20 Blood Vessels

The blood vessels of the body form a closed delivery system powered by the pumping heart. The realization that blood is pumped in a circle dates back to the 1620s and is based on the careful experiments of William Harvey, an English physician. Before that time, it was taught—as proposed by the ancient Greek physician Galen—that blood moved through the body like an ocean tide, first moving out from the heart, then ebbing back into the heart via the same vessels.

Blood vessels are not rigid tubes that simply direct the flow of blood but rather are dynamic structures that pulsate, constrict and relax, and even proliferate, according to the changing needs of the body. This chapter examines the structure and function of these important circulatory pathways through the body.

Red and white blood cells and platelets flowing through a blood vessel (simulated SEM-like view).

The three major types of blood vessels are *arteries, capillaries,* and *veins.* When the heart contracts, it forces blood into the large arteries that leave the ventricles. The blood then moves into successively smaller branches of arteries, finally reaching the smallest branches, the *arterioles* (ar-te′-re-ōlz; "little arteries"), which feed into the *capillaries* of the organs. Blood leaving the capillaries is collected by *venules,* small veins that merge to form larger veins that ultimately empty into the heart. This pattern of vessels applies to both the pulmonary and systemic circuits. Altogether, the blood vessels in an adult human body stretch for 100,000 km or 60,000 miles, a distance equivalent to almost 2½ times around the Earth.

Notice that arteries are said to "branch," "diverge," or "fork" as they carry blood *away* from the heart. Veins, by contrast, are said to "join," "merge," "converge," or "serve as tributaries" as they carry blood *toward* the heart.

This chapter is divided into two parts: Part One considers the general characteristics of blood vessels, and Part Two discusses the specific vessels in the pulmonary and systemic circulations.

PART 1: GENERAL CHARACTERISTICS OF BLOOD VESSELS

The first part of this chapter begins by examining the structure of the blood vessel walls and then describes the structure and function of each type of blood vessel.

STRUCTURE OF BLOOD VESSEL WALLS

➤ Describe the three tunics that form the wall of an artery or vein.

The walls of all blood vessels, except the very smallest, are composed of three distinct layers, or *tunics* ("cloaks")—the tunica intima, tunica media, and tunica externa—that surround the central blood-filled space, the **lumen** (Figure 20.1). The description of these tunics covers features that are common to arteries as well as veins.

The innermost tunic of a vessel wall is the **tunica intima** (too′nĭ-kah in′tĭ-mah), which is in "intimate" contact with the blood in the lumen. This tunic contains the *endothelium,* the simple squamous epithelium that lines the lumen of all vessels. The flat endothelial cells form a smooth surface that minimizes the friction of blood moving across them. In vessels larger than about 1 mm in diameter, a thin layer of loose connective tissue, the **subendothelial layer,** lies just external to the endothelium.

The middle tunic, or **tunica media,** consists primarily of *circularly* arranged sheets of smooth muscle fibers, between which lie circular sheets of elastin and collagen fibrils. Contraction of the smooth muscle cells decreases the diameter of the vessel, a process called *vasoconstriction.* Relaxation of the smooth muscle cells, a process called *vasodilation,* increases the vessel's diameter. Both activities are regulated by *vasomotor nerve fibers* of the sympathetic division of the autonomic nervous system. The elastin and collagen contribute elasticity and strength for resisting the blood pressure that each heartbeat exerts on the vessel wall. The tunica media is thicker in arteries than in veins. In arteries, which function to maintain blood pressure, the tunica media is the thickest layer.

The outermost layer of the vessel wall is the **tunica externa** or *tunica adventitia* (ad″ven-tish′e-ah). This tunic is a layer of connective tissue that contains many collagen and elastic fibers. Its cells and fibers run *longitudinally.* Functionally, the tunica externa protects the vessel, further strengthens its wall, and anchors the vessel to surrounding structures.

TYPES OF BLOOD VESSELS

As you read about the three types of blood vessels—arteries, capillaries, and veins—you will learn about these vessels in the order in which a drop of blood would encounter them as it passes through the systemic or pulmonary circuit. Accordingly, the discussion begins with arteries.

Arteries

➤ Compare and contrast the structure and functions of elastic arteries, muscular arteries, and arterioles.

Arteries are vessels that carry blood away from the heart. It is a common misconception that *all* arteries carry oxygen-rich blood, whereas *all* veins carry oxygen-poor blood. This notion is correct for the systemic circuit, but it is not correct for the pulmonary circuit, whose arteries carry oxygen-poor blood to the lungs for oxygenation (see Figure 19.1, p. 556).

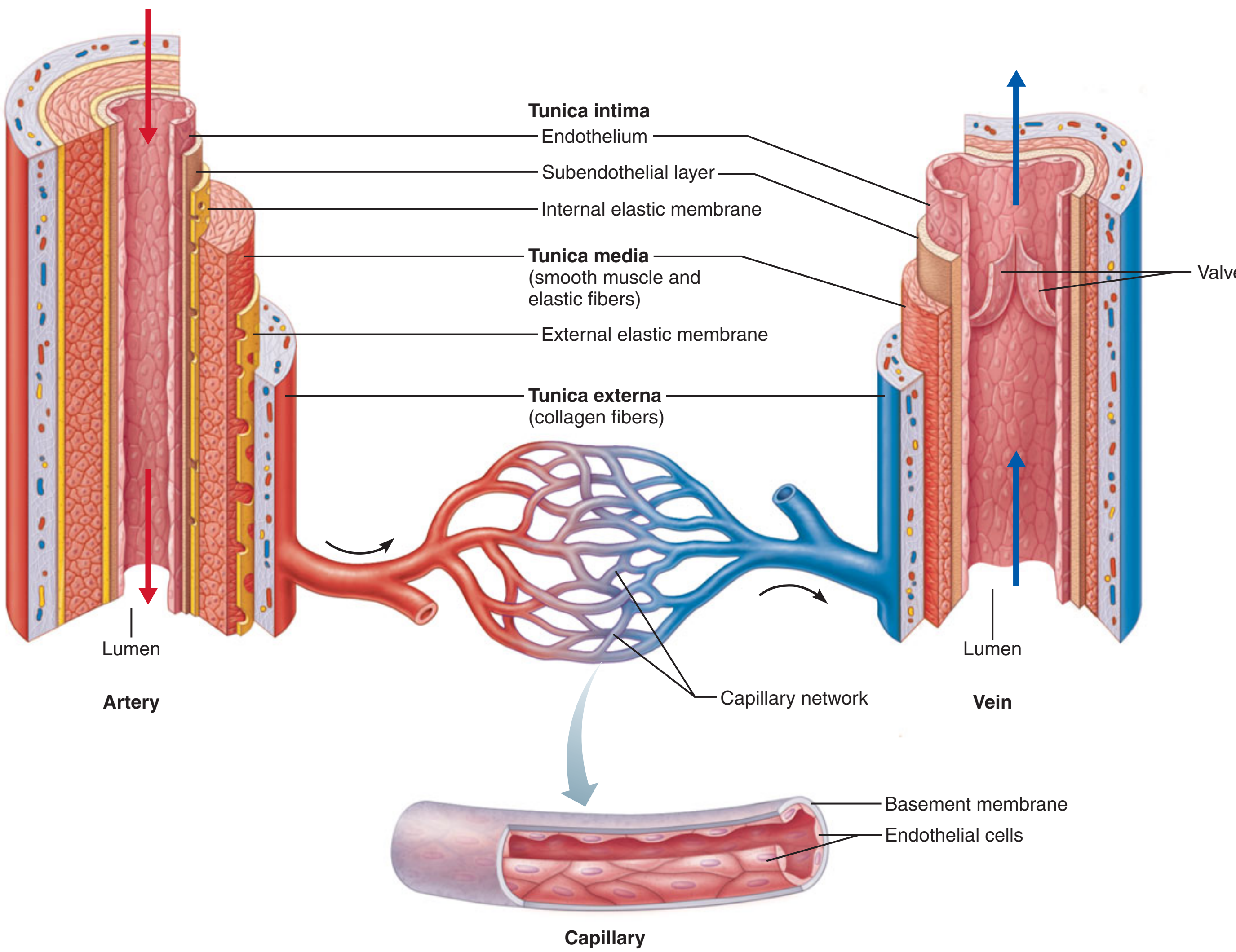
The passage of blood through the arteries proceeds from elastic arteries, to muscular arteries, to arterioles.

Elastic Arteries

Elastic arteries are the largest arteries near the heart—the aorta and its major branches—with diameters ranging from 2.5 cm (about the width of the thumb) to 1 cm (slightly less than the width of the little finger). Their large lumen allows them to serve as low-resistance conduits for conducting blood between the heart and the medium-sized muscular arteries. For this reason, elastic arteries are sometimes called *conducting arteries.* More elastin occurs in the walls of these arteries than in any other type of vessel, and the sheets of elastin in the tunica media are remarkably thick (Figure 20.2a).

The high elastin content of conducting arteries dampens the surges of blood pressure resulting from the rhythmic contractions of the heart. When the heart forces blood into the arteries, the elastic elements in these vessels expand in

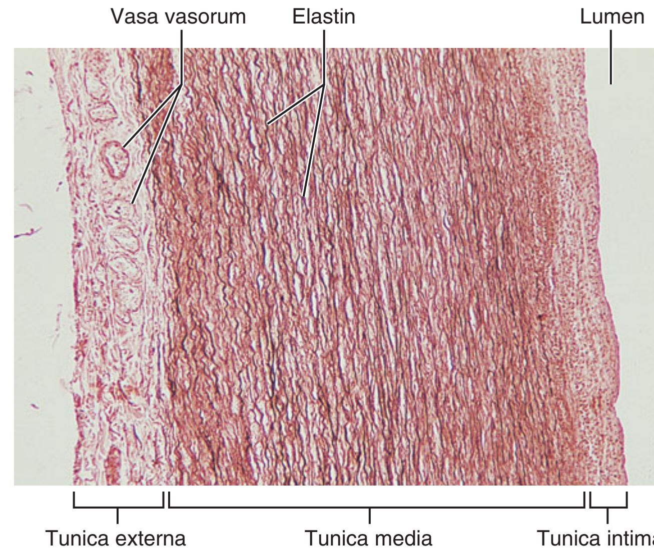
(a)



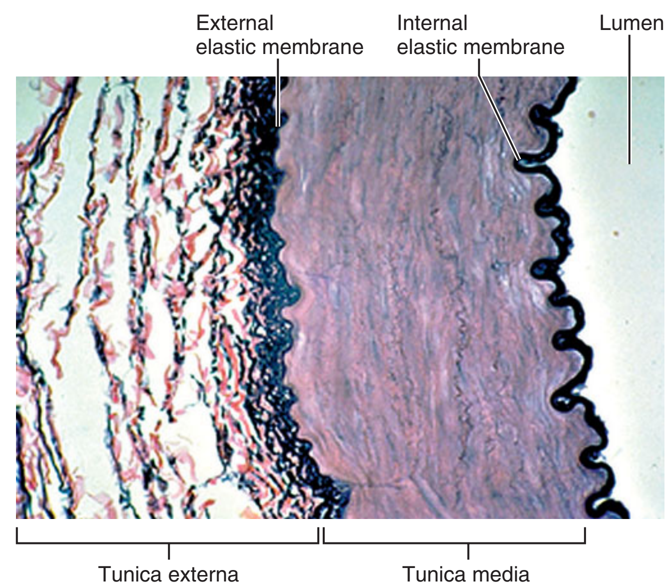
(b)

FIGURE 20.1 Generalized structure of arteries, veins, and capillaries.
(a) Photomicrograph of a muscular artery and a vein, in cross section (14×).
(b) Comparison of wall structure of arteries, veins, and capillaries. The artery has a thicker wall, a thicker tunica media, a narrower lumen than the similarly sized vein, and thickened elastic membranes not present in the vein. The vein, by contrast, has a thicker tunica externa, a wider lumen, and valves.

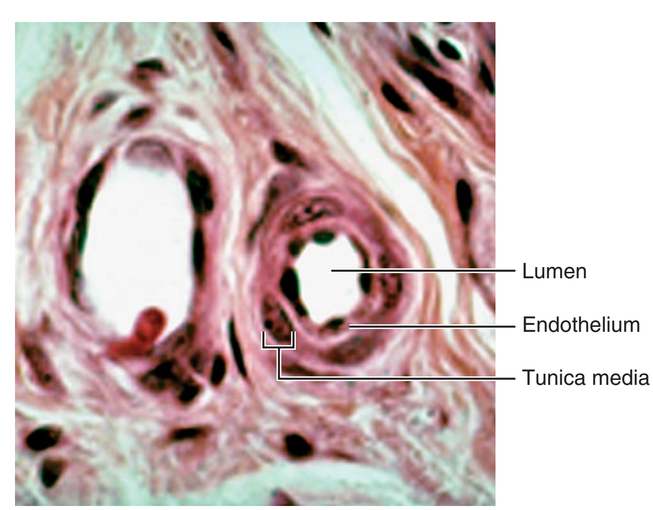
FIGURE 20.2 Comparison of arterial wall structure. **(a)** Section through the wall of the aorta, showing its layers, its abundant elastin (stained brown), and the vasa vasorum in the tunica externa. **(b)** The elastic tissue in muscular arteries forms two distinct layers, the internal elastic membrane in the tunica intima, and the external elastic membrane in the tunica media. **(c)** In an arteriole, the tunica media is composed of only a few layers of smooth muscle cells, and the tunica intima is reduced to flattened endothelial cells.



(a) Elastic artery (aorta, 12×)



(b) Muscular artery (40×)



(c) Small arteriole (285×)

response to increased blood pressure, in effect storing some of the energy of the flowing fluid; then, when the heart relaxes, the elastic elements recoil, propelling the blood onward. As the blood proceeds through smaller arteries, there is a marked decline both in its absolute pressure (due to resistance imparted by the arterial walls) and in the size of the pressure vacillations (due to the elastic recoil of the arteries just described). By the time the blood reaches the thin-walled capillaries, which are too fragile to withstand strong surges in blood pressure, the pressure of the blood is considerably lower and completely steady.

Muscular Arteries

Muscular (distributing) arteries lie distal to the elastic arteries and supply groups of organs, individual organs, and parts of organs. These "middle-sized" arteries constitute most of the named arteries seen in the anatomy laboratory. They range in diameter from about 1 cm to 0.3 mm (as thick as a sharpened pencil lead). They are called "muscular" because their tunica media is thicker relative to the size of the lumen than that of any other type of vessel (see Figure 20.1). By actively changing the diameter of the artery, this muscular layer regulates the amount of blood flowing to the organ supplied according to the specific needs of that organ.

As in all vessels, concentric sheets of elastin occur within the tunica media of muscular arteries—although these sheets are not as thick or abundant as those of elastic arteries. Additionally, as a feature unique to muscular arteries, especially thick sheets of elastin lie on each side of the smooth muscle of the tunica media: A wavy *internal elastic membrane* forms the outer layer of the tunica intima, and an *external elastic membrane* forms the outer layer of the tunica media (Figure 20.2b). The elastin in muscular arteries, like that in elastic arteries, helps dampen the pulsatile pressure produced by the heartbeat.

Arterioles

Arterioles are the smallest arteries, with diameters ranging from about 0.3 mm to 10 μm. Their tunica media contains only one or two layers of smooth muscle cells. Larger arterioles have all three tunics plus an internal elastic network in the tunica intima. Smaller arterioles (Figure 20.2c), which lead into the capillary beds, are little more than a single layer of smooth muscle cells spiraling around an underlying endothelium.

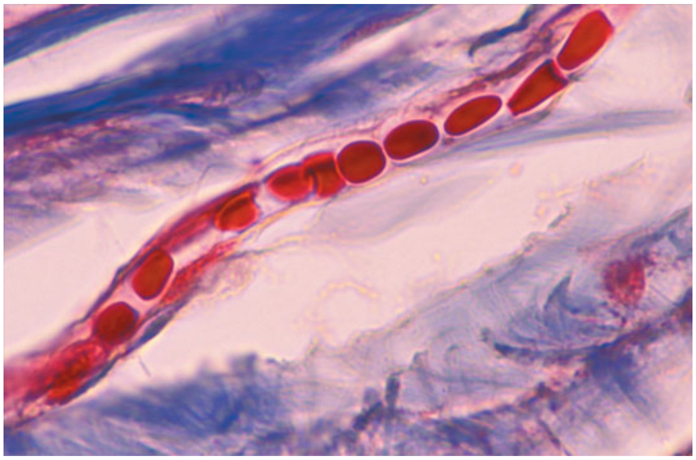
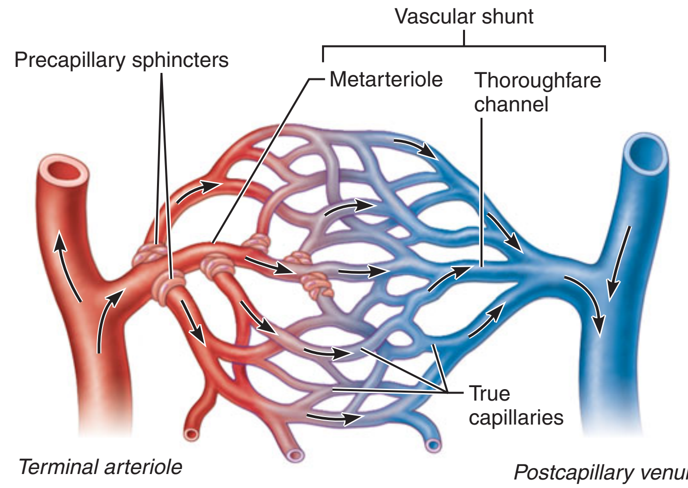
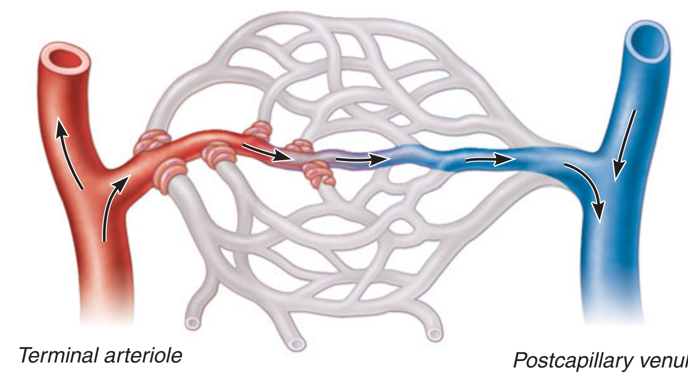


FIGURE 20.3 Red blood cells passing through a capillary (320×).



(a) Sphincters open—blood flows through true capillaries.



(b) Sphincters closed—blood flows through metarteriole–thoroughfare channel and bypasses true capillaries.

FIGURE 20.4 Anatomy of a capillary bed.

The diameter of each arteriole is regulated in two ways: (1) Local factors in the tissues signal the smooth muscle cells to contract or relax, thus regulating the amount of blood sent downstream to each capillary bed; and (2) the sympathetic nervous system adjusts the diameter of arterioles throughout the body to regulate systemic blood pressure. For example, a widespread sympathetic vasoconstriction raises blood pressure during fight-or-flight responses (discussed in Chapter 15, p. 464).

Capillaries

➤ Describe the structure and function of capillaries, sinusoids, and capillary beds, and explain the structural basis of capillary permeability.

Capillaries are the smallest blood vessels, with a diameter of 8–10 μm, just large enough to enable erythrocytes to pass through in single file **(Figure 20.3)**. They are composed of only a single layer of endothelial cells surrounded by a basement membrane (see Figure 20.1b). They are the body's most important blood vessels because they renew and refresh the surrounding tissue fluid (interstitial fluid; p. 80) with which all body cells are in contact. Capillaries deliver to this fluid the oxygen and nutrients cells need, and they remove the carbon dioxide and nitrogenous wastes that cells deposit into the fluid. Along with these universal functions, some capillaries also perform site-specific functions. In the lungs, oxygen enters the blood (and carbon dioxide leaves it) through capillaries. Capillaries in the small intestine receive digested nutrients; those in the endocrine glands pick up hormones; and those in the kidneys remove nitrogenous wastes from the body.

Capillary Beds

Capillaries supply body tissues through structures called capillary beds. A *capillary bed* is a network of the body's smallest vessels **(Figure 20.4)**. Capillary beds run throughout almost all tissues, especially the loose connective tissues. A terminal arteriole leads to a **metarteriole**—a vessel that is structurally intermediate between an arteriole and a capillary—from which branch true capillaries. The metarteriole continues into a **thoroughfare channel,** a vessel structurally intermediate between a capillary and a venule. True capillaries merge into the thoroughfare channel, which then joins a venule. Smooth muscle cells called **precapillary sphincters** wrap around the root of each true capillary where it leaves the metarteriole.

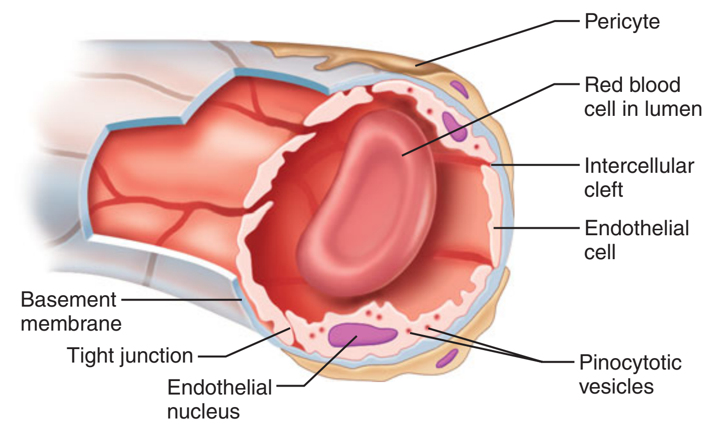
The precapillary sphincters regulate the flow of blood to the tissue according to that tissue's needs for oxygen and nutrients. When the tissue is functionally active, the sphincters are relaxed, enabling blood to flow through the wide-open capillaries and supply the surrounding tissue cells. When the tissue has lower demands (such as when nearby tissue cells already have adequate oxygen), the precapillary sphincters contract, closing off the true capillaries and forcing blood to flow straight from the metarteriole into the thoroughfare channel and venule—thereby bypassing the true capillaries. In this way, capillary beds precisely control the amount of blood supplying a tissue at any time.

Even though most tissues and organs have a rich capillary supply, not all do. Tendons and ligaments are poorly vascularized. Epithelia and cartilage contain no capillaries;

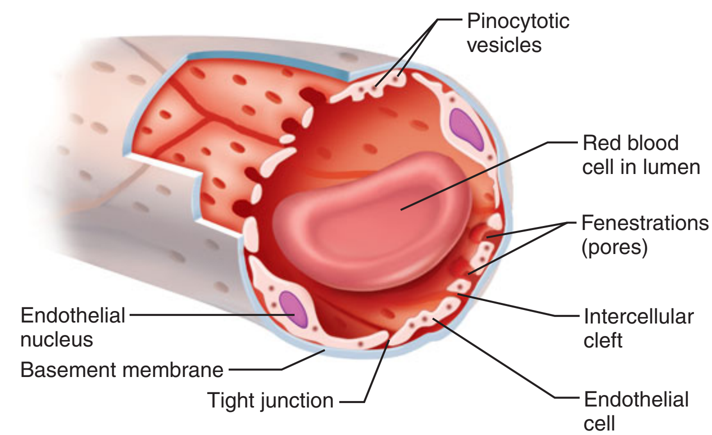
instead, they receive nutrients indirectly via diffusion from nearby vascularized connective tissues. The cornea and the lens have no capillary supply at all and are nourished by the aqueous humor and other sources (described on pp. 490 and 493).

