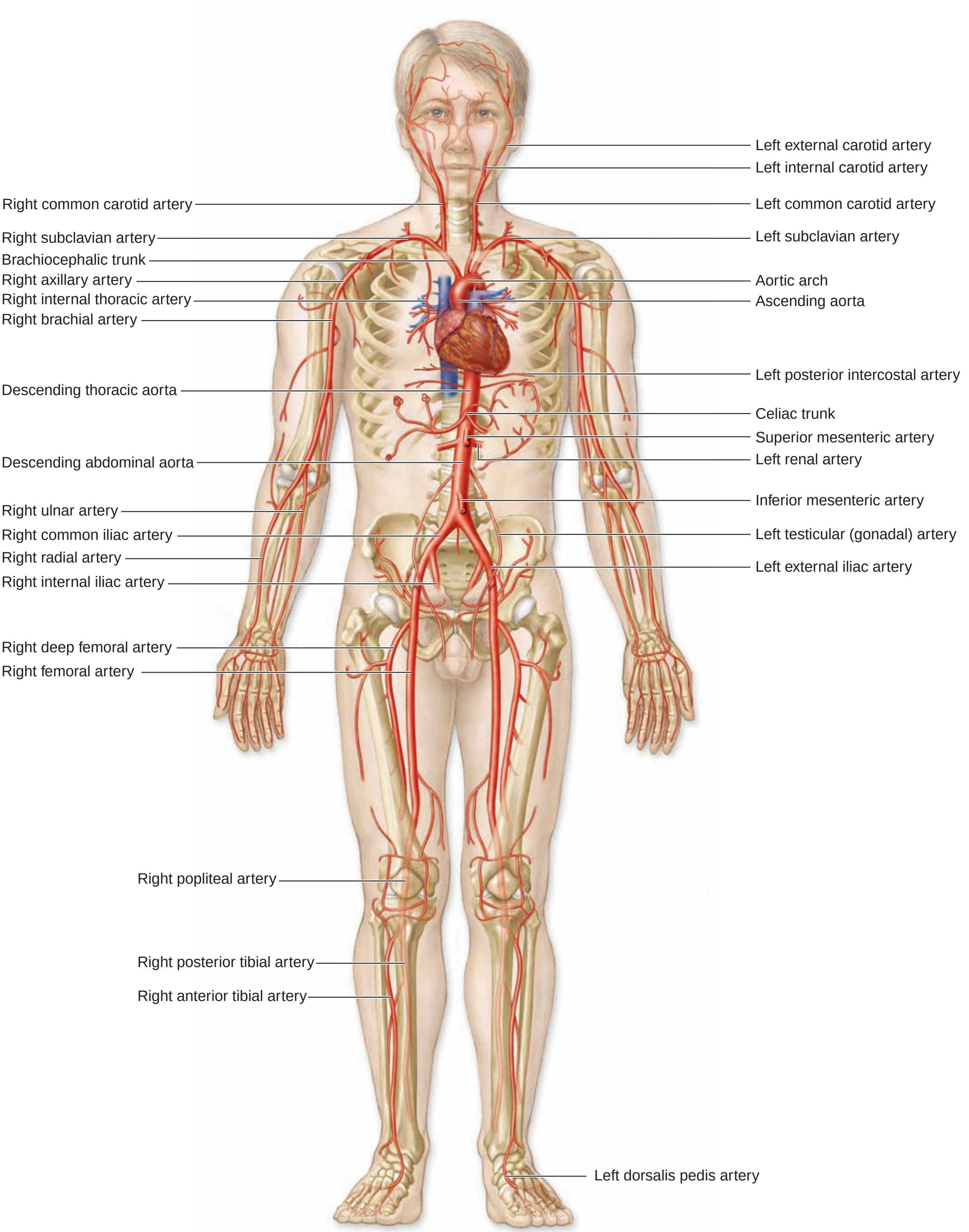
The **vertebral arteries** emerge from the subclavian arteries and travel through the transverse foramina of the cervical vertebrae before entering the skull through the foramen magnum, where they merge to form the **basilar** (bas′i-lăr; *basis* = base) **artery.** The basilar artery travels immediately anterior to the pons and extends many branches prior to subdividing into the **posterior cerebral arteries,** which supply the posterior portion of the cerebrum.

The **cerebral arterial circle** (*circle of Willis*) is an important anastomosis of arteries around the sella turcica. The circle is formed from posterior cerebral arteries, **posterior communicating arteries** (branches of the posterior cerebral arteries), internal carotid arteries, **anterior cerebral arteries,** and **anterior communicating arteries** (which connect the two anterior cerebral arteries). This arterial circle equalizes blood pressure in the brain and can provide collateral channels should one vessel become blocked.

WHAT DO YOU THINK?

2. If both common carotid arteries were blocked, would any blood be able to reach the brain? Why or why not?

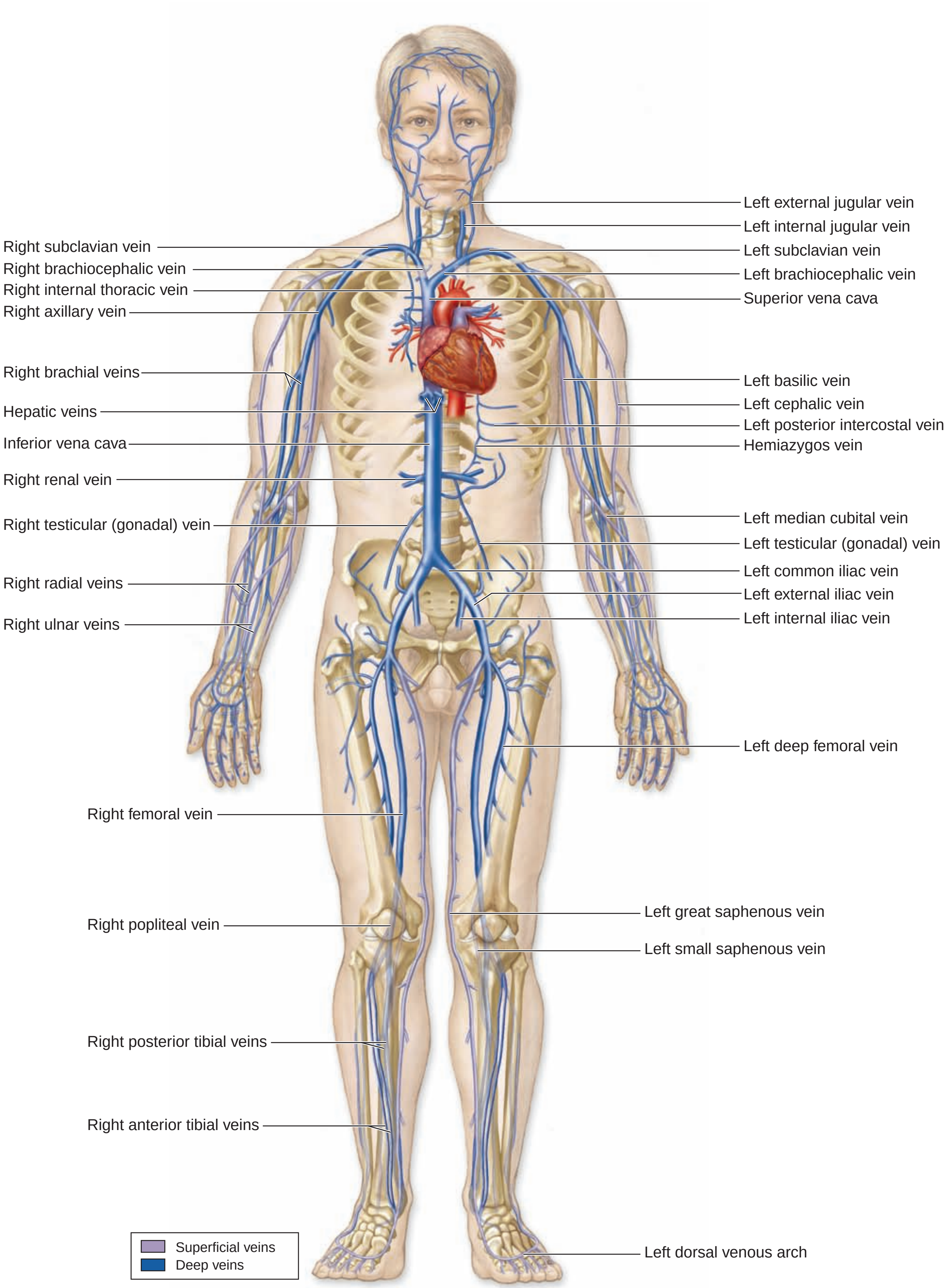
Some cranial venous blood is drained by the **vertebral veins** that extend through the transverse foramina of the cervical vertebrae and drain into the brachiocephalic veins. However, most of the venous blood of the cranium drains through several large veins



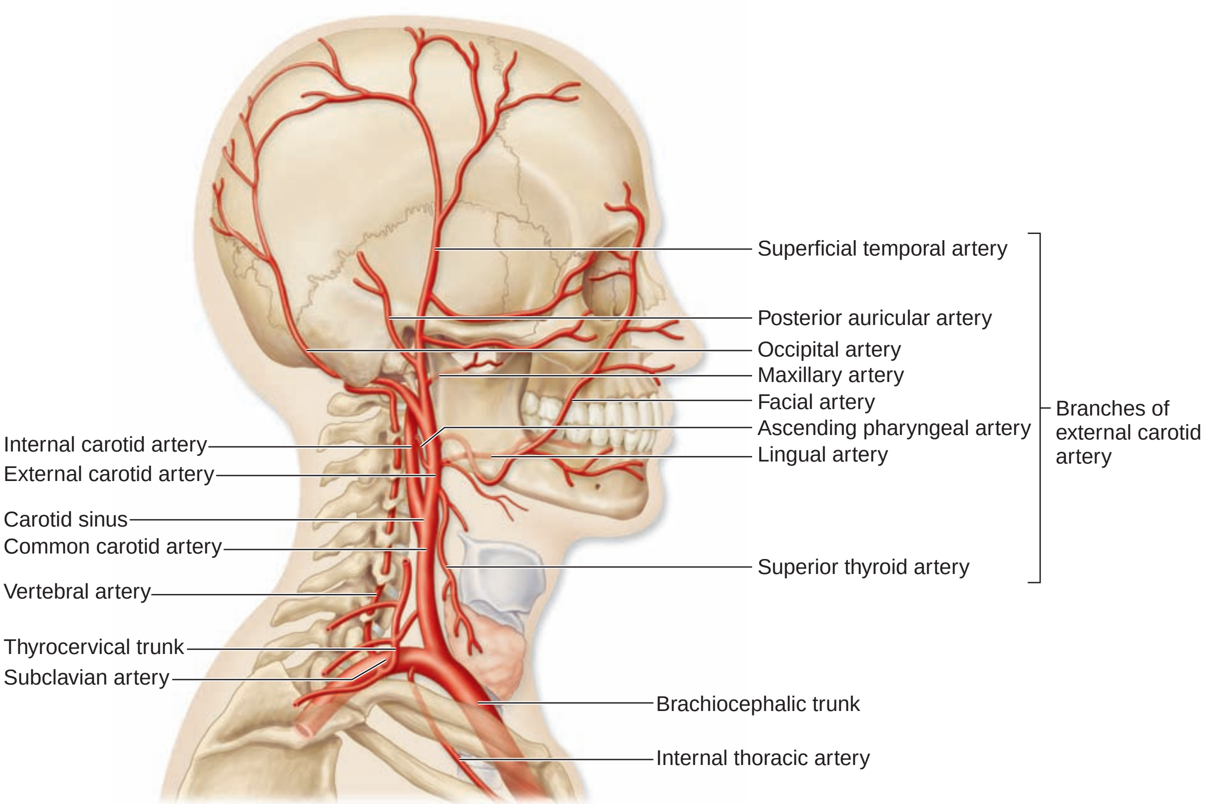
(a) Arteries, anterior view

Figure 23.9

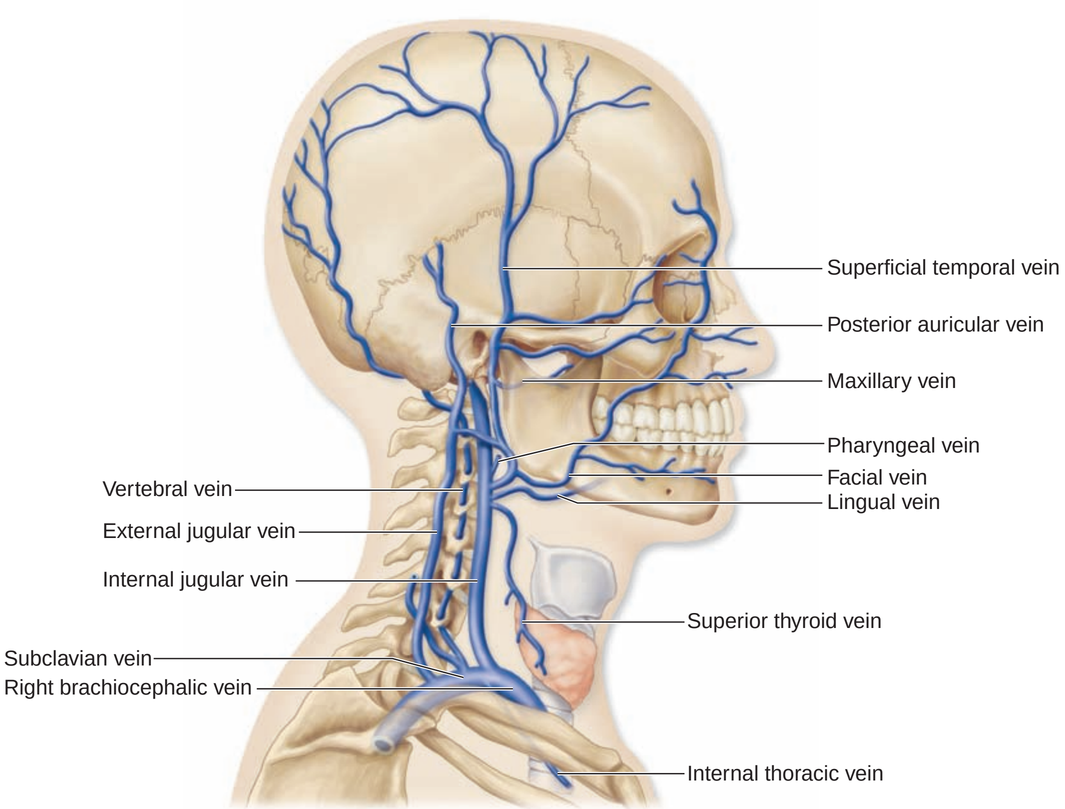
General Vascular Distribution. Arteries in the systemic circulation carry blood from the heart to systemic capillary beds; systemic veins return this blood to the heart. (*a*) Anterior view of the systemic arteries. (*b*) Anterior view of the systemic veins.



(b) Veins, anterior view



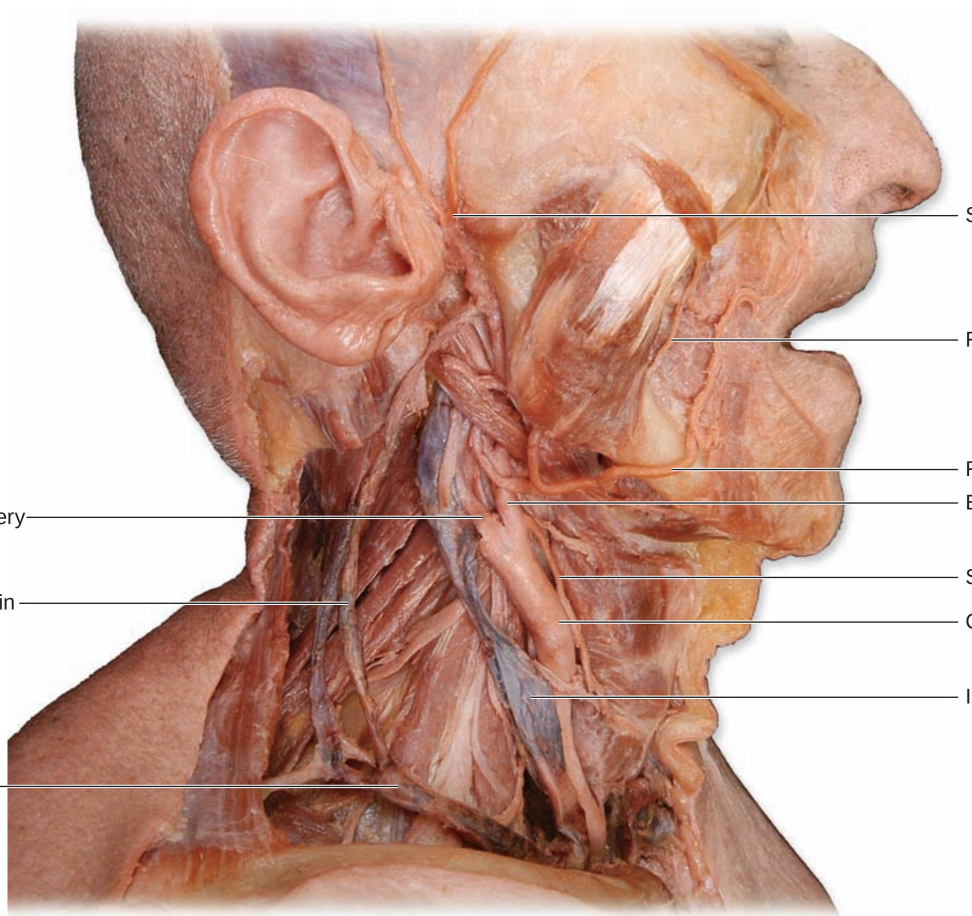
(a) Arteries, right lateral view



(b) Veins, right lateral view

Figure 23.10

Blood Flow to the External Head and Neck. Right lateral views show (*a*) major arteries and (*b*) major veins of the head and neck. (*c*) A cadaver photo shows the major vessels of the head and neck. AP|R



