

SELECTED KEY TERMS

The following terms and other boldface terms in the chapter are defined in the Glossary

anastomosis
aneurysm
aorta
arteriole
artery
atherosclerosis
capillary
embolus
endarterectomy
endothelium
hemorrhage
hypertension
hypotension
ischemia
phlebitis
pulse
shock
sinusoid
sphygmomanometer
thrombus
varicose vein
vasoconstriction
vasodilation
vein
vena cava
venous sinus
venule

LEARNING OUTCOMES

After careful study of this chapter, you should be able to:

1. Differentiate among the five types of blood vessels with regard to structure and function
2. Compare the pulmonary and systemic circuits relative to location and function
3. Name the four sections of the aorta and list the main branches of each section
4. Define anastomosis; cite the function of anastomoses and give several examples
5. Compare superficial and deep veins and give examples of each type
6. Name the main vessels that drain into the superior and inferior venae cavae
7. Define *venous sinus* and give several examples of venous sinuses
8. Describe the structure and function of the hepatic portal system
9. Explain the forces that affect exchange across the capillary wall
10. Describe the factors that regulate blood flow
11. Define *pulse* and list factors that affect pulse rate
12. List the factors that affect blood pressure
13. Explain how blood pressure is commonly measured
14. List reasons why hypertension should be controlled
15. List some disorders that involve the blood vessels
16. List steps in first aid for hemorrhage
17. List four types of shock
18. Show how word parts are used to build words related to the blood vessels and circulation (see Word Anatomy at the end of the chapter)



chapter

15

Blood Vessels and Blood Circulation



The blood vessels, together with the four chambers of the heart, form a closed system in which blood is carried to and from the tissues. Although whole blood does not leave the vessels, components of the plasma and tissue fluids can be exchanged through the walls of the tiniest vessels, the capillaries.

The vascular system is easier to understand if you refer to the appropriate illustrations in this chapter as the vessels are described. When this information is added to what you already know about the blood and the heart, a picture of the cardiovascular system as a whole will emerge.

► Blood Vessels

Blood vessels may be divided into five groups, named below according to the sequence of blood flow from the heart:

- **Arteries** carry blood away from the heart and toward the tissues. The heart's ventricles pump blood into the arteries.
- **Arterioles** (ar-TE-re-olz) are small subdivisions of the arteries. They carry blood into the capillaries.
- **Capillaries** are tiny, thin-walled vessels that allow for exchanges between systems. These exchanges occur between the blood and the body cells and between the blood and the air in the lung tissues. The capillaries connect the arterioles and venules.
- **Venules** (VEN-ulz) are small vessels that receive blood from the capillaries and begin its transport back toward the heart.
- **Veins** are vessels formed by the merger of venules. They continue the transport of blood until it is returned to the heart

Checkpoint 15-1 What are the five types of blood vessels?

Blood Circuits

The vessels together may be subdivided into two groups, or circuits: pulmonary and systemic. Figure 15-1 shows the vessels in these two circuits; the anatomic relation of the circuits to the heart is shown in Chapter 14's Figure 14-4.

The Pulmonary Circuit The pulmonary circuit delivers blood to the lungs where carbon dioxide is eliminated and oxygen is replenished. The pulmonary vessels that carry blood to and from the lungs include the following:

- The pulmonary artery and its branches, which carry blood from the right ventricle to the lungs
- The capillaries in the lungs, through which gases are exchanged
- The pulmonary veins, which carry blood back to the left atrium

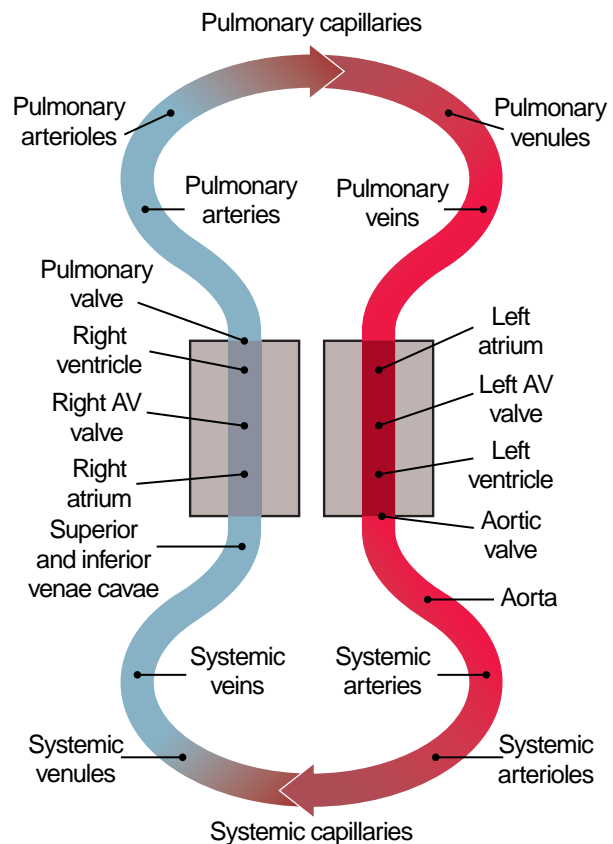


Figure 15-1 Blood flow in a closed system of vessels. Oxygen content changes as blood flows through the capillaries. **ZOOMING IN** ♦ Judging from color coding, which vessels pick up oxygen? Which vessels release oxygen?

The pulmonary vessels differ from those in the systemic circuit in that the pulmonary arteries carry blood that is *low* in oxygen, and the pulmonary veins carry blood that is *high* in oxygen. All the remaining arteries carry highly oxygenated blood, and all remaining veins carry blood that is low in oxygen.

The Systemic Circuit The systemic (sis-TEM-ik) circuit serves the rest of the body. These vessels supply nutrients and oxygen to all the tissues and carry waste materials away from the tissues for disposal. The systemic vessels include the following:

- The aorta (a-OR-tah), which receives blood from the left ventricle and then branches into the systemic arteries carrying blood to the tissues
- The systemic capillaries, through which materials are exchanged
- The systemic veins, which carry blood back toward the heart. The venous blood flows into the right atrium of the heart through the superior vena cava and inferior vena cava.

Checkpoint 15-2 What are the two blood circuits and what areas does each serve?

Vessel Structure

The arteries have thick walls because they must be strong enough to receive blood pumped under pressure from the heart's ventricles (Fig. 15-2). The three tunics (coats) of the arteries resemble the three tissue layers of the heart:

- ▶ The innermost membrane of simple, flat epithelial cells makes up the **endothelium** (en-do-THE-le-um), forming a smooth surface over which the blood flows easily.
- ▶ The middle and thickest layer is made of smooth (involuntary) muscle, which is under the control of the autonomic nervous system.
- ▶ An outer tunic is made of a supporting connective tissue.

Elastic tissue between the layers of the arterial wall allows these vessels to stretch when receiving blood and then return to their original size. The amount of elastic tissue diminishes as the arteries branch and become smaller.

The small subdivisions of the arteries, the arterioles, have thinner walls in which there is little elastic connective tissue but relatively more smooth muscle. The autonomic nervous system controls this involuntary muscle.

The vessels become narrower (constrict) when the muscle contracts and widen (dilate) when the muscle relaxes. In this manner, the arterioles regulate the amount of blood that enters the various tissues at a given time. Change in the diameter of the arterioles is also a major factor in blood pressure control.

The microscopic capillaries that connect arterioles and venules have the thinnest walls of any vessels: one cell layer. The capillary walls are transparent and are made of smooth, squamous epithelial cells that are a continuation of the lining of the arteries. The thinness of these walls allows for exchanges between the blood and the body cells and between the lung tissue and the outside air. The capillary boundaries are the most important center of activity for the entire circulatory system. Their function is explained later in this chapter (see also Box 15-1).

The smallest veins, the venules, are formed by the union of capillaries, and their walls are only slightly thicker than those of the capillaries. As the venules merge to form veins, the smooth muscle in the vessel walls becomes thicker and the venules begin to acquire the additional layers found in the larger vessels.