Capillary Permeability

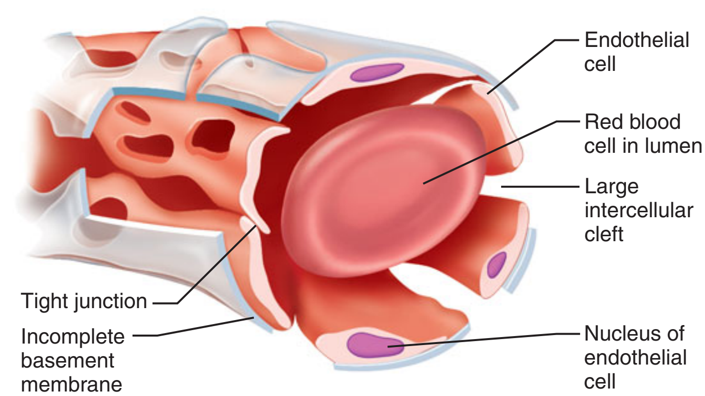
The structure of capillaries is well suited for their function in the exchange of nutrients and wastes between the blood and the tissue fluid. As mentioned, a capillary is a tube consisting of a layer of thin endothelial cells surrounded by a basement membrane **(Figure 20.5)**. The endothelial cells are held together by tight junctions and occasional desmosomes. Tight junctions block the passage of small molecules (p. 74), but such junctions do not surround the whole perimeter of the endothelial cells. There are gaps of unjoined membrane, called **intercellular clefts,** through which small molecules exit and enter the capillary. External to the endothelial cells, the delicate capillary is strengthened and stabilized by scattered **pericytes** (per′ĭ-sīts; "surrounding cells"), spider-shaped cells whose thin processes form a network that is widely spaced so as not to interfere with capillary permeability.



(a) Continuous capillary. Least permeable and most common (e.g., skin, muscle).



(b) Fenestrated capillary. Large fenestrations (pores) increase permeability. Occurs in special locations (e.g., kidney, small intestine).



(c) Sinusoidal capillary. Most permeable. Occurs in special locations (e.g., liver, bone marrow, spleen).

FIGURE 20.5 Capillary structure.

Some capillaries are *continuous* and others are *fenestrated* (fen′is-tra-ted; "with windows"). The only structural difference between these two types is that fenestrated capillaries have pores (fenestrations) spanning the endothelial cells. Continuous capillaries lack such pores. Continuous capillaries (Figure 20.5a) are the more common type, occurring in most organs of the body, such as skeletal muscles, skin, and the central nervous system. Fenestrated capillaries (Figure 20.5b), by contrast, occur only where there are exceptionally high rates of exchange of small molecules between the blood and the surrounding tissue fluid. For example, capillaries in the small intestine, which receive the digested nutrients from food, and those in the glomeruli of the kidneys, which filter blood, are fenestrated. So are capillaries in the synovial membranes of joints, where many water molecules exit the blood to contribute to the synovial fluid.

Routes of Capillary Permeability Molecules pass into and out of capillaries through four routes: (1) by direct diffusion through the endothelial cell membranes; (2) through the intercellular clefts; (3) through pinocytotic vesicles that invaginate from the plasma membrane and migrate across the endothelial cell; and (4) through the fenestrations in fenestrated capillaries. Most exchange of small molecules is thought to occur through the intercellular clefts, and pinocytotic vesicles transport dissolved gases, nutrients, and waste products. Carbon dioxide and oxygen seem to be the only important molecules that diffuse directly through endothelial cells, because these uncharged molecules easily diffuse through the lipid-containing membranes of cells.

Low-Permeability Capillaries: The Blood-Brain Barrier The *blood-brain barrier* (introduced on p. 411), which prevents all but the most vital molecules (and normally even leukocytes) from leaving the blood and entering brain tissue, derives from the structure of capillaries in the brain. These capillaries *lack* the structural features that account for capillary permeability: Brain capillaries are continuous capillaries with complete tight junctions; intercellular clefts are absent. The vital molecules that must cross brain capillaries are "ushered through" by highly selective transport mechanisms in the plasma membranes of the endothelial cells. The blood-brain barrier is *not* a barrier against uncharged and

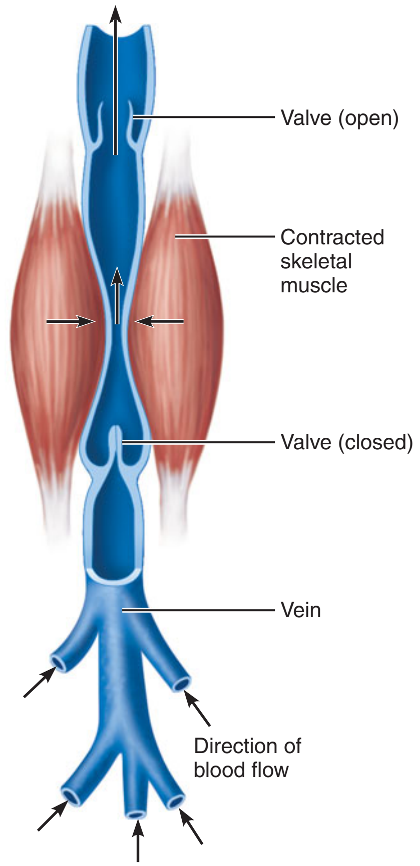


FIGURE 20.6 Blood flow through veins. Valves keep venous blood moving in one direction; the valves are opened by blood flowing toward the heart and are closed by backflow. The skeletal muscular pump aids venous return: Contracting skeletal muscles press against a vein and propel blood toward the heart, forcing valves proximal to the muscles to open and valves distal to close.

lipid-soluble molecules such as oxygen, carbon dioxide, and some anesthetics, which diffuse unhindered through the endothelial cells and freely enter brain tissue.

During prolonged emotional stress, the tight junctions between the endothelial cells of brain capillaries are opened, so that the blood-brain barrier fails and toxic substances in the blood can enter brain tissue. This mechanism has been implicated in the neurological symptoms associated with Gulf War syndrome—a syndrome marked by numerous chronic symptoms, including chronic fatigue, dizziness, memory loss, and depression, seen in some soldiers who served in the Persian Gulf War in 1991. Further study of the disruption of the blood-brain barrier could one day help medical scientists who are seeking ways to deliver beneficial drugs—antibiotics and chemicals to kill brain tumors—into the brain.

Sinusoids

Some organs contain wide, leaky capillaries called **sinusoids** or **sinusoidal capillaries** (Figure 20.5c). Each sinusoid follows a twisted path and has both expanded and narrowed regions. Sinusoids are usually fenestrated, and their endothelial cells have fewer cell junctions than do ordinary capillaries. In some sinusoids, in fact, the intercellular clefts are wide open. Sinusoids occur wherever there is an extensive exchange of *large* materials, such as proteins or cells, between the blood and surrounding tissue. For example, they occur in the bone marrow and spleen, where many blood cells move through their walls. The large diameter and twisted course of sinusoids ensure that blood slows when flowing through these vessels, allowing time for the many exchanges that occur across their walls.

Veins

- Compare postcapillary venules to capillaries.
- Explain how to distinguish a vein from an artery in histological sections.
- Describe the structural features of arteries and veins that help maintain the flow of blood through these vessels.

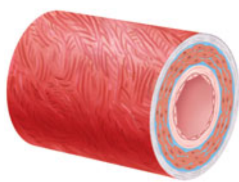
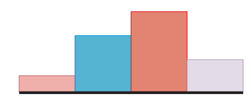
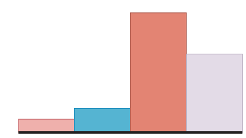
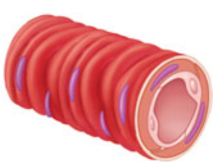
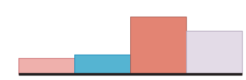
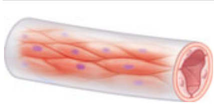
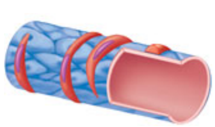
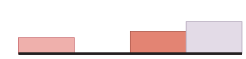
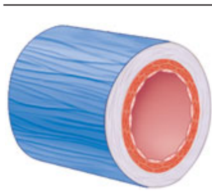
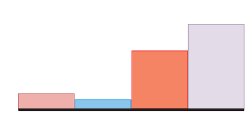
Veins are the blood vessels that conduct blood from the capillaries toward the heart. Veins in the systemic circuit carry blood that is relatively oxygen-poor, but the pulmonary veins carry oxygen-rich blood returning from the lungs. Because blood pressure declines substantially while blood passes through the high-resistance arterioles and capillary beds, blood pressure in the veins is much lower than in the arteries. Because they do not withstand as much pressure, the walls of veins are thinner than those of comparable arteries.

The smallest veins are called **venules** and are 8–100 μm in diameter. The smallest venules, called **postcapillary venules** (Figure 20.4), consist of an endothelium on which lie pericytes. These venules function very much like capillaries. In fact, during inflammatory responses, more fluid and leukocytes leave the circulation through postcapillary venules than through capillaries. Larger venules have a tunica media that consists of one or two layers of smooth muscle cells and a thin tunica externa.

Venules join to form veins. The lumens of veins are larger than those of arteries of comparable size (Figure 20.1a); at any given time veins hold fully 65% of the body's blood. In veins, the tunica externa is thicker than the tunica media, a relationship that is the opposite of that in arteries. In the body's largest veins—the venae cavae, which return systemic blood to the heart—the tunica externa is further thickened by longitudinal bands of smooth muscle. Veins have less elastin in their walls than do arteries, because veins do not need to dampen any pulsations (all of which are smoothed out by arteries before the blood reaches the veins). The structural differences between vessel types are summarized in **Table 20.1**.

Several mechanisms counteract the low venous blood pressure and help move the blood back to the heart. One structural feature of some veins is **valves** that prevent the backflow of blood away from the heart (Figure 20.1 and **Figure 20.6**). Each of these valves has several cusps formed from the tunica intima. The flow of blood toward the heart pushes the cusps apart, opening the valve, and any backflow pushes the cusps together, closing the valve. Valves are most abundant in veins

TABLE 20.1 Summary of Blood Vessel Anatomy

		Relative Tissue Makeup			
Vessel Type/Illustration*	**Average Lumen Diameter (D) and Wall Thickness (T)**	**Endothelium**	**Elastic Tissues**	**Smooth Muscles**	**Fibrous (Collagenous) Tissues**
 Elastic artery	D: 1.5 cm T: 1.0 mm				
 Muscular artery	D: 6.0 mm T: 1.0 mm				
 Arteriole	D: 37.0 μm T: 6.0 μm				
 Capillary	D: 9.0 μm T: 0.5 μm				
 Venule	D: 20.0 μm T: 1.0 μm				
 Vein	D: 5.0 mm T: 0.5 mm				

*Size relationships are not proportional. Smaller vessels are drawn relatively larger so detail can be seen. See column 2 for actual dimensions.

of the limbs, where the superior direction of venous flow is most directly opposed by gravity. A few valves occur in the veins of the head and neck, but none are located in veins of the thoracic and abdominal cavities.

One functional mechanism that aids the return of venous blood to the heart is the normal movement of the body and limbs, for instance, during walking. Swinging a limb moves the blood in the limb, and the venous valves ensure that this blood moves only in the proper direction. Another mechanism aiding venous return is the skeletal muscular pump, in which contracting skeletal muscles press against the thin-walled veins, forcing valves proximal to the area of contraction to open and propelling blood toward the heart (Figure 20.6). Valves distal to the contracting muscles are closed by backflowing blood.

The effectiveness of venous valves in preventing the backflow of blood is easily demonstrated. Hang one hand by your side until the veins on its dorsal surface become distended with blood. Next, place two fingertips against one of the distended veins, and, pressing firmly, move the superior finger proximally along the vein, and then release that finger. The vein stays flat and collapsed despite the pull of gravity. Finally, remove the distal fingertip, and watch the vein refill rapidly with blood.

VARICOSE VEINS When the valves in veins weaken and fail, the result is **varicose veins.** The veins twist and swell with pooled blood, and venous drainage slows considerably. Fully 15% of all adults suffer from varicose veins, usually in the lower limbs. The left lower limb is more susceptible to varicose veins than the right. Where the aorta divides into the right and left common iliac arteries, the right common iliac artery crosses over the left common iliac vein, the vessel that drains the left lower limb. The higher pressure in the artery can compress the deeper left common iliac vein and impede venous drainage from the left lower limb. Women are affected more often than men. Varicose veins can be hereditary but also occur in people whose jobs require prolonged standing in one position, such as store clerks, hairdressers, dentists, and nurses. (In nonmoving legs, the venous blood drains so slowly that it accumulates, stretches the venous walls and valves, and causes the valves to fail.) Obesity and pregnancy can cause or worsen the problem, because increased weight constricts the leg-draining veins in the superior thigh.

Some varicose veins are caused by elevated venous pressure due to straining to deliver a baby or to have a bowel movement. This straining raises the intra-abdominal pressure, preventing drainage of blood from the veins of the anal canal at the inferior end of the large intestine. The resulting varicosities in these anal veins are called **hemorrhoids.**

In severe cases, varicose veins slow the circulation through a body region so greatly that the tissues in it die of oxygen starvation. To prevent this, physicians either remove the affected veins or inject them with an irritating solution that scars them and fuses them shut. Drainage of the body region then proceeds normally, through alternative vascular pathways called anastomoses, which are described next.

VASCULAR ANASTOMOSES

➤ Define vascular anastomoses and explain their functions.

Where vessels unite or interconnect, they form **vascular anastomoses** (ah-nas″to-mo′sēz; "coming together"). Most organs receive blood from more than one arterial branch, and neighboring arteries often connect with one another to form *arterial anastomoses.* Arterial anastomoses provide alternative pathways, or *collateral channels,* for blood to reach a given body region. If one arterial branch is blocked or cut, the collateral channels can often provide the region with an adequate blood supply. Arterial anastomoses occur around joints, where active body movements may hinder blood flow through one channel (see Figure 20.11 for examples), as well as in the abdominal organs, brain, and heart. Because of the many anastomoses among the smaller branches of the coronary artery in the heart wall, a coronary artery can be 90% occluded by atherosclerosis before a myocardial infarction occurs. By contrast, because arterial anastomoses are poorly developed in the kidneys, spleen, parts of bone diaphyses nearest the epiphyses, and central artery of the retina, blockage of such arteries causes severe tissue damage.

Veins anastomose much more freely than arteries. You may be able to see *venous anastomoses* through the skin on the dorsal surface of your hand. Because of the abundant anastomoses, occlusion of a vein rarely blocks blood flow or leads to tissue death.

VASA VASORUM

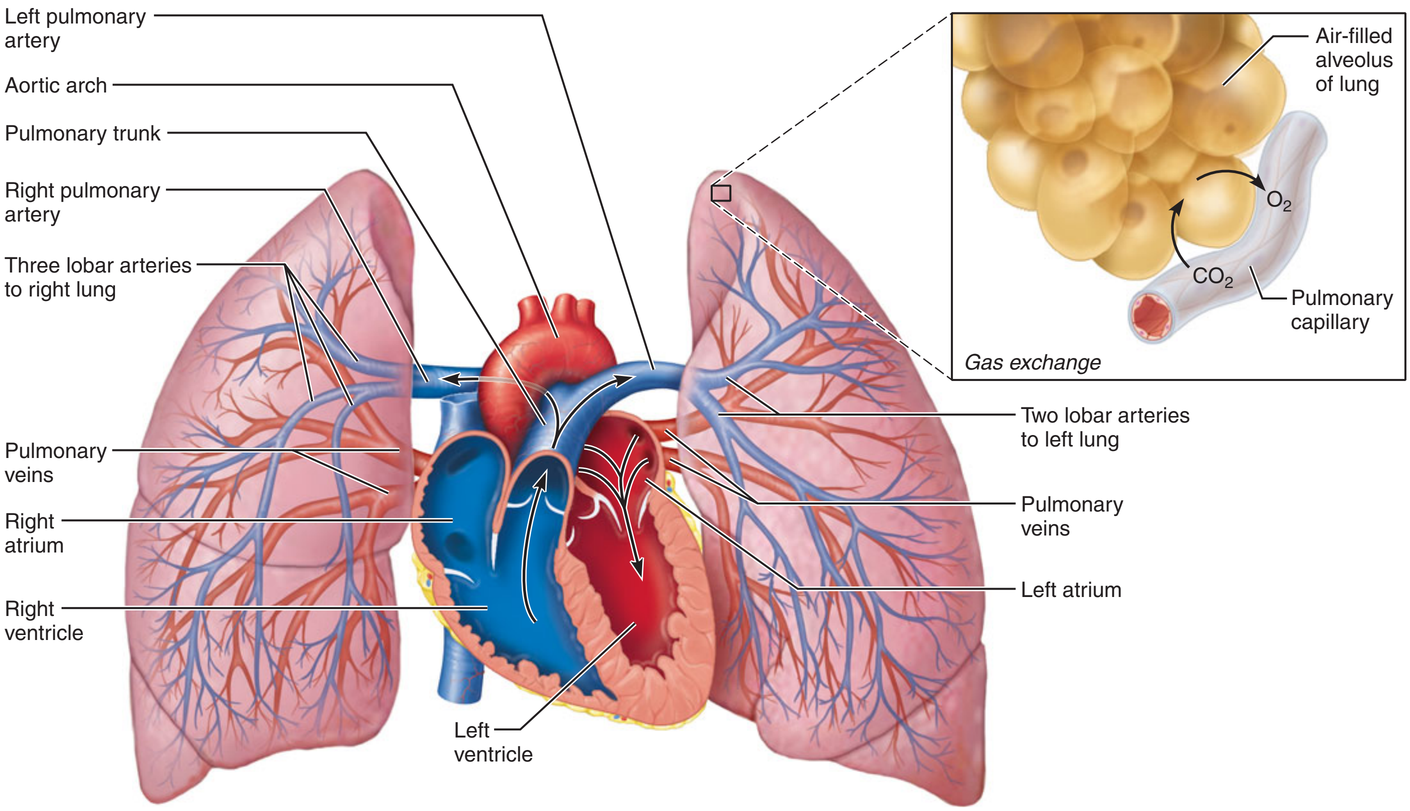
➤ Define vasa vasorum.

The walls of blood vessels contain living cells and therefore require a blood supply of their own. For this purpose, the larger arteries and veins have tiny arteries, capillaries, and veins in their tunica externa. These little vessels, the **vasa vasorum** (va′sah va-sor′um; "vessels of the vessels"), arise either as tiny branches from the same vessel or as small branches from other, nearby vessels and nourish the outer half of the wall of the larger vessel (Figure 20.2a). The inner half, by contrast, gets its nutrients by diffusion from the blood in the vessel's own lumen. Small blood vessels need no vasa vasorum because their walls are entirely supplied by luminal blood.

check your understanding

1. What structural features of capillaries make them well suited for their function of nourishing body tissues and removing waste products?
2. What components in the wall of a muscular artery help to move blood through these vessels? What mechanisms aid in maintaining the movement of venous blood?
3. Define each of the following: (a) vasa vasorum, (b) arterial anastomoses, (c) varicose veins, (d) artery.

For answers, see Appendix B.



The pulmonary arterial system is shown in blue to indicate that the blood carried is oxygen-poor. The pulmonary venous drainage is shown in red to indicate that the blood transported is oxygen-rich.

FIGURE 20.7 Pulmonary circulation.

PART 2: BLOOD VESSELS OF THE BODY

➤ Define pulmonary and systemic circuits.

Recall from Chapter 19 that the complex system of blood vessels in the body called the *vascular system* has two basic circuits: The *pulmonary circuit* carries blood to and from the lungs for the uptake of oxygen and the removal of carbon dioxide, whereas the *systemic circuit* carries oxygenated blood throughout the body and picks up carbon dioxide from body tissues (see Figure 19.1, p. 556). Blood vessels in the systemic circuit also (1) pick up nutrients from the digestive tract and deliver them to cells throughout the body, (2) receive nitrogenous wastes from body cells and transport them to the kidneys for elimination in the urine, and (3) pick up hormones or other signaling molecules and transport them to their target organ.

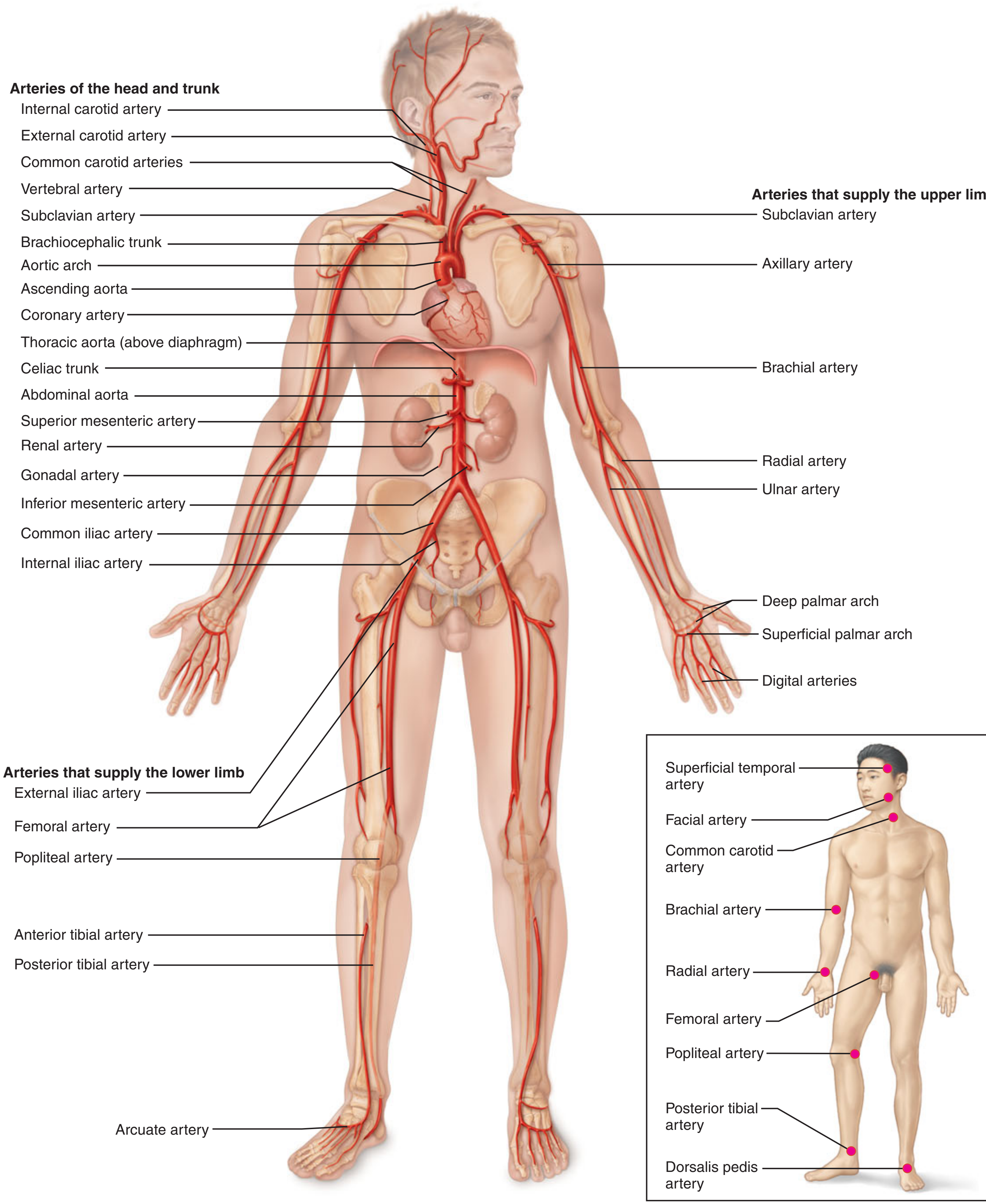
As you read about the vessels, note that arteries and veins tend to run together, side by side (see Figure 20.1a). In many places, these vessels also run with nerves. Note also that by convention, vessels carrying oxygen-rich blood are depicted as red, whereas those transporting oxygen-poor blood are depicted as blue, regardless of vessel type.