(c) Head and neck vessels, right lateral view

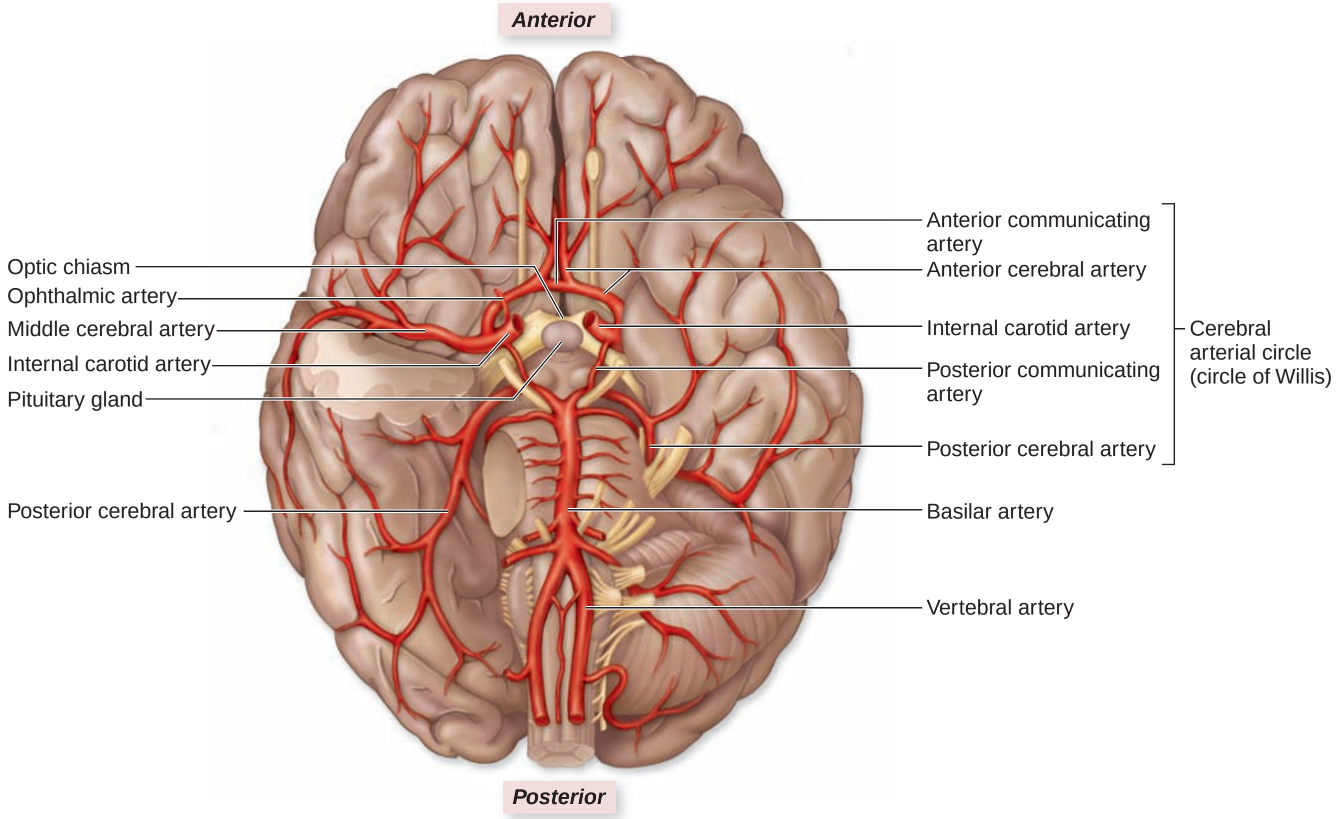
collectively known as the **dural** (doo-răl) **venous sinuses** (figure 23.11*b*). Recall that these large veins are formed between the two layers of dura mater and also receive excess CSF. There are no valves in the dural venous sinus system, so potentially the blood can flow in more than just one direction.

The **dural venous sinus system** has several components (see also figure 15.5). The **superior sagittal sinus** is located superior to the longitudinal fissure of the brain; it drains into one of the transverse sinuses (usually the right one). The **inferior sagittal sinus** occupies the inferior free edge of the falx cerebri. The **straight sinus** is formed by the merging of the inferior sagittal sinus and the great cerebral vein; this sinus drains into **left** and **right transverse sinuses** that run horizontally along the internal margin of the occipital bone. Finally, the S-shaped **left** and **right sigmoid** (sig′moyd; *sigma* = letter S) **sinuses** are a continuation of the transverse sinuses; they drain into the internal jugular veins. The internal jugular veins and subclavian veins merge to form the brachiocephalic veins that drain into the superior vena cava. Additional components of the dural venous sinus system include the **occipital** and **marginal sinuses,** the **superior** and **inferior petrosal sinuses,** and the **cavernous sinuses.** AP|R

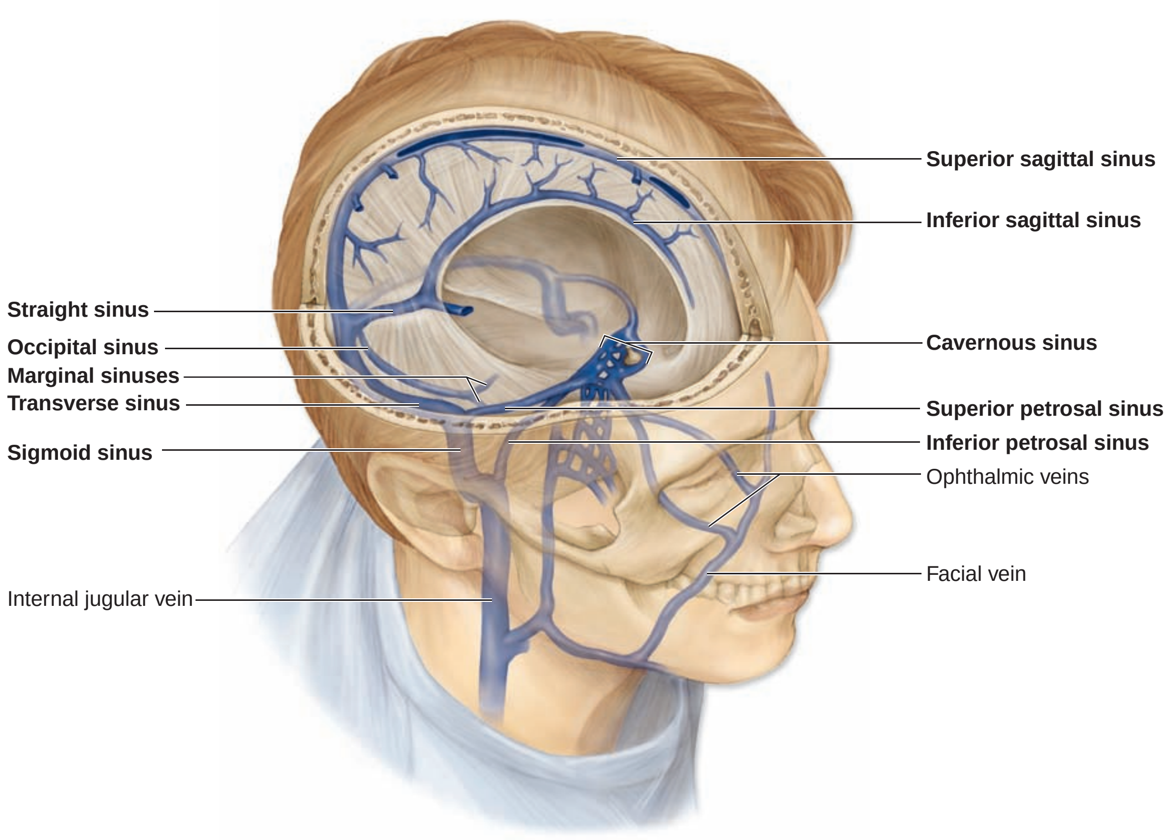
23.3d Blood Flow Through the Thoracic and Abdominal Walls

The arterial flow to the thoracic and abdominal walls is supplied by several pairs of arteries **(figure 23.12)**. A left and right **internal thoracic artery** emerges from each subclavian artery to supply the mammary gland and anterior thoracic wall. Each internal thoracic artery has the following branches: the first six **anterior intercostal arteries** that supply the anterior intercostal spaces, and a **musculophrenic** (mŭs′kū-lō-fren′ik; *phren* = diaphragm) **artery** that divides into anterior intercostal arteries 7–9. The internal thoracic artery then becomes the **superior epigastric** (ep-i-gas′trik; *epi* = upon, *gastric* = stomach) **artery,** which carries blood to the superior abdominal wall. The **inferior epigastric artery,** a branch of the external iliac artery, supplies the inferior abdominal wall. Together, the superior and inferior epigastric arteries form extensive anastomoses.

The left and right **costocervical** (kos′tō-ser′vi-kal) **trunks** and **thyrocervical trunks** emerge from each subclavian artery. The costocervical trunk has a branch called the **supreme intercostal artery,** which branches into the first and second **posterior intercostal arteries.** Posterior intercostal arteries 3–11 are branches



(a) Arteries of the brain, inferior view



(b) Cranial and facial veins, right superior anterolateral view

Figure 23.11

Blood Flow Through the Cranium. The internal carotid and vertebral arteries supply blood to the cranium, and blood is drained from the cranium by the internal jugular veins. (*a*) The arterial circulation is revealed in an inferior view of the brain with a portion of the right temporal lobe and right cerebellar hemisphere removed. (*b*) Venous drainage of the cranium is shown from a superior anterolateral view. The dural venous sinuses are labeled in bold. AP|R

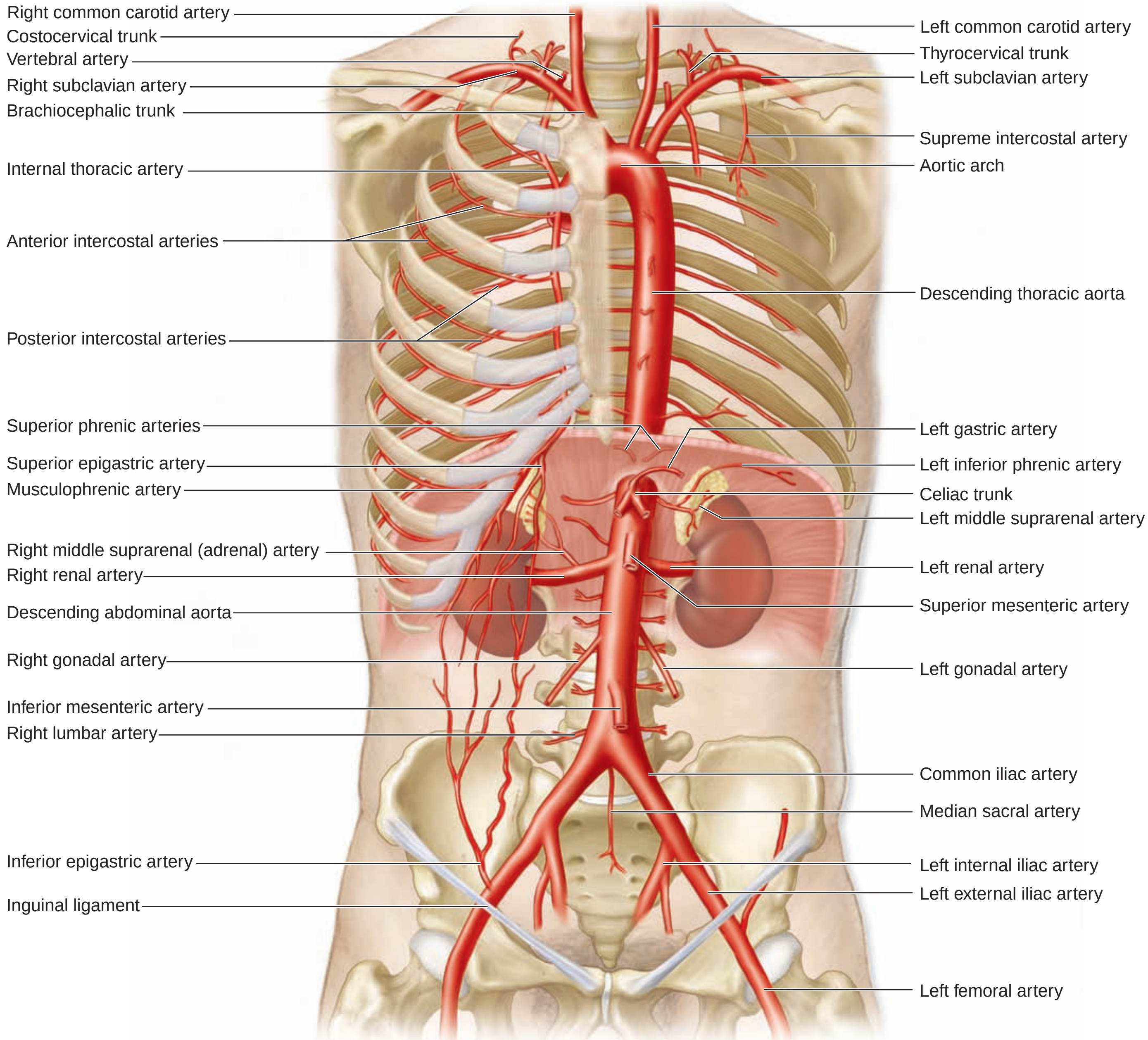


Figure 23.12

Arterial Circulation to the Thoracic and Abdominal Body Walls. The torso is supplied by arteries that have extensive anastomoses. In this illustration, the more anteriorly placed arteries as well as the "vessel arcs" formed by the anterior and posterior intercostal arteries are shown on the right side of the body. The left side of the body illustrates the deeper, posteriorly placed arteries only. AP|R

of the descending thoracic aorta. The posterior and anterior intercostal arteries anastomose, and each pair forms a horizontal vessel arc that spans a segment of the thoracic wall.

Finally, five pairs of **lumbar arteries** branch from the descending abdominal aorta to supply the posterolateral abdominal wall.

In addition to the paired vessels just described, an unpaired **median sacral artery** arises at the bifurcation of the aorta in the pelvic region to supply the sacrum and coccyx.

Venous drainage of the thoracic and abdominal walls is a bit more complex than the arterial pathways **(figure 23.13)**. **Anterior intercostal veins,** a **superior epigastric vein,** and a **musculophrenic vein** all merge into the **internal thoracic vein.** Each internal thoracic vein drains into its respective brachiocephalic vein. The **inferior epigastric vein** merges with the **external iliac vein** that eventually drains into the inferior vena cava. The first and second **posterior intercostal veins** then merge with the **supreme intercostal vein** that drains into the brachiocephalic vein. Remember, the brachiocephalic veins merge to form the superior vena cava.

The **lumbar veins** and **posterior intercostal veins** drain into the azygos system of veins along the posterior thoracic wall. The **hemiazygos** (hem′ē-az′ī-gos) and **accessory hemiazygos veins** on the left side of the vertebrae drain the left-side veins. The **azygos vein** drains the right-side veins and also receives blood from the hemiazygos veins. The azygos vein also receives blood from the esophageal veins, bronchial veins, and pericardial veins. The azygos vein merges with the superior vena cava.

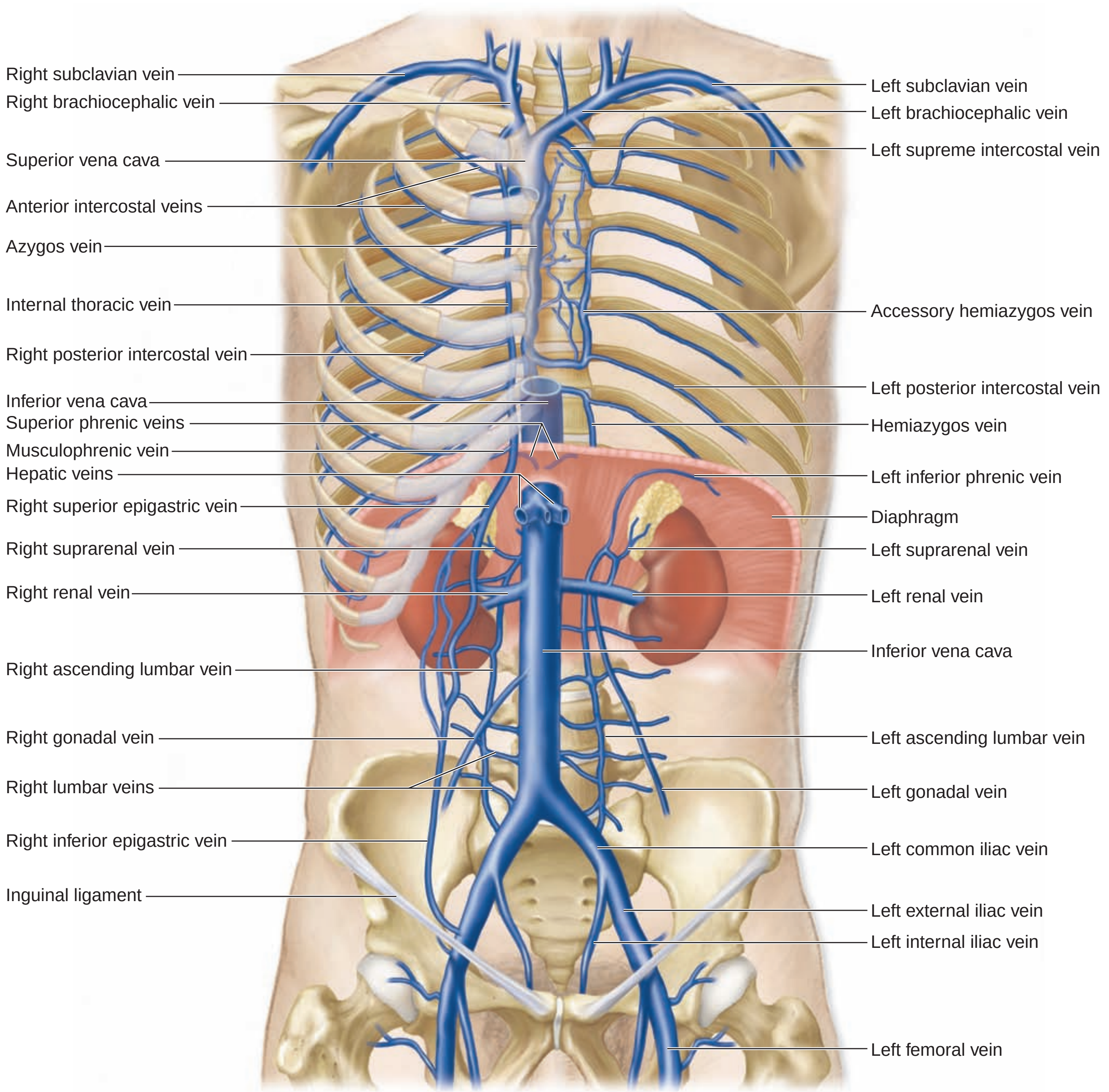


Figure 23.13

Venous Circulation to the Thoracic and Abdominal Body Walls. The right side of this body primarily illustrates the more anteriorly placed veins as well as the "vessel arcs" formed by the anterior and posterior intercostal veins. The left side of the body illustrates the deeper, posteriorly placed veins only. AP|R

Figure 23.14 shows the arteries and veins of the posterior thoracic and abdominal walls.

23.3e Blood Flow Through the Thoracic Organs

The main thoracic organs include the heart, the lungs, the esophagus, and the diaphragm. The vessels of the heart were described in chapter 22; the vessels of the other thoracic organs are discussed here (see figures 23.12 and 23.13).