The walls of the veins have the same three layers as those of the arteries. However, the middle smooth muscle tunic is relatively thin in the veins. A vein wall is much

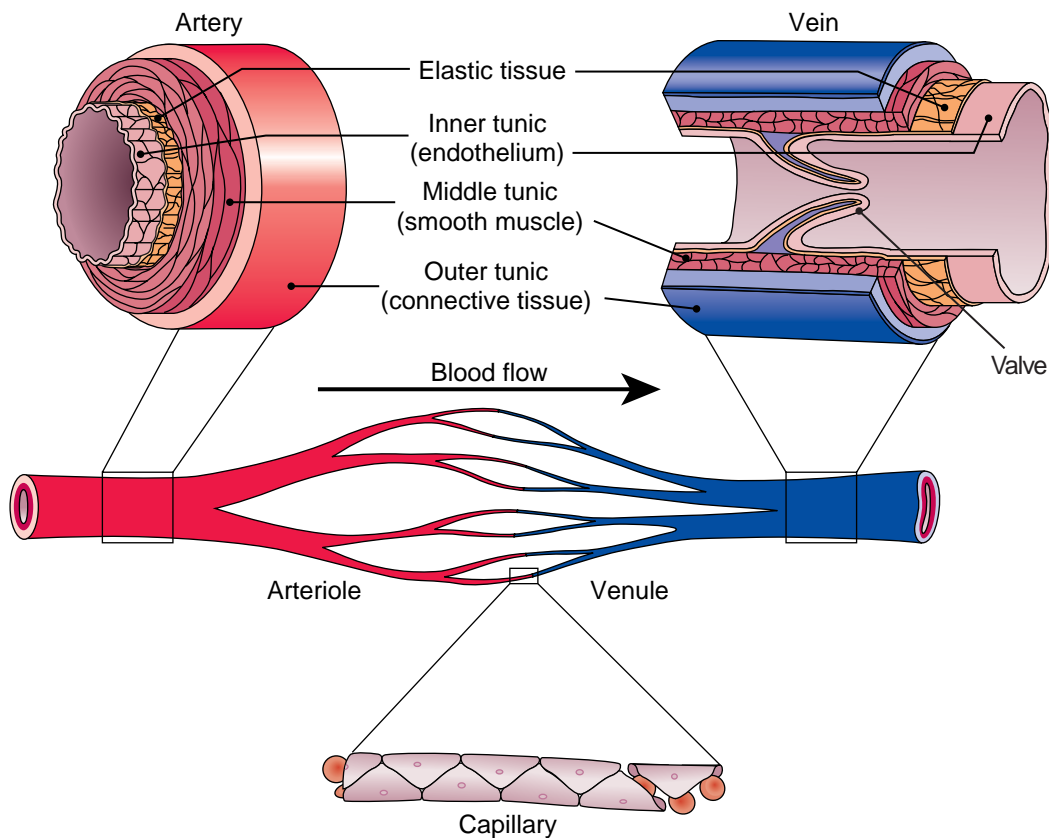


Figure 15-2 Sections of small blood vessels. Drawings show the thick wall of an artery, the thin wall of a vein, and the single-layered wall of a capillary. A venous valve also is shown. The arrow indicates the direction of blood flow. **ZOOMING IN ♦ Which vessels have valves that control blood flow?**

Box 15-1 A Closer Look

Capillaries: The Body's Free Trade Zones

The exchange of substances between body cells and the blood occurs along about 50,000 miles (80,000 kilometers) of capillaries. Rates of exchange vary because, based on their structure, different types of capillaries vary in permeability.

Continuous capillaries are the most common type and are found in muscle, connective tissue, the lungs, and the central nervous system (CNS). These capillaries are composed of a continuous layer of endothelial cells. Adjacent cells are loosely attached to each other, with small openings called intercellular clefts between them. Although continuous capillaries are the least permeable, water and small molecules can diffuse easily through their walls. Large molecules, such as plasma proteins and blood cells, cannot. In certain regions of the body, like the CNS, adjacent endothelial cells are joined tightly together, making the capillaries impermeable to many substances (see Box 10-1 in Chapter 10, The Blood Brain Barrier: Access Denied).

Fenestrated (FEN-es-tra-ted) capillaries are much more permeable than continuous capillaries, because they have many holes, or fenestrations, in the endothelium. These sieve-like capillaries are permeable to water and solutes as large as peptides. In the digestive tract, fenestrated capillaries permit rapid absorption of water and nutrients into the bloodstream. In the kidneys, they permit rapid filtration of blood plasma, the first step in urine formation.

Discontinuous capillaries, or sinusoids, are the most permeable. In addition to fenestrations, they have large spaces between endothelial cells that allow the exchange of water, large solutes, such as plasma proteins, and even blood cells. Sinusoids are found in the liver and red bone marrow, for example. Albumin, clotting factors, and other proteins formed in the liver enter the bloodstream through sinusoids. In red bone marrow, newly formed blood cells travel through sinusoids to join the bloodstream.

thinner than the wall of a comparably sized artery. These vessels also have less elastic tissue between the layers. As a result, the blood within the veins is carried under much lower pressure. Because of their thinner walls, the veins are easily collapsed. Only slight pressure on a vein by a tumor or other mass may interfere with return blood flow.

Most veins are equipped with one-way valves that permit blood to flow in only one direction: toward the heart (see Fig. 15-2). Such valves are most numerous in the veins of the extremities. Figure 15-3 is a cross-section of an artery and a vein as seen through a microscope.

Checkpoint 15-3 What type of tissue makes up the middle layer of arteries and veins, and how is this tissue controlled?

Checkpoint 15-4 How many cell layers make up the wall of a capillary?

Systemic Arteries

The systemic arteries begin with the aorta, the largest artery, which measures about 2.5 cm (1 inch) in diameter. This vessel receives blood from the left ventricle then travels downward through the body, branching to all organs.

The Aorta and Its Parts

The aorta ascends toward the right from the left ventricle. Then it curves posteriorly and to the left. It continues downward posterior to the heart and just anterior to the vertebral column, through the diaphragm, and into the

abdomen (Figs. 15-4 and 15-5). The aorta is one continuous artery, but it may be divided into sections:

- The **ascending aorta** is near the heart and inside the pericardial sac.
- The **aortic arch** curves from the right to the left and also extends posteriorly.
- The **thoracic aorta** lies just anterior to the vertebral col-

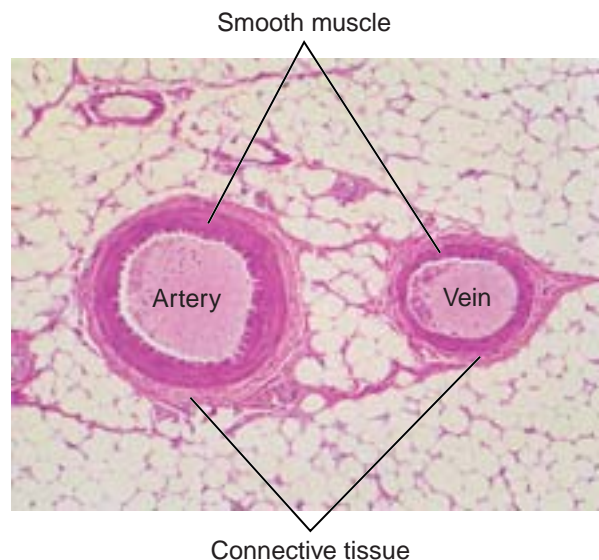


Figure 15-3 Cross-section of an artery and vein. The smooth muscle and connective tissue of the vessels are visible in this photomicrograph. (Reprinted with permission from Cormack DH. *Essential Histology*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2001.) **ZOOMING IN** ♦ Which type of vessel shown has a thicker wall?

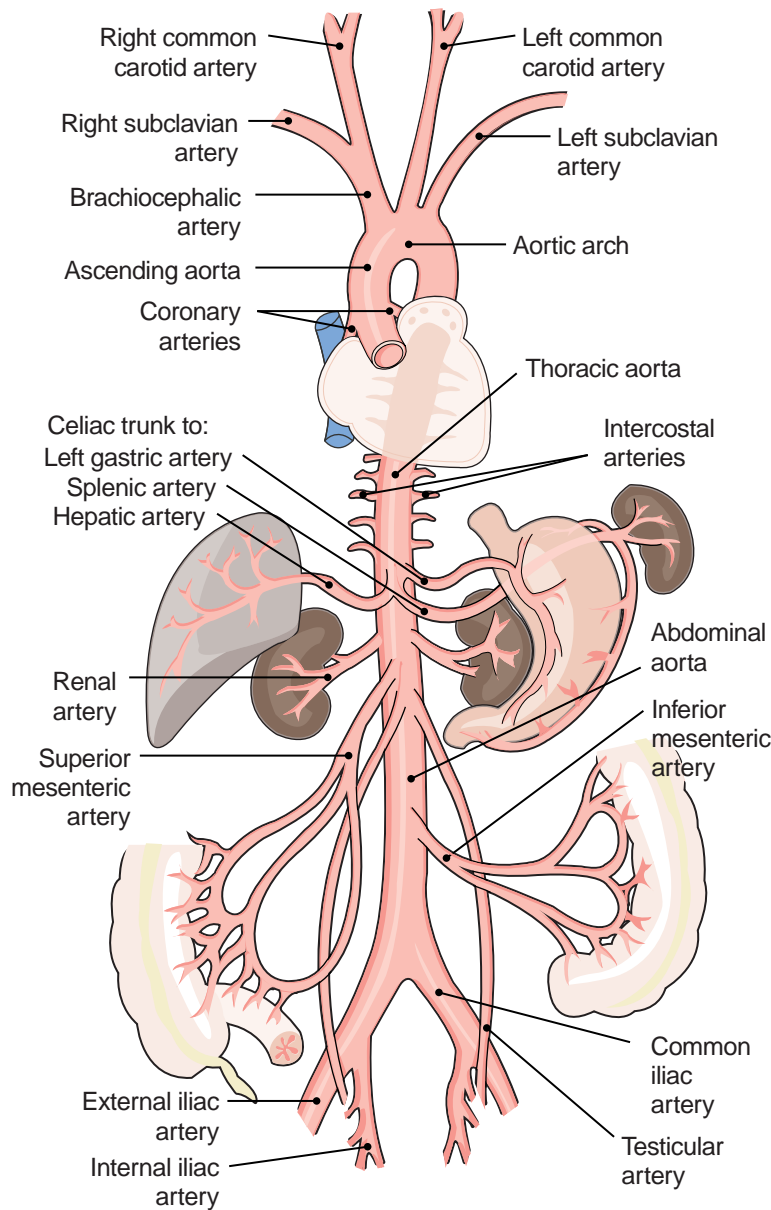


Figure 15-4 The aorta and its branches. *ZOOMING IN* ♦ How many brachiocephalic arteries are there?

um posterior to the heart and in the space behind the pleura.