THE PULMONARY CIRCULATION

➤ Name the major vessels of the pulmonary circuit.

The pulmonary circulation begins as oxygen-poor blood leaves the right ventricle of the heart via the **pulmonary trunk** (Figure 20.7). This large artery exits the ventricle anterior to the aorta, ascends to the aorta's left, and reaches the concavity of the aortic arch, where it branches at a T-shaped divergence into the **right** and **left pulmonary arteries.** Each pulmonary artery penetrates the medial surface of a lung and then divides into several **lobar arteries** serving the lobes of the lung, three in the right lung and two in the left lung. Within the lung, the arteries branch along with the lung's air passageways (bronchi). As the branching arteries decrease in size, they become arterioles and finally the pulmonary capillaries that surround the delicate air sacs (lung alveoli). Gas exchange occurs across these capillaries, and the newly oxygenated blood enters venules and then progressively larger veins. The largest venous tributaries form the superior and inferior **pulmonary veins,** which exit the medial aspect of each lung. In the mediastinum posterior to the heart, the four pulmonary veins run horizontally, just inferior to the pulmonary arteries, and empty into the left atrium.

The arteries and veins of the pulmonary circuit have thinner walls than do systemic vessels of comparable diameter,



(a) Anterior view

(b) Pulse points

FIGURE 20.8 Major arteries of the systemic circulation.

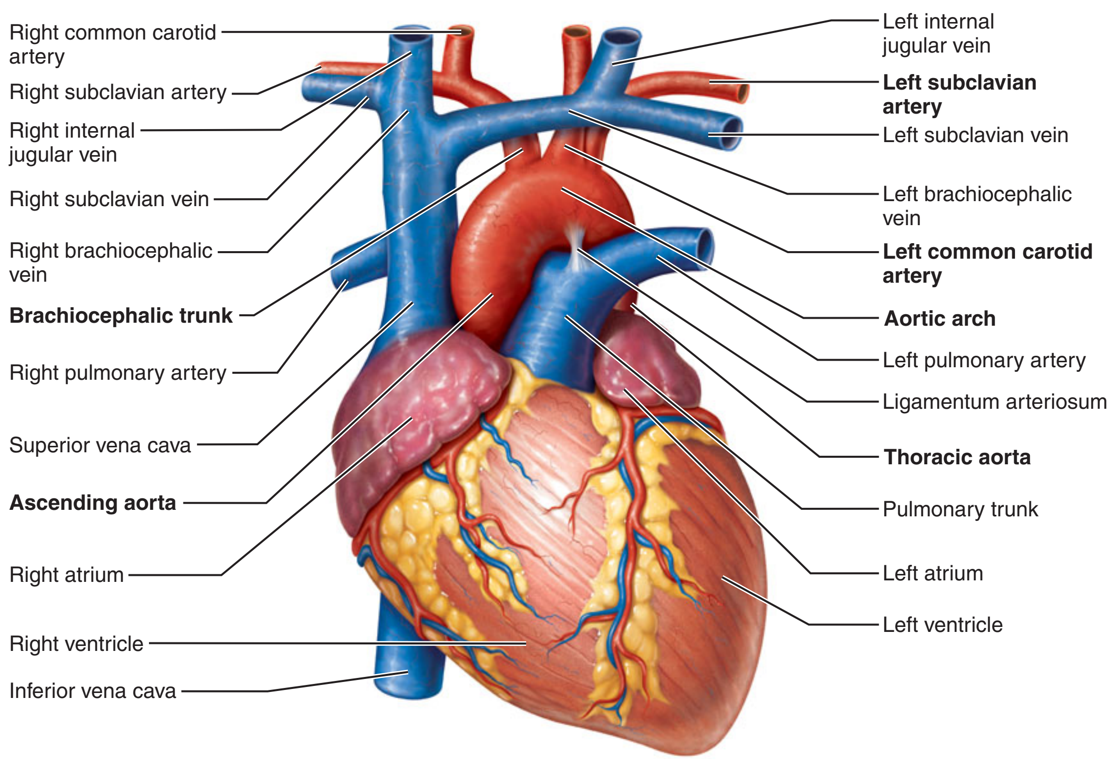


FIGURE 20.9 **The great vessels that exit and enter the heart.**

reflecting the fact that the maximum arterial pressure in the pulmonary circuit is much lower, only one-sixth of that in the systemic circuit.

check your understanding

4. Why is the pulmonary artery illustrated in blue in Figure 20.7? Is the blood in this vessel traveling toward the heart or away from the heart?

For the answer, see Appendix B.

THE SYSTEMIC CIRCULATION

- Identify the location of pulse points in the limbs, head, and neck.
- List the major arteries and veins of the systemic circuit. Describe their locations and the body regions they supply.

Before you examine the systemic vessels, it is worth noting that the vessels on the right and left sides of the body are not always mirror images of each other. That is, some of the large, deep vessels of the trunk region are asymmetrical (their initial symmetry is lost during embryonic development). In the head and limbs, by contrast, almost all vessels are bilaterally symmetrical.

Systemic Arteries

The systemic arteries **(Figure 20.8a)** carry oxygenated blood from the heart to the capillaries of organs throughout the body. The elastin in the walls of these arteries maintains the pulsatile flow. Arterial pulses can be palpated in the muscular arteries at numerous body locations (Figure 20.8b) and can be used to determine heart rate and to assess blood flow to a body region after trauma, surgery, or disease. Deep pressure at a pulse point is a first aid technique used to limit blood flow through a vessel that is hemorrhaging and thus limit blood loss.

As you examine the arterial vessels, you will begin with the aorta and then consider the systemic arteries in a generally superior-to-inferior direction.

Aorta

The **aorta,** the largest artery in the body, leaves the heart, arcs superiorly and then descends along the bodies of the vertebrae to the inferior part of the abdomen (see Figure 20.8). Along this course, the aorta is divided into the following three parts.

Ascending Aorta The **ascending aorta (Figure 20.9)**, one of the great vessels leaving the heart, arises from the left ventricle and ascends for only about 5 cm. It begins posterior to the pulmonary trunk, passes to the right of that vessel, and then curves left to become the aortic arch. The only branches of the ascending aorta are the two *coronary arteries* that supply the wall of the heart (described on p. 572).

Aortic Arch Arching posteriorly and to the left, the **aortic arch** lies posterior to the manubrium of the sternum. The **ligamentum arteriosum,** a fibrous remnant of a fetal artery called the *ductus arteriosus,* interconnects the aortic arch and the pulmonary trunk (Figure 20.9).

Three arteries branch from the aortic arch and run superiorly (Figure 20.9). The first and largest branch is the **brachiocephalic trunk** (bra″ke-o-sĕ-fal′ik; "arm-head"), which ascends to the right toward the base of the neck, where it divides into the *right common carotid* and *right subclavian* arteries. The second and third branches of the aortic arch are the **left common carotid** and **left subclavian arteries,** respectively. These three branches of the aorta supply the head and neck, upper limbs, and the superior part of the thoracic wall. Note that the brachiocephalic trunk on the right has no corresponding artery on the left because the left common carotid and subclavian arteries arise directly from the aorta.

This is the typical branching pattern of these vessels off the aortic arch; however, as with all vessels, there is some variability from this pattern. The most frequent variation is the branching of the left common carotid artery from the brachiocephalic trunk. Less commonly, four large arteries (the right and left common carotids, and the right and left subclavian arteries) arise separately from the aortic arch, or the left common carotid artery and the left subclavian artery arise from a left brachiocephalic trunk.

Descending Aorta Continuing from the aortic arch, the **descending aorta** runs posterior to the heart and inferiorly on the bodies of the thoracic and lumbar vertebrae. It has two parts, the *thoracic aorta* and the *abdominal aorta.*

The **thoracic aorta** (Figure 20.9) descends on the bodies of the thoracic vertebrae (T_5–T_{12}) just to the left of the midline. Along the way, it sends many small branches to the thoracic organs and body wall. (These branches are described on p. 594).

The thoracic aorta passes through the diaphragm at the level of vertebra T_{12} and enters the abdominal cavity as the **abdominal aorta** (Figure 20.8a), which lies on the lumbar vertebral bodies in the midline. The abdominal aorta ends at the level of vertebra L_4, where it divides into the right and left *common iliac arteries,* which supply the pelvis and lower limbs.

Arteries of the Head and Neck

Four pairs of arteries supply the head and neck: the *common carotid arteries* plus three branches from each subclavian artery—the *vertebral artery,* the *thyrocervical trunk,* and the *costocervical trunk* **(Figure 20.10a)**.

Common Carotid Arteries Most parts of the head and neck receive their blood from the **common carotid arteries,** which ascend through the anterior neck just lateral to the trachea. The neck is divided into two triangles by the sternocleidomastoid muscle (shown in Figure 11.30, p. 332). The common carotid arteries are located in the anterior triangle just deep to the sternocleidomastoid and relatively thin infrahyoid muscles. These vessels are more vulnerable than most other arteries in the body because their relatively superficial location makes them vulnerable to slashing wounds. If a common carotid artery is cut, the victim can bleed to death in minutes. At the superior border of the larynx—the level of the "Adam's apple"—each common carotid ends by dividing into an external and internal carotid artery.

The **external carotid arteries** supply most tissues of the head external to the brain and orbit. As each external carotid ascends, it sends a branch to the thyroid gland and larynx **(superior thyroid artery),** to the tongue **(lingual artery),** to the skin and muscles of the anterior face **(facial artery),** to the posterior part of the scalp **(occipital artery),** and to the region around the ear **(posterior auricular artery).** Near the temporomandibular joint, each external carotid ends by splitting into the superficial temporal and maxillary arteries. The **superficial temporal artery** ascends just anterior to the ear and supplies most of the scalp. Branches of this vessel bleed profusely in scalp wounds. The **maxillary artery** runs deep to the ramus of the mandible and anteriorly into the maxillary bone, passing through the chewing muscles. Along the way, it sends branches to the upper and lower teeth, the cheeks, nasal cavity, and muscles of mastication.

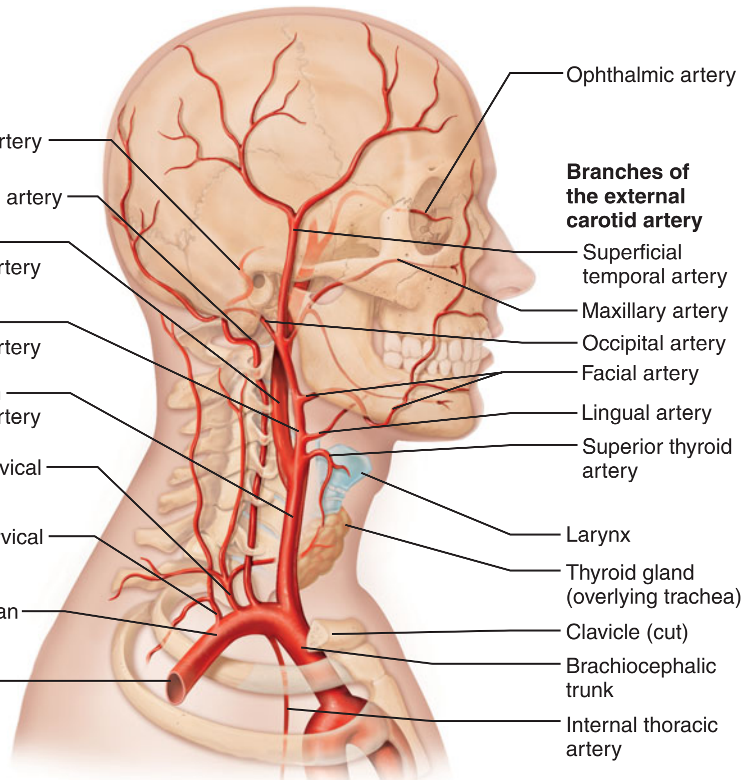
Pulse points for some of these vessels are indicated in Figure 20.8b. The external carotid artery pulse can be felt where it branches from the common carotid artery, just anterior to the sternocleidomastoid and superior to the level of the larynx. A pulse from the facial artery can be felt at the inferior margin of the mandible just anterior to the masseter muscle, and pulsations in the superficial temporal artery can be felt on the temple just anterior to the auricle (external ear).

A clinically important branch of the maxillary artery is the *middle meningeal artery* (not illustrated), which enters the skull through the foramen spinosum and supplies the broad inner surfaces of the parietal bone and squamous region of the temporal bone, as well as the underlying dura mater. Blows to the side of the head often tear this artery, producing an intracranial hematoma that can compress the cerebrum and disrupt brain function.

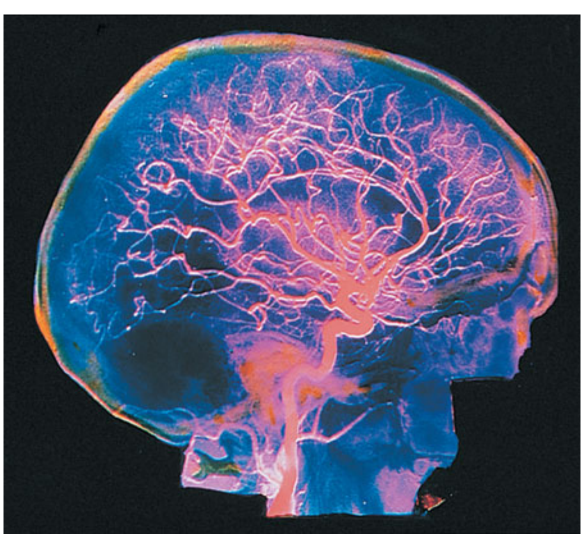
The **internal carotid arteries** supply the orbits and most of the cerebrum. Each internal carotid ascends through the superior neck directly lateral to the pharynx and enters the skull through the carotid canal in the temporal bone. From there, it runs medially through the petrous region of the temporal bone, runs forward along the body of the sphenoid bone, and bends superiorly to enter the sella turcica just posterior to the optic canal. Here, it gives off the **ophthalmic artery** to the eye and orbit (Figure 20.10a) and divides into the *anterior* and *middle cerebral arteries* (Figure 20.10c).

Each **anterior cerebral artery** anastomoses with its partner on the opposite side through a short **anterior communicating artery** (Figure 20.10c) and supplies the medial and superior surfaces of the frontal and parietal lobes. Each **middle cerebral artery** runs through the lateral fissure of a cerebral hemisphere and supplies the lateral parts of the temporal and parietal lobes. Together, the anterior and middle cerebral arteries supply over 80% of the cerebrum; the rest of the cerebrum is supplied by the posterior cerebral artery (described shortly).

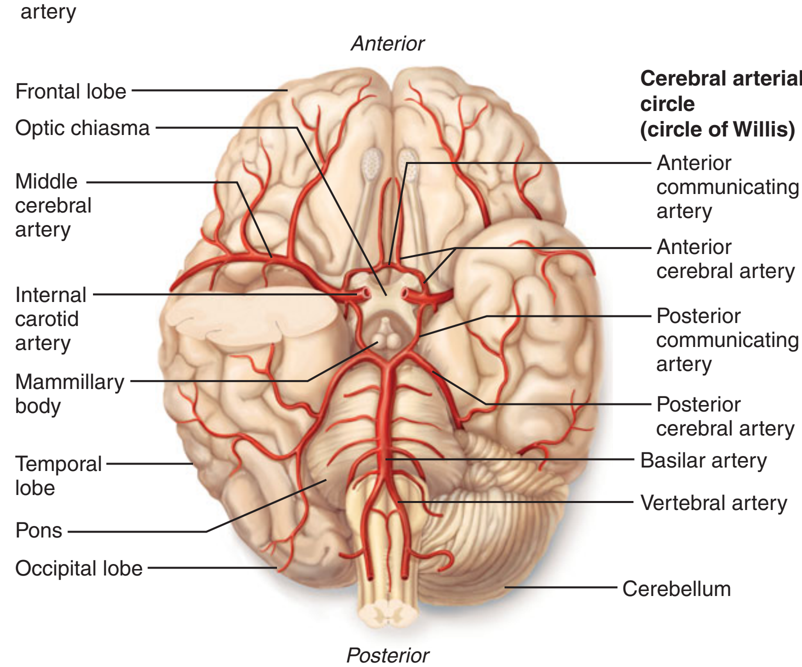
Vertebral Arteries The blood supply to the posterior brain comes from the right and left **vertebral arteries,** which arise from the subclavian arteries at the root of the neck (Figure 20.10a). The vertebral arteries ascend through the foramina in the transverse processes of cervical vertebrae C_6 to C_1 and enter the skull through the foramen magnum. Along the way, they send branches to the vertebrae and cervical spinal cord. Within the cranium, the right and left vertebral arteries join to form the unpaired **basilar** (bas′ĭ-lar) **artery** (Figure 20.10c), which ascends along the ventral midline of the brain



(a) Arteries of the head and neck, right aspect



(b) Colorized arteriograph of the arterial supply of the brain



(c) Major arteries serving the brain (inferior view, right side of cerebellum and part of right temporal lobe removed)

FIGURE 20.10 Arteries of the head, neck, and brain.

stem, sending branches to the cerebellum, pons, and inner ear. At the border of the pons and midbrain, it divides into a pair of **posterior cerebral arteries,** which supply the occipital lobes plus the inferior and medial parts of the temporal lobes of the cerebral hemispheres.

Short **posterior communicating arteries** connect the posterior cerebral arteries to the middle cerebral arteries anteriorly. The two posterior communicating arteries and the single anterior communicating artery complete the formation of an arterial anastomosis called the **cerebral arterial circle** (formerly the **circle of Willis**). This circle forms a loop around the pituitary gland and optic chiasma, and it unites the brain's anterior and posterior blood supplies provided by the internal carotid and vertebral arteries. By interconnecting the arteries that supply the anterior, posterior, left, and right parts of the brain, this anastomosis provides alternate routes for blood to reach brain areas that are affected if either a carotid or vertebral artery becomes occluded.

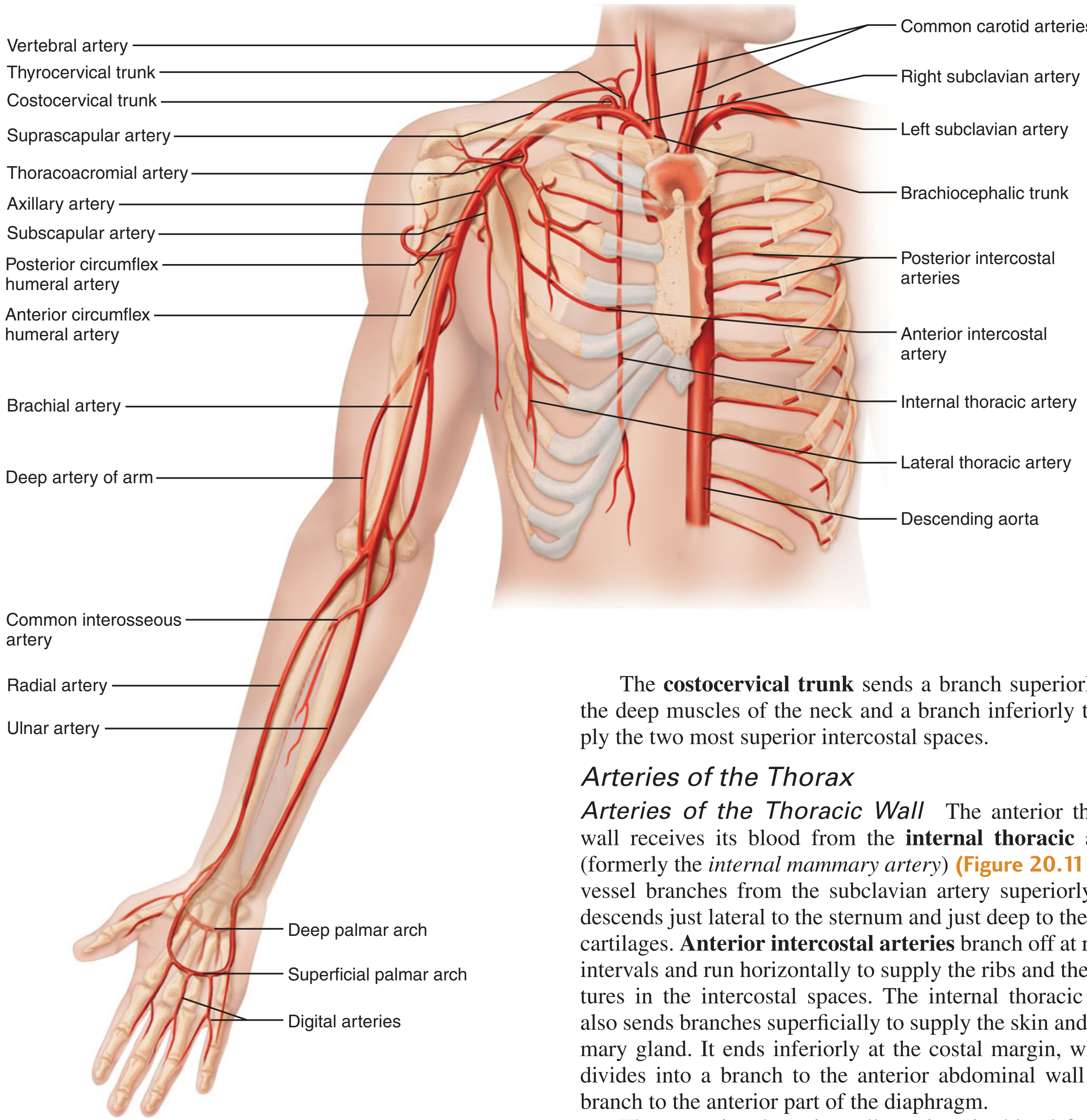


FIGURE 20.11 Arteries of the thorax and right upper limb.