Lungs

The bronchi, bronchioles, and connective tissue of the lungs are supplied by three or four small **bronchial arteries** that emerge as tiny branches from the anterior wall of the descending thoracic aorta. Left and right **bronchial veins** drain into the azygos system of veins. The rest of the lung receives its oxygen via diffusion directly from the tiny air sacs (alveoli) of the lungs.

Esophagus

Several small **esophageal** (ē-sof′ă-jē′ăl, ē′sŏ-faj′ē-ăl) **arteries** emerge from the anterior wall of the descending thoracic aorta and supply the esophagus. Additionally, the **left gastric artery** forms several **esophageal branches** that supply the abdominal portion of the esophagus. **Esophageal veins** drain the esophageal wall, and may take either of two routes: into the azygos vein or into the left gastric vein. The latter merges with the hepatic portal vein.

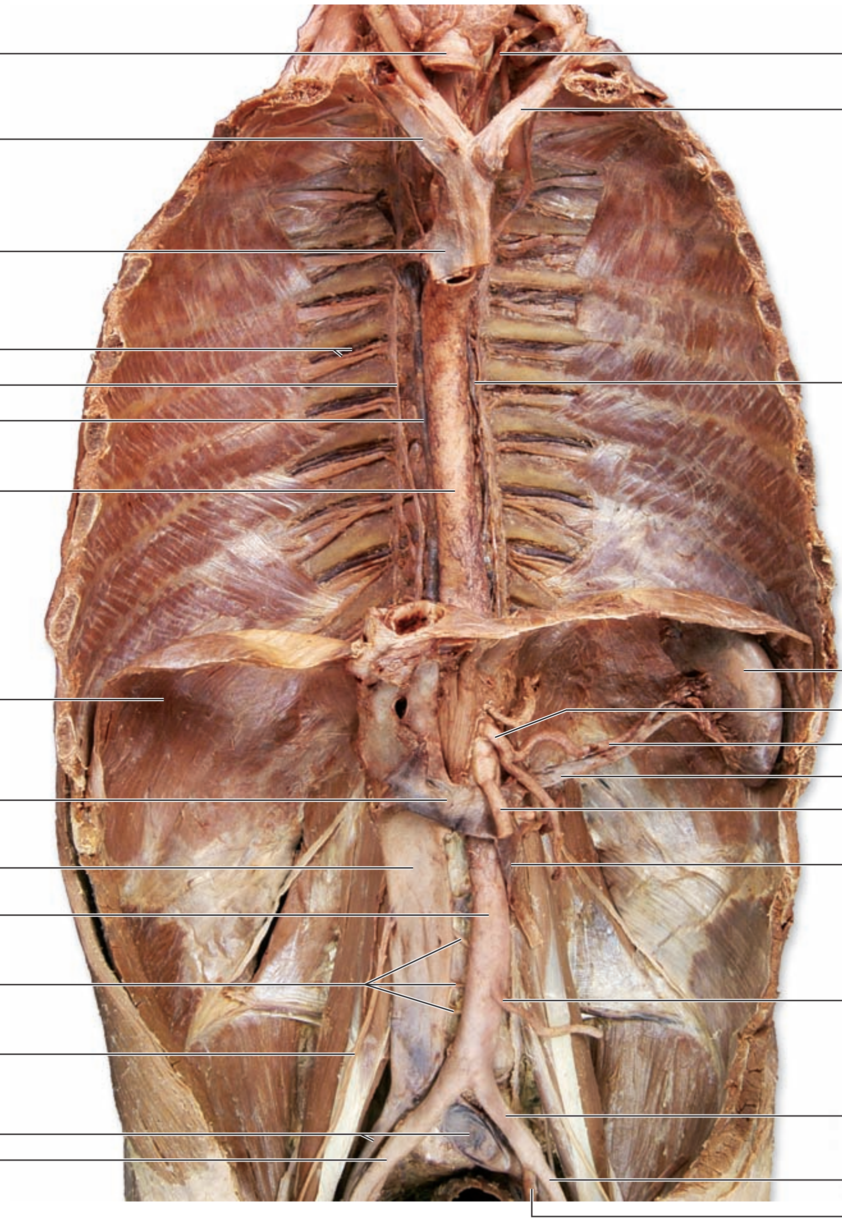


Figure 23.14
Vessels of the Posterior Body Wall. A cadaver photo illustrates the venous and arterial supply to the posterior thoracic and abdominal walls. APR

Diaphragm

Arterial blood is supplied to the diaphragm by paired vessels. **Superior phrenic** (fren′ik; *phren* = diaphragm) **arteries** emerge from the descending thoracic aorta; both **musculophrenic arteries** and pericardiacophrenic arteries arise from the internal thoracic artery; and **inferior phrenic arteries** emerge from the descending abdominal aorta to supply the diaphragm. Superior phrenic and inferior phrenic veins merge with the inferior vena cava, while the musculophrenic and pericardiacophrenic veins drain into the internal thoracic veins that merge with the brachiocephalic veins.

WHAT DID YOU LEARN?

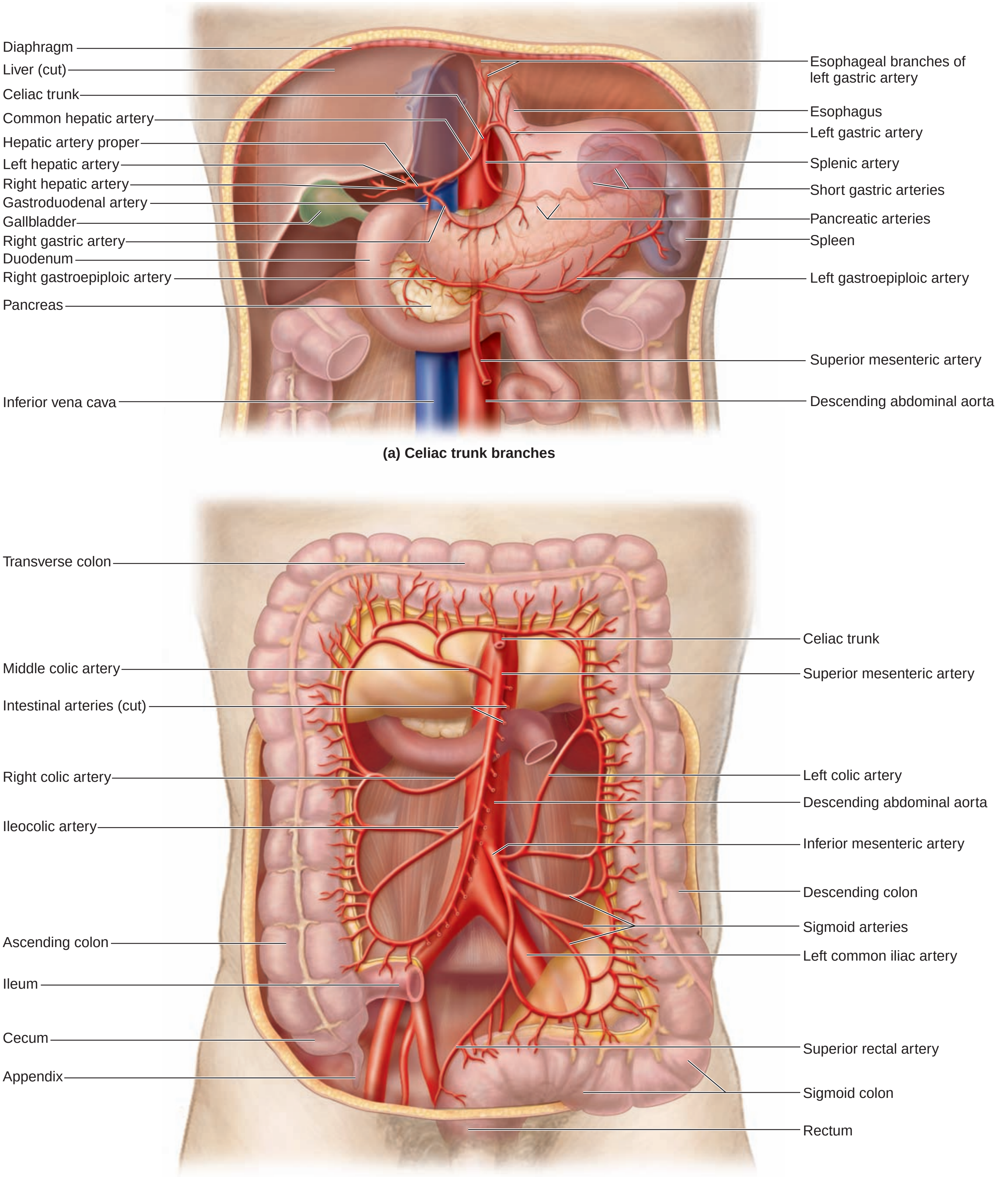
5. What are the three main branches of the aortic arch, and which main body regions are supplied by each branch?
6. Which arteries supply the brain?
7. Describe venous drainage into the azygos system.

23.3f Blood Flow Through the Gastrointestinal Tract

Arterial Supply to the Abdomen

Three unpaired arteries emerge from the anterior wall of the descending abdominal aorta to supply the gastrointestinal (GI) tract. From superior to inferior, these arteries are the celiac trunk, superior mesenteric artery, and inferior mesenteric artery.

The **celiac** (sē′lē-ak; *koilia* = belly) **trunk** is located immediately inferior to the aortic opening (hiatus) of the diaphragm (**figure 23.15*a***). It supplies the stomach, part of the duodenum, the liver, part of the pancreas, and the spleen. Three branches emerge from this arterial trunk: the left gastric, splenic, and common hepatic arteries. (1) The **left gastric artery** supplies the lesser curvature of the stomach, and extends some esophageal branches. The left gastric artery anastomoses with the right gastric artery. (2) The **splenic** (splen′ik) **artery** supplies the spleen part of the stomach (via branches called the **left gastroepiploic**



(a) Celiac trunk branches

(b) Superior and inferior mesenteric arteries

Figure 23.15

Arterial Supply to the Gastrointestinal Tract and Abdominal Organs. The celiac trunk, superior mesenteric artery, and inferior mesenteric artery supply most of the abdominal organs. (*a*) Branches of the celiac trunk supply part of the esophagus, stomach, spleen, pancreas, liver, and gallbladder. (*b*) Branches of the superior mesenteric and inferior mesenteric arteries primarily supply the intestines. AP|R

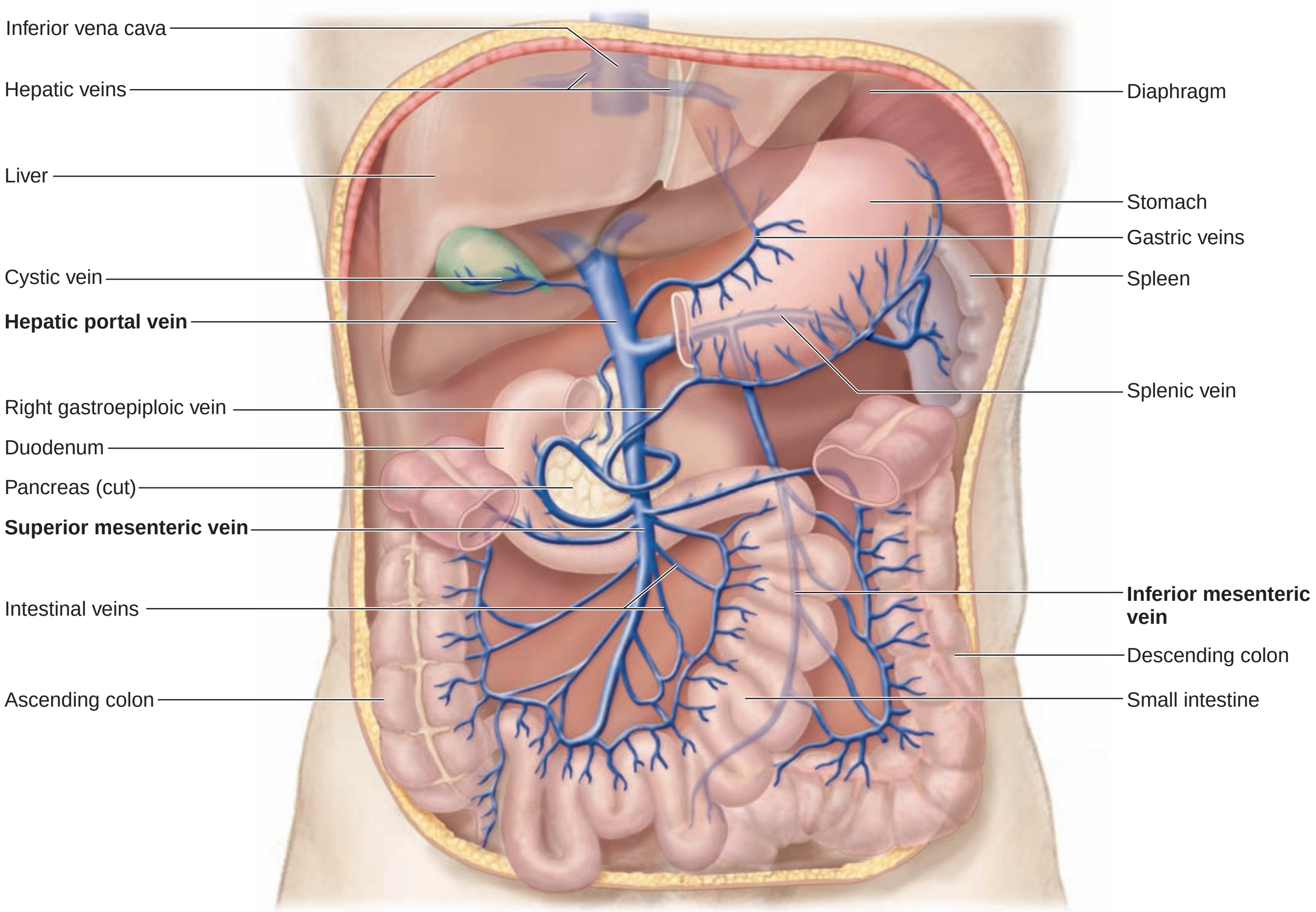


Figure 23.16

Hepatic Portal System. The hepatic portal system is a network of veins that transports venous blood from the GI tract to the liver for nutrient processing. AP|R

[gas′trō-ep′i-plō′ik] **artery** and short gastric arteries), and the pancreas (via branches called pancreatic arteries). (3) The last branch of the celiac trunk is the **common hepatic** (he-pat′ik; *hepat* = liver) **artery,** which extends to the right side of the body where it divides into a hepatic artery proper and a gastroduodenal artery. The **hepatic artery proper** supplies the liver (via **left** and **right hepatic arteries**), the gallbladder (via the **cystic artery**), and part of the stomach (via the **right gastric artery**). The **gastroduodenal** (gas′trō-doo′ō-dē′năl) **artery** supplies the greater curvature of the stomach (via the **right gastroepiploic artery**), the duodenum, and the pancreas (via the superior pancreaticoduodenal arteries).

The **superior mesenteric** (mez-en-ter′ik; *mesos* = middle, *enteron* = intestine) **artery** is located immediately inferior to the celiac trunk (figure 23.15*b*). The superior mesenteric artery supplies blood to most of the small intestine, the pancreas, and the proximal part of the large intestine. Its branches include: (1) the inferior pancreaticoduodenal arteries that anastomose with the superior pancreaticoduodenal arteries to supply the duodenum and pancreas; (2) 18–20 **intestinal arteries** that supply the jejunum and ileum; (3) the **ileocolic** (il′ē-ō-kol′ik) **artery** that supplies the ileum, cecum, and appendix; (4) the **right colic artery** that typically supplies the ascending colon; and (5) the **middle colic artery** that supplies most of the transverse colon.

The **inferior mesenteric artery** is the most inferior of the three unpaired arteries that arise from the descending abdominal aorta. It emerges approximately 5 centimeters superior to bifurcation of the aorta at about the level of vertebra L3. The branches of the inferior mesenteric artery include: (1) the **left colic artery** that supplies the distal part of the transverse colon and part of the descending colon; (2) the **sigmoid arteries** that supply the inferior descending colon and the sigmoid colon; and (3) the **superior rectal** (rek′tăl; *rectus* = straight) **artery** that is a continuation of the inferior mesenteric artery and supplies the rectum.

Venous Return from the Abdomen

In contrast to most arteries and veins that run parallel to one another, the celiac artery and the common hepatic artery do not have corresponding veins of the same name. Rather, the veins of the gastrointestinal tract all merge into some part of the hepatic portal system.

Hepatic Portal System

The **hepatic portal** (pōr′tăl; *porta* = gate) **system** is a venous network that drains the GI tract and shunts the blood to the liver for absorption and processing of transported materials **(figure 23.16)**. Following nutrient absorption, the blood exits the liver through **hepatic veins** that merge with the inferior vena cava.

The hepatic portal system is needed because the GI tract absorbs digested nutrients, and these nutrients must be absorbed

Figure 23.17

Major Vessels of the Posterior Abdominal Wall. In this cadaver photo, note that the inferior mesenteric vein varies from the "average" hepatic portal system pattern by draining into the superior mesenteric vein.

and processed in the liver. The liver also detoxifies harmful agents that have been absorbed by the gastrointestinal blood vessels. The most efficient route for handling and processing the absorbed nutrients and any absorbed harmful substances is a system of vessels that drains the GI tract directly into the liver, rather than distributing these materials throughout the entire cardiovascular system. The hepatic portal system also receives products of erythrocyte destruction from the spleen, so that the liver can "recycle" some of these components.

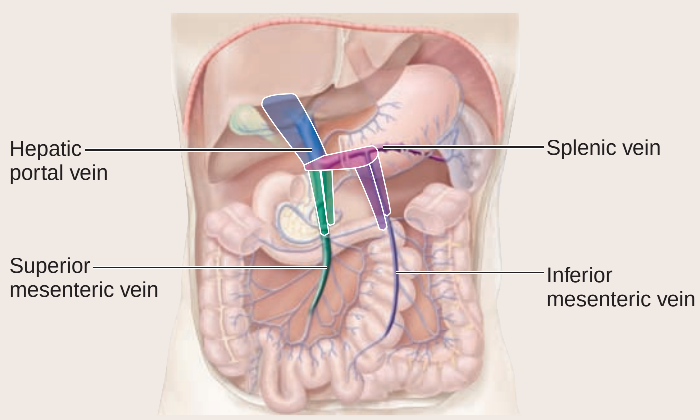
The **hepatic portal vein** is the large vein that receives deoxygenated (oxygen-poor) but nutrient-rich blood from the gastrointestinal organs. Three main venous branches merge to form this vein: (1) The **inferior mesenteric vein,** a vertically positioned vein draining the distal part of the large intestine, receives blood from the superior rectal vein, sigmoid veins, and left colic vein. The inferior mesenteric vein typically (but not always) drains into the splenic vein. (2) The **splenic vein,** a horizontally positioned vein draining the spleen, receives blood from pancreatic veins, short gastric veins, and the right gastroepiploic vein. (3) The **superior mesenteric vein,** another vertically positioned vein on the right side of the body, drains the small intestine and part of the large intestine. It receives blood from the intestinal veins, pancreaticoduodenal veins, ileocolic vein, and right and middle colic veins. Some small veins, such as the left and right gastric veins, drain directly into the hepatic portal vein.