- ♦ The **abdominal aorta** is the longest section of the aorta, spanning the abdominal cavity.

The thoracic and abdominal aorta together make up the descending aorta.

Branches of the Ascending Aorta and Aortic Arch The first, or ascending, part of the aorta has two branches near the heart, called the **left and right coronary arteries**, which supply the heart muscle. These form a crown around the heart's base and give off branches to all parts of the myocardium.

The arch of the aorta, located immediately beyond the ascending aorta, divides into three large branches.

- ♦ The **brachiocephalic** (brak-e-o-seh-FAL-ik) artery is a short vessel that supplies the arm and the head on the right side. After extending upward somewhat less than 5 cm (2 inches), it divides into the **right subclavian** (sub-KLA-ve-an) artery, which extends under the right clavicle (collar bone) and supplies the right upper extremity (arm), and the **right common carotid** (kah-ROT-id) artery, which supplies the right side of the neck, head and brain. Note that the brachiocephalic artery is unpaired.
- ♦ The **left common carotid** artery extends upward from the highest part of the aortic arch. It supplies the left side of the neck and the head.
- ♦ The **left subclavian** artery extends under the left clavicle and supplies the left upper extremity. This is the last branch of the aortic arch.

Branches of the Thoracic Aorta

The thoracic aorta supplies branches to the chest wall, **esophagus** (e-SOF-ah-gus), and bronchi (the subdivisions of the trachea), and their treelike subdivisions in the lungs. There are usually 9 to 10 pairs of **intercostal** (in-ter-KOS-tal) arteries that extend between the ribs, sending branches to the muscles and other structures of the chest wall.

Branches of the Abdominal Aorta

As in the case of the thoracic aorta, there are unpaired branches extending anteriorly and paired arteries

extending laterally. The unpaired vessels are large arteries that supply the abdominal viscera. The most important of these visceral branches are as follows:

- ♦ The **celiac** (SE-le-ak) **trunk** is a short artery about 1.25 cm (1/2 inch) long that subdivides into three branches: the **left gastric** artery goes to the stomach, the **splenic** (SPLEN-ik) artery goes to the spleen, and the **hepatic** (heh-PAT-ik) artery carries oxygenated blood to the liver.
- ♦ The **superior mesenteric** (mes-en-TER-ik) artery, the largest of these branches, carries blood to most of the small intestine and to the first half of the large intestine.
- ♦ The much smaller **inferior mesenteric** artery, located below the superior mesenteric artery and near the end

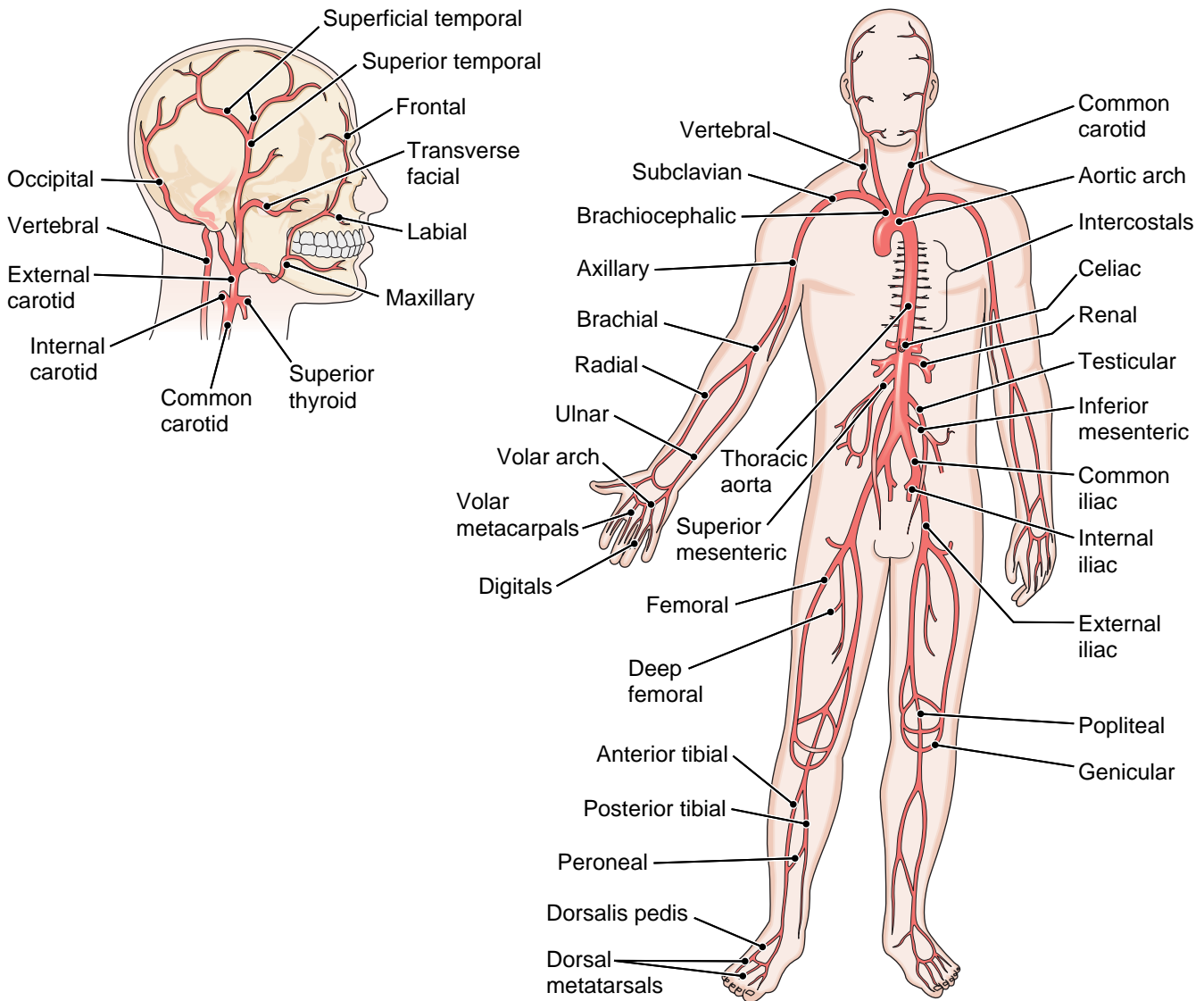


Figure 15-5 Principal systemic arteries.

of the abdominal aorta, supplies the second half of the large intestine.

The paired lateral branches of the abdominal aorta include the following right and left vessels:

- The **phrenic** (FREN-ik) arteries supply the diaphragm.
- The **suprarenal** (su-prah-RE-nal) arteries supply the adrenal (suprarenal) glands.
- The **renal** (RE-nal) arteries, the largest in this group, carry blood to the kidneys.
- The **ovarian** arteries in women and **testicular** (tes-TIK-u-lar) arteries in men (formerly called the spermatic arteries), supply the sex glands.
- Four pairs of **lumbar** (LUM-bar) arteries extend into the musculature of the abdominal wall.

Checkpoint 15-5 What are the subdivisions of the aorta, the largest artery?

The Iliac Arteries and Their Subdivisions

The abdominal aorta finally divides into two **common iliac** (IL-e-ak) arteries. Both of these vessels, which are about 5 cm (2 inches) long, extend into the pelvis, where each one subdivides into an **internal** and an **external iliac** artery.

The internal iliac vessels then send branches to the pelvic organs, including the urinary bladder, the rectum, and some reproductive organs.

Each external iliac artery continues into the thigh as the **femoral** (FEM-or-al) artery. This vessel gives rise to branches in the thigh and then becomes the **popliteal** (pop-LIT-e-al) artery, which subdivides below the knee. The subdivisions include the posterior and anterior **tibial** arteries and the **dorsalis pedis** (dor-SA-lis PE-dis), which supply the leg and the foot.

Arteries That Branch to the Arm and Head

Each common carotid artery travels along the trachea enclosed in a sheath with the internal jugular vein and the vagus nerve. Just anterior to the angle of the mandible (lower jaw) it branches into the **external** and **internal carotid arteries**. You can feel the pulse of the carotid artery just anterior to the large sternocleidomastoid muscle in the neck and below the jaw. The internal carotid artery travels into the head and branches to supply the eye, the anterior portion of the brain, and other structures in the cranium. The external carotid artery branches to the thyroid gland and to other structures in the head and upper part of the neck.