Thyrocervical and Costocervical Trunks The rest of the neck receives its blood from two smaller branches of the subclavian arteries, the *thyrocervical* and *costocervical trunks* (Figure 20.10a).

The **thyrocervical** (thi″ro-ser′vĭ-kal) **trunk,** which arises first, sends two branches posteriorly over the scapula to help supply the scapular muscles, and one branch anteriorly to the inferior part of the thyroid gland *(inferior thyroid artery).* The ascending neck branch illustrated in Figure 20.10a comes off the base of the inferior thyroid artery and helps to supply the cervical vertebrae and spinal cord.

The **costocervical trunk** sends a branch superiorly into the deep muscles of the neck and a branch inferiorly to supply the two most superior intercostal spaces.

Arteries of the Thorax

Arteries of the Thoracic Wall The anterior thoracic wall receives its blood from the **internal thoracic artery** (formerly the *internal mammary artery*) **(Figure 20.11)**. This vessel branches from the subclavian artery superiorly, then descends just lateral to the sternum and just deep to the costal cartilages. **Anterior intercostal arteries** branch off at regular intervals and run horizontally to supply the ribs and the structures in the intercostal spaces. The internal thoracic artery also sends branches superficially to supply the skin and mammary gland. It ends inferiorly at the costal margin, where it divides into a branch to the anterior abdominal wall and a branch to the anterior part of the diaphragm.

The posterior thoracic wall receives its blood from the **posterior intercostal arteries.** The superior two pairs arise from the costocervical trunk, whereas the inferior nine pairs issue from the thoracic aorta. All of the posterior intercostal arteries run anteriorly in the costal grooves of their respective ribs. In the lateral thoracic wall, they form anastomoses with the anterior intercostal arteries. Inferior to the twelfth rib, one pair of *subcostal arteries* (not illustrated) branches from the thoracic aorta. Finally, a pair of *superior phrenic arteries* (not illustrated) leaves the most inferior part of the thoracic aorta to supply the posterior, superior part of the diaphragm.

Arteries of the Thoracic Visceral Organs Many thoracic viscera receive their functional blood supply from small branches off the thoracic aorta. Because these vessels are so small, they are not illustrated. The *bronchial arteries* supply systemic (oxygenated) blood to the lung structures. Usually, two bronchial arteries serve the left lung, and one serves the right lung; in some people they arise from posterior intercostal arteries instead of the aorta. Bronchial arteries enter the lung's medial surface along with the large pulmonary vessels.

The thoracic aorta also sends several small branches to the esophagus directly anterior to it, as well as to the posterior part of the mediastinum and pericardium.

Arteries of the Upper Limbs

The upper limb is supplied by arteries that arise from the subclavian artery (Figure 20.11). After giving off its branches to the neck and thorax (the vertebral artery, the thyrocervical and costocervical trunks, and the internal thoracic artery), each subclavian artery runs laterally onto the first rib, where it underlies the clavicle. From here, the subclavian artery enters the axilla as the *axillary artery.*

Axillary Artery The **axillary artery** descends through the axilla, giving off the following branches: (a) the **thoracoacromial** (tho″rah-ko-ah-kro′me-al) **artery,** which arises just inferior to the clavicle and branches to supply much of the pectoralis and deltoid muscles; (b) the **lateral thoracic artery,** which descends along the lateral edge of pectoralis minor and sends important branches to the breast; (c) the **subscapular artery,** which serves the dorsal and ventral scapular regions and the latissimus dorsi muscle; and (d) **anterior** and **posterior circumflex humeral arteries,** which wrap around the surgical neck of the humerus and help supply the deltoid muscle and shoulder joint. The axillary artery continues into the arm as the *brachial artery.* The boundary for this transition is the inferior border of the teres major muscle.

Brachial Artery The **brachial artery** descends along the medial side of the humerus deep to the biceps muscle in the **medial bicipital furrow** or **groove** (shown in Figure 11.33a, p. 335) and supplies the anterior arm muscles. The brachial pulse can be felt at this location, and firm pressure here can stop bleeding from a hemorrhage in more distal parts of the limb. The brachial artery is used in measuring blood pressure with a sphygmomanometer (sfig″mo-mah-nom′ĕ-ter), a device whose cuff is wrapped around the arm superior to the elbow. One major branch, the **deep artery of the arm** (also called *profunda brachii* = deep brachial), wraps around the posterior surface of the humerus with the radial nerve and serves the triceps muscle. As the brachial artery nears the elbow, it sends several small branches inferiorly, the **ulnar collateral arteries,** that form anastomoses with branches ascending from arteries in the forearm to supply the elbow joint. These vessels also provide collateral circulation to the more distal regions of the limb when the elbow is bent. The brachial artery crosses the anterior aspect of the elbow joint deep to the bicipital aponeurosis in the midline of the arm, another site at which its pulse is easily felt, and where one listens when measuring blood pressure. Immediately beyond the elbow joint, the brachial artery splits into the *radial* and *ulnar arteries,* which descend through the anterior aspect of the forearm.

Radial Artery The **radial artery** descends along the medial margin of the brachioradialis muscle, supplying muscles of the lateral anterior forearm, the lateral part of the wrist, and the thumb and index finger. At the root of the thumb just lateral to the tendon of flexor carpi radialis (shown in Figure 11.35, p. 337), it lies very near the surface and provides a convenient site for taking the pulse. A branch of the radial artery continues into the anatomical snuff box and a radial pulse can be detected there also.

Ulnar Artery The **ulnar artery,** which descends along the medial side of the anterior forearm, lies between the superficial and deep flexor muscles and sends branches to the muscles that cover the ulna. Proximally, it gives off a major branch called the **common interosseous artery,** which splits immediately into *anterior* and *posterior interosseous arteries.* These vessels descend along the respective surfaces of the interosseous membrane between the radius and the ulna. The anterior interosseous artery supplies the deep flexor muscles, whereas the posterior interosseous artery and its branches supply all the extensors on the posterior forearm. The ulnar artery continues into the hand, crossing the wrist just lateral to the tendon of flexor carpi ulnaris.

Palmar Arches In the palm, branches of the radial and ulnar arteries join to form two horizontal arches, the **superficial** and **deep palmar arches.** The superficial arch underlies the skin and fascia of the hand, whereas the deep arch lies against the metacarpal bones. The **digital arteries,** which supply the fingers, branch from these arches. (The radial and ulnar arteries also form a *carpal arch* on the dorsal side of the wrist. Branches from this dorsal arch run distally along the metacarpal bones.)

Arteries of the Abdomen

The arteries to the abdominal organs arise from the abdominal aorta (Figure 20.8a and **Figure 20.12**). In a person at rest, about half of the entire arterial flow is present in these vessels. Three midline branches (the *celiac trunk, superior mesenteric artery,* and *inferior mesenteric artery*) bring blood to the digestive tube, the inner tube. Paired branches supply structures of the outer tube (adrenal glands, kidneys, gonads, and abdominal body wall). You will consider these arteries from superior to inferior in the order they arise from the aorta.

Inferior Phrenic Arteries The paired **inferior phrenic arteries** branch from the abdominal aorta at the level of vertebra T_{12}, just inferior to the aortic opening (hiatus) of the diaphragm (Figure 20.12). These arteries supply the inferior surface of the diaphragm.

Celiac Trunk The short, wide, unpaired *celiac* (se′le-ak) **trunk** **(Figure 20.13a)** supplies the viscera in the superior part of the abdominal cavity (*coelia* = abdominal cavity). Specifically, it sends branches to the stomach, liver, gallbladder, pancreas, spleen, and a part of the small intestine (duodenum). It emerges midventrally from the aorta at the level of T_{12} and divides almost immediately into three branches: the *left gastric, splenic,* and *common hepatic arteries.*

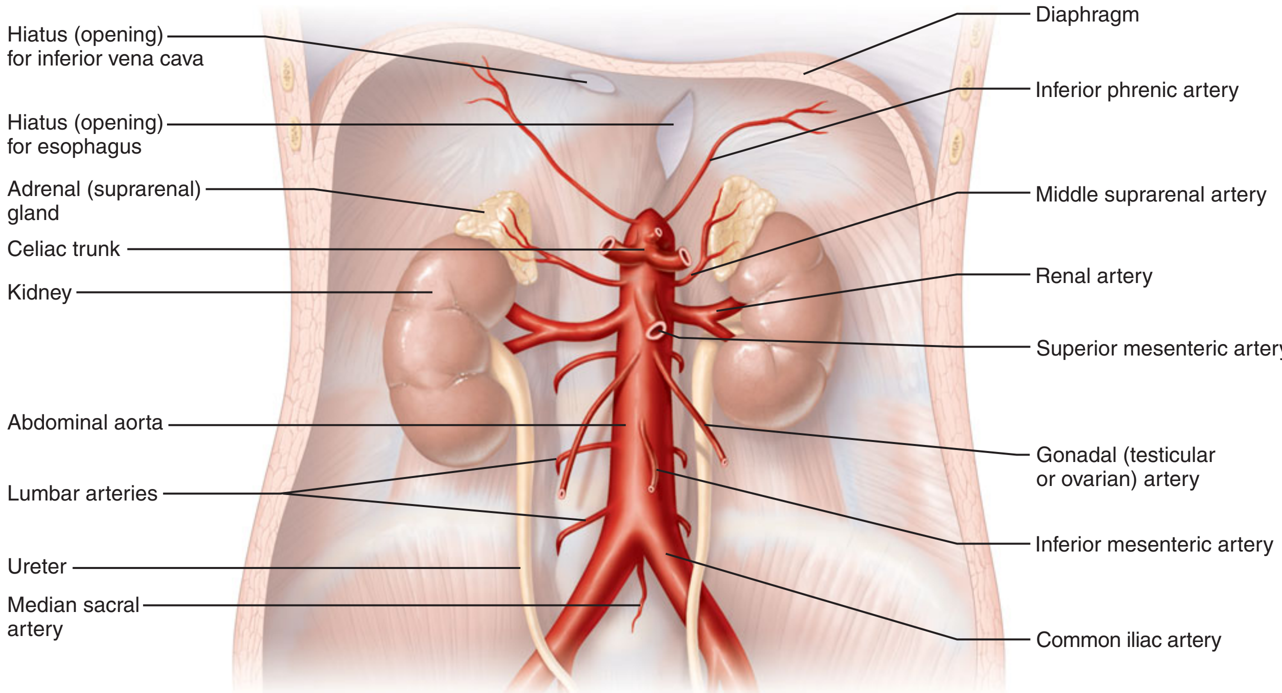


FIGURE 20.12 Major branches of the abdominal aorta. (See *A Brief Atlas of the Human Body,* Second Edition, Figure 70.)

The **left gastric artery** (*gaster* = stomach) runs superiorly and to the left, to the junction of the stomach with the esophagus, where it gives off several esophageal branches and descends along the right (lesser) curvature of the J-shaped stomach.

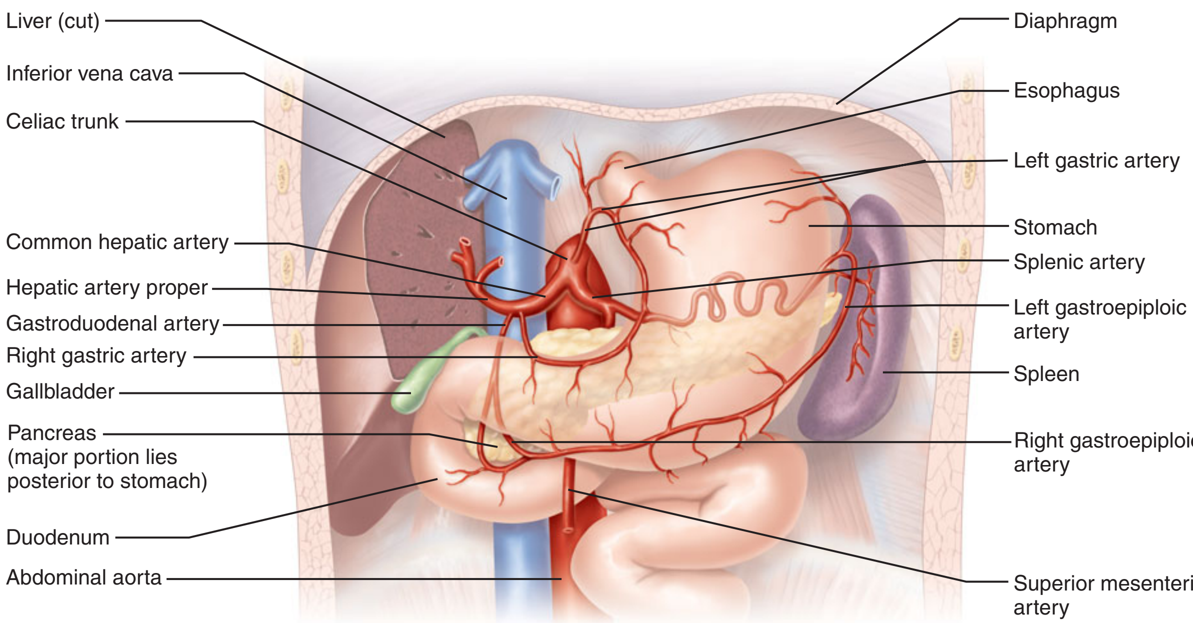
The large **splenic artery** runs horizontally and to the left, posterior to the stomach, to enter the spleen. It passes along the superior border of the pancreas, sending branches to this organ. Near the spleen, it sends several short branches superiorly to the stomach's dome *(short gastric arteries)* and sends a major branch along the stomach's left (greater) curvature—the **left gastroepiploic** (gas″tro-ep″ĭ-plo′ik) **artery.**

The **common hepatic artery** (*hepar, hepat* = liver) is the only branch of the celiac trunk that runs to the right. At the junction of the stomach with the small intestine (duodenum), this artery divides into an ascending branch, the *hepatic artery proper,* and a descending branch, the *gastroduodenal artery.* The **hepatic artery proper** divides into *right* and *left branches* just before entering the liver; the *cystic artery* to the gallbladder usually arises from the right branch of the hepatic artery. The **right gastric artery,** which can arise either from the hepatic artery proper or from the common hepatic artery, runs along the stomach's lesser curvature from the right. The **gastroduodenal artery** (gas″tro-du″o-de′nal), the descending branch of the common hepatic artery, runs inferiorly between the duodenum and the head of the pancreas. One branch, the **superior pancreaticoduodenal artery,** helps supply the pancreas, plus the nearby duodenum. The other branch, the **right gastroepiploic artery,** runs along the stomach's greater curvature from the right.

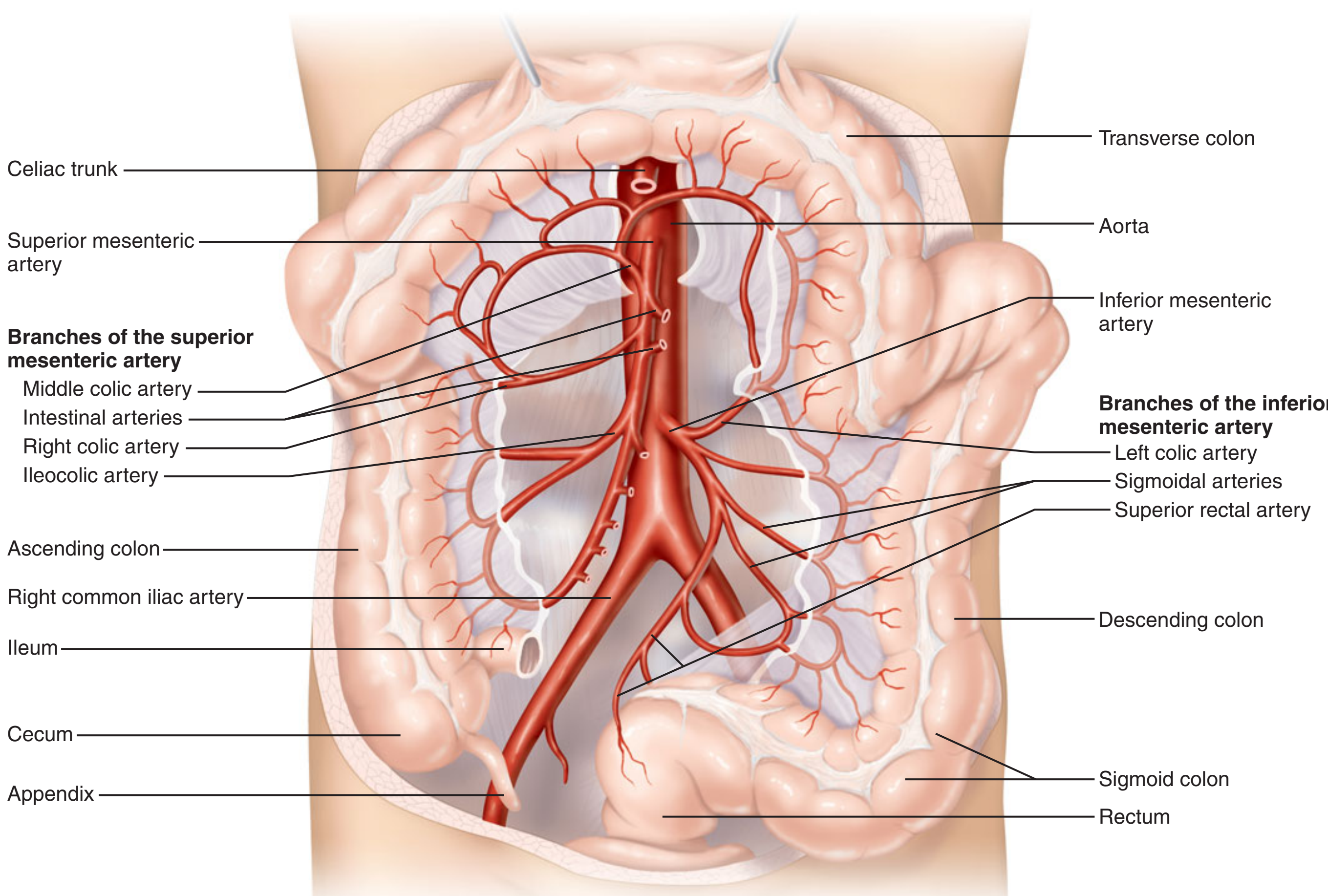
Superior Mesenteric Artery The large, unpaired **superior mesenteric** (mes″en-ter′ik) **artery** serves most of the intestines (Figure 20.13b). It arises midventrally from the aorta, posterior to the pancreas at the level of L_1. From there, it runs inferiorly and anteriorly to enter the mesentery, a drapelike membrane that supports the long, coiled parts of the small intestine (the jejunum and the ileum). The superior mesenteric artery angles gradually to the right as it descends through the mesentery. From its left side arise many **intestinal arteries** to the jejunum and ileum. From its right side emerge branches that supply the proximal half of the large intestine: the ascending colon, cecum, and appendix via the **ileocolic artery;** part of the ascending colon via the **right colic artery;** and part of the transverse colon via the **middle colic artery.**

Suprarenal Arteries The paired **middle suprarenal arteries** (see Figure 20.12), which emerge from the sides of the aorta at L_1, supply blood to the adrenal (suprarenal) glands on the superior poles of the kidneys. The adrenal glands also receive *superior suprarenal* branches from the nearby inferior phrenic arteries, and *inferior suprarenal* branches (not illustrated) from the nearby renal arteries.

Renal Arteries The paired **renal arteries** to the kidneys (*ren* = kidney) stem from the sides of the aorta, between vertebrae L_1 and L_2 (Figure 20.12). The kidneys remove nitrogenous wastes from the blood delivered via the renal arteries. As mentioned previously, the transportation of cellular wastes to the kidney is an important function of the vascular system, so the renal circulation is a major functional subdivision of the systemic circuit.

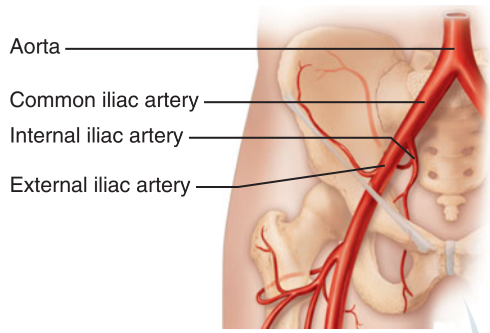


(a) The celiac trunk and its major branches. The left half of the liver has been removed.

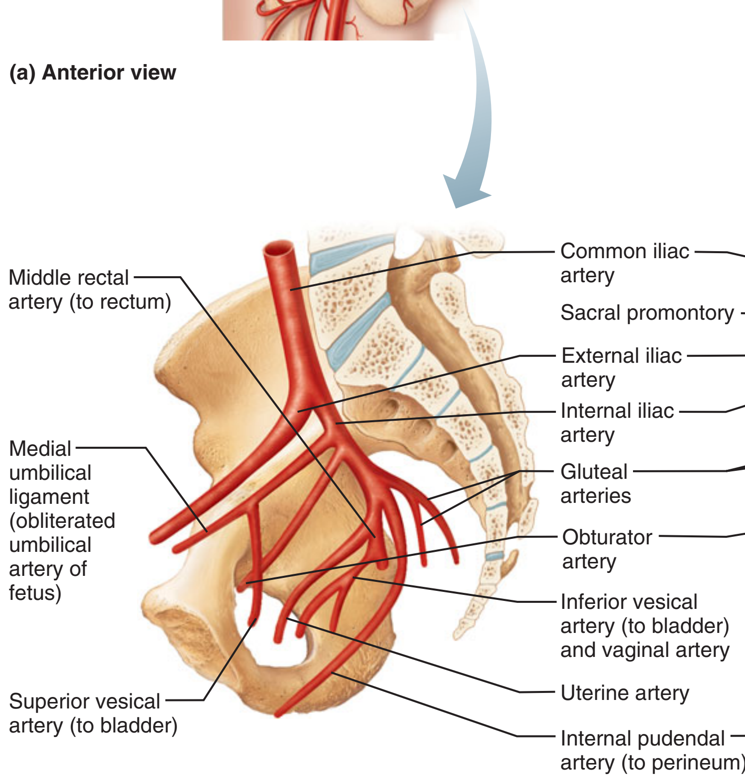


(b) Distribution of the superior and inferior mesenteric arteries. The transverse colon has been pulled superiorly.