Figure 23.17 is a cadaver photo showing the arteries and veins of the posterior abdominal wall region. Note in this example that the inferior mesenteric vein drains into the superior mesenteric vein, not the splenic vein. This figure illustrates that the hepatic portal system can show great variation in some individuals.

The venous blood in the hepatic portal vein flows through the sinusoids of the liver for absorption, processing, and storage of nutrients. In these sinusoids, the venous blood mixes with some arterial blood entering the liver in the hepatic arteries. Thus, liver

Study Tip!

Although the pattern of the veins of the hepatic portal system can vary, together they typically resemble the side view of a chair. The front leg of the "chair" represents the inferior mesenteric vein, while the back leg represents the superior mesenteric vein. The seat of the chair is the splenic vein, while the back represents the hepatic portal vein.



The configuration of the veins of the hepatic portal system resembles the side view of a chair.

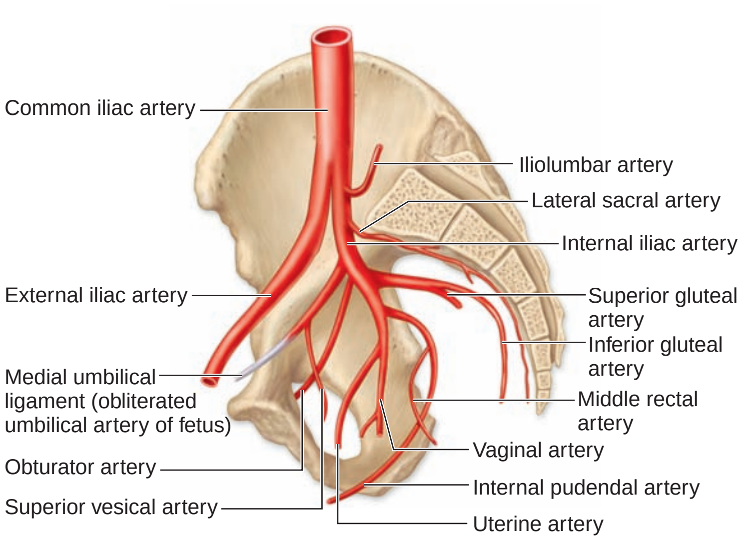


Figure 23.18

Arterial Supply to the Pelvis. Branches of the right internal iliac artery distribute blood to the pelvic organs. Shown is a female pelvis; a male pelvis would have no uterine artery, and instead of a vaginal artery, would have an inferior vesical artery. AP|R

cells also receive oxygenated blood. Once nutrient absorption has occurred, blood leaves the liver through **hepatic veins** that merge with the inferior vena cava. AP|R

23.3g Blood Flow Through the Posterior Abdominal Organs, Pelvis, and Perineum

In addition to the arteries already mentioned, three other paired arterial branches emerge from the sides of the descending abdominal aorta: (1) The **middle suprarenal artery** supplies each adrenal gland; (2) the **renal** (rē′năl) **artery** supplies each kidney; and (3) the **gonadal** (gō-nad′ăl) **artery** supplies each gonad (testes in males, ovaries in females) (see figure 23.12). (Note: The right middle suprarenal artery may branch from the right renal artery in some individuals.) Subsequently, these organs are drained by veins having the same name as the arteries. **Left suprarenal** and **gonadal veins** typically merge with and drain into the **left renal vein.** The left renal vein, **right renal vein, right suprarenal vein,** and **right gonadal vein** merge directly into the inferior vena cava.

The primary arterial supply to the pelvis and perineum is from the **internal iliac artery,** one of the two main branches of the common iliac artery **(figure 23.18)**. Some branches of the internal iliac artery include: (1) the **superior** and **inferior gluteal** (gloo′tē-ăl) **arteries** that supply the gluteal region; (2) the **obturator** (ob′too-rā-tŏr) **artery** that supplies medial muscles of the thigh; (3) the **internal pudendal** (pū-den′dăl; *pudeo* = to feel ashamed) **artery** that supplies the anal canal and perineum; (4) the **middle rectal artery** that supplies the lower portion of the rectum; and (5) the **uterine** (ū′ter-in) **artery** and **vaginal artery** (in females) that supply the uterus and vagina. Some minor branches of the internal iliac artery include the iliolumbar arteries that supply the posterior abdominal wall muscles, the lateral sacral arteries that supply the region around the sacrum, and the vesical arteries that supply the bladder and the prostate (in males).

The pelvis and perineum are drained by veins with the same name as the supplying arteries. The veins merge with the **internal iliac vein** that merges with the **common iliac vein,** which subsequently drains into the inferior vena cava.

WHAT DID YOU LEARN?

8 What three main branches arise from the celiac trunk?

9 Describe the hepatic portal system. Which veins drain into it? What is the main function of the hepatic portal system?

10 What branches of the internal iliac artery are seen in females only?

23.3h Blood Flow Through the Upper Limb

Blood flow through the upper limb closely mirrors its flow through the lower limb in many respects. Both the upper and lower limbs are supplied by a main arterial vessel: the subclavian artery for the upper limb and the femoral artery for the lower limb. This artery bifurcates at the elbow or knee. Arterial and venous arches are seen in both the hand and foot. Finally, both the upper limb and the lower limb have superficial and deep networks of veins.

Arterial Flow

A **subclavian artery** supplies blood to each upper limb **(figure 23.19*a*)**. The left subclavian artery emerges directly from the aortic arch, while the right subclavian artery is a division of the brachiocephalic trunk. The subclavian artery extends multiple branches: (1) the vertebral artery, (2) the thyrocervical trunk (to supply the thyroid gland and some neck and shoulder muscles), (3) the costocervical trunk, and (4) the internal thoracic artery.

After the subclavian artery passes over the lateral border of the first rib, it is renamed the **axillary** (ak′sil-ār-ē) **artery.** The axillary artery extends many branches to the shoulder and thoracic region, including the supreme thoracic artery (not to be confused with the supreme intercostal artery), the thoracoacromial artery, the lateral thoracic artery, the humeral circumflex arteries, and the subscapular artery. When the axillary artery passes the inferior border of the teres major muscle, it is renamed the **brachial** (brā′kē-ăl) **artery.** The brachial artery travels alongside the humerus. One of its branches is the **deep brachial artery** (also known as the *profunda brachii artery* or *deep artery of the arm*), which supplies blood to most brachial (arm) muscles. In the cubital fossa, the brachial artery divides into an **ulnar** (ŭl′năr) **artery** and a **radial** (rā′dē-ăl) **artery.** Both arteries supply the forearm and wrist before they anastomose and form two arterial arches in the palm: the **superficial palmar** (pawl′măr) **arch** (formed primarily from the ulnar artery) and the **deep palmar arch** (formed primarily from the radial artery). **Digital arteries** emerge from the arches to supply the fingers.

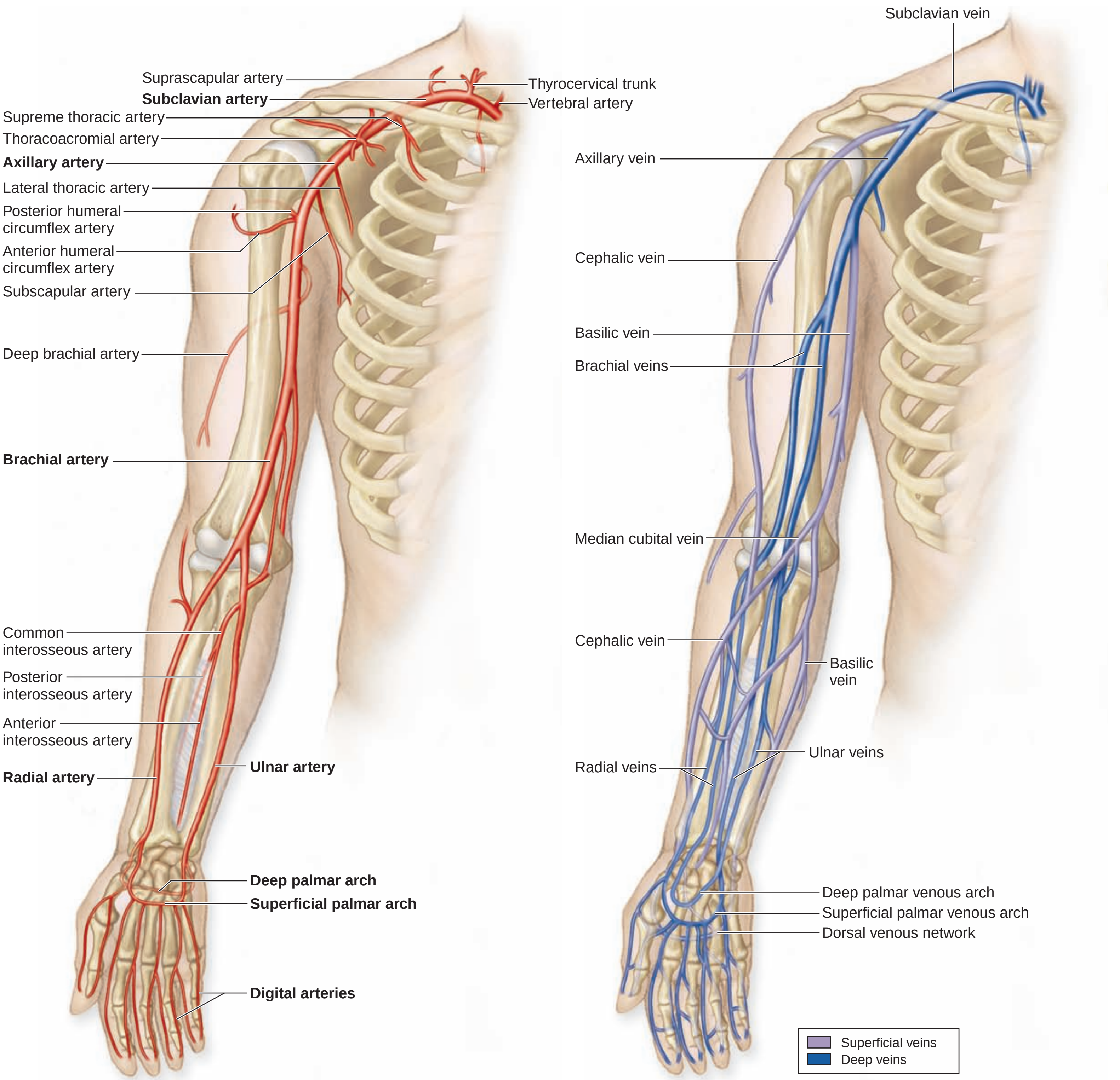
WHAT DO YOU THINK?

3 If the left ulnar artery were cut, would any blood be able to reach the left hand and fingers? Why or why not?

Venous drainage of the upper limb is through two groups of veins: superficial and deep.

Superficial Venous Drainage of the Upper Limb

On the dorsum of the hand, a **dorsal venous network** (or *arch*) of veins drains into both the **basilic** (ba-sil′ik) **vein** and the **cephalic** (se-fal′ik) **vein** (figure 23.19*b*). The basilic vein runs adjacent to the medial surface of the upper limb and eventually helps form the axillary vein. The cephalic vein runs alongside the lateral aspect of the upper limb, enters the deltopectoral triangle, and drains into the axillary vein. These superficial veins have perforating branches that allow them to connect to the deeper veins.

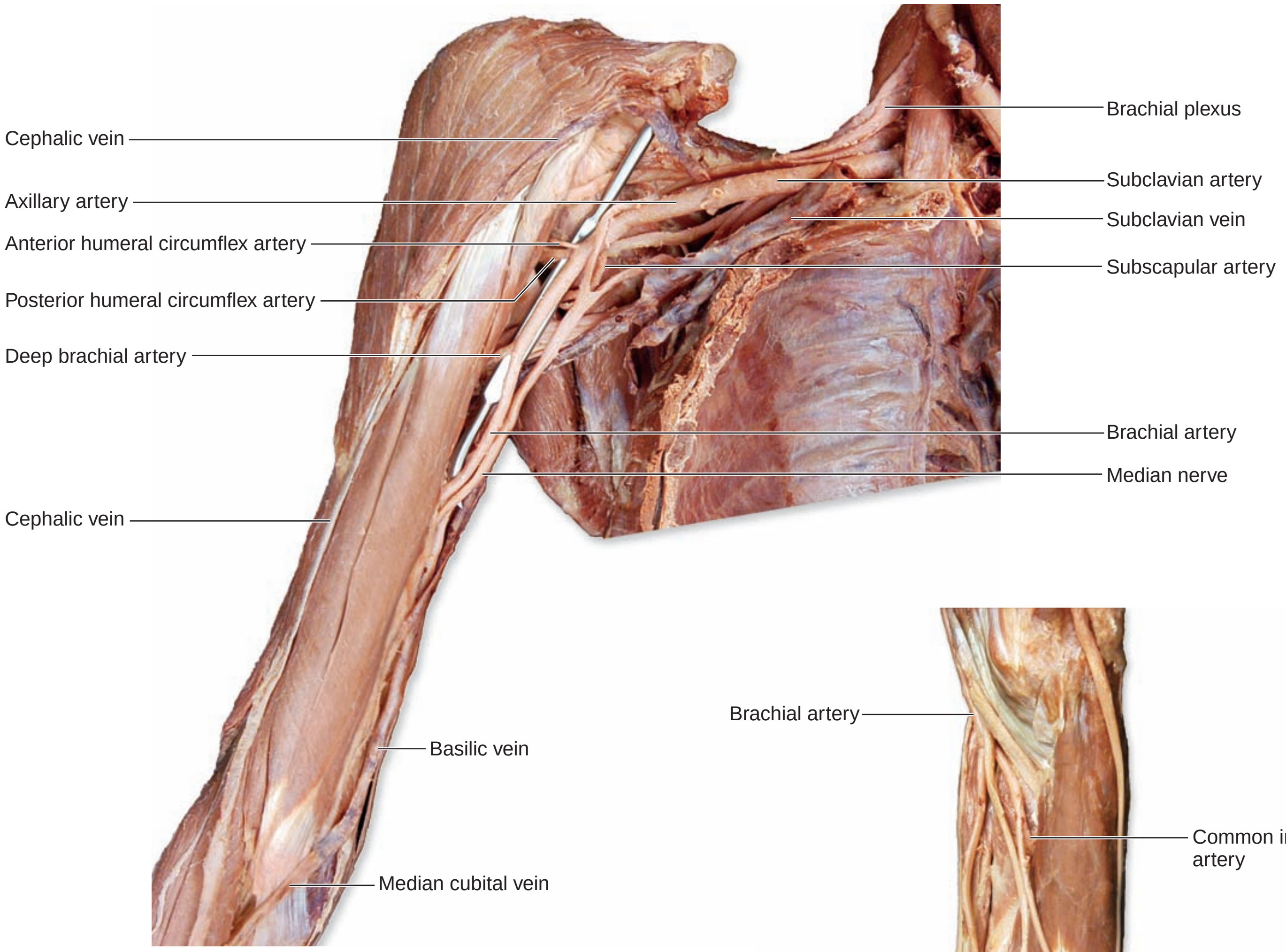


(a) Arteries of right upper limb

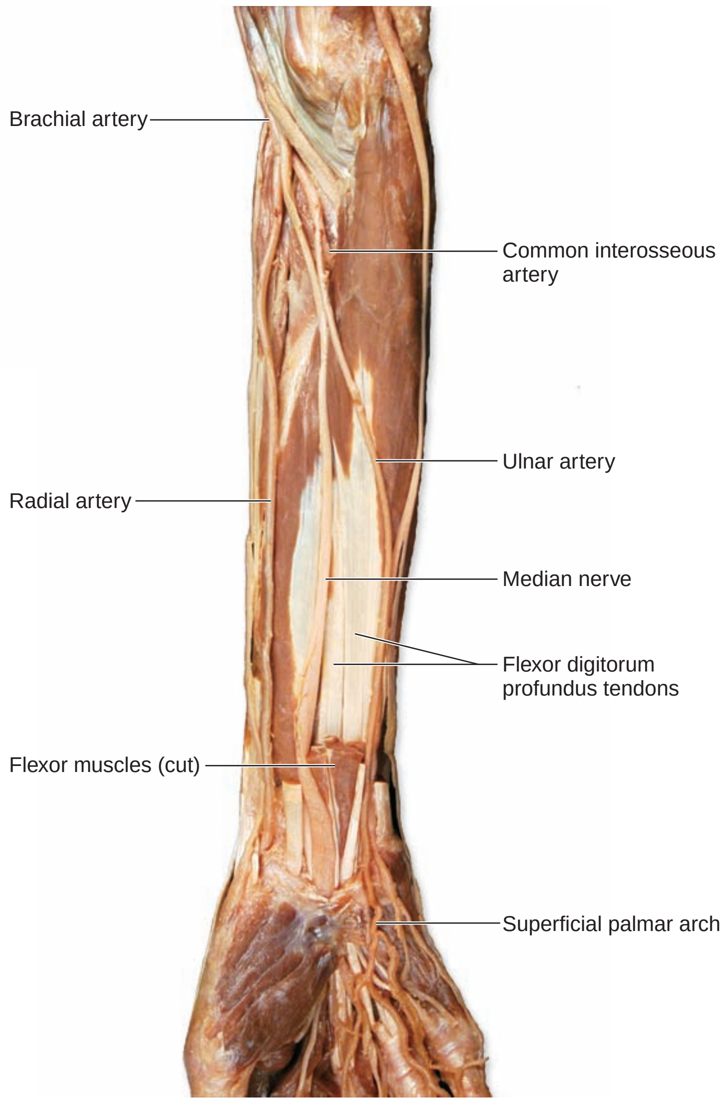
(b) Veins of right upper limb

Figure 23.19

Vascular Supply to the Upper Limb. The subclavian artery carries oxygenated blood to the upper limb; veins merge to return deoxygenated blood to the heart. (*a*) Arteries that supply the upper limb. (*b*) Veins that return blood from the upper limb. (*c*) Cadaver photo of the major vessels of the right arm. (*d*) Cadaver photo of the major vessels of the right forearm. AP|R



(c) Right axilla and arm, anterior view

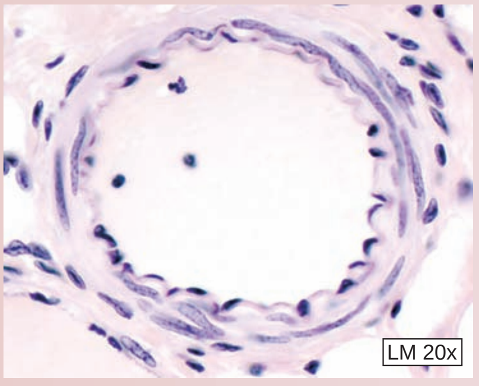


(d) Right forearm, anterior view

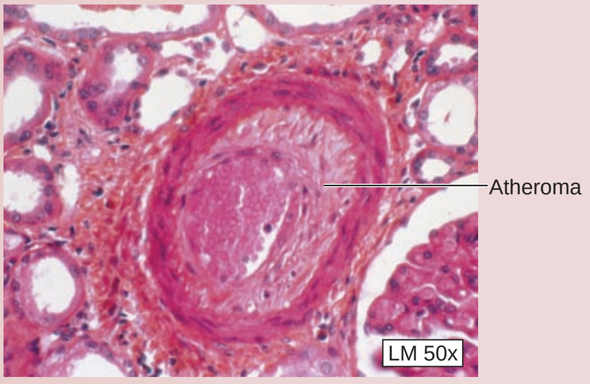
CLINICAL VIEW: In Depth

Atherosclerosis

Atherosclerosis (ath′er-ō-skler-ō′sis, *athere* = gruel, *sclerosis* = hardening) is a progressive disease of the elastic and muscular arteries. It is characterized by the presence of an **atheroma** (or *atheromatous plaque*), which leads to thickening of the tunica intima and narrowing of the arterial lumen. Atherosclerosis is linked to over 50% of all deaths in the United States, and it is a leading cause of morbidity and mortality in other countries of the western world as well.