The **subclavian** (sub-KLA-ve-an) artery supplies blood to the arm and hand. Its first branch, however, is the **vertebral** (VER-the-bral) artery, which passes through the transverse processes of the first six cervical vertebrae and supplies blood to the posterior portion of the brain. The subclavian artery changes names as it travels through the arm and branches to the arm and hand. It first becomes the **axillary** (AK-sil-ar-e) artery in the axilla (armpit). The longest part of this vessel, the **brachial** (BRA-ke-al) artery, is in the arm proper. The brachial artery subdivides into two branches near the elbow: the **radial artery**, which continues down the thumb side of the forearm and wrist, and the **ulnar artery**, which extends along the medial or little finger side into the hand.

Just as the larger branches of a tree divide into limbs of varying sizes, so the arterial tree has a multitude of subdivisions. Hundreds of names might be included. We have mentioned only some of them.

Checkpoint 15-6 What arteries are formed by the final division of the abdominal aorta?

Checkpoint 15-7 What areas are supplied by the brachiocephalic artery?

Anastomoses

A communication between two vessels is called an **anastomosis** (ah-nas-to-MO-sis). By means of arterial anastomoses, blood reaches vital organs by more than one route. Some examples of such end-artery unions are as follows:

- The circle of Willis (Fig. 15-6) receives blood from the two internal

carotid arteries and from the **basilar** (BAS-il-ar) artery, which is formed by the union of the two vertebral arteries. This arterial circle lies just under the center of the brain and sends branches to the cerebrum and other parts of the brain.

- The **superficial palmar arch** is formed by the union of the radial and ulnar arteries in the hand. It sends branches to the hand and the fingers.
- The **mesenteric arches** are made of communications between branches of the vessels that supply blood to the intestinal tract.
- **Arterial arches** are formed by the union of branches of the tibial arteries in the foot. There are similar anastomoses in other parts of the body.

Arteriovenous anastomoses are blood shunts found in a few areas, including the external ears, the hands, and the feet. In this type of shunt, a small vessel known as a *metarteriole* or *thoroughfare channel*, connects the arterial system directly with the venous system, bypassing the capillaries (Fig. 15-7). This pathway provides a more rapid flow and a greater blood volume to these areas, thus protecting these exposed parts from freezing in cold weather.

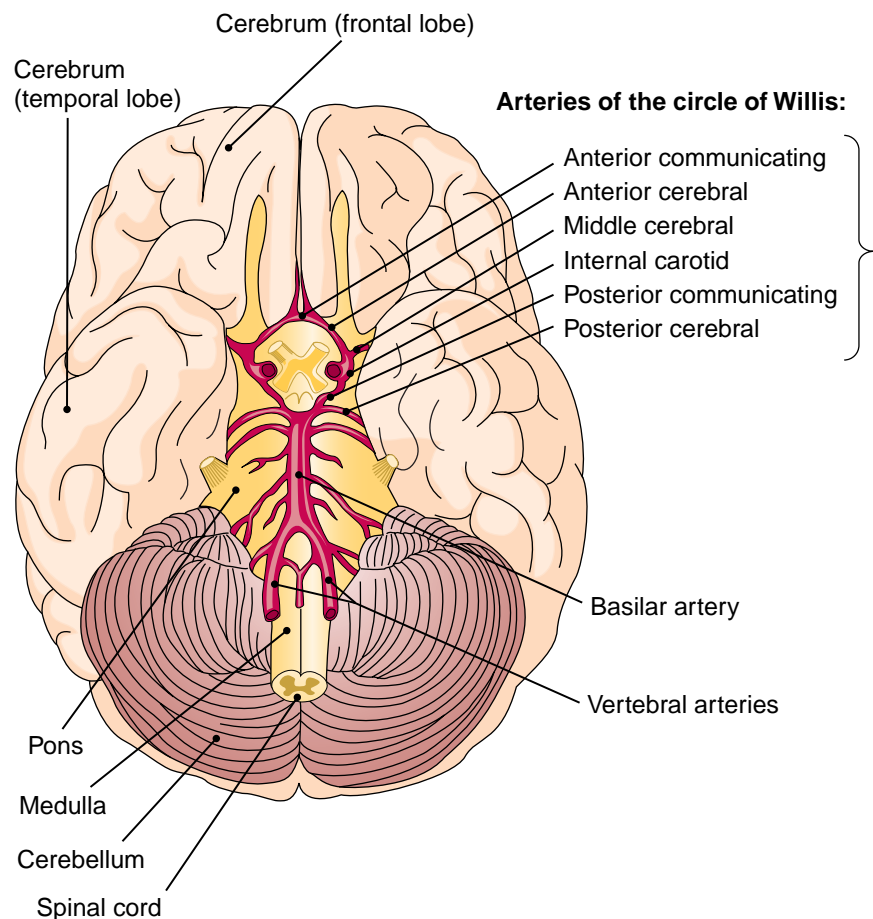


Figure 15-6 Arteries that supply the brain. The bracket at right groups the arteries that make up the circle of Willis.

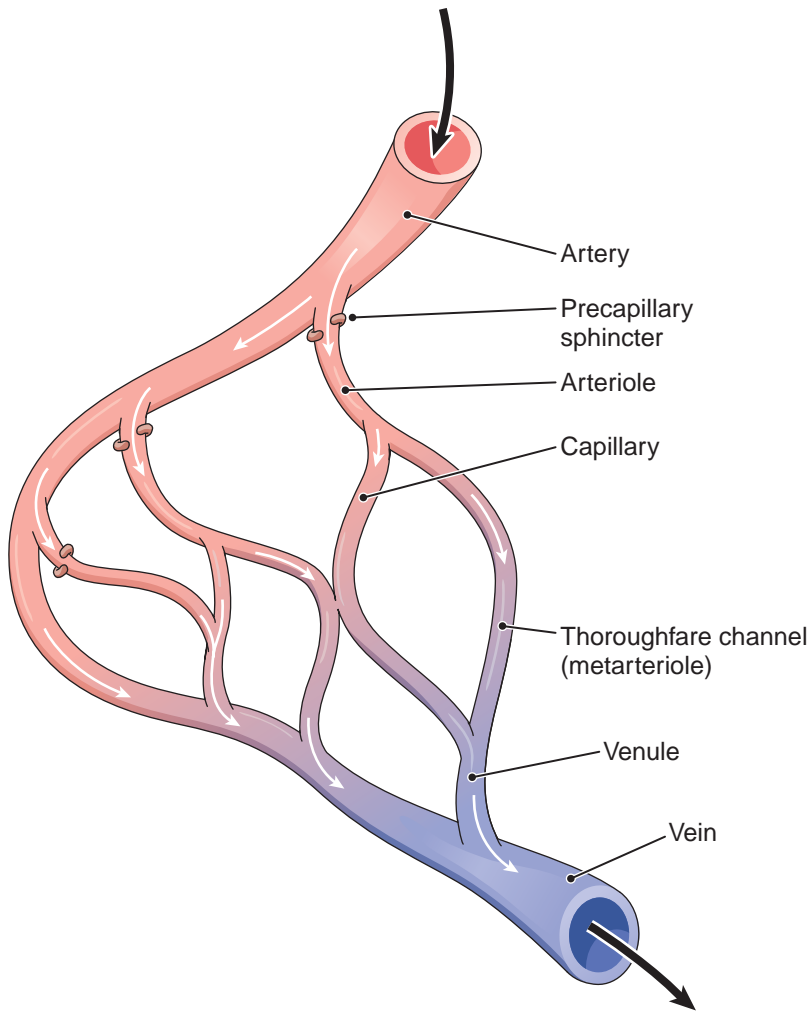


Figure 15-7 Capillary network showing an arteriovenous shunt (anastomosis). A connecting vessel, known as a thoroughfare channel or metarteriole, carries blood directly from an arteriole to a venule, bypassing the capillaries.

Checkpoint 15-8 What is an anastomosis?

Systemic Veins

Whereas most arteries are located in protected and rather deep areas of the body, many of the principal systemic veins are found near the surface (Fig. 15-8). The most important of the **superficial veins** are in the extremities, and include the following:

- The veins on the back of the hand and at the front of the elbow. Those at the elbow are often used for drawing blood for test purposes, as well as for intravenous injections. The largest of this group of veins are the **cephalic** (seh-FAL-ik), the **basilic** (bah-SIL-ik), and the **median cubital** (KU-bih-tal) veins.
- The **saphenous** (sah-FE-nus) veins of the lower extremities, which are the body's longest veins. The great saphenous vein begins in the foot and extends up the

medial side of the leg, the knee, and the thigh. It finally empties into the femoral vein near the groin.

The **deep veins** tend to parallel arteries and usually have the same names as the corresponding arteries. Examples of these include the **femoral** and the **external and internal iliac** vessels of the lower part of the body, and the **brachial, axillary, and subclavian** vessels of the upper extremities. Exceptions are found in the veins of the head and the neck. The two **jugular** (JUG-u-lar) veins on each side of the neck drain the areas supplied by the carotid arteries (*jugular* is from a Latin word meaning “neck”). The larger of the two veins, the **internal jugular**, receives blood from the large veins (cranial venous sinuses) that drain the head and also from regions of the face and neck. The smaller **external jugular** drains the areas supplied by the external carotid artery. Both veins empty directly into the subclavian vein on the left and the right. A **brachiocephalic vein** is formed on each side by the union of the subclavian and the jugular veins (see Fig. 15-8). (Remember, there is only *one* brachiocephalic artery.)