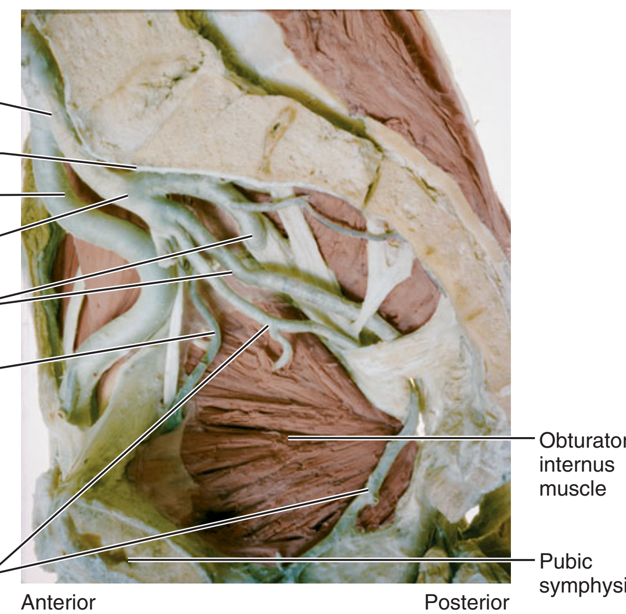
FIGURE 20.13 Midline branches off the abdominal aorta supplying the organs of the digestive tract. (See *A Brief Atlas of the Human Body*, Second Edition, Figure 68.)



(a) Anterior view



(b) Medial view of the right pelvis of a female



(c) Medial view, pelvic organs and levator ani removed

FIGURE 20.14 Arterial supply to the pelvis.

Gonadal Arteries The paired arteries to the gonads are more specifically called **testicular arteries** in males and **ovarian arteries** in females (Figure 20.12). They branch from the aorta at L_2, the level where the gonads first develop in the embryo. The ovarian arteries extend inferiorly into the pelvis to serve the ovaries and part of the uterine tubes. The longer testicular arteries extend through the anterior abdominal wall, passing through the inguinal canal to the scrotum, where they serve the testes.

Inferior Mesenteric Artery The unpaired **inferior mesenteric artery** (see Figures 20.12 and 20.13b) is the final major branch of the abdominal aorta, arising midventrally at the level of L_3. It serves the distal half of the large intestine, from the last part of the transverse colon to the middle part of the rectum. Its branches are the **left colic** (which joins with the middle colic artery on the transverse colon), **sigmoidal,** and **superior rectal arteries.**

Lumbar Arteries Four pairs of **lumbar arteries** arise from the posterolateral surface of the aorta in the lumbar region (Figure 20.12). These segmental arteries run horizontally to supply the posterior abdominal wall.

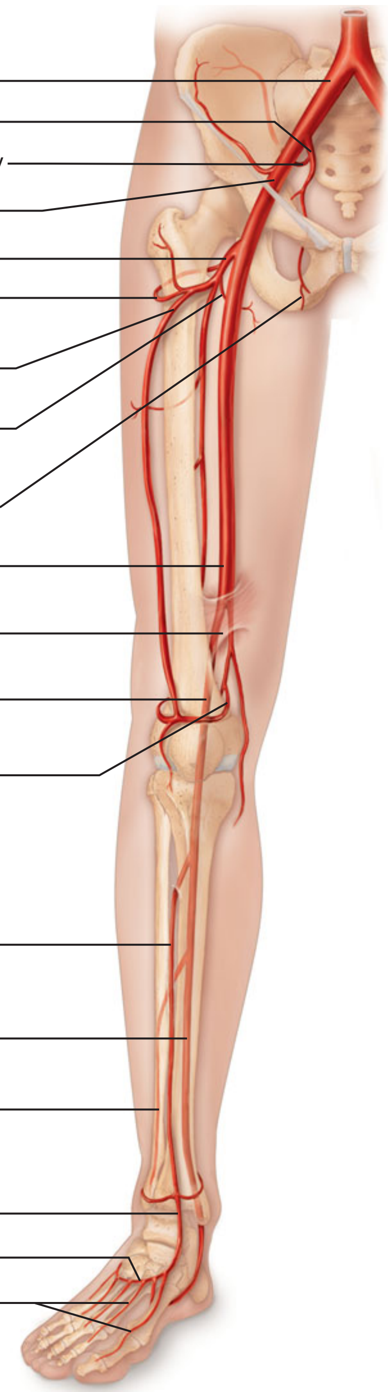
Median Sacral Artery The unpaired **median sacral artery** issues from the most inferior part of the aorta (Figure 20.12). As it descends, this thin artery supplies the sacrum and coccyx along the midline.

Common Iliac Arteries At the level of L_4, the aorta splits into the right and left **common iliac arteries** (Figure 20.12), which supply the inferior part of the anterior abdominal wall, as well as the pelvic organs and the lower limbs.

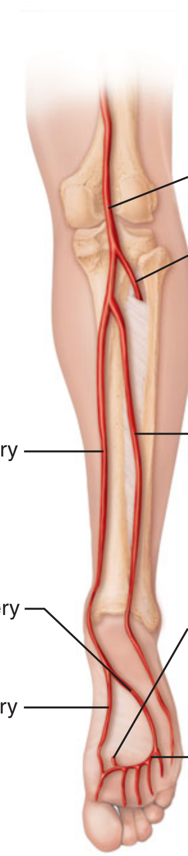
Arteries of the Pelvis and Lower Limbs

At the level of the sacroiliac joint on the pelvic brim, each common iliac artery forks into two branches: the *internal iliac artery,* which mainly supplies the pelvic organs, and the *external iliac artery,* which supplies the lower limb **(Figure 20.14a)**.

Internal Iliac Arteries The branches of **internal iliac arteries** (Figure 20.14b and c) supply blood to the pelvic walls, pelvic viscera, buttocks, medial thighs, and perineum.



(a) Anterior view



(b) Posterior view of leg

FIGURE 20.15 Arteries of the right pelvis and lower limb.

Among the most important branches are the superior and inferior **gluteal arteries,** which run posteriorly through the greater sciatic notch to supply the gluteal muscles; the **internal pudendal artery,** which leaves the pelvic cavity to supply the perineum and external genitalia; and the **obturator artery,** which descends through the obturator foramen into the thigh adductor muscles. Other branches run to the bladder *(superior* and *inferior vesical arteries),* the rectum *(middle rectal artery),* the uterus and vagina in females *(uterine* and *vaginal arteries),* and the pelvic reproductive glands in males (branches from the inferior vesical and middle rectal arteries).

External Iliac Artery The right and left **external iliac arteries** carry blood to the lower limbs **(Figure 20.15)**. Originating from the common iliac arteries in the pelvis, each external iliac artery descends along the arcuate line of the ilium bone, sends some small branches to the anterior abdominal wall, and enters the thigh by passing deep to the midpoint of the inguinal ligament. At this point, the external iliac artery is called the femoral artery.

Femoral Artery The **femoral artery** descends vertically through the thigh medial to the femur and along the anterior surface of the adductor muscles. Superiorly, the artery descends through the femoral triangle, a region in the proximal thigh bordered by the sartorius muscle laterally and the adductor longus muscle medially. Inferiorly, the femoral artery passes through a gap in the adductor magnus muscle (the adductor hiatus) and emerges posterior to the distal femur as the *popliteal artery.*

Even though the superior part of the femoral artery is enclosed in a tube of dense fascia, it is relatively superficial and not protected by any overlying musculature. This lack of protection makes the proximal femoral artery a convenient place to take a pulse or apply pressure to stop bleeding from a hemorrhage in the distal limb, but it also makes it susceptible to injury.

Several arteries arise from the femoral artery in the thigh (see Figure 20.15a). The largest branch, which arises superiorly and is called the **deep artery of the thigh** (or *profunda femoris* = deep femoral), is the main supplier of the thigh muscles: adductors, hamstrings, and quadriceps. Proximal branches of the deep femoral artery are the **medial** and **lateral circumflex femoral arteries,** which circle the neck and upper shaft of the femur. The medial circumflex artery is the major vessel to the head of the femur. If a fracture of the hip tears this artery, the bone tissue of the head of the femur dies. A long, **descending branch of the lateral circumflex artery** (see Figure 20.15a) runs along the anterior aspect of the vastus lateralis muscle, which it supplies.

Popliteal Artery The **popliteal artery** (pop″lĭ-te′al), the inferior continuation of the femoral artery, lies within the popliteal fossa (the region posterior to the knee), a deep location that offers protection from injury. You may be able to feel a popliteal pulse if you flex your leg at the knee and push your fingers firmly into the popliteal fossa. If a clinician is unable to feel a patient's popliteal pulse, the femoral artery may be narrowed by atherosclerosis. The popliteal artery gives off several **genicular arteries** (je-nik′u-lar; "knee") that circle the knee joint like horizontal hoops. Just inferior to the head of the fibula, the popliteal artery splits into the *anterior* and *posterior tibial arteries.*

Anterior Tibial Artery The **anterior tibial artery** runs through the anterior muscular compartment of the leg, descending along the interosseous membrane lateral to the tibia and sending branches to the extensor muscles along the way (Figure 20.15a). At the ankle, it becomes the **dorsalis pedis artery** ("artery of the dorsum of the foot"). At the base of the metatarsal bones, the **arcuate artery** branches from the dorsalis pedis and sends smaller branches distally along the metatarsals. The end part of the dorsalis pedis penetrates into the sole, where it forms the medial end of the plantar arch (described shortly).

The dorsalis pedis artery is superficial, and the pulse from this artery can be palpated in the proximal space between the first and second metatarsals (the pedal pulse point). The absence of this pulse can indicate that the blood supply to the leg is inadequate. Routine checking of the pedal pulse is indicated for patients known to have impaired circulation to the legs and for those recovering from surgery to the leg or thigh.

Posterior Tibial Artery The **posterior tibial artery** (Figure 20.15b), which descends through the posteromedial part of the leg, lies directly deep to the soleus muscle. Proximally, it gives off a large branch, the **fibular (peroneal) artery,** which descends along the medial aspect of the fibula. Together, the posterior tibial and fibular arteries supply the flexor muscles in the leg, and the fibular arteries send branches to the fibularis muscles.

Inferiorly, the posterior tibial artery passes behind the medial malleolus of the tibia, where its pulse can be palpated. On the medial side of the foot, it divides into **medial** and **lateral plantar arteries.** These serve the sole, and the lateral plantar artery forms the lateral end of the **plantar arch.** Metatarsal and digital arteries to the toes arise from the plantar arch.

check your understanding

5. Name the three vessels that branch off the aortic arch and the body region each serves.
6. Name the four major vessels that supply blood to the brain. From what vessel does each arise?
7. What vessel is palpated to feel a pulse in each of the following locations: (a) thigh, (b) arm, (c) wrist, (d) foot, (e) neck?
8. Name the vessels that branch off the abdominal aorta to supply blood to the digestive organs, and indicate which organs each supplies.

For answers, see Appendix B.

Systemic Veins

Having considered the arteries of the body, you now turn to the veins **(Figure 20.16)**. Although most veins run with corresponding arteries, there are some important differences in the distributions of arteries and veins:

1. Whereas just one systemic artery leaves the heart—the aorta exiting the left ventricle, three major veins enter the right atrium of the heart: the superior and inferior venae cavae and the coronary sinus.
2. All large and medium-sized arteries have deep locations for protection. In contrast, many veins lie just beneath the skin, unaccompanied by any arteries; these are called *superficial veins*.
3. Several parallel veins often take the place of a single larger vein. Such multivein bundles, including networks of veins forming anastomoses, are called *venous plexuses.*
4. Two important body areas have unusual patterns of venous drainage. First, veins from the brain drain into *dural sinuses,* which are not typical veins but endothelium-lined channels supported by walls of dura mater. Second, venous blood draining from the digestive organs enters a special subcirculation, the *hepatic portal system,* and passes through capillaries in the

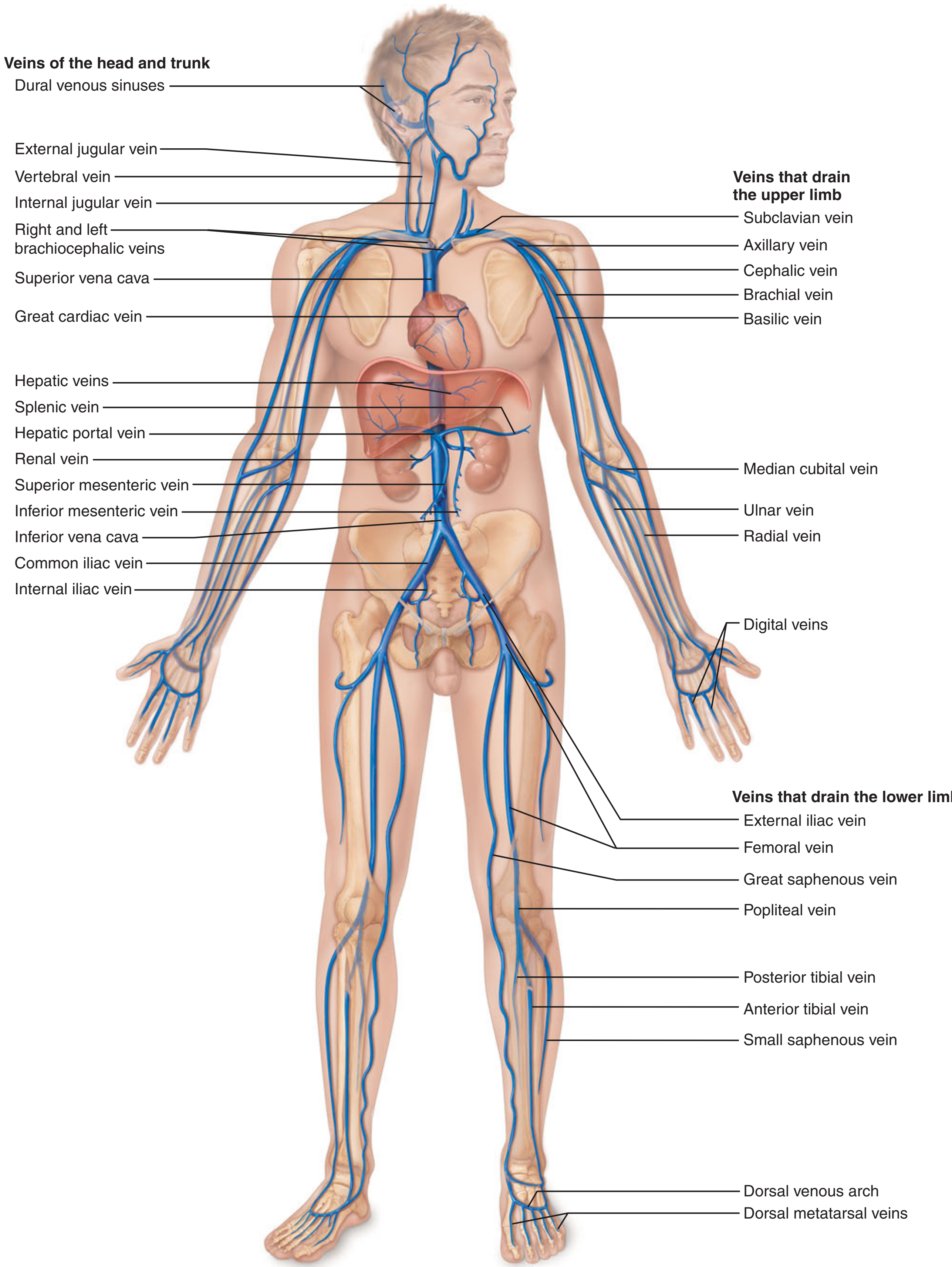
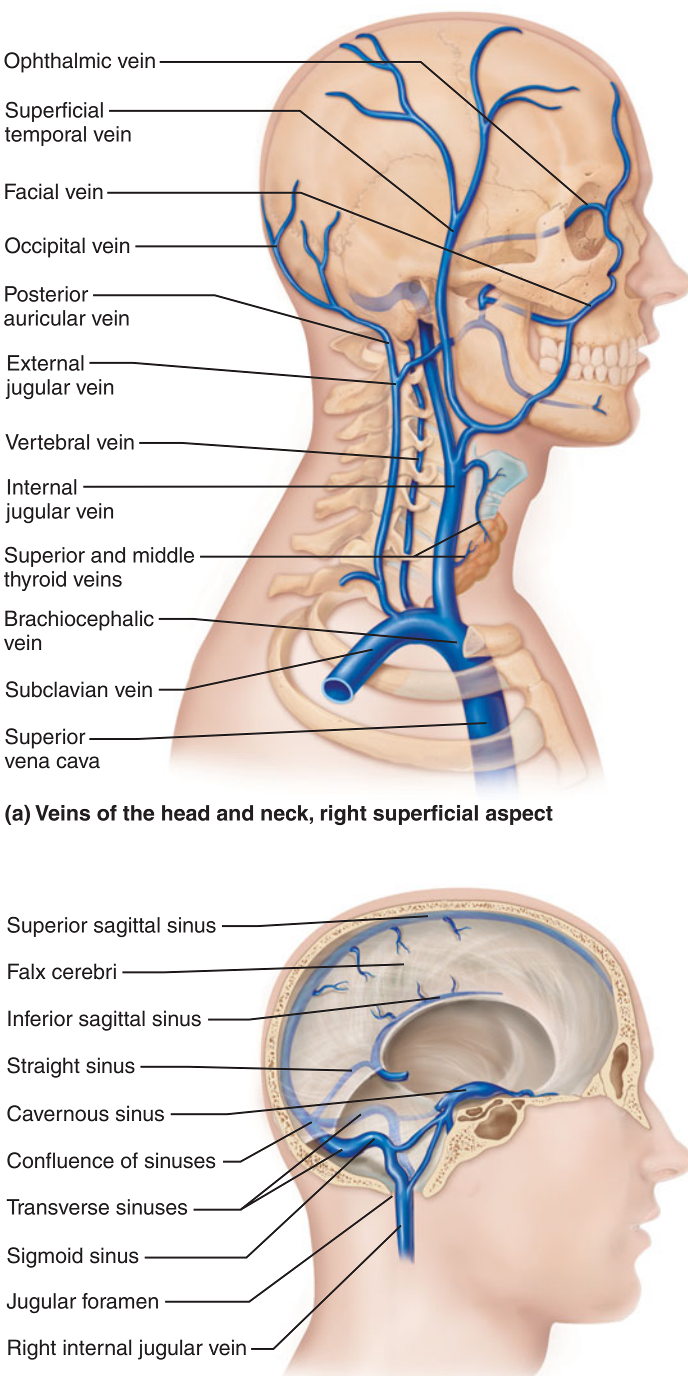


FIGURE 20.16 **Major veins of the systemic circulation, anterior view.**



(a) Veins of the head and neck, right superficial aspect

(b) Dural venous sinuses of the brain

FIGURE 20.17 Venous drainage of the head, neck, and brain.

liver before the blood reenters the general systemic circulation. The dural sinuses and hepatic portal system are considered shortly.

Venae Cavae and Their Major Tributaries

The unpaired *superior* and *inferior venae cavae,* the body's two largest veins, empty directly into the right atrium of the heart (see Figure 20.9). The name *vena cava* means "cavelike vein."

Superior Vena Cava The **superior vena cava** (Figure 20.16) receives the systemic blood from all body regions superior to the diaphragm excluding the heart wall. This vein arises from the union of the **left** and **right brachiocephalic veins** posterior to the manubrium and descends to join the right atrium. Of the two brachiocephalic veins, the left is longer and nearly horizontal, whereas the right is vertical (see Figure 20.9). Each brachiocephalic vein is formed by the union of an *internal jugular vein* and a *subclavian vein.*

Inferior Vena Cava The **inferior vena cava,** which ascends along the posterior wall of the abdominal cavity and is the widest blood vessel in the body, returns blood to the heart from all body regions inferior to the diaphragm (Figure 20.16). It begins inferiorly at the union of the two common iliac veins on the body of vertebra L_5, and ascends on the right side of the vertebral bodies to the right of the abdominal aorta. Upon penetrating the central tendon of the diaphragm at T_8, the inferior vena cava joins the right atrium.

Veins of the Head and Neck

Most blood draining from the head and neck enters three pairs of veins: (1) the internal jugular veins from the dural sinuses, (2) the external jugular veins, and (3) the vertebral veins **(Figure 20.17a)**. Even though most of the extracranial veins have the same names as the extracranial arteries (facial, ophthalmic, occipital, and superficial temporal), their courses and interconnections differ substantially.

Dural Sinuses Most veins of the brain drain into the intracranial **dural sinuses** (Figure 20.17b), which form an interconnected series of channels in the skull and lie between the two layers of cranial dura mater (p. 408). The **superior** and **inferior sagittal sinuses** lie in the falx cerebri between the cerebral hemispheres. The inferior sagittal sinus drains posteriorly into the **straight sinus.** The superior sagittal and straight sinuses then drain posteriorly into the **transverse sinuses,** which run in shallow grooves on the internal surface of the occipital bone. Each transverse sinus in turn drains into an S-shaped sinus **(sigmoid sinus),** which becomes the **internal jugular vein** as it leaves the skull through the jugular foramen.

The paired **cavernous sinuses** border the body of the sphenoid bone laterally, and each has an internal carotid artery *running within it.* The following cranial nerves also run within the cavernous sinus (or in its wall of dura mater) on their way to the orbit and the face: the oculomotor, trochlear, abducens, and the maxillary and ophthalmic divisions of the trigeminal nerve. The cavernous sinus drains into the transverse sinus and the internal jugular vein but also communicates with the **ophthalmic vein** of the orbit (Figure 20.17a), which in turn communicates with the facial vein, which drains the nose and upper lip.

Several other dural sinuses exist, but they are small and are not considered here.

MEDICAL IMPORTANCE OF THE CAVERNOUS SINUS Squeezing pimples on the nose or upper lip can spread infection through the facial vein into the cavernous sinus and, from there, through the other dural sinuses in the skull. For this reason, the nose and upper lip are called the *danger triangle of the face*.

Blows to the head can rupture the internal carotid artery within the confines of the cavernous sinus. Leaked blood then accumulates within this sinus and exerts crushing pressure on the contained cranial nerves, disrupting their functions. For example, damage to the oculomotor, trochlear, and abducens nerves leads to a loss of ability to move the eyes.

Internal Jugular Veins The large **internal jugular veins** drain almost all of the blood from the brain (Figure 20.17a). From its origin at the base of the skull, each such vein descends through the neck deep to the sternocleidomastoid muscle. Superiorly, the internal jugular vein lies lateral to the internal carotid artery and inferiorly it is lateral to the common carotid artery (shown in Figure 11.11b, p. 283). Along the way, the internal jugular vein receives blood from some deep veins of the face and neck—branches of the **facial** and **superficial temporal veins.** At the base of the neck, the internal jugular vein joins the subclavian vein to form the brachiocephalic vein. The jugular veins are named for their end point, as *jugulum* means "the throat just above the clavicle."

Just as wounds to the neck can cut the carotid arteries, they can also sever the internal jugular veins. However, cut veins do not bleed as quickly as arteries of comparable size, because the blood pressure in them is lower than in arteries. For this reason, the chances of surviving are greater if a neck wound affects the vein and not the artery.