(a) Normal artery



(b) Atherosclerotic artery

ETIOLOGY OF ATHEROSCLEROSIS

Although the cause of atherosclerosis is not completely understood, the **response-to-injury hypothesis** is the most widely accepted. This proposal states that injury (especially repeated injury) to the endothelium of an arterial wall results in an inflammatory reaction that eventually leads to the development of an atheroma. The injury could be caused by infection, trauma to the vessel, or hypertension. The injured endothelium becomes more permeable, which encourages leukocytes and platelets to adhere to the lesion and initiate an inflammatory response. Low-density lipoproteins (LDLs) and very-low-density lipoproteins (VLDLs) enter the tunica intima, combine with oxygen, and remain stuck to the vessel wall. This oxidation of lipoproteins attracts monocytes, which adhere to the endothelium and migrate into the wall. As the monocytes migrate into the wall, they digest the lipids and develop into structures called **foam cells**. Eventually, smooth muscle cells from the tunica media migrate into the atheroma and proliferate, causing further enlargement of the atheroma. Atherosclerotic plaques cause narrowing of the lumen of the blood vessel, thereby restricting blood flow to the regions the artery supplies. In addition, the plaque may rupture, causing a blood clot to form and completely block the artery.

Atherosclerosis is a progressive disease. The plaques begin to develop in early adulthood and grow and enlarge as we age. People are unaware of the plaques until they become large enough to restrict blood flow in an artery and cause vascular complications.

RISK FACTORS FOR ATHEROSCLEROSIS

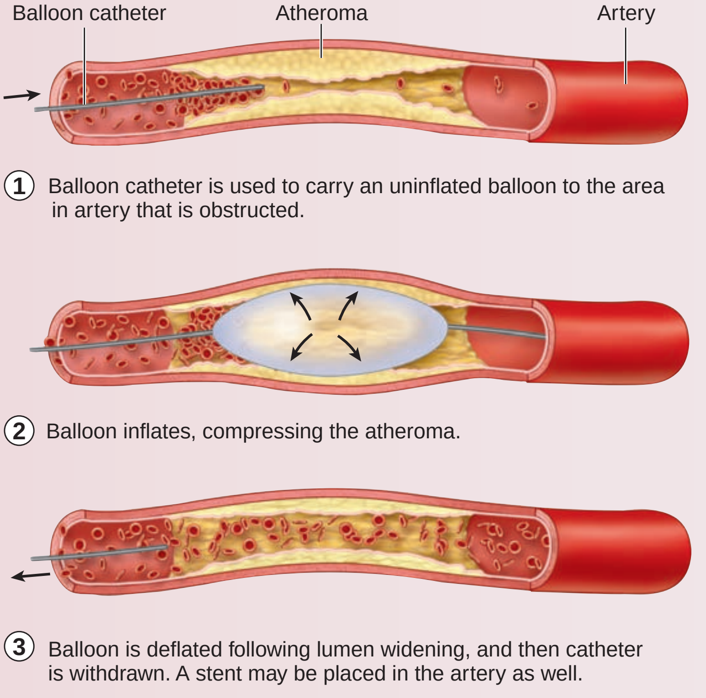
Some individuals are genetically prone to atherosclerosis. **Hypercholesterolemia** (an increased amount of cholesterol in the blood), which also tends to run in families, has been positively associated with the rate of development and severity of atherosclerosis. In addition, males tend to be affected more than females, and symptomatic atherosclerosis increases with age. Finally, smoking and hypertension both cause vascular injury, which increases the risk.

TREATMENT AND PREVENTION OPTIONS

If an artery is occluded (blocked) in one or just a few areas, a treatment called **angioplasty** (an′jē-ō-plas-tē; *angeion* = vessel, *plastos* = formed) is used. A physician inserts a balloon-tip catheter into an artery, and positions it at the site where the lumen is narrowed. Then the balloon is inflated, forcibly expanding the narrowed area. To ensure that the area remains open, a stent may be placed at the site. A stent is a piece of wire-mesh that springs open to keep the vessel lumen open. The stent becomes a permanent part of the vessel. For occluded coronary arteries, a much more invasive treatment known as **coronary bypass surgery** may be needed. A vein (e.g., great saphenous vein) or artery (e.g., internal thoracic artery) is detached from its original location and grafted from the aorta to the coronary artery system, thus bypassing the area(s) of atherosclerotic narrowing.

Ideally, the best treatment for atherosclerosis is to try to prevent it by:

- Maintaining a healthy diet and watching your cholesterol level. High cholesterol levels can be treated with drugs called statins.
- Not smoking.
- Monitoring your blood pressure regularly. If you have hypertension, seek treatment as soon as possible.



Angioplasty is used to expand the narrowed region of an artery.

In the cubital region, an obliquely positioned **median cubital vein** connects the cephalic and basilic veins. The median cubital vein is a common site for **venipuncture,** in which a vein is punctured to draw blood or inject a solute. All of these superficial veins are highly variable among individuals and have multiple superficial tributaries draining into them.

Deep Venous Drainage of the Upper Limb

The digital veins and **superficial** and **deep palmar venous arches** drain into pairs of **radial veins** and **ulnar veins** that run parallel to arteries of the same name. (Paired veins that run alongside an artery are collectively known as *venae commitantes*.) At the level of the cubital fossa, the radial and ulnar veins merge to form a pair of **brachial veins** that travel with the brachial artery. Brachial veins and the basilic vein merge to form the **axillary vein.** Superior to the lateral border of the first rib, the axillary vein is renamed the **subclavian vein.** When the subclavian vein and jugular veins of the neck merge, they form the brachiocephalic vein. As we have seen, the left and right brachiocephalic veins form the superior vena cava.

The combined arteries and veins of the upper limbs are shown in cadaver photos in figure 23.19*c, d*.

23.3i Blood Flow Through the Lower Limb

The arterial and venous blood flow of the lower limb is very similar to that of the upper limb. As we discuss lower limb blood flow, compare it with that of the upper limb.

Arterial Flow

The main arterial supply for the lower limb is the external iliac artery, which is a branch of the common iliac artery **(figure 23.20*a*)**. The external iliac artery travels inferior to the inguinal ligament, where it is renamed the **femoral** (fem′ō-răl) **artery.** The **deep femoral artery** (*profunda femoris artery* or *deep artery of the thigh*) emerges from the femoral artery to supply the hip joint (via medial and lateral femoral circumflex arteries) and many of the thigh muscles, before traversing posteromedially along the thigh. The femoral artery passes through an opening in the adductor magnus muscle and enters the posteriorly placed popliteal fossa, where the vessel is renamed the **popliteal** (pop-lit′ē-ăl, pop-li-tē′ăl) **artery.** The popliteal artery supplies the knee joint and muscles in this region.

The popliteal artery divides into an **anterior tibial** (tib′ē-ăl) **artery** that supplies the anterior compartment of the leg, and a **posterior tibial artery** that supplies the posterior compartment of the leg. The posterior tibial artery extends a branch called the **fibular** (fib′ū-lăr) **artery,** which supplies the lateral compartment leg muscles.

The posterior tibial artery continues to the plantar side of the foot, where it branches into **medial** and **lateral plantar arteries.** The anterior tibial artery crosses over the anterior surface of the ankle, where it is renamed the **dorsalis pedis artery.** The dorsalis pedis artery and a branch of the lateral plantar artery unite to form the **plantar** (plan′tăr) **arch** of the foot. **Digital arteries** extend from the plantar arch and supply the toes.

WHAT DO YOU THINK?

4. If the right femoral artery were blocked, would any blood be able to reach the right leg? Why or why not?

Venous drainage of the lower limb is through two groups of veins: superficial and deep.

Superficial Venous Drainage of the Lower Limb

On the dorsum of the foot, a **dorsal venous arch** drains into the **great saphenous** (să-fē′nŭs) **vein** and the **small saphenous vein** (figure 23.20*b*). The great saphenous vein originates in the medial ankle and extends adjacent to the medial surface of the entire lower limb before it drains into the femoral vein. The small saphenous vein extends adjacent to the lateral ankle and then travels along the posterior calf, before draining into the popliteal vein. These superficial veins have perforating branches that connect to the deeper veins. If the valves in these veins (or the perforating branches) become incompetent, varicose veins develop (see the Clinical View on page 690).

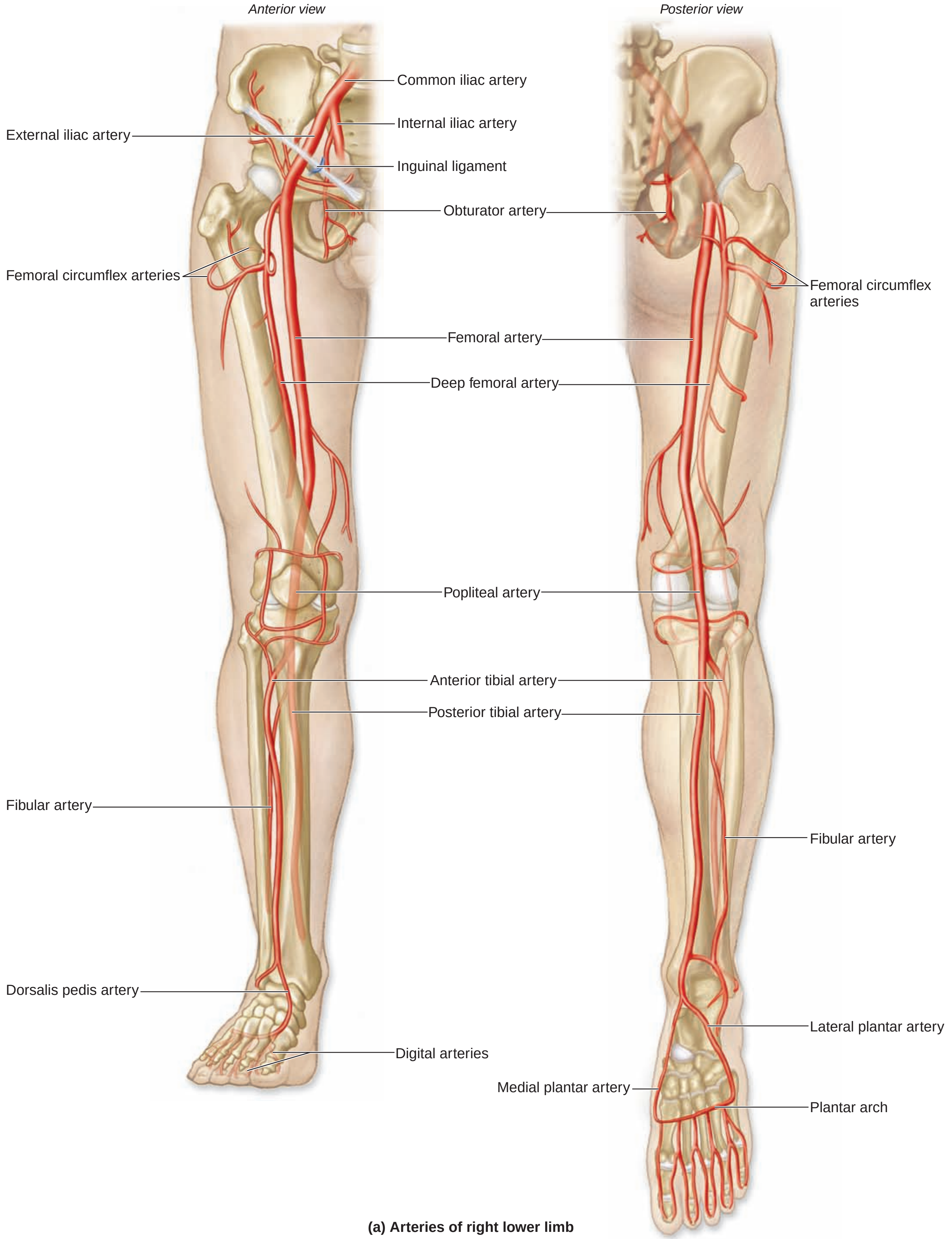
Deep Venous Drainage of the Lower Limb

The digital veins and deep veins of the foot drain into pairs of **medial** and **lateral plantar veins.** These veins drain into a pair of **posterior tibial veins.** A pair of **fibular veins** travel alongside the fibular artery and drain into the posterior tibial veins. On the dorsum of the foot and ankle, deep veins drain into a pair of **anterior tibial veins,** which traverse alongside the anterior tibial artery. The anterior and posterior tibial veins merge to form a **popliteal vein** that accompanies the popliteal artery in the popliteal fossa. This vein curves to the anterior portion of the thigh and is renamed the **femoral vein.** Once this vein passes superior to the inguinal ligament, it is renamed once again as the **external iliac vein.** The external and internal iliac veins merge in the pelvis, forming the **common iliac vein.** Left and right common iliac veins then merge to form the inferior vena cava.

Figure 23.21 shows arteries and veins of the lower limb in the femoral region.

WHAT DID YOU LEARN?

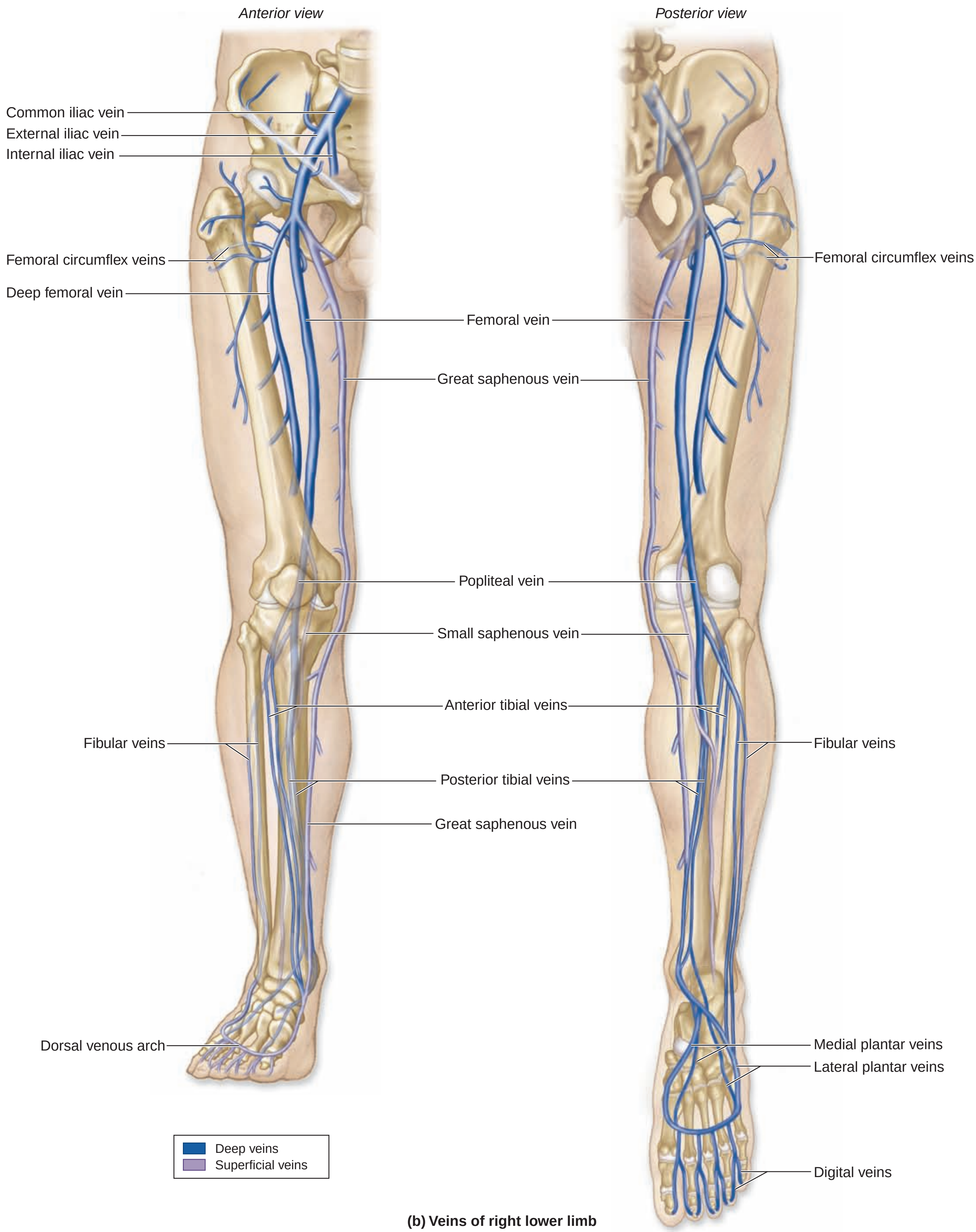
11. What are the superficial veins that help drain the upper limb?
12. How does arterial blood travel through the lower limb? List the branching that occurs, beginning with the external iliac artery.