The Venae Cavae and Their Tributaries

Two large veins receive blood from the systemic vessels and empty directly into the heart's right atrium. The veins of the head, neck, upper extremities, and chest all drain into the **superior vena cava** (VE-nah KA-vah). This vessel is formed by the union of the right and left brachiocephalic veins, which drain the head, neck, and upper extremities. The unpaired **azygos** (AZ-ih-gos) vein drains the veins of the chest wall and empties into the superior vena cava just before the latter empties into the heart (see Fig. 15-8) (*azygos* is from a Greek word meaning “unpaired”).

The **inferior vena cava**, which is much longer than the superior vena cava, returns the blood from the parts of the body below the diaphragm. It begins in the lower abdomen with the union of the two common iliac veins. It then ascends along the posterior wall of the abdomen, through a groove in the posterior part of the liver, through the diaphragm, and finally through the lower thorax to empty into the right atrium of the heart.

Drainage into the inferior vena cava is more compli-

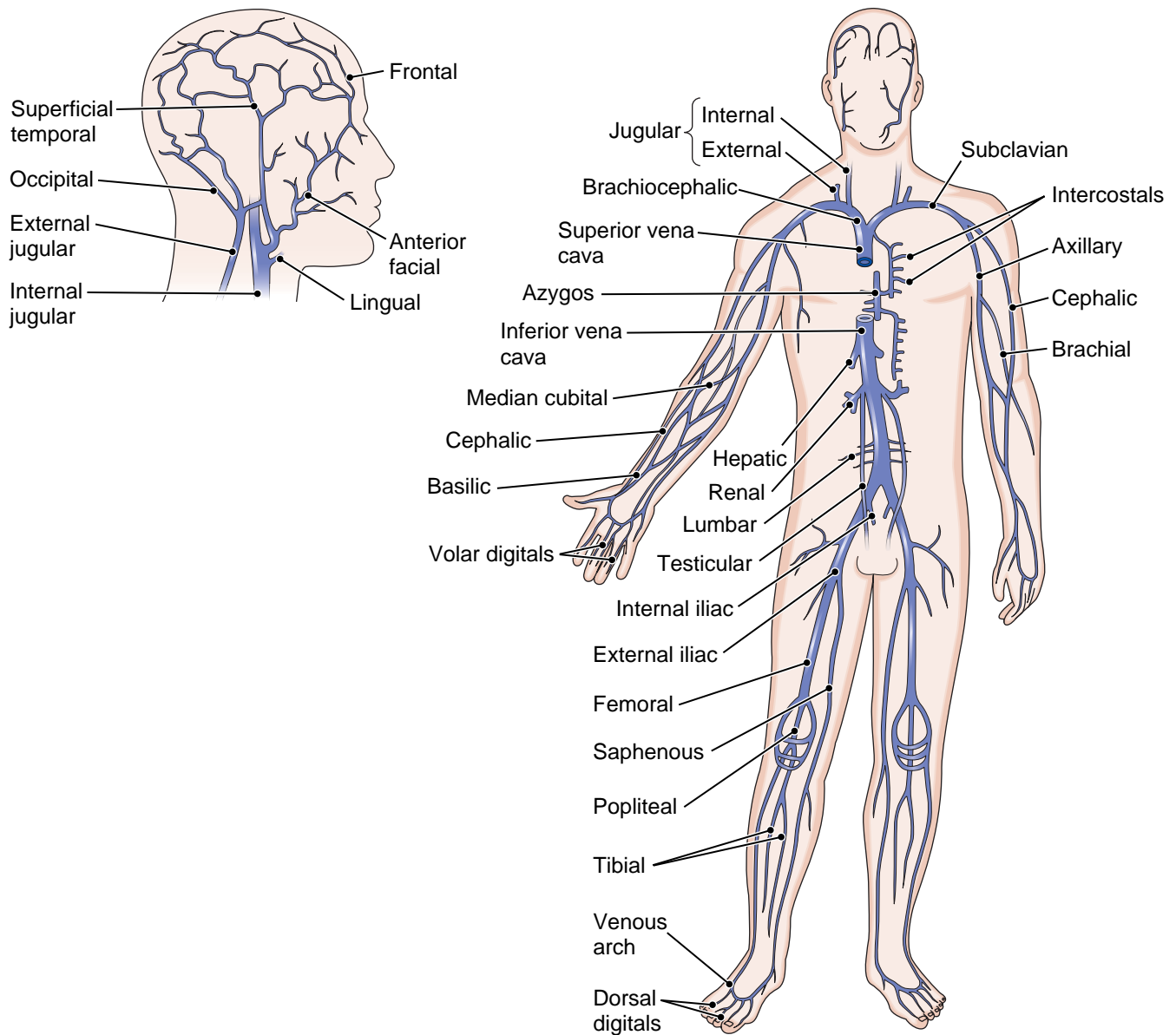


Figure 15-8 Principal systemic veins. *ZOOMING IN* ♦ How many brachiocephalic veins are there?

cated than drainage into the superior vena cava. The large veins below the diaphragm may be divided into two groups:

- The right and left veins that drain paired parts and organs. They include the **iliac** veins from near the groin, four pairs of **lumbar** veins from the dorsal part of the trunk and from the spinal cord, the **testicular** veins from the male testes and the **ovarian** veins from the female ovaries, the **renal** and **suprarenal** veins from the kidneys and adrenal glands near the kidneys, and finally the large **hepatic** veins from the liver. For the most part, these vessels empty directly into the inferior vena cava. The left testicular in the male and the left ovarian in the female empty into the left renal vein, which then takes this blood to the inferior vena cava;

these veins thus constitute exceptions to the rule that the paired veins empty directly into the vena cava.

- Unpaired veins that come from the spleen and parts of the digestive tract (stomach and intestine) empty into a vein called the **hepatic portal vein**. Unlike other lower veins, which empty into the inferior vena cava, the hepatic portal vein is part of a special system that enables blood to circulate through the liver before returning to the heart. This system, the hepatic portal system, will be described in more detail later.

Checkpoint 15-9 Veins are described as superficial or deep. What does superficial mean?

Checkpoint 15-10 What two large veins drain the systemic blood vessels and empty into the right atrium?

Venous Sinuses

The word *sinus* means “space” or “hollow.” A **venous sinus** is a large channel that drains deoxygenated blood, but does not have the usual tubular structure of the veins. One example of a venous sinus is the **coronary sinus**, which receives most of the blood from the heart wall (see Fig. 14-8 in Chapter 14). It lies between the left atrium and left ventricle on the posterior surface of the heart, and empties directly into the right atrium, along with the two venae cavae.

Other important venous sinuses are the **cranial venous sinuses**, which are located inside the skull and drain the veins from all over the brain (Fig. 15-9). The largest of the cranial venous sinuses are the following:

- ▶ The two **cavernous sinuses**, situated behind the eyeballs, drain the eyes’ **ophthalmic** (of-THAL-mik) veins. They give rise to the **petrosal** (peh-TRO-sal) sinuses, which drain into the jugular veins.
- ▶ The **superior sagittal** (SAJ-ih-tal) **sinus** is a single long space located in the midline above the brain and in the

fissure between the cerebrum’s two hemispheres. It ends in an enlargement called the **confluence** (KON-flu-ens) of sinuses.

- ▶ The two **transverse sinuses**, also called the **lateral sinuses**, are large spaces between the layers of the dura mater (the outermost membrane around the brain). They begin posteriorly from the confluence of sinuses and then extend laterally. As each sinus extends around the skull’s interior, it receives additional blood, including blood draining through the inferior sagittal sinus and straight sinus. Nearly all of the blood leaving the brain eventually empties into one of the transverse sinuses. Each sinus extends anteriorly to empty into an internal jugular vein, which then passes through a hole in the skull to continue downward in the neck.

Checkpoint 15-11 What is a venous sinus?

The Hepatic Portal System

Almost always, when blood leaves a capillary bed, it flows directly back to the heart. In a portal system, however, blood circulates through a second capillary bed, usually in a second organ, before it returns to the heart. A portal system is a kind of detour in the pathway of venous return that transports materials directly from one organ to another. Chapter 12 described the small local portal system that carries secretions from the hypothalamus to the pituitary gland. A much larger portal system is the **hepatic portal system**, which carries blood from the abdominal organs to the liver (Fig. 15-10).

The hepatic portal system includes the veins that drain blood from capillaries in the spleen, stomach, pancreas, and intestine. Instead of emptying their blood directly into the inferior vena cava, they deliver it through the hepatic portal vein to the liver. The portal vein’s largest tributary is the **superior mesenteric vein**, which drains blood from the proximal portion of the intestine. It is joined by the **splenic vein** just under the liver. Other tributaries of the portal circulation are the **gastric**, **pancreatic**, and **inferior mesenteric veins**. As it enters the liver, the portal vein divides and subdivides into ever smaller branches.