External Jugular Veins The **external jugular vein** is a superficial vein that descends vertically through the neck on the surface of the sternocleidomastoid muscle. To make this vein visible on your neck, stand before a mirror and gently compress the skin superior to your clavicle with your fingers. Superiorly, its tributaries drain the posterior scalp, lateral scalp, and some of the face (see Figure 20.17a). The external jugular vein, which is not accompanied by any corresponding artery, empties inferiorly into the subclavian vein.

Vertebral Veins Unlike the vertebral arteries, the **vertebral veins** do not serve much of the brain, instead draining only the cervical vertebrae, cervical spinal cord, and small muscles in the superior neck. Originating inferior to the occipital condyle, each vertebral vein descends through the transverse foramina of vertebrae C_1–C_6 in the form of a venous plexus. Emerging from C_6 as a single vein, the vertebral vein continues inferiorly to join the brachiocephalic vein in the root of the neck.

Veins of the Thorax

Blood draining from the first few intercostal spaces enters the brachiocephalic veins. Blood from the other intercostal spaces, as well as from some of the thoracic viscera, drains into a group of veins called the *azygos* (āz′ĭ-gos, or a-zi′gus) *system* (**Figure 20.18**). This group of veins, which flank the vertebral column and ultimately empty into the superior vena cava, consists of the *azygos vein,* the *hemiazygos vein,* and the *accessory hemiazygos vein.*

Azygos Vein The **azygos vein,** whose name means "unpaired," ascends along the right or the center of the thoracic vertebral bodies. It receives all of the right **posterior intercostal veins** (except the first), plus the subcostal vein. Superiorly, at the level of T_4, the azygos arches over the great vessels that run to the root of the right lung and joins the superior vena cava.

Hemiazygos Vein The **hemiazygos vein** (hem″ĭ-āz′ĭ-gos), which ascends on the left side of the vertebral column, corresponds to the inferior half of the azygos on the right (*hemiazygos* = half the azygos). It receives the ninth through eleventh left posterior intercostal veins and the subcostal vein. At about midthorax, the hemiazygos runs roughly horizontally across the vertebrae and joins the azygos vein.

Accessory Hemiazygos Vein The **accessory hemiazygos vein** can be thought of as a superior continuation of the hemiazygos, receiving the fourth (or fifth) through the eighth left posterior intercostal veins; it also courses to the right to join the azygos.

The superior parts of the azygos and accessory hemiazygos veins also receive the small *bronchial veins,* which drain unoxygenated systemic blood from the bronchi in the lungs. Veins from the thoracic part of the esophagus also enter the azygos system.

Veins of the Upper Limbs

The veins of the upper limbs (Figure 20.18) are either deep or superficial.

Deep Veins The deep veins of the upper limbs (shown in Figure 20.18 as light blue vessels) follow the paths of their companion arteries and have the same names. All except the largest, however, are actually two parallel veins that flank their artery on both sides. The **deep** and **superficial palmar venous arches** of the hand empty into the **radial** and **ulnar veins** of the forearm, which unite just inferior to the elbow joint to form the **brachial vein** of the arm. As the brachial vein enters the axilla, it empties into the **axillary vein,** which becomes the **subclavian vein** at the first rib.

Superficial Veins The superficial veins of the upper limb (shown in Figure 20.18 as dark blue vessels) are larger than the deep veins and are visible beneath the skin. They form anastomoses frequently along their course. They begin with the *dorsal venous network* (not illustrated). These veins are readily apparent on the dorsal surface of the hand because of the thinness of the skin. This network provides a preferred site for inserting intravenous catheters. The dorsal venous

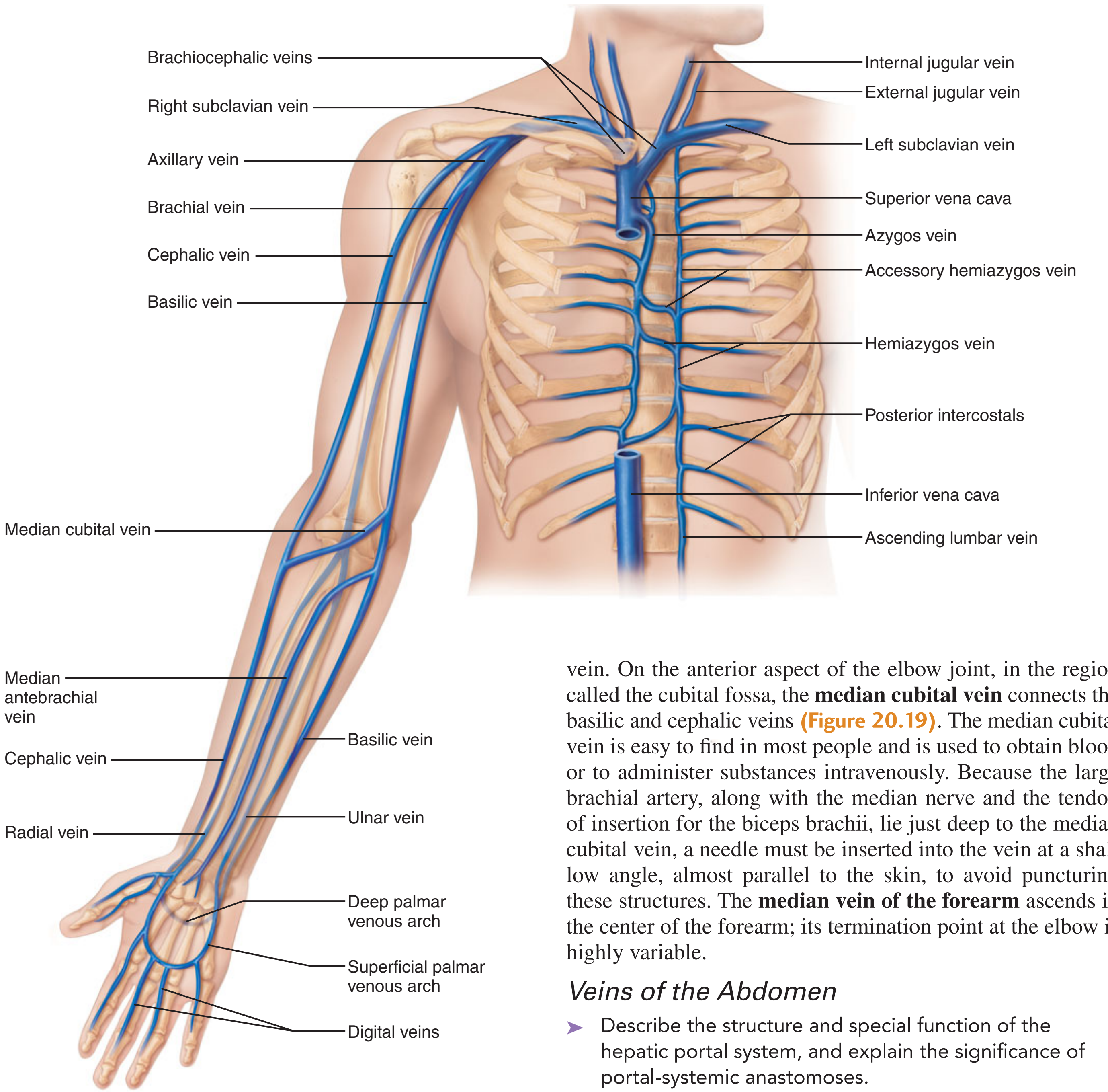


FIGURE 20.18 Veins of the thorax and right upper limb, anterior view. For clarity, the many anastomoses of the superficial veins are not shown.

network drains superiorly into the **cephalic vein,** which starts at the lateral side of this network, then bends around the distal radius to enter the anterior forearm. From there, this vein ascends through the anterolateral side of the entire limb and ends inferior to the clavicle, where it joins the axillary vein. The **basilic vein** arises from the medial aspect of the hand's dorsal venous network, then ascends along the posteromedial forearm and the anteromedial surface of the arm. In the axilla, the basilic vein joins the brachial vein to become the axillary vein. On the anterior aspect of the elbow joint, in the region called the cubital fossa, the **median cubital vein** connects the basilic and cephalic veins **(Figure 20.19)**. The median cubital vein is easy to find in most people and is used to obtain blood or to administer substances intravenously. Because the large brachial artery, along with the median nerve and the tendon of insertion for the biceps brachii, lie just deep to the median cubital vein, a needle must be inserted into the vein at a shallow angle, almost parallel to the skin, to avoid puncturing these structures. The **median vein of the forearm** ascends in the center of the forearm; its termination point at the elbow is highly variable.

Veins of the Abdomen

➤ Describe the structure and special function of the hepatic portal system, and explain the significance of portal-systemic anastomoses.

Blood returning from the abdominopelvic viscera and the abdominal wall reaches the heart via the inferior vena cava **(Figure 20.20)**. Most venous tributaries of this great vein share the names of the corresponding arteries. The veins from the paired abdominal organs, the pelvis, and the abdominal wall drain directly into the inferior vena cava. Blood from the digestive organs returns via the hepatic portal system (discussed below).

Lumbar Veins Several pairs of **lumbar veins** drain the posterior abdominal wall, running horizontally with the corresponding lumbar arteries.

Gonadal (Testicular or Ovarian) Veins The right and left **gonadal veins** ascend along the posterior abdominal wall with the gonadal arteries. The right gonadal vein

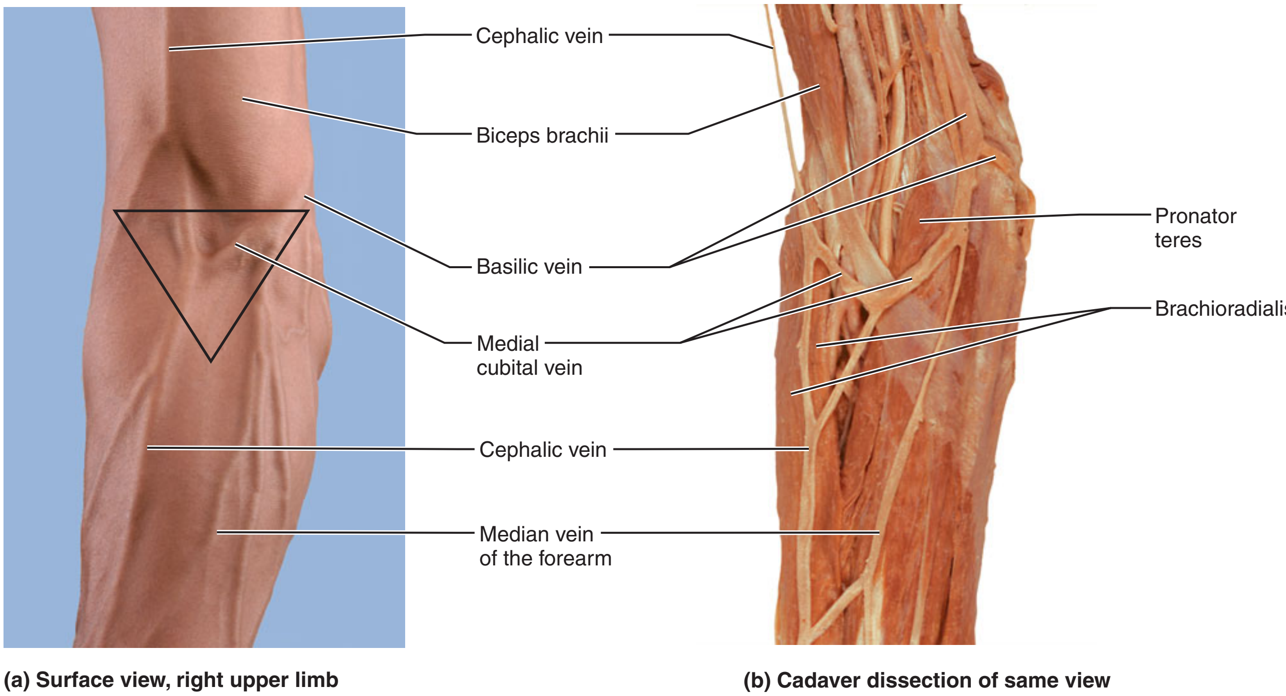


FIGURE 20.19 The superficial veins of the right upper limb. The cubital fossa is outlined by the triangle.

drains into the anterior surface of the inferior vena cava at L_2. The left gonadal vein drains into the left renal vein (Figure 20.20).

Renal Veins The right and left **renal veins** drain the kidneys; each lies just anterior to the corresponding renal artery.

Suprarenal Veins Although each adrenal gland has several main arteries, it has just one **suprarenal vein.** The right suprarenal vein empties into the nearby inferior vena cava; the left suprarenal vein drains into the left renal vein.

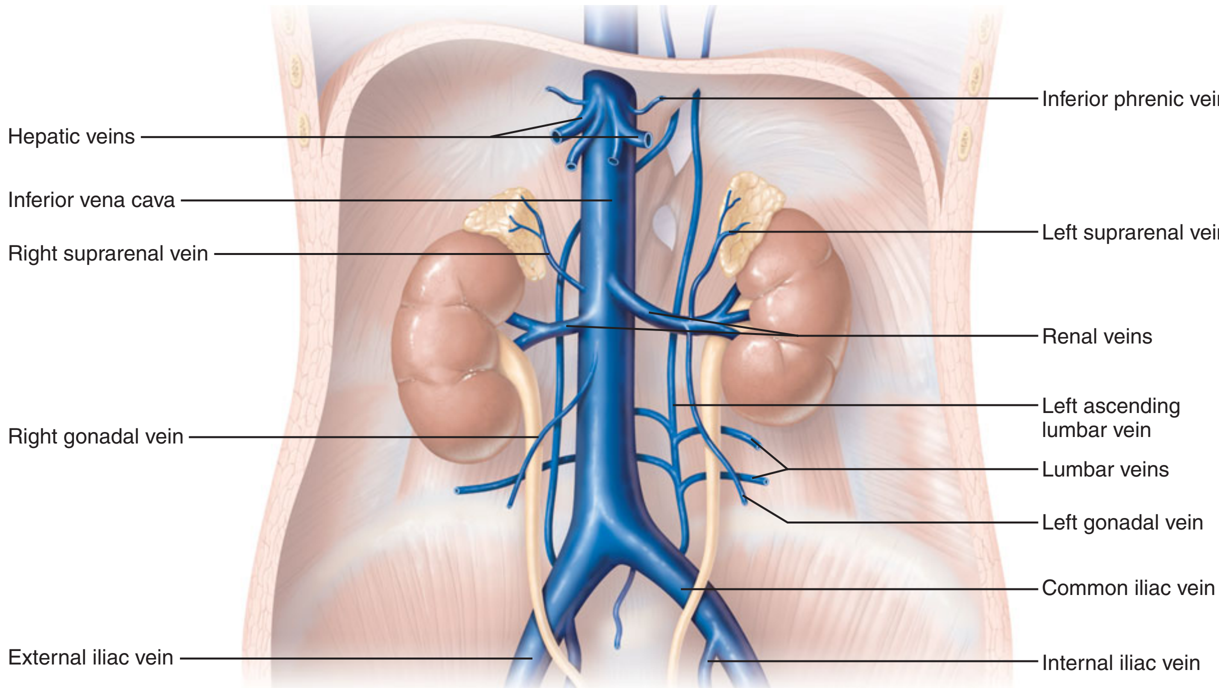
Hepatic Veins The right and left **hepatic veins** exit the liver superiorly and empty into the most superior part of the inferior vena cava. These robust veins carry all the blood that originated in the digestive organs in the abdominal and pelvic cavities and arrived via the hepatic portal system (discussed next).

Hepatic Portal System The **hepatic portal system** is a specialized part of the vascular circuit that serves a function unique to digestion: It picks up digested nutrients from the stomach and intestines and delivers these nutrients to the liver for processing and storage.

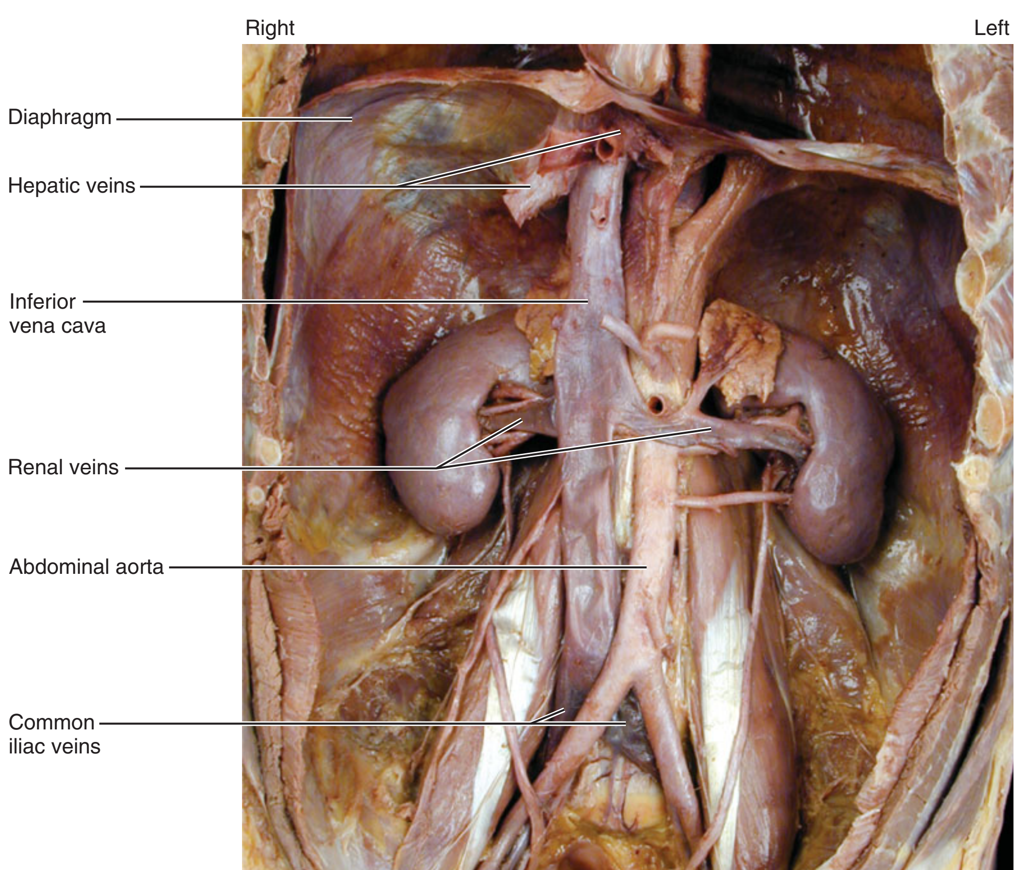
Like all portal systems, the hepatic portal system is a series of vessels in which two separate capillary beds lie between the arterial supply and the final venous drainage (Figure 20.21a). In this case, capillaries in the stomach and intestines receive the digested nutrients and then drain into the tributaries of the **hepatic portal vein.** This vein then delivers the nutrient-rich blood to a second capillary bed—the *liver sinusoids*—through which nutrients reach liver cells for processing. The liver cells also break down toxins that enter the blood through the digestive tract. After passing through the liver sinusoids, the blood enters the hepatic veins and inferior vena cava, thereby reentering the general systemic circulation. (For a more complete discussion of liver functions, see Chapter 23.)

As you study the hepatic portal system, be careful not to confuse the *hepatic veins* with the *hepatic portal vein*. The following veins of the hepatic portal system are tributaries of the hepatic portal vein (Figure 20.21b):

1. **Superior mesenteric vein.** This large vein ascends just to the right of the superior mesenteric artery. It drains the entire small intestine, the first half of the large intestine (ascending and transverse colon), and some of the stomach. Its superior part lies posterior to the stomach and pancreas.
2. **Splenic vein.** Even though the spleen is not a digestive organ, venous blood leaving it drains through the hepatic portal system. As a result, any microbes that escape the spleen's infection-fighting activities (discussed in Chapter 21) are carried to the liver for destruction. The splenic vein runs horizontally, posterior to the stomach and pancreas, and joins the superior mesenteric vein to form the hepatic portal vein. Its tributaries correspond to the branches of the splenic artery.
3. **Inferior mesenteric vein.** This vein ascends along the posterior abdominal wall, well to the left of the inferior mesenteric artery. Its tributaries drain the organs that are supplied by that artery—namely, the distal region of the colon and the superior rectum. The inferior mesenteric vein empties into the splenic vein posterior to the stomach and pancreas.



(a) Tributaries of the inferior vena cava; venous drainage of the paired abdominal organs.



(b) Dissection of the posterior abdominal wall illustrating abdominal vessels.

FIGURE 20.20 Tributaries of the inferior vena cava. In (a), notice the asymmetry in venous return: the left gonadal and suprarenal veins drain into the left renal vein. On the right side these vessels drain directly into the inferior vena cava.

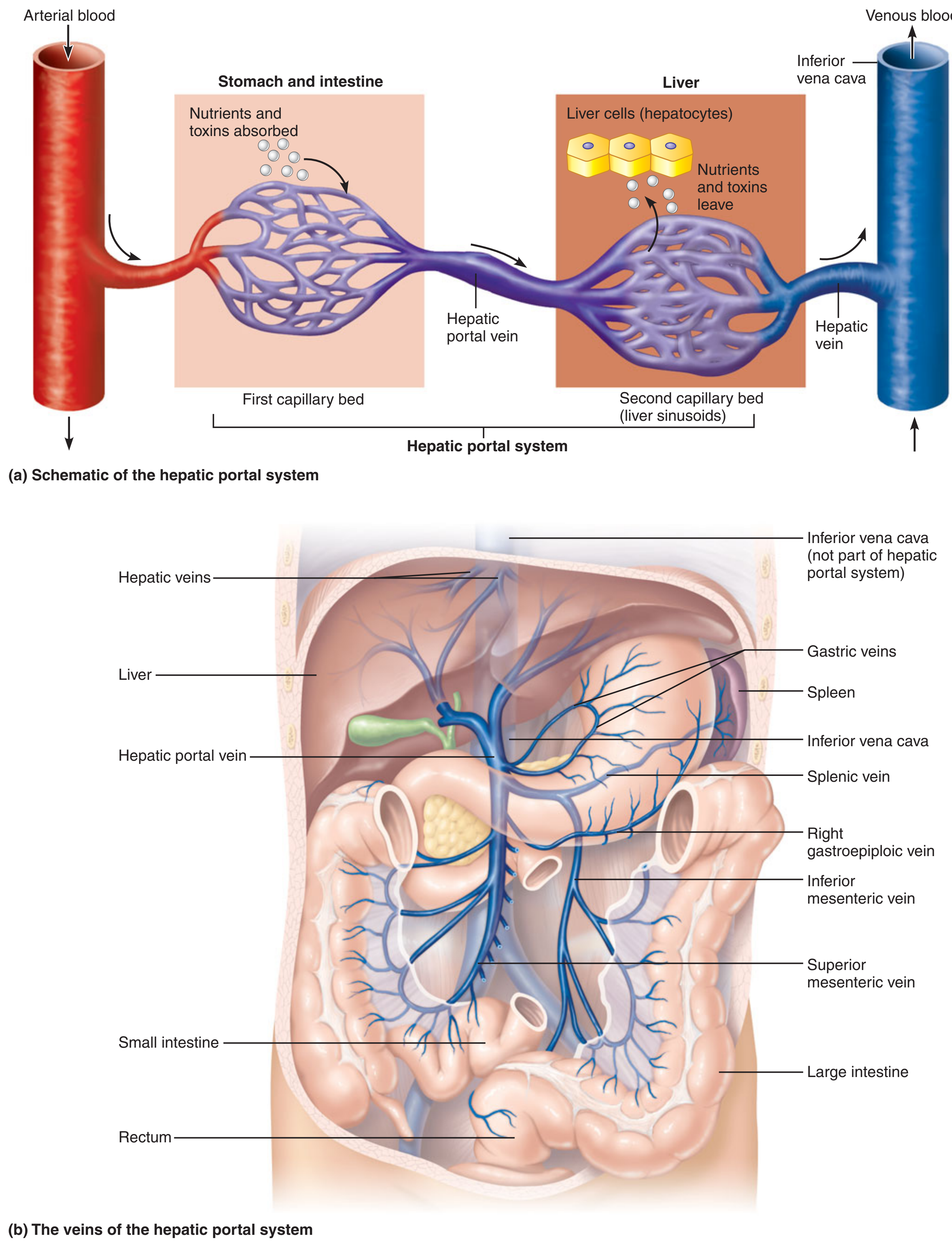


FIGURE 20.21 The hepatic portal system. (See *A Brief Atlas of the Human Body,* Second Edition, Figure 68.)