(a) Arteries of right lower limb

Figure 23.20

Vascular Supply to the Lower Limb. The external iliac artery carries oxygenated blood to the lower limb; veins merge to return deoxygenated blood to the heart. (*a*) Anterior and posterior views of arteries distributed throughout the right lower limb. (*b*) Anterior and posterior views of veins that return blood from the right lower limb. AP|R



(b) Veins of right lower limb

Figure 23.21

Vascular Supply to the Lower Limb. A cadaver photo shows major vessels of the anterior thigh.

23.4 Pulmonary Circulation

Learning Objective:

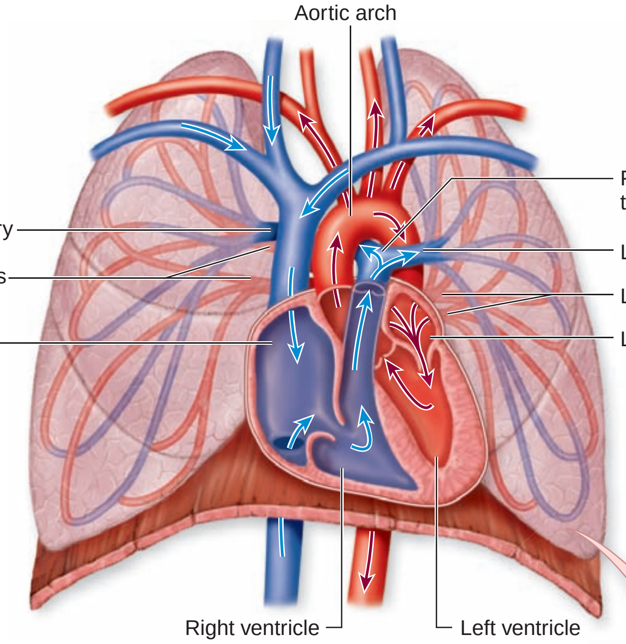
1. **List the pulmonary circulation vessels, and trace their pathways.**

The pulmonary circulation is responsible for carrying deoxygenated blood from the right side of the heart to the lungs, and then returning the newly oxygenated blood to the left side of the heart **(figure 23.22)**. Blood low in oxygen is pumped out of the right ventricle into the **pulmonary trunk.** This vessel travels superiorly and slightly to the left before it bifurcates into a **left pulmonary artery** and a **right pulmonary artery** that go to the lungs. The pulmonary arteries divide into smaller arteries that continue to subdivide to form arterioles. These arterioles finally branch into pulmonary capillaries, where gas exchange occurs. Carbon dioxide is removed from the blood and enters the tiny air sacs (alveoli) of the lungs, while oxygen moves in the opposite direction, from the air sacs into the blood. The capillaries merge to form venules and then the **pulmonary veins.** Typically, two left and two right pulmonary veins carry the newly oxygenated blood to the left atrium of the heart.

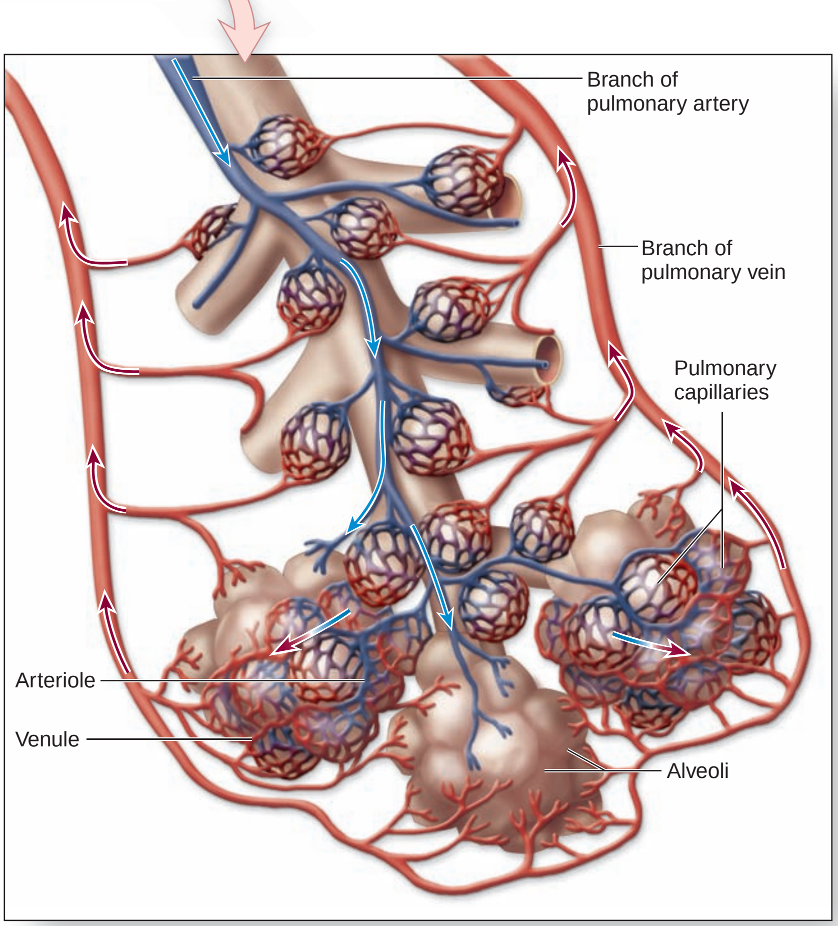
Compared to the systemic circulation, the vessels that make up the pulmonary circulation are relatively short. Blood doesn't need to be pumped as far in the pulmonary circulation, since the lungs are close to the heart. In addition, the pulmonary arteries have less elastic connective tissue and wider lumens than systemic arteries. As a result, blood pressure is lower in the pulmonary arteries than in the systemic arteries, and pressure is correspondingly lower on the right side of the heart than on the left side.

WHAT DID YOU LEARN?

13 Compare the bronchial arteries and veins (discussed earlier in this chapter) with the pulmonary arteries and veins.



(a)



(b)

Figure 23.22

Pulmonary Circulation. The pulmonary circulation conducts blood from the heart to and from the gas exchange surfaces of the lungs. Blood circulation through the heart is indicated by colored arrows (blue = deoxygenated blood; red = oxygenated blood). (*a*) Deoxygenated blood is pumped from the right ventricle to the lungs through the pulmonary arteries. Oxygenated blood returns to the heart from the lungs within the pulmonary veins. (*b*) At the microscopic level, pulmonary capillaries are associated with the alveoli of the lungs.

23.5 Review of Heart, Systemic, and Pulmonary Circulation

Learning Objectives:

1. **Trace and describe the flow of blood and oxygenation of blood in the systemic and pulmonary circulations.**
2. **Identify the heart chambers involved in the systemic and pulmonary circulations.**

A simplified flowchart of blood circulation is outlined in **figure 23.23** and described here:

1. The systemic circulation begins when oxygenated blood flows from the left atrium to the left ventricle and then is pumped into the aorta.
2. Blood in the aorta enters elastic arteries and then flows into muscular arteries before entering arterioles.
3. Blood enters the systemic capillaries from arterioles; gases, nutrients, and wastes are exchanged in the capillaries.
4. Deoxygenated blood that is low in nutrients exits capillary beds. It drains into venules that merge to form veins.
5. Deoxygenated blood is conducted by the venous circulation to either the superior vena cava or the inferior vena cava for entry into the right atrium of the heart. Now the blood has entered the pulmonary circulation.
6. Blood flows from the right atrium into the right ventricle, and then it is pumped into the pulmonary trunk.
7. The pulmonary trunk bifurcates into left and right pulmonary arteries that carry deoxygenated blood to the lungs.

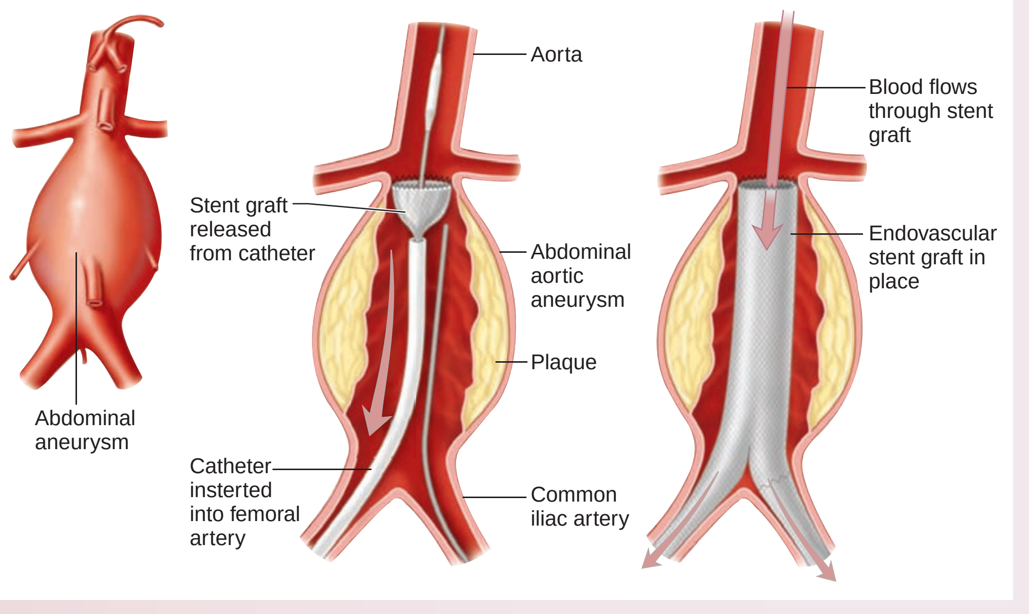
CLINICAL VIEW

Aneurysms

An aneurysm is a localized, abnormal dilation of a blood vessel. Although an aneurysm can form in any type of vessel, aneurysms are particularly common in arteries, especially the aorta, because of the higher blood pressure on the arterial side of the circulation. After being initiated by a weakness in the wall of the vessel, an aneurysm tends to increase in size over a period of weeks or months until it ruptures.

Abdominal aortic aneurysm is a relatively common medical problem, and is most often a consequence of atherosclerosis. Most abdominal aortic aneurysms develop between the level of the renal arteries and the point near where the aorta bifurcates into the common iliac arteries. Since no pain fibers are associated with the aorta, an aneurysm can increase in size and reach the point of rupture without the patient ever being aware of it. A ruptured aorta is a surgical emergency that few people survive. An abdominal aortic aneurysm may be detected during a physical exam as a pulsating abdominal mass. X-ray and ultrasound studies can confirm the diagnosis and determine the size and extent of the aneurysm. For a number of years, aortic aneurysm repair has involved removing the dilated segment of aorta and replacing it with an artificial vascular prosthesis. This risky surgical procedure requires making a large abdominal incision to gain access to the dilated segment of aorta. More recently, stent grafts have been developed that can be inserted through an incision in the femoral artery, positioned in the area of the aneurysm using x-ray guidance, and then expanded to reinforce the weakened and dilated area of the aortic wall. This procedure is less invasive and traumatic than major abdominal surgery. Unfortunately, the stent graft does not always lead to a complete cure, and complications are still possible.

A berry (cerebral or saccular) aneurysm is a weak area in a cerebral blood vessel that balloons out and fills with blood. It is so named because it is a saclike outpocketing of a cerebral blood vessel that appears berry-shaped. Usually, berry aneurysms develop at the point where a blood vessel bifurcates because the blood vessel walls near this location are structurally weaker. Most cerebral aneurysms are located along the arteries that form the cerebral arterial circle. All cerebral aneurysms have the potential to rupture and cause bleeding within the brain, which can cause serious complications such as hemorrhagic stroke, subarachnoid hemorrhage, nerve damage, or death. The disorder may result from congenital defects or from other conditions such as high blood pressure, atherosclerosis, head trauma, or infection. A small aneurysm generally will not produce symptoms, but a larger one that is steadily growing may press on tissues and nerves. Symptoms may include pain above and behind the eye, numbness, weakness, or paralysis on one side of the face, dilated pupils, and vision changes. When a berry aneurysm ruptures, an individual may experience a sudden and extremely severe headache (described by patients as the "worst headache of my life"), double vision, nausea, vomiting, stiff neck, and/or loss of consciousness. A ruptured berry aneurysm is an emergency condition; about 25% of people die within 1 day, and another 25% die within 3 to 4 months. Treatment of the aneurysm typically involves using sutures, clamps, or other materials to repair the ruptured site.



Systemic circulation (black arrows)

1. Oxygenated blood flows from the left atrium to the left ventricle and then is pumped into the aorta.
2. Blood passes from the aorta into elastic arteries and then into muscular arteries before entering arterioles.
3. Blood in arterioles enters systemic capillaries for exchange of gases and nutrients.
4. Deoxygenated blood exits capillary beds into venules and then into veins.
5. Deoxygenated blood is conducted to either the superior or inferior vena cava and then enters the right atrium of the heart.

Pulmonary circulation (yellow arrows)

6. Blood flows from the right atrium to the right ventricle and is then pumped into the pulmonary trunk.
7. The pulmonary trunk conducts deoxygenated blood into pulmonary arteries to the lungs.
8. The blood passes through smaller and smaller arteries before entering pulmonary capillaries for gas exchange.
9. Oxygenated blood exits the lung via a series of progressively larger veins that merge to form the pulmonary veins.
10. Pulmonary veins drain into the left atrium.
11. The cycle repeats.

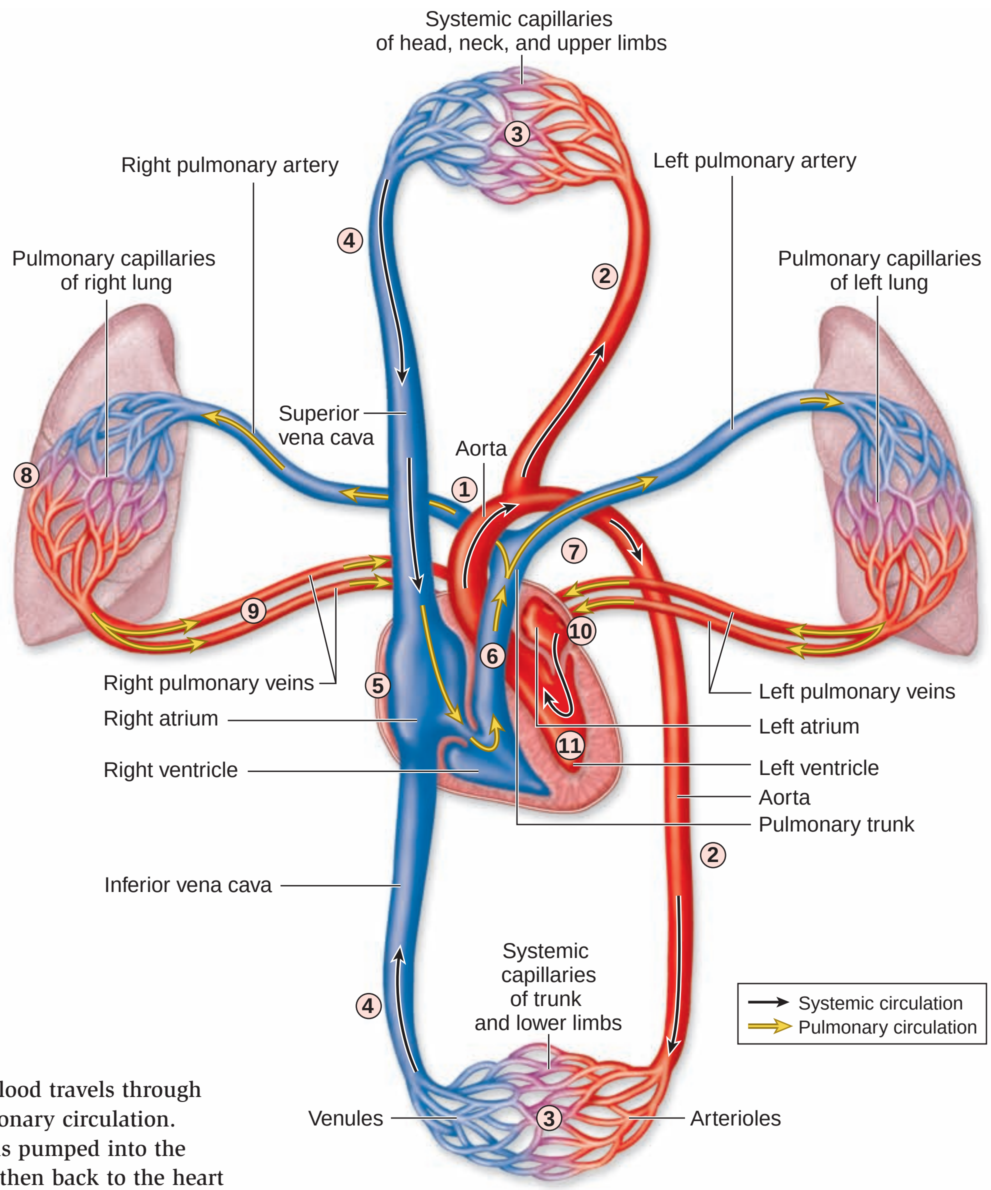


Figure 23.23

Cardiovascular System Circulatory Routes. Blood travels through two routes: the systemic circulation and the pulmonary circulation. In the systemic circulation (black arrows), blood is pumped into the arteries, through the systemic capillary beds, and then back to the heart in systemic veins. In the pulmonary circulation (yellow arrows), blood is pumped through the pulmonary arteries to pulmonary capillary beds in the lungs and then back to the heart in pulmonary veins. AP|R

8. This blood passes through a series of smaller and smaller arteries before entering pulmonary capillaries, where gas exchange occurs.
9. Oxygenated blood exits the lung through a series of progressively larger veins that merge to form the pulmonary veins.
10. Pulmonary veins empty into the left atrium.
11. The cycle repeats.

Keep in mind that this outline is an oversimplification of complex events. For example, remember that both ventricles contract together. Thus, while some blood is traveling through the systemic vessels, blood is also traveling through the pulmonary vessels.

WHAT DID YOU LEARN?

14. Oxygenated blood leaves what chamber of the heart and travels through which major vessel?

23.6 Aging and the Cardiovascular System

Learning Objective:

1. **Describe the structure, function, and durability of blood vessels during aging.**

As adults get older, the heart and blood vessels become less resilient. Many of the elastic arteries are less able to withstand the forces from the pulsating blood. Systolic blood pressure may increase with age, exacerbating this problem. As a result, older individuals are more apt to develop an **aneurysm** (an′ū-rizm; *aneurysma* = a dilation), whereby part of the arterial wall thins and balloons out. This wall is more prone to rupture, which can cause massive bleeding and may lead to death. In addition, as we grow older, the incidence and severity of atherosclerosis increases, at least for people living in the developed world.

WHAT DID YOU LEARN?