Eventually, the portal blood flows into a vast network of sinuslike vessels called **sinusoids** (SI-nus-oyds). These enlarged capillary channels allow liver

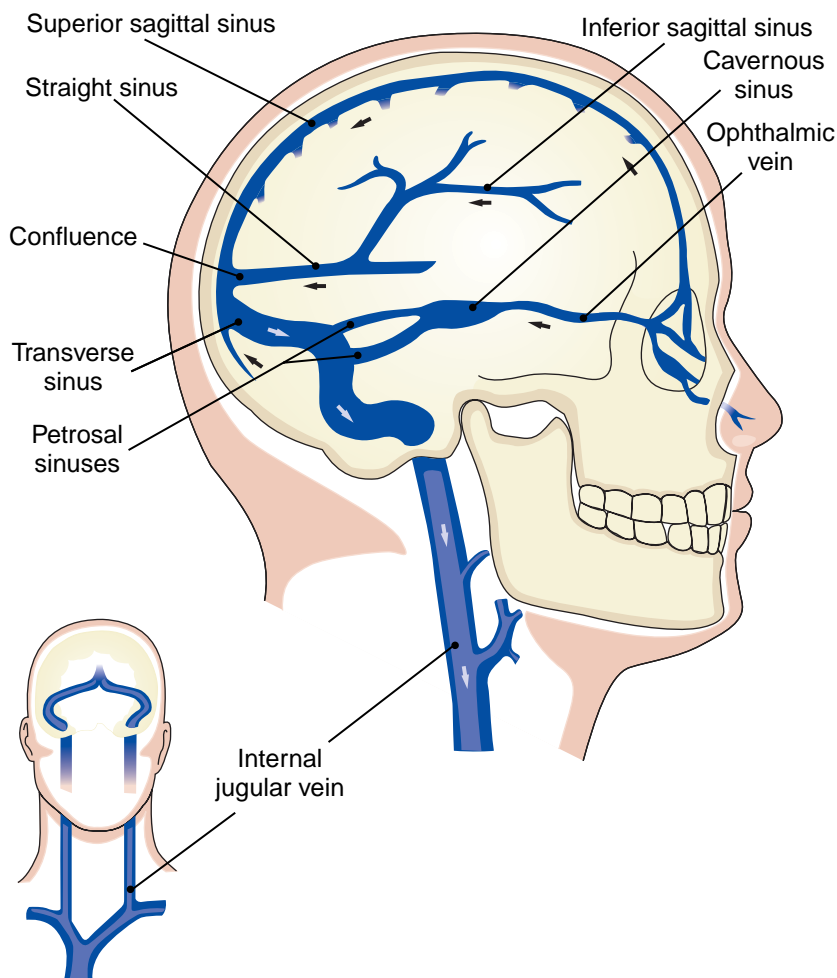


Figure 15-9 **Cranial venous sinuses.** The inset shows the paired transverse sinuses, which carry blood from the brain to the jugular veins.

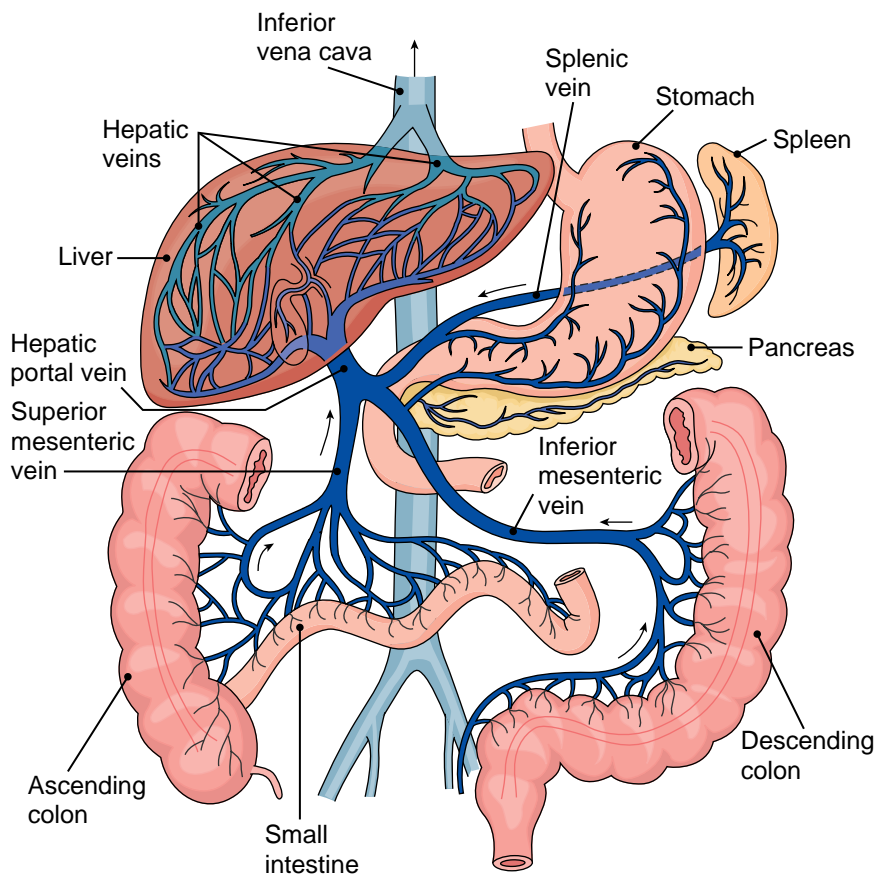


Figure 15-10 Hepatic portal system. Veins from the abdominal organs carry blood to the hepatic portal vein leading to the liver. Arrows show the direction of blood flow. **ZOOMING IN ♦** What vessel do the hepatic veins drain into?

cells close contact with the blood coming from the abdominal organs. (Similar blood channels are found in the spleen and endocrine glands, including the thyroid and adrenals.) After leaving the sinusoids, blood is finally collected by the hepatic veins, which empty into the inferior vena cava.

The purpose of the hepatic portal system is to transport blood from the digestive organs and the spleen to the liver sinusoids, so that the liver cells can carry out their functions. For example, when food is digested, most of the end products are absorbed from the small intestine into the bloodstream and transported to the liver by the portal system. In the liver, these nutrients are processed, stored, and released as needed into the general circulation.

Checkpoint 15-12 The hepatic portal system takes blood from the abdominal organs to what organ?

► The Physiology of Circulation

Circulating blood might be compared to a train that travels around the country, picking up and delivering passengers at each stop on its route. For example, as blood flows

through capillaries surrounding the air sacs in the lungs, it picks up oxygen and unloads carbon dioxide. Later, when this oxygenated blood is pumped to capillaries in other parts of the body, it unloads the oxygen and picks up carbon dioxide and other substances generated by the cells (Fig. 15-11). The microscopic capillaries are of fundamental importance in these activities. It is only through and between the cells of these thin-walled vessels that the necessary exchanges can occur.

All living cells are immersed in a slightly salty liquid called **tissue fluid**, or **interstitial fluid**. Looking again at Figure 15-11, one can see how this fluid serves as “middleman” between the capillary membrane and the neighboring cells. As water, oxygen, and other necessary cellular materials pass through the capillary walls, they enter the tissue fluid. Then, these substances make their way by diffusion to the cells. At the same time, carbon dioxide and other end products of metabolism leave the cells and move in the opposite direction. These substances enter the capillaries and are carried away in the bloodstream for processing in other organs or elimination from the body.

Capillary Exchange

Diffusion is the main process by which substances move between the cells and the capillary blood. Recall that diffusion is the movement of a substance from an area where it is in higher concentration to an area where it is in lower concentration. Diffusion does not require transporters or cellular energy.

An additional force that moves materials from the blood into the tissues is the pressure of the blood as it flows through the capillaries. Blood pressure is the force that filters, or “pushes” water and dissolved materials out of the capillary into the tissue fluid. Fluid is drawn back into the capillary by osmotic pressure, the “pulling force” of substances dissolved and suspended in the blood. Osmotic pressure is maintained by plasma proteins (mainly albumin), which are too large to go through the capillary wall. These processes result in the constant exchange of fluids across the capillary wall.

The movement of blood through the capillaries is relatively slow, owing to the much larger cross-sectional area of the capillaries compared with that of the vessels from which they branch. This slow progress through the capillaries allows time for exchanges to occur.