The *hepatic portal vein* is a short, vertical vessel that lies directly inferior to the liver and anterior to the inferior vena cava (Figure 20.21b). Inferiorly, it begins posterior to the pancreas as the union of the superior mesenteric and splenic veins. Superiorly, it enters the underside of the liver and divides into right and left branches, whose smaller branches reach the liver sinusoids.

On its way to the liver, the hepatic portal vein receives the right and left gastric veins from the stomach.

Portal-Systemic Anastomoses

In conditions that lead to scarring and degeneration (cirrhosis) of the liver, especially chronic alcoholism, blood flow through the liver sinusoids is blocked. This blockage raises the blood pressure throughout the hepatic portal system and results in **portal hypertension.** Fortunately, some veins of the portal system form anastomoses with veins that drain into the venae cavae, providing emergency pathways through which the "backed up" portal blood can return to the heart. These pathways are the *portal-systemic (portal-caval) anastomoses.* The main ones are (1) veins in the inferior esophagus, (2) the hemorrhoidal veins in the wall of the anal canal, and (3) superficial veins in the anterior abdominal wall around the navel. These connecting veins are small, however, and they swell and burst when forced to carry large volumes of portal blood. When these anastomosing veins start to fail, as in alcoholics with cirrhosis of the liver, the person may vomit blood from torn esophageal veins, develop hemorrhoids from swollen hemorrhoidal veins, and exhibit a snakelike network of distended veins through the skin around the navel. This network is called a *caput medusae* (kap′ut me-du′se)—the Medusa head—after a monster in Greek mythology whose hair was made of writhing snakes.

Of all the symptoms of cirrhosis, swelling and bursting of veins in the inferior esophagus is the most serious. Bleeding of esophageal veins is associated with a 50% mortality rate, and if the bleeding recurs, another 30% die. Varicose esophageal veins are treated by injecting a hardening agent into them or by tying them off with bands. Also, an implanted metal tube can be run from the inferior vena cava behind the liver into the portal vein, creating a new portal-caval shunt that relieves portal hypertension entirely.

Veins of the Pelvis and Lower Limbs

Veins draining the pelvis and lower limbs **(Figure 20.22)** are either deep or superficial.

Deep Veins Like those in the upper limb, most deep veins in the lower limbs share the names of the arteries they accompany, and all but the largest are actually two parallel veins. Arising on the sole of the foot from the union of the medial and lateral **plantar veins,** the **posterior tibial vein** ascends deep within the calf muscles and receives the **fibular (peroneal) vein.** The **anterior tibial vein,** which is the superior continuation of the **dorsalis pedis vein** of the foot, ascends to the superior part of the leg, where it unites with the posterior tibial vein to form the **popliteal vein.** The popliteal vein passes through the popliteal fossa and ascends to become the **femoral vein,** which drains the thigh. The femoral vein is located with the femoral artery and nerve in the femoral triangle. This vessel continues superiorly deep to the inguinal ligament and becomes the **external iliac vein.** In the pelvis, the external iliac vein unites with the **internal iliac vein** to form the **common iliac vein.**

Superficial Veins Two large superficial veins, the *great* and *small saphenous veins* (sah-fe′nus; "obvious"), arise from the **dorsal venous arch** located on the dorsal surface of the foot. The saphenous veins frequently form anastomoses with each other and with deep veins along their course. The **great saphenous vein,** the longest vein in the body, ascends along the medial side of the entire limb to empty into the femoral vein just distal to the inguinal ligament. The **small saphenous vein** runs along the lateral side of the foot and then along the posterior calf (Figure 20.22b and c). Posterior to the knee, it empties into the popliteal vein.

MEDICAL IMPORTANCE OF THE SAPHENOUS VEINS The great saphenous vein is the vessel most commonly used in coronary artery bypass operations (see A Closer Look, Chapter 19, on p. 574). Here, it should be noted that when suturing this vein onto a coronary artery, the surgeon must orient it so that blood flow will open, rather than close, its valves. The saphenous veins are more likely to weaken and become varicose than any other veins in the lower limb, because they are poorly supported by surrounding tissue. Furthermore, when valves begin to fail in veins throughout a lower limb, the normal contractions of the leg muscles can squeeze blood out of the deep veins into the superficial veins through the anastomoses between these two groups of veins. This influx of blood engorges and weakens the saphenous veins even further. Even when the saphenous veins do not fail, they are often involved in *venous disease of the lower limb* (see "Disorders of the Blood Vessels" on p. 611).

check your understanding

9. Consider the hepatic veins and the hepatic portal vein. What organ or organs does each vein drain? Into what vessel does each vein empty?
10. In what body region are each of the following veins located: (a) cephalic vein, (b) popliteal vein, (c) transverse sinus, (d) saphenous vein, (e) azygos vein?
11. Describe the clinical importance of the median cubital vein and the saphenous vein.

For answers, see Appendix B.

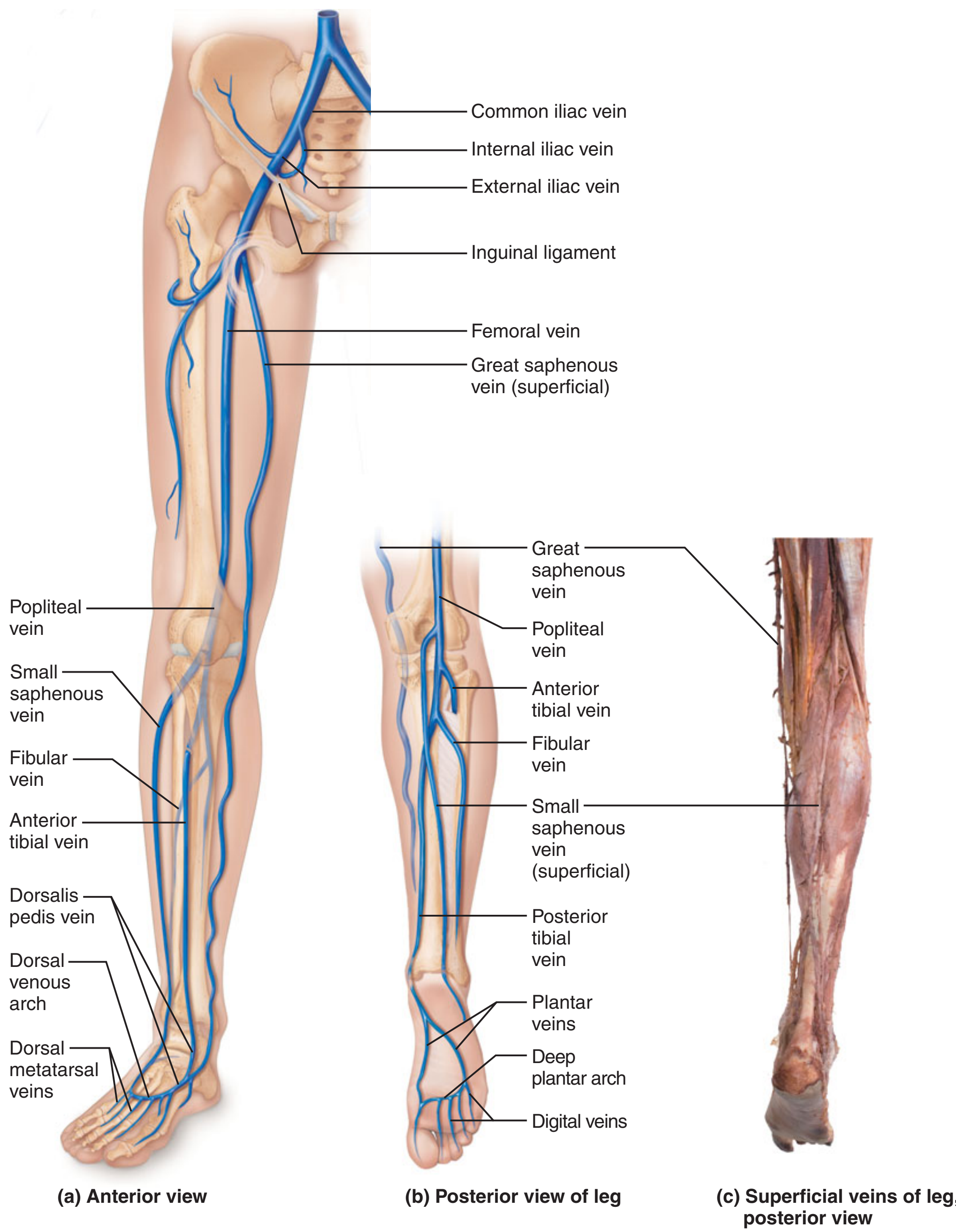


FIGURE 20.22 **Veins of the right lower limb and pelvis.**

DISORDERS OF THE BLOOD VESSELS

➤ Define atherosclerosis, deep vein thrombosis and venous disease of the lower limb, aneurysm, microangiopathy of diabetes, and arteriovenous malformation.

The primary disorder of blood vessels, atherosclerosis, is covered in **A Closer Look** on p. 610. This section considers some other common and serious vessel disorders.

Deep vein thrombosis of the lower limb is the formation of clots in the veins of the lower extremity (usually in the thigh). In half the patients with this condition, the clot detaches, travels to the heart and pulmonary trunk, then blocks a branch of the pulmonary artery (pulmonary embolism). Extremely common, deep vein thrombosis affects 1% to 2% of hospital patients or 2 million Americans per year. It is usually caused by the sluggish flow of blood in veins of inactive and bedridden patients, so that thrombi form on the cusps of the venous valves. Alternatively, it can result from abnormal clotting chemistry or from inflammatory damage to the venous endothelium (in this latter case it is called *thrombophlebitis*). Deep vein thrombosis can be diagnosed by ultrasonography of the veins in the lower limb and is treated with anticlotting

a closer look

Atherosclerosis? Get Out the Cardiovascular Drāno

When pipes get clogged, it is usually because we've dumped something down the drain that shouldn't be there—a greasy mass or a hairball. Sometimes, pipes get blocked when something is growing inside them (tree roots, for example), trapping the normal sludge coming through (see top photo). In **arteriosclerosis,** the walls of our arteries become thicker and stiffer, and hypertension results. In **atherosclerosis,** the most common form of arteriosclerosis, small, patchy thickenings called *atheromas* form that can intrude into the vessel lumen, making it easy for arterial spasms or a roaming blood clot to close the vessel completely.

Although all blood vessels are susceptible to atherosclerosis, the aorta and the coronary arteries are most often affected.

Atherosclerosis: Onset and Stages

Atherosclerosis begins with damage to the tunica intima caused by bloodborne chemicals, hypertension, or viral or bacterial infections. Researchers suspect that almost any type of chronic infection—including respiratory, periodontal, and urinary tract problems—could set the stage for atherosclerosis.

Irritation of the endothelium prompts an inflammatory response. The injured endothelial cells release inflammatory agents and growth (mitosis-inducing) factors. Low-density lipoproteins (LDLs, the so called "bad cholesterol") are attracted to the inflamed area. LDLs deliver cholesterol to tissue cells. In the inflamed vessel, they invade the tunica intima and accumulate in the vessel wall. Monocytes, a type of white blood cell, respond to the area of inflammation, enter the tunica intima, and differentiate into macrophages, which phagocytose the LDLs within the vessel wall. The endothelial cells and the macrophages continue to secrete inflammatory chemicals and growth factors, thus stimulating growth of the vessel wall. As the fatty plaque develops, the macrophages become so engorged with LDLs that they are transformed into lipid-laden *foam cells* and lose their scavenging ability.

Smooth muscle cells migrating from the tunica media also take up lipids and become foam cells. The accumulating foam cells initiate the **fatty streak stage.** The smooth muscle cells also deposit collagen and elastin fibers, thickening the intima and producing fibrous lesions with a core of dead and dying foam cells called **fibrous** or **atherosclerotic plaques.** At first the vessel walls accommodate the growing plaque by expanding outward, but eventually these fatty mounds begin to protrude into the vessel lumen, producing full-blown atherosclerosis (see bottom photo).

As enlarging plaques hinder diffusion of nutrients from the blood to deeper tissues of the artery wall, smooth muscle cells in the tunica media die and the elastic fibers deteriorate. These elements are replaced by nonelastic scar tissue, and calcium salts are deposited in the lesions. These events constrict the vessel and cause the arterial walls to fray and ulcerate, conditions that encourage blood sludging and backup, platelet adhesion, and thrombus formation. The vessels' increased rigidity leads to hypertension. Together, these events increase the risk of myocardial infarcts, strokes, and aneurysms and are responsible for the pain (angina) that occurs when heart muscle is ischemic.

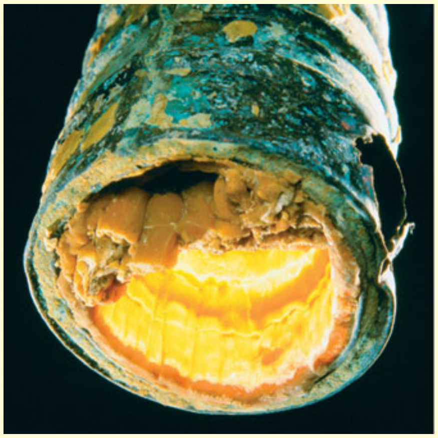
The inflammatory process in the vessel wall makes these cholesterol-rich plaques susceptible to rupture, exploding off fragments that trigger massive clots that can cause lethal heart attacks. The victim appears perfectly healthy until he or she drops dead!

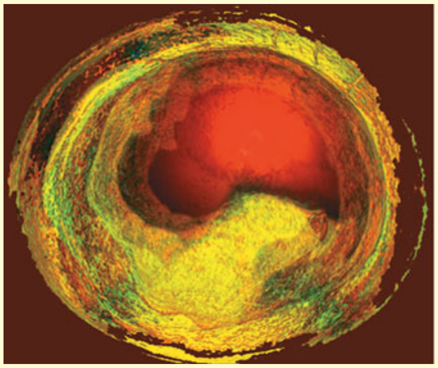
Treatment and Prevention

Surgical interventions, angioplasty, and coronary bypass surgery (A Closer Look in Chapter 19, p. 574) have been used for decades to open clogged vessels or reroute blood around a clot to restore myocardial circulation. Anticlotting drugs, such as low-dose aspirin taken regularly, can reduce clot formation. Cholesterol-lowering drugs (statins) not only lower blood cholesterol but also act as antinflammatory agents.

When an atheroma ruptures and induces clot formation, *thrombolytic (clot-dissolving) agents* are used. These revolutionary drugs include *tissue plasminogen activator (tPA).* Injecting tPA directly into the heart restores blood flow quickly and puts an early end to many heart attacks in progress.

Of course, it's best to prevent atherosclerosis from progressing in the first place—by quitting smoking, losing weight to reduce blood lipid (triglyceride) levels, eating a healthy diet rich in antioxidants, and exercising regularly.





Top A pipe clogged by accumulated deposits. **Bottom** Atherosclerotic plaques nearly close a human artery.

drugs. Another treatment involves inserting a filter into the inferior vena cava to prevent emboli from reaching the lungs.

Venous disease is another common venous disorder of the lower limb, affecting 600,000 people, most of them elderly, in the United States. This disease is characterized by inadequate drainage of venous blood from the limb, whose tissues become ischemic and vulnerable to damage and ulceration. It is caused by the failure of valves in interconnecting veins that normally function to prevent blood in the limb's deep veins from flowing outward into the superficial saphenous veins. When these valves fail, the skeletal muscle pump propels the deep venous blood into the saphenous veins, which cannot drain so much blood quickly enough. Blood backs up in the saphenous veins, and so much fluid pours out of the capillaries serving these veins that the leg tissue develops edema and becomes ischemic. The slightest trauma to this oxygen-starved tissue leads to tissue damage, so ulcers form in the lower limb. Venous disease can lead to varicose saphenous veins (p. 608) when the overloaded saphenous veins fail and tear. Treating this disease involves elevating and compressing the lower limb to speed the drainage of blood.

An **aneurysm** (an′u-rizm; "widening") is a saclike widening or outpocketing of an artery (or vein) that places the vessel at risk of rupturing. The aneurysm may result from a congenital weakness of an artery wall or, more often, from a gradual weakening of the vessel by hypertension or arteriosclerosis. The most common sites of aneurysms are the abdominal aorta **(Figure 20.23)** and the arteries to the brain and kidneys. Aortic aneurysms are present in 1% of women and 8% of men over age 65, and their rupture causes 10,000 deaths per year in the United States. If detected before rupture—by palpation, ultrasound, or CT scans—they are treated by replacing the affected section of the vessel with a synthetic graft or by placing a strong-walled tube inside the part of the vessel where the aneurysm is present.

Microangiopathy of diabetes (mi″kro-an″je-op′ah-the; "small vessel disease") is a common complication of long-term diabetes mellitus. The elevated blood sugar levels of diabetes lead to the deposit of glycoproteins in the basement membrane of the body's capillaries. This results in thickened but leaky capillary walls, and a slowed rate of turnover of the tissue fluid upon which tissue cells rely for oxygen and nutrients. The organs most affected and damaged by this microangiopathy are the kidneys, retina, peripheral nerves, and feet. Foot ulcers commonly develop.

Arteriovenous malformation is a congenital condition in which capillaries fail to develop in a certain location, so that an artery continues directly into a vein. Relatively common among birth defects, it affects 1 in 700 people and usually occurs in the cerebrum of the brain. Without an intervening bed of capillaries to lower the high pressure of arterial blood before it reaches the vein, the vein weakens and forms a bulging aneurysm, which can compress nearby structures or burst to cause a stroke. Arteriovenous malformation is treated by surgically closing or removing the damaged segment of vein.

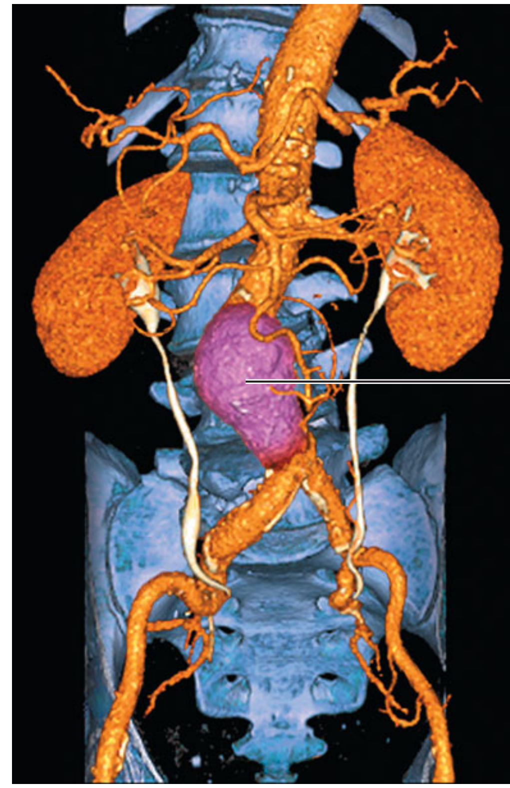


FIGURE 20.23 Sixty-four-slice CT angiogram of an abdominal aortic aneurysm.

BLOOD VESSELS THROUGHOUT LIFE

- Trace the cardiovascular circuit in the fetus, and explain how it changes at birth.
- List some effects of aging on the blood vessels.

As described in Chapter 18, the earliest blood vessels develop from blood islands around the yolk sac in the 3-week embryo. By the end of week 3, splanchnic mesoderm *within* the embryo itself has begun to form networks of blood vessels that grow throughout the body, both by sprouting extensions and by splitting into more branches. At first, the vessels consist only of endothelium, but adjacent mesenchymal cells soon surround these tubes, forming the muscular and fibrous tunics of the vessel walls. Ultimately, the networks are remodeled into treelike arrangements of larger and smaller vessels.

After the basic pattern of vessels is established in the embryo, vessel formation slows, but it continues throughout life: to support the growth of a fetus, to facilitate wound healing, and to rebuild the vessels lost each month after a woman's menstrual period. In adults, as in embryos, new capillaries sprout from existing vessels as tubular outgrowths of the endothelium, in direct relation to tissue demands for oxygen.

Fetal Circulation

All major vessels are in place by the third month of development, and blood is flowing through these vessels in the same direction as in adults (Figure 20.24). However, there are two major differences between fetal and postnatal circulation: First, the fetus must supply blood to the *placenta*, a pancake-shaped organ at the end of the umbilical cord through which oxygen and nutrients are obtained from the mother's uterus. Second, because the fetal respiratory organ is the placenta and the fetus does not breathe, its lungs do not need much blood. Therefore, the fetus sends very little blood around the pulmonary circuit. Despite these special features and needs, the fetus must be able to convert rapidly at birth to the postnatal circulatory pattern. The following sections explore the two special features of fetal circulation in more detail.

Vessels to and from the Placenta

The fetal vessels that carry blood to and from the placenta are called *umbilical vessels* because they run in the umbilical cord (Figure 20.24a). The paired **umbilical arteries** branch from the internal iliac arteries in the pelvis and carry blood to the placenta to pick up oxygen and nutrients. The unpaired **umbilical vein** returns this blood to the fetus, delivering some of it to the portal vein so that its nutrients can be processed by the liver cells. However, there is too much returning blood for the liver to process, so most of the blood is diverted through a shunt called the **ductus venosus** ("venous duct"). Whether it goes through the portal system or the ductus venosus, all returning blood proceeds into the hepatic veins, inferior vena cava, and right atrium of the heart. In the inferior vena cava, this oxygen-rich placental blood mixes with the oxygen-poor blood returning to the heart from the caudal parts of the fetal body.