15. How are aging and blood pressure related?

23.7 Blood Vessel Development

Learning Objectives:

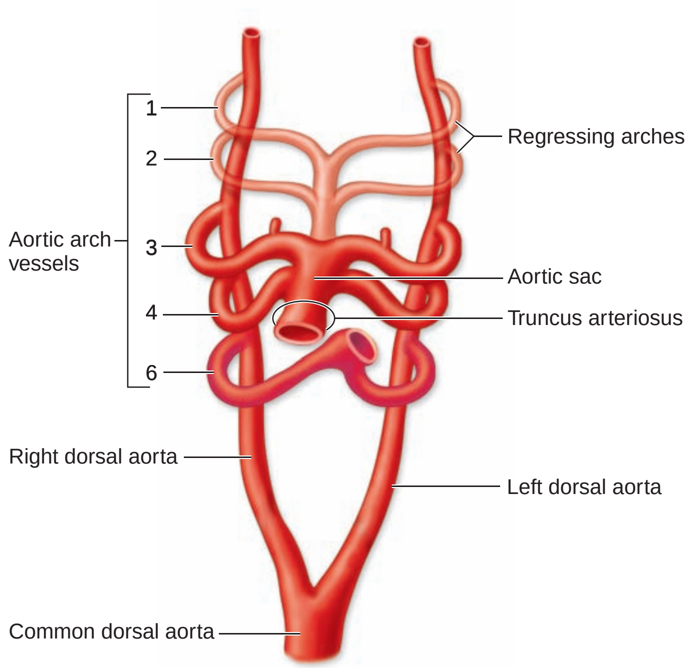
1. Explain the developmental fates of the embryonic vessels.
2. Compare and contrast the fetal and postnatal circulatory patterns.

The heart and its blood vessels begin to develop in the embryo during the third week. The blood vessels form by a process called **vasculogenesis** (vas′kū-lō-jen′ĕ-sis; *vasculum* = small vessel, *genesis* = production), whereby some of the mesoderm forms cells called angioblasts, and these angioblasts connect to form the first primitive blood vessels. These vessels then grow and invade developing tissues throughout the embryo.

23.7a Artery Development

The embryo initially has both a **left** and **right dorsal aorta** **(figure 23.24*a*)**. These two vessels remain separate until the level of the fourth thoracic vertebra, where they fuse to form a **common dorsal aorta** that supplies blood to the inferior part of the body. Eventually, the superior part of the right dorsal aorta degenerates and disappears, leaving the left dorsal aorta and common dorsal aorta (figure 23.24*b, c*). The left dorsal aorta and common dorsal aorta form the descending thoracic aorta.

Beginning the fourth week, the truncus arteriosus of the heart connects to the left and right dorsal aortae by a series of paired **aortic arch vessels** (figure 23.24*a*). These vessels are numbered 1–6. Aortic arch vessels 1 and 2 primarily regress, and only a small portion of them remains to form small segments of arteries in the head. Aortic arch vessel 5 never forms in humans. The remaining aortic arch vessels—3, 4, and 6—develop into adult arteries (figure 23.24*b, c*). In addition, the most superior part of the truncus arteriosus (called the **aortic sac**) forms the brachiocephalic trunk. The dorsal aorta (now part of the descending aorta) develops vascular "sprouts" that form many of the blood vessels in the body. These blood vessel sprouts grow and migrate to the areas that need vascularization.

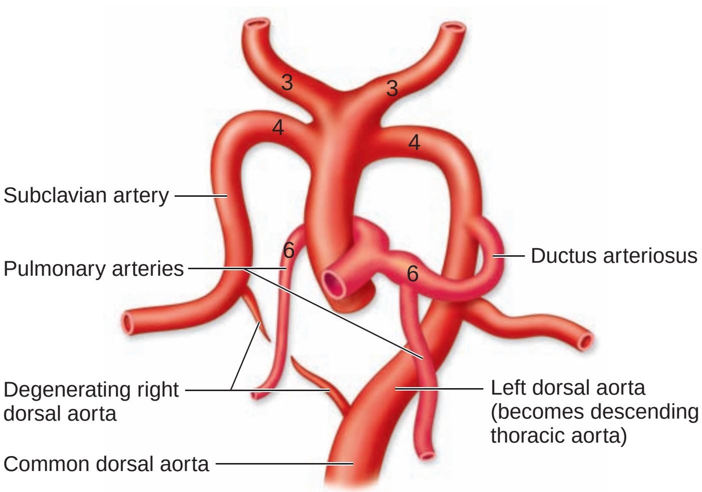


(a) Late week 4 to early week 5: Paired aortic arch vessels connect to left and right dorsal aortae

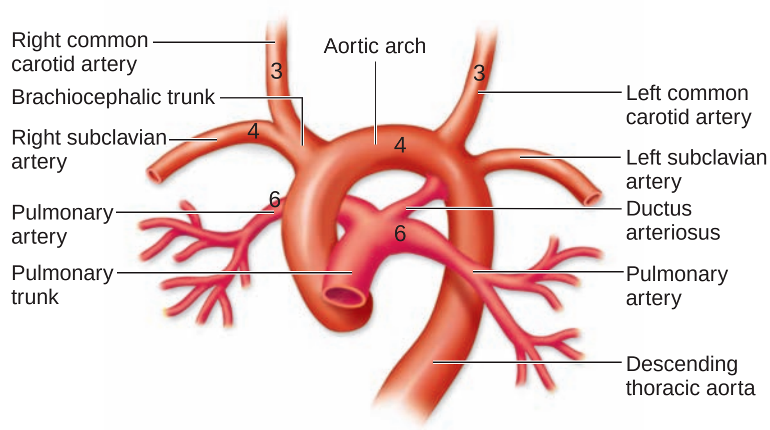
Figure 23.24

Thoracic Artery Development. Aortic arch vessels form most of the major thoracic and head and neck arteries. (*a*) By late week 4/early week 5, paired aortic arch vessels arise from the truncus arteriosus and attach to paired left and right dorsal aortae. (*b*) During week 7, the right dorsal artery starts to degenerate, and the left dorsal aorta becomes the descending thoracic aorta. (*c*) By week 8, the aortic arch vessels have undergone remodeling to form the aortic arch, major branches of the arch, and the pulmonary arteries.

Aortic Arch Vessel	Postnatal Structure Formed by Vessels
1	Small part of maxillary arteries
2	Small part of stapedial arteries
3	Left and right common carotid arteries
4	Right vessel: proximal part of right subclavian artery Left vessel: aortic arch (connects to the left dorsal aorta)
6	Right vessel: right pulmonary artery Left vessel: left pulmonary artery and ductus arteriosus



(b) Week 7: Right dorsal aorta degenerates; left dorsal aorta becomes descending thoracic aorta



(c) Week 8: Aortic arch and branches formed

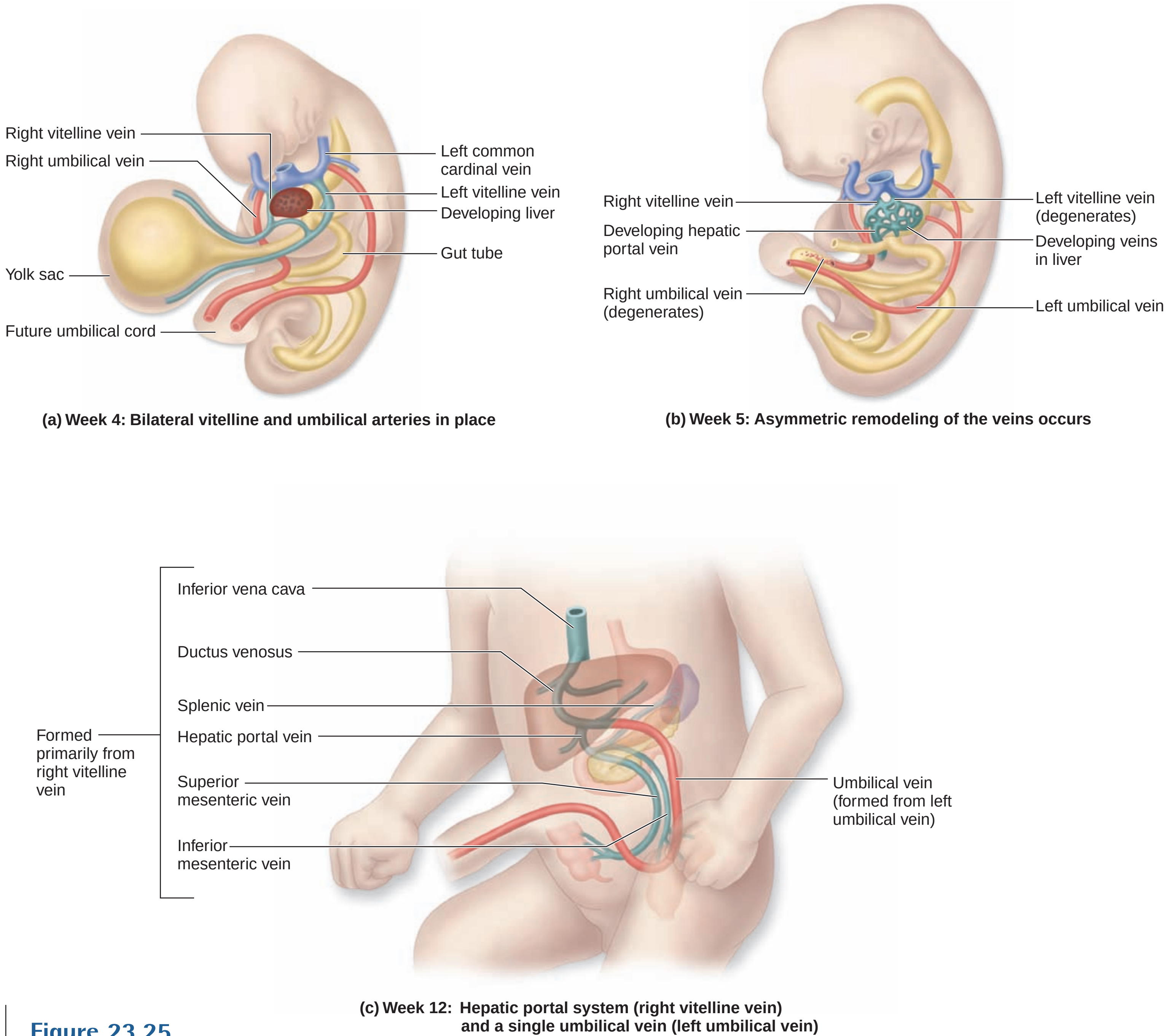


Figure 23.25

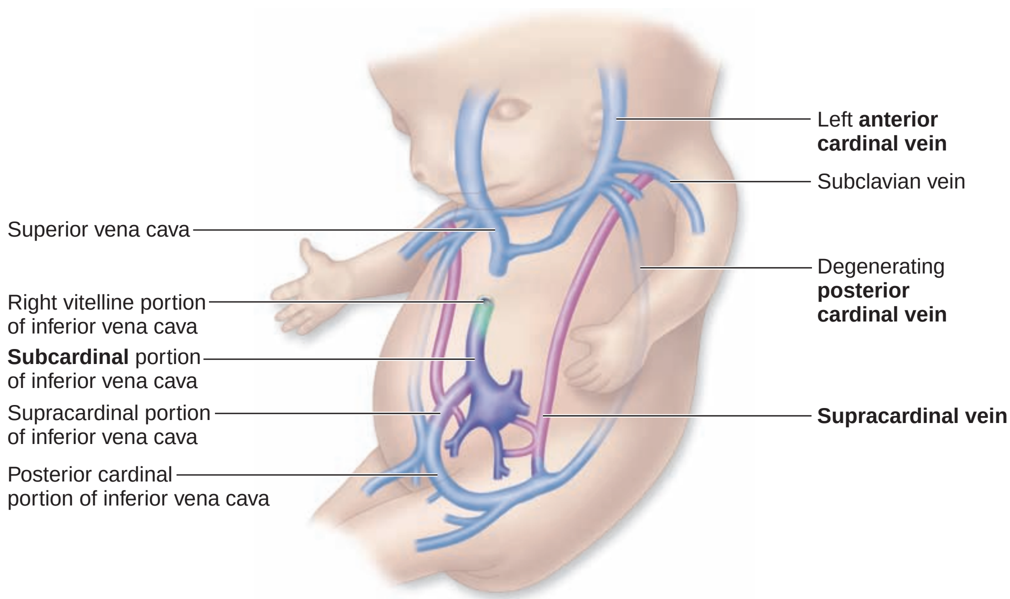
Development of Vitelline and Umbilical Veins. The vitelline veins carry blood from the yolk sac, while the umbilical veins carry oxygenated blood to the embryo. (*a*) At week 4, the bilateral vessels are present. (*b*) By week 5, the vitelline vessels form the blood vessels in the liver, and the right vitelline vein forms the hepatic portal vein. (*c*) By week 12, the right vitelline vein forms most of the hepatic portal system, while the left vitelline vein regresses. Conversely, the right umbilical vein regresses, and the left umbilical vein persists as the single umbilical vein.

23.7b Vein Development

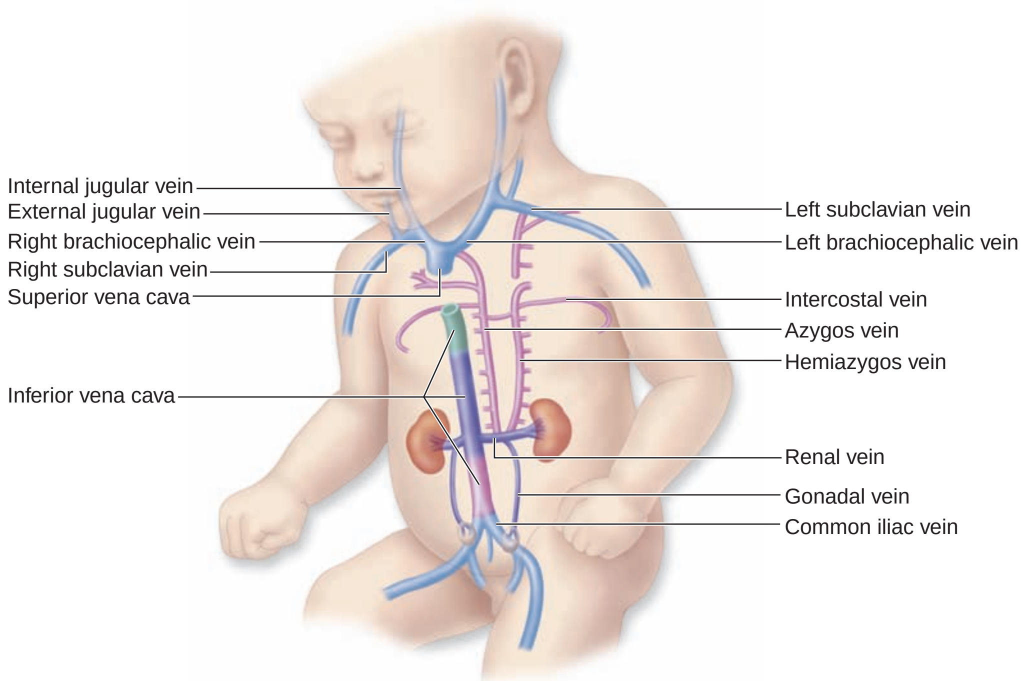
The venous system of the embryo develops from three venous systems: the **vitelline** (vī-tel′in; *vitellus* = yolk) **system,** the **umbilical** (ŭm-bil′i-kăl) **system,** and the **cardinal** (kar′di-năl; *cardinalis* = principal) **system.** All three systems initially are bilateral and connect to the sinus venosus of the heart. However, these three systems are eventually remodeled so that venous blood return is shifted to the right side of the heart. Each system is responsible for a specific body area: The vitelline system drains the gastrointestinal region; the umbilical system carries oxygenated blood from the placenta; and the cardinal system forms most of the veins of the head, neck, and body wall. (Limb veins are formed from separate venous plexuses that interconnect with the cardinal system.)

The vitelline system of veins consists of **left** and **right vitelline veins,** which are apparent through the fourth week **(figure 23.25)**. Beginning in the fifth week and continuing through the twelfth week, the left vitelline vein primarily degenerates, and the right vitelline vein forms the hepatic portal system, the sinusoids of the liver, and the portion of the inferior vena cava between the liver and the heart. Also formed from the right vitelline vein is the **ductus venosus** (dŭk′tŭs vē-nō′sŭs)**,** which connects the umbilical vein to the inferior vena cava and heart, and shunts blood away from the fetal liver.

The umbilical system of veins originally begins with a **left** and **right umbilical vein.** However, by the second month of development, the right umbilical vein disappears, and the left umbilical vein connects directly to the ductus venosus. Thus,



(a) Week 8: Supra- and subcardinal veins undergo asymmetric remodeling



(b) Birth: Mature vessel pattern formed

Figure 23.26

Cardinal Vein Development. The primary venous drainage for the embryo is initially formed by the cardinal veins. (*a*) By week 8, some of these cardinal veins undergo asymmetric remodeling and begin to form some of the named veins in the body. (*b*) At birth, the cardinal veins have been remodeled to form the inferior vena cava and the posterior thoracic and abdominal wall vessels.

within the umbilical cord are one umbilical vein and a pair of umbilical arteries.

The cardinal system of veins consists of a series of paired veins: the **anterior cardinal veins, posterior cardinal veins, supracardinal veins,** and **subcardinal veins** (**figure 23.26**). The anterior cardinal veins develop into the veins of the head and neck and the veins superior to the heart. By the eighth week of development, the posterior cardinal veins degenerate and are largely replaced by the supracardinal and subcardinal veins. The supracardinal and subcardinal veins undergo asymmetrical remodeling, whereby venous blood flow is shifted to the right side of the body. The subcardinal veins form veins that drain the posterior abdominal wall, while the supracardinal veins form the hemiazygos and azygos system of veins. The inferior vena cava is formed from parts of the right vitelline, right subcardinal, right supracardinal, and right posterior cardinal veins. The mature vessel pattern is formed well before birth and shown in figure 23.26*b*.