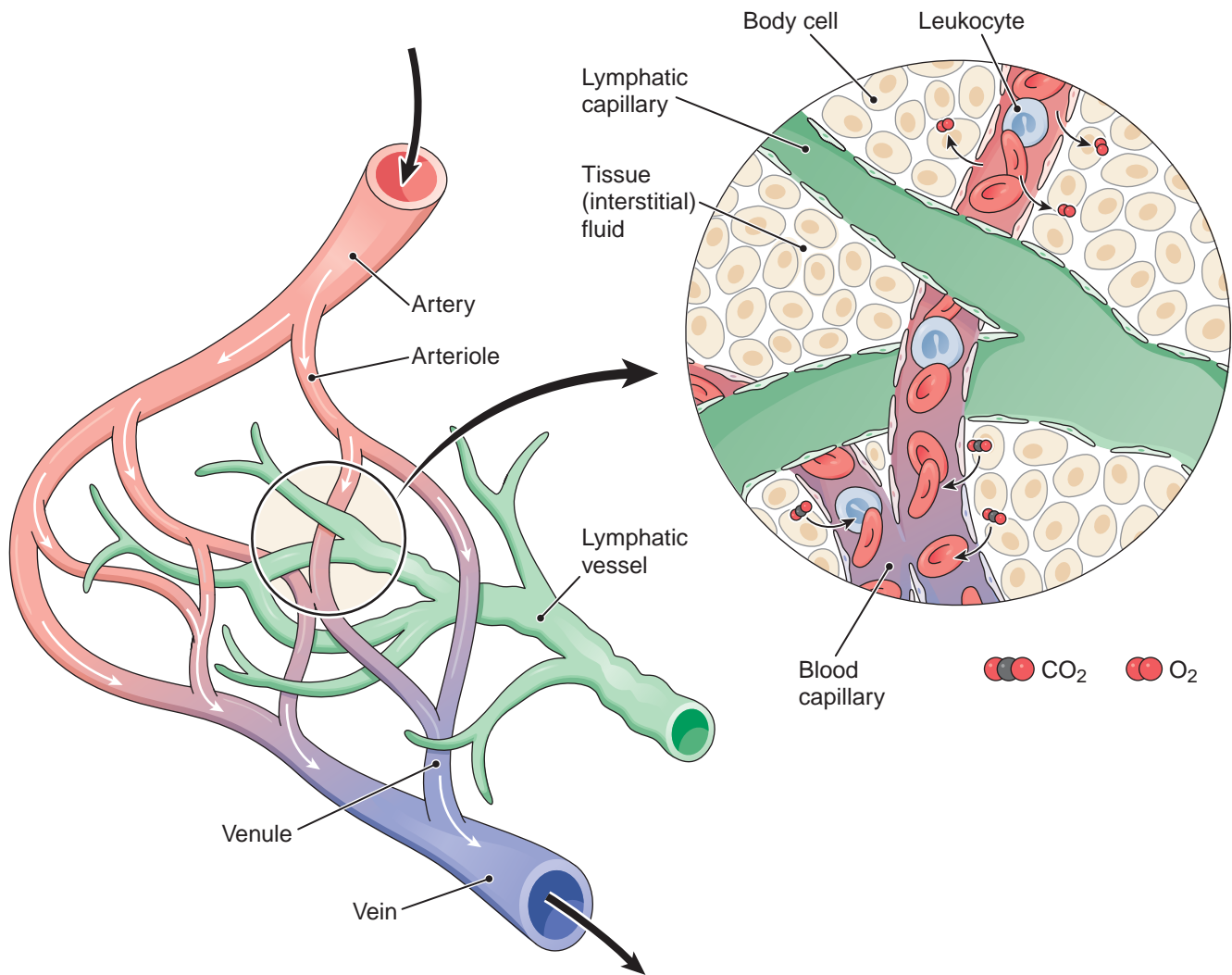


Figure 15-11 Connection between small blood vessels through capillaries. The blood delivers oxygen (O_2) to the tissues and picks up carbon dioxide (CO_2) for transport to the lungs. Note the lymphatic capillaries, which aid in tissue drainage.

Note that even when the capillary exchange process is most efficient, some water is left behind in the tissues. Also, some proteins escape from the capillaries into the tissues. The lymphatic system, discussed in Chapter 16, collects this extra fluid and protein and returns them to the circulation (see Fig. 15-11).

Checkpoint 15-13 As materials diffuse back and forth between the blood and tissue fluid across the capillary wall, what force helps to push materials out of the capillary? What force helps to draw materials into the capillary?

The Dynamics of Blood Flow

Blood flow is carefully regulated to supply tissue needs without unnecessary burden on the heart. Some organs, such as the brain, liver, and kidneys, require large quantities of blood even at rest. The requirements of some tissues, such as the skeletal muscles and digestive organs,

increase greatly during periods of activity. For example, the blood flow in muscle can increase 25 times during exercise. The volume of blood flowing to a particular organ can be regulated by changing the size of the blood vessels supplying that organ.

An increase in a blood vessel's diameter is called **vasodilation**. This change allows for the delivery of more blood to an area. **Vasoconstriction** is a decrease in a blood vessel's diameter, causing a decrease in blood flow. These *vasomotor activities* result from the contraction or relaxation of smooth muscle in the walls of the blood vessels, mainly the arterioles. A **vasomotor center** in the medulla of the brain stem regulates vasomotor activities, sending its messages through the autonomic nervous system.

Blood flow into an individual capillary is regulated by a **precapillary sphincter** of smooth muscle that encircles the entrance to the capillary (see Fig. 15-7). This sphincter widens to allow more blood to enter when tissues need more oxygen.

Checkpoint 15-14 Name the two types of vasomotor changes.

Checkpoint 15-15 Where are vasomotor activities regulated?

Return of Blood to the Heart Blood leaving the capillary networks returns in the venous system to the heart, and even picks up some speed along the way, despite factors that work against its return. Blood flows in a closed system and must continually move forward as the heart contracts. However, by the time blood arrives in the veins, little force remains from the heart's pumping action. Also, because the veins expand easily under pressure, blood tends to pool in the veins. Considerable amounts of blood are normally stored in these vessels. Finally, the force of gravity works against upward flow from regions below the heart. Several mechanisms help to overcome these forces and promote blood's return to the heart in the venous system. These are:

- **Contraction of skeletal muscles.** As skeletal muscles contract, they compress the veins and squeeze blood forward (Fig. 15-12).
- **Valves in the veins** prevent back flow and keep blood flowing toward the heart.
- **Breathing.** Pressure changes in the abdominal and thoracic cavities during breathing also promote blood return in the venous system. During inhalation, the di-

aphragm flattens and puts pressure on the large abdominal veins. At the same time, chest expansion causes pressure to drop in the thorax. Together, these actions serve to both push and pull blood through these cavities and return it to the heart.

As evidence of these effects, if a person stands completely motionless, especially on a hot day when the superficial vessels dilate, enough blood can accumulate in the lower extremities to cause fainting from insufficient oxygen to the brain.

The Pulse

The ventricles regularly pump blood into the arteries about 70 to 80 times a minute. The force of ventricular contraction starts a wave of increased pressure that begins at the heart and travels along the arteries. This wave, called the **pulse**, can be felt in any artery that is relatively close to the surface, particularly if the vessel can be pressed down against a bone. At the wrist, the radial artery passes over the bone on the forearm's thumb side, and the pulse is most commonly obtained here. Other vessels sometimes used for taking the pulse are the carotid artery in the neck and the dorsalis pedis on the top of the foot.

Normally, the pulse rate is the same as the heart rate, but if a heartbeat is abnormally weak, or if the artery is

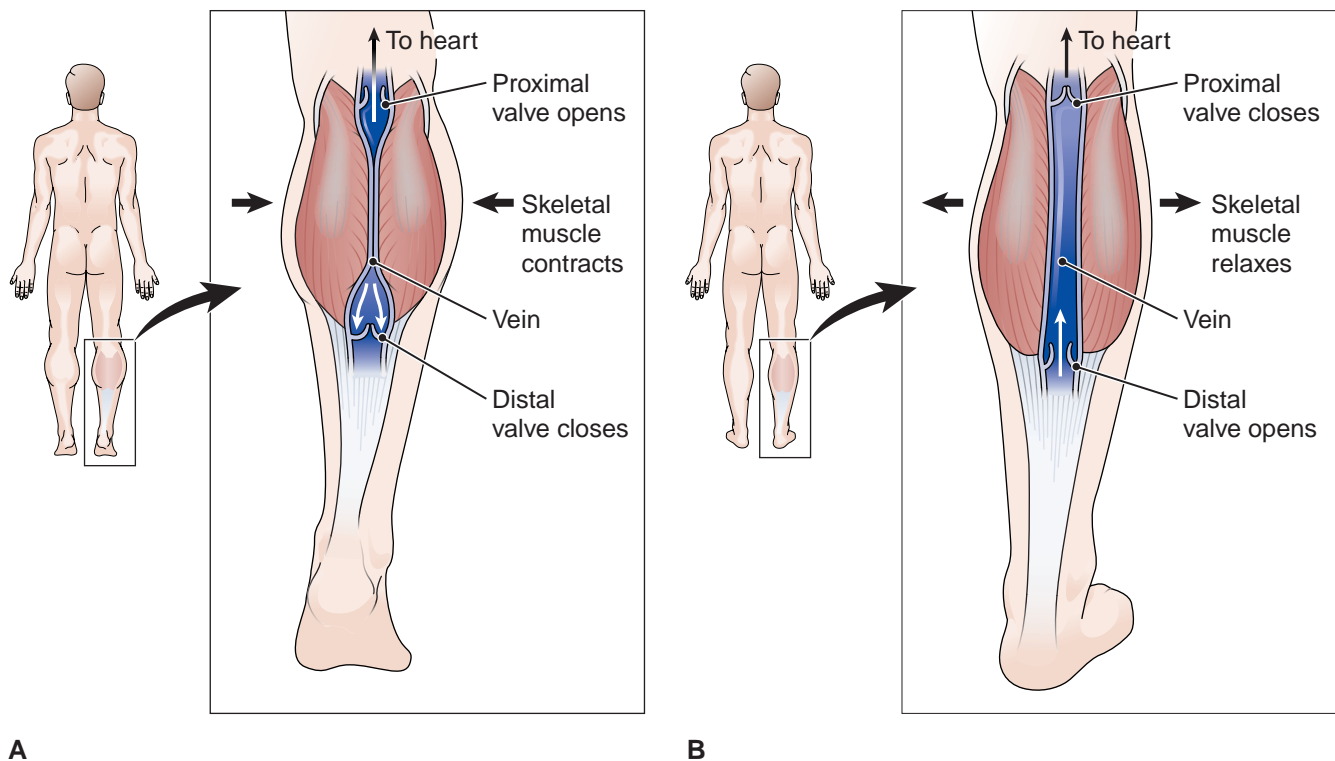


Figure 15-12 Role of skeletal muscles and valves in blood return. (A) Contracting skeletal muscle compresses the vein and drives blood forward, opening the proximal valve, while the distal valve closes to prevent backflow of blood. (B) When the muscle relaxes again, the distal valve opens, and the proximal valve closes until blood moving in the vein forces it open again. **ZOOMING IN** ♦ Which of the two valves shown is closer to the heart?