At birth, most parts of these umbilical vessels are discarded when the umbilical cord is cut, but the parts remaining in the baby's body constrict rapidly and then gradually degenerate into fibrous bands called *ligaments* (Figure 20.24b). Throughout postnatal life, the remnant of the umbilical vein is the **ligamentum teres** ("round ligament"). The ductus venosus becomes the **ligamentum venosum** on the liver's inferior surface, and the umbilical arteries become **medial umbilical ligaments** in the anterior abdominal wall inferior to the navel.

Shunts Away from the Pulmonary Circuit

As mentioned, the fetal lungs and pulmonary circuit need very little blood. As in the adult, the right heart receives all blood returning from the systemic circuit and pumps blood into the pulmonary trunk. However, the fetal lungs are not inflated, and thus the resistance in the pulmonary circuit is great. Consequently, blood is diverted from the pulmonary circuit through two shunts: the *foramen ovale* and the *ductus arteriosus*.

1. **Foramen ovale.** Slightly less than half the blood entering the fetal heart is diverted from the right atrium to the left atrium through a hole in the interatrial septum, the foramen ovale (introduced on p. 559). That is, each time the atria contract, the full right atrium squeezes some of its blood through this hole into the almost-empty left atrium. The foramen ovale is actually a valve with two flaps that prevent any blood from flowing in the opposite direction.
2. **Ductus arteriosus.** Despite the shunt through the foramen ovale, most of the blood that enters the fetal right atrium continues into the right ventricle, which pumps it into the pulmonary trunk. Because resistance in the pulmonary arteries is high and blood prefers to follow the path of least resistance, much of the blood from the pulmonary trunk enters a wide arterial shunt called the ductus arteriosus. This shunt carries blood from the most cranial part of the pulmonary trunk to the adjacent aortic arch, so that only a small amount of blood reaches the lungs. The blood in the aorta goes to nourish the tissues throughout the body, and some proceeds to the placenta to pick up more oxygen and nutrients. Interestingly, the ductus arteriosus empties into the aorta distal to the branching of the coronary arteries and the large arteries off the aortic arch (Figure 20.23a), thus the heart and the brain receive the most highly oxygenated blood in the fetal systemic circuit.

What happens to the foramen ovale and the ductus arteriosus (Figure 20.23b) at birth? When the newborn takes its first breaths, the lungs inflate. There is no longer high resistance in the pulmonary vessels, and the lungs receive more blood. The ductus arteriosus constricts and closes. For the first time, oxygenated pulmonary blood begins pouring into the left atrium, raising the pressure within this chamber. This pressure pushes the two valve flaps of the foramen ovale together, closing it. Both the foramen ovale and ductus arteriosus are now functionally closed, and the postnatal circulatory plan is established.

Although the foramen ovale and ductus arteriosus close shortly after birth, they do not immediately fuse shut. It takes about 3 months for the ductus arteriosus to become the solid ligamentum arteriosum, and about a year for the flaps of the foramen ovale to fuse together as the fossa ovalis.

Blood Vessels in Adulthood

The most important aspect of the aging of the vascular system is the progression of atherosclerosis (discussed on p. 610). Because of the high fat content in the American diet, almost everyone in the United States develops atherosclerotic plaques in the major arteries before the age of 40. Although the degenerative process of atherosclerosis begins in youth, its consequences are rarely apparent until middle to old age, when it may lead to myocardial infarction or stroke.

Gender has an effect on how atherosclerosis develops with age. Until puberty, the blood vessels of boys and girls look alike, but from puberty to about the age of 45 years, women have strikingly less atherosclerosis than men, probably because of protective effects of estrogen. This "gap between the sexes" closes between the ages of 45 and 65, and after age 65 the incidence of heart disease is slightly higher in women. Furthermore, when a woman does experience a heart attack, she is more likely to die from it than is a man. Some of the reasons for this are unpreventable (the average woman having a heart attack is 10 years older than the average male victim, and the vessel-damaging aspects of diabetes seem to

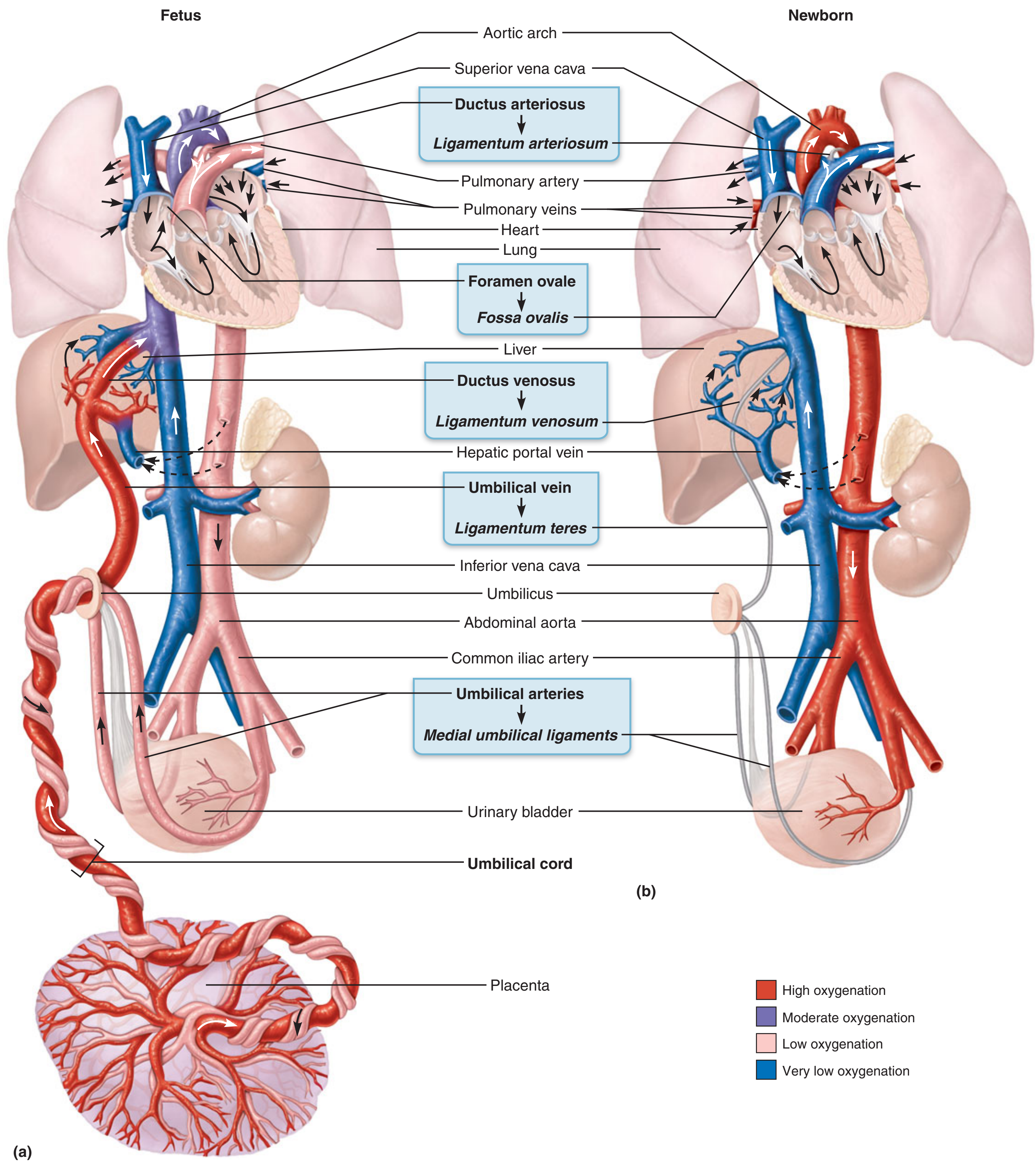


FIGURE 20.24 Fetal and newborn circulation. Arrows on vessels indicate the direction of blood flow. Arrows in color screens go from fetal structure to what it becomes after birth. **(a)** Special adaptations for fetal life. The umbilical arteries carry waste-laden, low-oxygen blood from the fetus to the placenta. The umbilical vein carries oxygen- and nutrient-rich blood from the placenta to the fetus. The ductus arteriosus and foramen ovale shunt blood away from the nonfunctional lungs, and the ductus venosus enables much of the blood to bypass the liver circulation. **(b)** Changes in the cardiovascular system at birth. The umbilical vessels and the lung shunts are occluded.

affect women more), but others are preventable. Many people wrongly believe that women do not get atherosclerosis, so some women may not recognize the symptoms of angina or a heart attack in time to seek help.

check your understanding

12. What lifestyle factors contribute to the development of atherosclerosis?
13. How does elevated blood glucose associated with diabetes mellitus affect the delivery of oxygen and nutrients to body tissues?
14. Which vessel in the fetus carries the most highly oxygenated blood?
15. Where is the ductus arteriosus located, and how does it function to shunt blood from the pulmonary circuit?

For answers, see Appendix B.

RELATED CLINICAL TERMS

ANGIOGRAPHY (an-jē-og′ra-fē; *angio* = vessel; *graphy* = writing) Diagnostic technique involving the infusion of a radiopaque substance into the bloodstream for X-ray examination of specific blood vessels. Angiography is the major way of diagnosing occlusion of coronary arteries and risk of heart attack. The images obtained with this procedure are called *angiograms*.

ANGIOSARCOMA Cancer originating from the endothelium of a blood vessel; may develop in liver vessels following exposure to chemical carcinogens.

BLUE BABY A baby with cyanosis (skin appears blue) due to relatively low levels of oxygen in the blood. This condition is caused by any congenital defect that leads to low oxygenation of the systemic blood, including patent (open) foramen ovale and patent ductus arteriosus (see above), failure of the lungs to inflate at birth, and other conditions (see p. 576).

CAROTID ENDARTERECTOMY Surgical procedure for scraping away atherosclerotic plaques that block the base of the internal carotid artery; done to decrease the risk of a stroke.

PHLEBITIS (fle-bi′tis; *phleb* = vein; *itis* = inflammation) Inflammation of a vein, accompanied by painful throbbing and redness of the skin over the inflamed vein; most often caused by bacterial infection or local physical trauma.

PHLEBOTOMY (fle-bot′o-me; *tomy* = cut) An incision made in a vein for withdrawing blood.

CHAPTER SUMMARY

You can use the following media study tool for additional help when you review specific key topics in Chapter 20.

PAL = **Practice Anatomy Lab™**

PART 1: GENERAL CHARACTERISTICS OF BLOOD VESSELS (pp. 581–588)

1. The main types of blood vessels are arteries, capillaries, and veins. Arteries carry blood away from the heart and toward the capillaries; veins carry blood away from the capillaries and toward the heart. Arteries "branch," whereas veins "serve as tributaries."

Structure of Blood Vessel Walls (p. 581)

2. All but the smallest blood vessels have three tunics: tunica intima (with an endothelium), tunica media (mostly smooth muscle), and tunica externa (external connective tissue). The tunica media, which changes the diameter and strengthens the wall of the vessel, is thicker in arteries than in other types of blood vessels.

Types of Blood Vessels (pp. 581–588)

3. The three classes of arteries, from large to small, are elastic arteries, muscular arteries, and arterioles. Elastic (conducting) arteries, the largest arteries near the heart, contain more elastin than does any other vessel type. The elastin in all arteries helps dampen the pressure pulses produced by the heartbeat.
4. Muscular (distributing) arteries carry blood to specific organs and organ regions. These arteries have a thick tunica media bordered by elastic lamina and are most active in vasoconstriction.
5. Arterioles, the smallest arteries, have one or two layers of smooth muscle cells in their tunica media. They regulate the flow of blood into capillary beds.
6. Capillaries, which have diameters slightly larger than erythrocytes, are endothelium-walled tubes arranged in networks called capillary beds. The most permeable capillaries have fenestrations (pores) in their endothelial cells; other capillaries are continuous (lack pores). Spider-shaped pericytes help support the capillary wall.
7. Sometimes, blood is shunted straight through a capillary bed (from arteriole to metarteriole to thoroughfare channel to venule) and does not enter the true capillaries to the surrounding tissue. Precapillary sphincters determine how much blood enters the true capillaries.
8. The four routes involved in capillary permeability are (1) through intercellular clefts between endothelial cells, (2) through the pores of fenestrated capillaries, (3) by direct diffusion of respiratory gases across the endothelium, and (4) through endothelial pinocytotic vesicles.
9. Sinusoids are wide, twisted, leaky capillaries.
10. The smallest veins, postcapillary venules, function like capillaries.
11. Because venous blood is under less pressure than arterial blood, the walls of veins are thinner than those of arteries of comparable size. Veins also have a wider lumen, a thinner tunica media, and a thicker tunica externa.
12. Many veins have valves that prevent the backflow of blood. The skeletal muscle pump aids to move blood through veins. Varicose veins are veins whose valves have failed.

Vascular Anastomoses (p. 588)

13. The joining together of arteries serving a common organ, called an arterial anastomosis, provides collateral channels for blood to

reach the same organ. Anastomoses between veins are more common than anastomoses between arteries.

Vasa Vorum **(p. 588)**

14. Vasa vasorum are small arteries, capillaries, and veins that supply the outer part of the wall of larger blood vessels.

PART 2: BLOOD VESSELS OF THE BODY **(pp. 589–614)**

The Pulmonary Circulation **(pp. 589–591)**

15. The pulmonary trunk splits inferior to the aortic arch into the right and left pulmonary arteries. These arteries divide into lobar arteries, then branch repeatedly in the lung. Arising from the capillary beds, pulmonary venous tributaries empty newly oxygenated blood into the superior and inferior pulmonary veins of each lung. The four pulmonary veins extend from the lungs to the left atrium.

The Systemic Circulation **(pp. 591–608)**

16. Figures 20.8 and 20.16 summarize the main arteries and veins of the systemic circulation. The systemic circuit begins with the aorta (ascending aorta, aortic arch, descending aorta) and ends with the two large venae cavae and the coronary sinus.

PAL **Human Cadaver/Cardiovascular System/Arteries, and Human Cadaver/Cardiovascular System/Veins**

17. A portal system is a set of vessels in which *two* capillary beds, interconnected by a vein, lie between the initial artery and final vein. The hepatic portal system is a special subcirculation that drains the digestive organs of the abdomen and pelvis (see Figure 20.21).

18. Cirrhosis of the liver leads to portal hypertension, in which blood backs up through the portal-systemic anastomoses, overloading these delicate veins. This overload leads to esophageal bleeding, hemorrhoids, and caput medusae.

Disorders of the Blood Vessels **(pp. 609–611)**

19. *Atherosclerosis,* the most important vascular disorder, is discussed in A Closer Look on p. 610. *Deep vein thrombosis of the lower limb* is the formation of clots in veins of the lower extremity. In *venous disease,* the failure of venous valves in some lower-limb veins results in inadequate drainage of venous blood from the limb, whose tissues consequently become ischemic and vulnerable to ulceration. An *aneurysm* is a widening or outpocketing of an artery (or vein). In *microangiopathy of diabetes,* the capillaries are leaky because of sugar deposits in their basement membrane. In *arteriovenous malformation,* the capillaries fail to develop between some important artery and the vein that drains it, often leading to a rupture or an aneurysm of the vein.

Blood Vessels Throughout Life **(pp. 611–614)**

20. The first blood vessels develop from blood islands on the yolk sac in the 3-week embryo. Soon, vessels begin forming from mesoderm inside the embryo. The formation of new vessels, whether in the embryo or adult, occurs mainly through the sprouting of endothelial buds from existing vessels.

21. The pattern of blood vessels is the same in both the fetus and the newborn, and blood flows through these vessels in the same directions. However, the fetus also has vessels to and from the placenta (umbilical arteries, umbilical vein, and ductus venosus) and two shunts that bypass the nearly nonfunctional pulmonary circuit (the foramen ovale in the interatrial septum, and the ductus arteriosus between the pulmonary trunk and aortic arch). Fetal shunts and vessels close shortly after birth.

22. The most important age-related vascular disorder is the progression of atherosclerosis.

REVIEW QUESTIONS

Multiple Choice/Matching Questions

For answers, see Appendix B.

1. Which of the following statements does *not* correctly describe veins? (a) They have less elastic tissue and smooth muscle than arteries. (b) They are subject to lower blood pressures than arteries. (c) They have larger lumens than arteries. (d) They always carry deoxygenated blood.

2. In atherosclerosis, which of the following layers of the artery wall thickens most? (a) tunica media, (b) tunica intima, (c) tunica externa.

3. Blood flow through the capillaries is steady despite the rhythmic pumping action of the heart because of the (a) elasticity of the large arteries only, (b) elasticity of all the arteries, (c) ligamentum arteriosum, (d) venous valves.

4. Fill in the blanks with the name of the appropriate vascular tunic (intima, media, or externa).

____ **(1)** contains endothelium

____ **(2)** the tunic with the largest vasa vasorum

____ **(3)** the thickest tunic in veins

____ **(4)** the outer tunic; is mostly connective tissue

____ **(5)** is mostly smooth muscle

____ **(6)** forms the valves of veins

5. Which of the following vessels is bilaterally symmetrical (that is, has an identical member of a pair on either side of the body)? (a) internal carotid artery, (b) brachiocephalic trunk, (c) azygos vein, (d) superior mesenteric vein.

6. Identify which artery is *missing* from the following sequence, which traces the flow of arterial blood to the right hand: Blood leaves the heart and passes through the aorta, the right subclavian artery, the axillary and brachial arteries, and through either the radial or ulnar artery to a palmar arch. (a) left coronary, (b) brachiocephalic, (c) cephalic, (d) right common carotid.

7. Which of the following veins do not drain directly into the inferior vena cava? (a) lumbar veins, (b) hepatic veins, (c) inferior mesenteric vein, (d) renal veins.

8. A stroke that blocks a posterior cerebral artery will most likely affect (a) hearing, (b) sight, (c) smell, (d) higher thought processes.

9. Tell which artery is *missing* from the following sequence, which traces the flow of arterial blood to the left parietal and temporal lobes of the brain: Blood leaves the heart and passes through the aorta, the left common carotid artery, and the middle cerebral artery. (a) vertebral, (b) brachiocephalic, (c) internal carotid, (d) basilar.

10. Tell which two veins are *missing* from the following sequence: Tracing the drainage of *superficial* venous blood from the leg, blood enters the great saphenous vein, femoral vein, inferior vena cava, and right atrium. (a) coronary sinus and superior vena cava,

(b) posterior tibial and popliteal, (c) fibular (peroneal) and popliteal, (d) external and common iliacs.

11. The inferior mesenteric artery supplies the (a) rectum and part of the colon, (b) liver, (c) small intestine, (d) spleen.

12. Tell which two vessels are *missing* from the following sequence: Tracing the drainage of venous blood from the small intestine, blood enters the superior mesenteric vein, hepatic vein, inferior vena cava, and right atrium. (a) coronary sinus and left atrium, (b) celiac and common hepatic veins, (c) internal and common iliac veins, (d) hepatic portal vein and liver sinusoids.

13. Tell which vessel is *missing* from the following vascular circuit: Tracing the circulation to and from the placenta, a drop of blood travels in the fetus from the left ventricle to the aorta, to a common iliac artery, to an internal iliac artery, to an umbilical artery, to capillaries in the placenta, to the ductus venosus, to a hepatic vein, to the inferior vena cava, to the right atrium, to the foramen ovale, to the left atrium, and to the left ventricle. (a) umbilical vein, (b) ligamentum arteriosum, (c) internal carotid artery, (d) capillaries in the small intestine.

14. A pressure point is a place where one presses on an artery through the body surface to stop bleeding more distally. Which of the following sites is not a pressure point for any major artery? (a) the medial bicipital furrow on arm, (b) the sciatic artery in middle of gluteus maximus, (c) the midinguinal point in the femoral triangle.

15. Which of the following is not a pulse point? (a) anatomical snuff box, (b) inferior margin of mandible anterior to masseter muscle, (c) center of distal forearm at palmaris longus tendon, (d) medial bicipital furrow on arm, (e) dorsum of foot between the first two metatarsals.

16. A nurse missed a patient's median cubital vein while trying to draw blood and then inserted the needle far too deeply into the cubital fossa. This error could cause any of the following problems *except* (a) paralysis of the ulnar nerve, (b) paralysis of the median nerve, (c) bruising the insertion tendon of the biceps brachii muscle, (d) blood spurting from the brachial artery.

Short Answer Essay Questions

17. (a) What structural features are responsible for the permeability of capillary walls? (b) Which of these features are absent from brain capillaries in the blood-brain barrier?

18. Distinguish among elastic arteries, muscular arteries, and arterioles relative to their location, histology, and functions.

19. (a) Name an organ containing fenestrated capillaries. (b) What is a sinusoid?

20. Sketch the arterial circle at the base of the brain, and label the important arteries that branch off this circle.

21. (a) What are the two large tributaries that form the hepatic portal vein? (b) What is the function of the hepatic portal circulation?

22. State the location and basic body regions drained by the azygos vein.

23. Name all four pulmonary veins.

24. What are the ductus venosus and ductus arteriosus, where are they located, what are their functions, and how are they different?

25. Differentiate between arteriosclerosis and atherosclerosis.

26. Figure 20.8b shows where to feel the pulses of various arteries. Name the artery from which each artery listed in the figure branches. Here is an example to get you started: The superficial temporal artery *is a branch of the external carotid artery*.

CRITICAL REASONING & CLINICAL APPLICATION QUESTIONS

1. In an eighth-grade health class, the teacher warned the students not to squeeze pimples or pluck hairs on their nose and upper lip. The students made fun of this warning, but they got the message when the teacher explained the danger triangle of the face. What is the danger of infections in this area?

2. Logically deduce which is the more difficult and dangerous surgery on a child: closing a patent ductus arteriosus or closing a patent foramen ovale. Explain your reasoning.

3. Samantha accidentally received a small but deep puncture wound from broken glass in the exact midline of the anterior side of her distal forearm. She worried during the 10-minute drive to the hospital that she would bleed to death because she had heard stories about people dying from slashing their wrist. Look at Figure 20.11, and determine whether her fear of bleeding to death is justified. Explain your reasoning.

4. Your friend, who knows little about science, is reading a magazine article about a patient who had an "aneurysm at the base of his brain that suddenly grew much larger." The surgeons' first goal was to "keep it from rupturing," and their second goal was to "relieve the pressure on the brain stem and cranial nerves." The surgeons were able to "replace the aneurysm with a section of plastic tubing," and the patient recovered. Your friend asks you what all this means. Explain. (Start by checking the section on blood vessel disorders.)

5. Describe some consequences of the loss of elasticity in the conducting arteries, as occurs in arteriosclerosis ("hardening of the arteries").

6. In coronary bypass surgery, the internal thoracic artery can be used as the bypass vessel by suturing its distal end onto the obstructed coronary artery in the heart wall. Explain why using this vessel is superior to using the great saphenous vein of the leg.

7. Occasionally, either the ductus arteriosus or the foramen ovale stays patent (open) after birth. What functional deficit do both these conditions produce?

8. (a) Explain in your own words why varicose veins are more common in the lower limbs than elsewhere in the body. (b) Give a functional reason why valves are more abundant in veins of the upper and lower limbs than in veins of the neck.