23.7c Comparison of Fetal and Postnatal Circulation

The cardiovascular system of the fetus is structurally and functionally different from that of the newborn. Whereas the fetus

CLINICAL VIEW

Patent Ductus Arteriosus

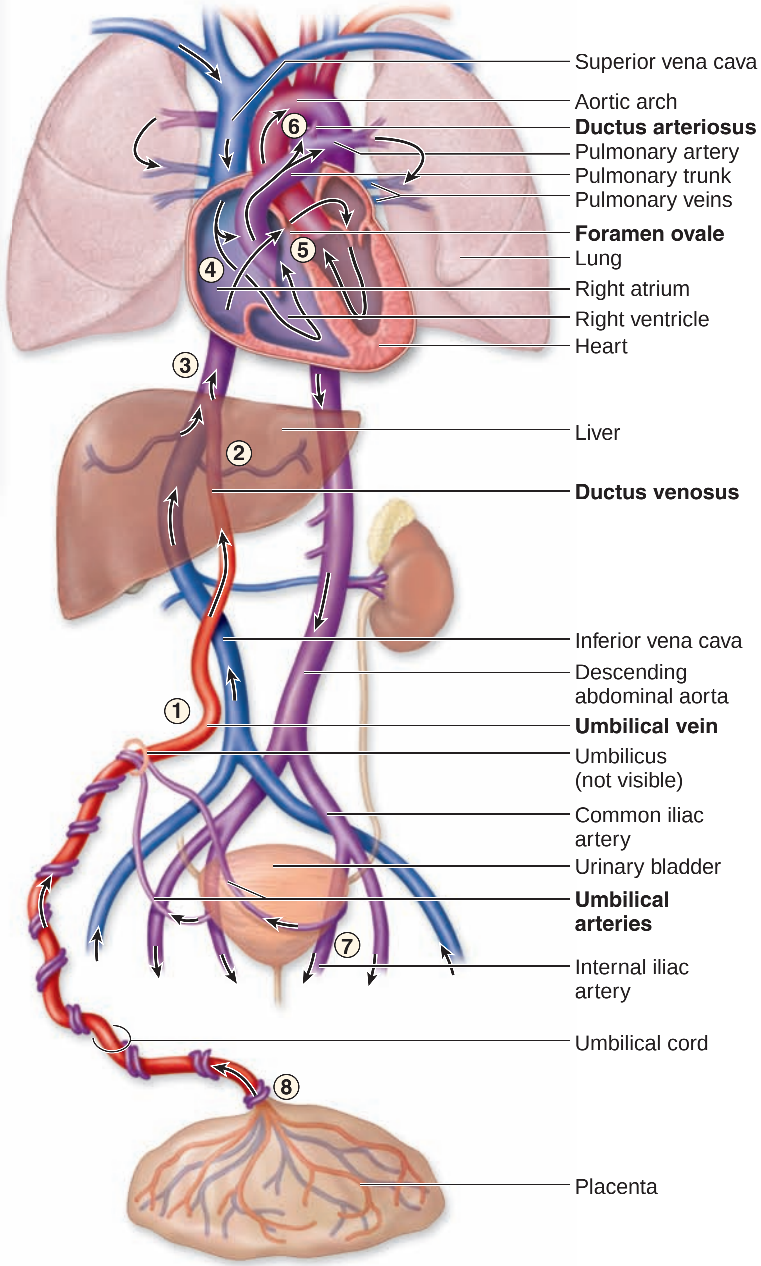
In some infants (especially premature infants), the ductus arteriosus fails to constrict and close after birth. This open (patent) ductus arteriosus occurs in approximately 8 per 10,000 births. Since the systemic circulation is under higher pressure than the pulmonary circulation, a patent ductus arteriosus serves as a conduit through which blood from the aorta can enter the pulmonary system. If left untreated, this shunting will, over a period of several years, result in high blood pressure in the pulmonary circuit. This pulmonary hypertension then leads to failure of the right ventricle. Because circulating chemicals called prostaglandins help keep the ductus arteriosus open during fetal life, the first form of treatment for a patent ductus arteriosus is prostaglandin-inhibiting medication. In the uncommon instance that medication does not work, the ductus arteriosus is surgically repaired.

receives oxygen and nutrients directly from the mother through the placenta, its postnatal cardiovascular system is independent. In addition, since the fetal lungs are not functional, the blood pressure in the pulmonary arteries and right side of the heart is greater than the pressure in the left side of the heart. Finally, several fetal vessels help shunt blood directly to the organs in need and away from the organs that are not yet functional. As a result, the fetal cardiovascular system has some structures that are modified or that cease to function once the human is born. **Figure 23.27** compares the fetal and postnatal circulation patterns.

Fetal circulation occurs as follows:

1. Oxygenated blood from the placenta enters the body of the fetus through the **umbilical vein.**
2. The blood from the umbilical vein is shunted away from the liver and directly toward the inferior vena cava through the **ductus venosus.**
3. Oxygenated blood in the ductus venosus mixes with deoxygenated blood in the inferior vena cava.
4. Blood from the superior and inferior venae cavae empties into the right atrium.
5. Since pressure is greater on the right side of the heart (compared to the left side), most of the blood is shunted from the right atrium to the left atrium via the **foramen ovale.** This blood flows into the left ventricle and then is pumped out through the aorta.
6. A small amount of blood enters the right ventricle and pulmonary trunk, but much of this blood is shunted from the pulmonary trunk to the aorta through a vessel detour called the **ductus arteriosus** (ar-tēr′ē-ō′sŭs).
7. Blood travels to the rest of the body, and the deoxygenated blood returns to the placenta through a pair of **umbilical arteries.**
8. Nutrient and gas exchange occurs at the placenta, and the cycle repeats.

At birth, the fetal circulation begins to change into the postnatal pattern. When the baby takes its first breath, pulmonary resistance drops, and the pulmonary arteries dilate. As a result,



Fetal Cardiovascular Structure	Postnatal Structure
Ductus arteriosus	Ligamentum arteriosum
Ductus venosus	Ligamentum venosum
Foramen ovale	Fossa ovalis
Umbilical arteries	Medial umbilical ligaments
Umbilical vein	Round ligament of liver (ligamentum teres)

Figure 23.27

Fetal Circulation. Structural changes in both the heart and blood vessels accommodate the different needs of the fetus and the newborn. The pathway of blood flow is indicated by black arrows. The numbers correspond to the steps listed in the text. The chart at the bottom of the drawing summarizes the fate of each of the fetal cardiovascular structures.

pressure on the right side of the heart decreases so that the pressure is greater on the left side of the heart, which handles the systemic circulation.

The postnatal changes occur as follows:

- The umbilical vein and umbilical arteries constrict and become nonfunctional. They turn into the **round ligament of the liver** (or *ligamentum* [lig′ă-men′tŭm; band] *teres*) and the **medial umbilical ligaments,** respectively.
- The ductus venosus ceases to be functional and constricts, becoming the **ligamentum venosum** (vē-nō′sŭm).
- Since pressure is now greater on the left side of the heart, the two flaps of the interatrial septum close off the foramen ovale. The only remnant of the foramen ovale is a thin, oval depression in the wall of the septum called the **fossa ovalis.**
- Within 10 to 15 hours after birth, the ductus arteriosus closes and becomes a fibrous structure called the **ligamentum arteriosum.**

WHAT DID YOU LEARN?

16 The hepatic portal system is formed primarily from what embryonic vein system?

17 Each medial umbilical ligament is a remnant of what embryonic vessel?

Clinical Terms

edema Noticeable swelling from fluid accumulation in body tissues. Edema most commonly occurs in the feet and legs, where it is referred to as peripheral edema.

hypotension Low blood pressure.

Korotkoff (kô-rot'kôf) **sounds** Distinctive sounds heard through a stethoscope when taking a blood pressure reading, resulting from blood turbulence in the artery. The sounds are first heard when the cuff pressure equals the systolic pressure and cease to be heard once the cuff has deflated past the diastolic pressure.

orthostatic hypotension Also known as a dizzy spell; a form of hypotension in which a person's blood pressure suddenly and temporarily falls when the person stands up quickly or stretches after standing. The pressure decrease is often most pronounced after lying down.

vasculitis (vas-kū-lī′tis) Inflammation of any type of blood vessel. If only arteries are inflamed, the condition is called *arteritis;* if only veins are inflamed, it is called *phlebitis.*

vasodilators Drugs that relax the smooth muscle in and/or around blood vessels, causing the vessels to dilate. Dilation of arteries leads to a reduction in systemic vascular resistance, which produces a fall in arterial blood pressure. Dilation of venous vessels decreases venous blood pressure.

Chapter Summary

	■ Blood vessels form a closed supply system to transport oxygen and nutrients to body tissues, and remove waste products from these tissues.
23.1 Anatomy of Blood Vessels 684	■ Arteries conduct blood away from the heart; capillaries exchange gases, nutrients, and wastes with body tissues; and veins conduct blood to the heart. **23.1a Blood Vessel Tunics 684** ■ The tunica intima (innermost layer) is composed of an endothelium, a basement membrane, and a layer of areolar connective tissue. ■ The tunica media (middle layer) is composed of smooth muscle. This is the largest tunic in an artery. ■ The tunica externa (outermost layer) is composed of areolar connective tissue and adipose connective tissue. This is the largest tunic in a vein. ■ Capillaries have a tunica intima, composed of an endothelial layer and a basement membrane only. **23.1b Arteries 685** ■ Elastic arteries have the largest diameter and the greatest proportion of elastic fibers in their walls. ■ Muscular arteries are medium-sized arteries with more smooth muscle and fewer elastic fibers to ensure vasodilation and vasoconstriction. ■ Arterioles are the smallest arteries. **23.1c Capillaries 688** ■ Capillaries, the smallest blood vessels, connect arterioles with venules. Gas and nutrient exchange occurs in the capillaries. ■ The three types of capillaries are continuous capillaries, fenestrated capillaries, and sinusoids. **23.1d Veins 689** ■ Venules are small veins that merge into larger veins. Blood pressure is low in the veins, which act as reservoirs and hold about 60% of the body's blood at rest. ■ One-way valves prevent blood backflow in veins.
23.2 Blood Pressure 691	■ Blood pressure is the force exerted by the blood on the vessel wall. Systolic blood pressure is a measure of pressure during ventricular contraction, and diastolic pressure is a measure of pressure during ventricular relaxation.

23.3 Systemic Circulation 692	■ The systemic circulation conducts oxygenated blood to and deoxygenated blood from peripheral capillary beds. **23.3a General Arterial Flow Out of the Heart 693** ■ The ascending aorta gives off the left and right coronary arteries to supply the heart. ■ The aortic arch has three branches: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. ■ The descending thoracic aorta extends several branches to supply the thoracic wall. ■ The descending abdominal aorta bifurcates into common iliac arteries; these vessels divide into internal and external iliac arteries.
	23.3b General Venous Return to the Heart 693 ■ Deoxygenated blood returns to the heart via the superior and inferior venae cavae. **23.3c Blood Flow Through the Head and Neck 693** ■ Common carotid arteries branch into the internal and external carotid arteries, which supply most of the blood to the head and neck. ■ The cerebral arterial circle is an arterial anastomosis that supplies the brain. ■ Vertebral veins and the dural venous sinuses drain the cranium. **23.3d Blood Flow Through the Thoracic and Abdominal Walls 697** ■ The thoracic and abdominal walls are supplied by paired arteries. ■ Hemiazygos and accessory hemiazygos veins drain the left side of the thorax, and the azygos vein drains the right side of the thorax. **23.3e Blood Flow Through the Thoracic Organs 700** ■ Bronchial arteries and bronchial veins supply the connective tissue, bronchi, and bronchioles of the lung. ■ Esophageal arteries and veins supply the esophagus. ■ Superior phrenic arteries, the musculophrenic arteries, and the inferior phrenic arteries and veins supply the diaphragm. **23.3f Blood Flow Through the Gastrointestinal Tract 701** ■ Three unpaired arteries supply the gastrointestinal tract organs: the celiac trunk, the superior mesenteric artery, and the inferior mesenteric artery. ■ The hepatic portal vein is a large vein that receives oxygen-poor but nutrient-rich blood from the gastrointestinal organs and takes it to the liver. Blood exits the liver via hepatic veins. **23.3g Blood Flow Through the Posterior Abdominal Organs, Pelvis, and Perineum 705** ■ Paired branches of the descending abdominal aorta supply the posterior abdominal organs and the pelvis and perineum. Venous drainage is by veins of the same name as the arteries. **23.3h Blood Flow Through the Upper Limb 705** ■ The subclavian artery continues as the axillary artery and then becomes the brachial artery. The brachial artery divides into an ulnar artery and a radial artery. ■ Anastomoses of ulnar and radial arteries form the superficial palmar arch and the deep palmar arch; digital arteries emerge from the arches to supply the fingers. ■ The superficial group of veins contains the basilic, median cubital, and cephalic veins that drain into the axillary vein. The deep group of veins contains veins that bear the same names as the arteries. **23.3i Blood Flow Through the Lower Limb 709** ■ The external iliac artery extends inferior to the inguinal ligament and is renamed the femoral artery. It enters the popliteal fossa, and then becomes the popliteal artery before dividing into anterior and posterior tibial arteries. The posterior tibial artery gives off a fibular artery. The posterior tibial artery branches into medial and lateral plantar arteries. ■ The superficial group of veins includes the great saphenous vein and the small saphenous vein. The deep group of veins consists of veins that bear the same names as the corresponding arteries.
23.4 Pulmonary Circulation 712	■ The pulmonary circulation carries deoxygenated blood to the lungs and returns oxygenated blood to the heart.
23.5 Review of Heart, Systemic, and Pulmonary Circulation 714	■ Oxygenated blood is pumped from the left ventricle through the systemic circulation and back to the right side of the heart. This deoxygenated blood is pumped from the right ventricle through the pulmonary circulation and returns as oxygenated blood to the left side of the heart.
23.6 Aging and the Cardiovascular System 715	■ As adults get older, the heart and blood vessels become less resilient, systolic blood pressure may rise, and the incidence and severity of atherosclerosis increase.

(continued on next page)

Chapter Summary *(continued)*

23.7 Blood Vessel Development 716	■ The blood vessels form by a process called vasculogenesis beginning in the third week of development. **23.7a Artery Development 716** ■ The right dorsal aorta regresses, and the left dorsal aorta (plus the common aorta) form the descending aorta. ■ Aortic arch vessels 1, 2, 3, 4, and 6 develop into parts of adult arteries in the head, neck, and thorax. **23.7b Vein Development 717** ■ Three bilateral venous systems connect the sinus venosus of the heart: the vitelline system, the umbilical system, and the cardinal system. These are the origin of the venous system. **23.7c Comparison of Fetal and Postnatal Circulation 718** ■ The fetal cardiovascular system contains some structures that are modified or cease to function once the baby is born.

Challenge Yourself

Matching

Match each numbered item with the most closely related lettered item.

______ 1. hepatic portal vein	a. common site for venipuncture
______ 2. capillary	b. drains venous blood from the brain
______ 3. median cubital vein	c. drains right posterior intercostal veins
______ 4. common iliac artery	d. sends oxygenated blood to right upper limb
______ 5. dural venous sinus	e. continuation of femoral artery
______ 6. azygos vein	f. drains directly into left atrium
______ 7. hemiazygos vein	g. composed of endothelium and basement membrane only
______ 8. popliteal artery	h. bifurcation of descending abdominal aorta
______ 9. brachiocephalic trunk	i. superior mesenteric vein drains into it
______ 10. pulmonary vein	j. left posterior intercostal veins drain into it

Multiple Choice

Select the best answer from the four choices provided.

______ 1. Which of the following is not a type of capillary?
a. continuous
b. sinusoid
c. elastic
d. fenestrated

______ 2. Some venous blood from the upper limb drains through the
a. cephalic vein.
b. great saphenous vein.
c. external jugular vein.
d. inferior vena cava.

______ 3. All of the following are direct branches of the celiac trunk except the
a. splenic artery.
b. right gastric artery.
c. left gastric artery.
d. common hepatic artery.

______ 4. Which type of vessel has a large number of smooth muscle cell layers in its tunica media as well as elastic tissue confined to an internal elastic lamina and external elastic lamina?
a. elastic artery
b. muscular artery
c. arteriole
d. venule

______ 5. Which statement is true about veins?
a. Veins always carry deoxygenated blood.
b. Veins drain into smaller vessels called venules.
c. The largest tunic in a vein is the tunica externa.
d. The lumen of a vein tends to be smaller than that of a comparably sized artery.

______ 6. Circle the correct pathway that blood follows through the upper limb arteries:
a. subclavian → axillary → ulnar → radial → brachial
b. subclavian → axillary → brachial → cephalic → basilic
c. subclavian → ulnar → brachial → radial
d. subclavian → axillary → brachial → radial and ulnar

______ 7. Which of the following veins typically does not drain directly into the inferior vena cava?
a. renal
b. hepatic portal
c. common iliac
d. right gonadal

______ 8. After birth, the umbilical vein becomes the
a. medial umbilical ligament.
b. ligamentum venosum.
c. ligamentum arteriosum.
d. round ligament of the liver.

_______ 9. The left fourth aortic arch vessel in an embryo becomes the
a. left common carotid artery.
b. left subclavian artery.
c. aortic arch.
d. left pulmonary artery.

_______ 10. Vasa vasorum are found in the tunica _______ of a large blood vessel.
a. intima
b. media
c. externa
d. All of these are correct.

Content Review

1. List and describe the three tunics in most blood vessels.
2. Compare and contrast arteries and veins with respect to function, tunic size, and lumen size.
3. Describe the three types of arteries, and give an example of each.
4. What is the main function of capillaries? What are the three kinds of capillaries?
5. Is blood pressure higher in arteries or veins? What are the consequences of hypertension?
6. Identify the three main branches of the aortic arch that receive oxygenated blood, and identify the areas of the body they supply.
7. How is blood flow through the upper and lower limbs similar?
8. Compare the systemic and pulmonary circulations. Discuss the function of arteries and veins in each system.
9. How does aging affect blood vessel anatomy and function?
10. What postnatal changes occur in the heart and blood vessels? Why do these occur?

Developing Critical Reasoning

1. Two 50-year-old men are trying to determine their risk for developing atherosclerosis. John jogs three times a week, maintains a healthy weight, and eats a diet low in saturated fats. Thomas rarely exercises, is overweight, and only occasionally eats healthy meals. Based on your knowledge of the cardiovascular system and atherosclerosis, which man do you think is more at risk for developing the disease? What other factors could put a person at risk for atherosclerosis?
2. Arteries tend to have a lot of vascular anastomoses around body joints (such as the elbow and knee). Propose a reason why this would be beneficial.
3. The internal thoracic artery is frequently used as a coronary bypass vessel (a replacement artery for a blocked coronary artery). What makes this vessel a good choice for this surgery? Will blood flow to the thoracic wall be compromised as a result? Why or why not?

Answers to "What Do You Think?"

1. A smoker would have elevated blood pressure, since nicotine increases cardiac output and causes vasoconstriction.
2. Blood could still reach the brain through the vertebral arteries. However, it is unlikely that these arteries could provide sufficient blood to the entire brain and head.
3. If the left ulnar artery were cut, the left hand and fingers could still receive blood via the left radial artery.
4. If the right femoral artery were blocked, blood flow to the right leg would be cut off; in other words, the popliteal artery and the branches to the leg would not receive any blood.