obstructed, the beat may not be detected as a pulse. In checking another person's pulse, it is important to use your second or third finger. If you use your thumb, you may find that you are getting your own pulse. When taking a pulse, it is important to gauge the strength as well as the regularity and rate.

Pulse Rate Various factors may influence the pulse rate. We describe just a few here:

- The pulse is somewhat faster in small people than in large people and usually is slightly faster in women than in men.
- In a newborn infant, the rate may be from 120 to 140 beats/minute. As the child grows, the rate tends to become slower.
- Muscular activity influences the pulse rate. During sleep, the pulse may slow down to 60 beats/minute, whereas during strenuous exercise, the rate may go up to well over 100 beats/minute. For a person in good condition, the pulse does not go up as rapidly as it does in an inactive person, and it returns to a resting rate more quickly after exercise.
- Emotional disturbances may increase the pulse rate.
- In many infections, the pulse rate increases with the increase in temperature.
- An excessive amount of secretion from the thyroid gland may cause a rapid pulse.

Checkpoint 15-16 What is the definition of *pulse*?

Blood Pressure

Blood pressure is the force exerted by the blood against the walls of the vessels. Blood pressure is determined by the heart's output and resistance to blood flow in the vessels. If either of these factors changes and there are no compensating changes, blood pressure will change (Fig. 15-13).

Cardiac Output As described in Chapter 14, the output of the heart, or cardiac output (CO) is the volume of

blood pumped out of each ventricle in one minute. Cardiac output is the product of two factors:

- **Heart rate**, the number of times the heart beats each minute. The basic heart rate is set internally by the SA node, but can be influenced by the autonomic nervous system, hormones, and other substances circulating in the blood, such as ions.
- **Stroke volume**, the volume of blood ejected from the ventricle with each beat. The sympathetic nervous system can stimulate more forceful heart contractions to increase ejection of blood. Also, if more blood returns to the heart in the venous system, stretching of the heart muscle will promote more forceful contractions.

Resistance to Blood Flow Resistance is opposition to blood flow owing to friction generated as blood slides along the vessel walls. Because the effects of resistance are seen mostly in small arteries and arterioles that are at a distance from the heart and large vessels, this factor is often described as *peripheral resistance*. Resistance in the vessels is affected by the following factors:

- **Vasomotor changes.** A narrow vessel offers more resistance to blood flow than a wider vessel, just as it is harder to draw fluid through a narrow straw than through a wide straw. Thus, vasoconstriction increases resistance to flow and vasodilation lowers resistance.
- **Elasticity of blood vessels.** Arteries normally expand to receive blood and then return to their original size. If vessels lose elasticity, as by atherosclerosis, they offer more resistance to blood flow. You've probably experienced this phenomenon if you've tried to blow up a firm, new balloon. More pressure is generated as you blow, and the balloon is a lot harder to inflate than a soft balloon, which expands easily under pressure. Blood vessels lose elasticity with aging, thus increasing resistance and blood pressure.
- **Viscosity, or thickness of the blood.** Just as a milkshake is harder to suck through a straw than milk is, increased blood viscosity will increase blood pressure. Increased numbers of red blood cells, as in polycythemia, or a loss of plasma volume, as by dehydration, will increase blood viscosity. The hematocrit test described in Chapter 13 is one measure of blood viscosity; it measures the relative percentage of packed cells in whole blood.
- **Total blood volume,** the total amount of blood that is in the vascular system at a given time. A loss of blood volume, as by hemorrhage, will lower blood pressure. An increase in blood volume will generate more pressure within the vessels. It will also increase cardiac output by increasing venous return of blood to the heart.

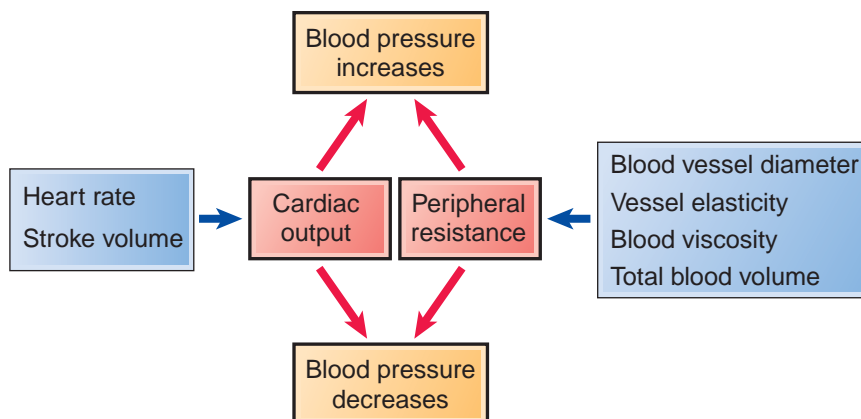


Figure 15-13 Factors that influence blood pressure.

To summarize, all of these relationships are expressed together by the following equation:

Blood pressure = cardiac output x peripheral resistance

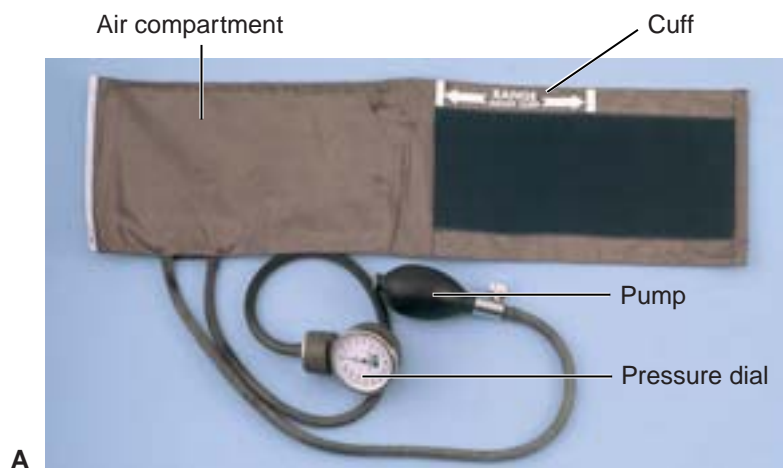
Measurement of Blood Pressure The measurement and careful interpretation of blood pressure may prove a valuable guide in the care and evaluation of a person's health. Because blood pressure decreases as the blood flows from arteries into capillaries and finally into veins, healthcare providers ordinarily measure arterial pressure only, most commonly in the brachial artery of the arm. They use an instrument called a **sphygmomanometer** (sfig-mo-mah-NOM-eh-ter) (Fig. 15-14), or more simply, a blood pressure cuff or blood pressure apparatus. They measure two variables:

- ▶ **Systolic pressure**, which occurs during heart muscle contraction, averages about 120 and is expressed in millimeters of mercury (mmHg).

- ▶ **Diastolic pressure**, which occurs during relaxation of the heart muscle, averages about 80 mmHg.

The sphygmomanometer is an inflatable cuff attached to a device for reading pressure. The examiner wraps the cuff around the patient's upper arm and inflates it with air until the brachial artery is compressed and the blood flow is cut off. Then, listening with a stethoscope, he or she slowly lets air out of the cuff until the first pulsations are heard. At this point, the pressure in the cuff is equal to the systolic pressure, and this pressure is read. Then, more air is let out until a characteristic muffled sound indicates the point where the vessel is open and the diastolic pressure is read. Sphygmomanometers originally displayed pressure readings on a graduated column of mercury, but alternate types display the readings on a dial, or measure blood pressure electronically and give a digital reading. Blood pressure is reported as systolic pressure first, then diastolic pressure, separated by a slash, such as 120/80 mmHg.

Considerable experience is required to ensure an accurate blood pressure reading. Often it is necessary to repeat measurements. Note also that blood pressure varies throughout the day and under different conditions, so a single reading does not give a complete picture. Some people typically have a higher reading in a doctor's office because of stress, or "white coat hypertension." They may need to take their blood pressure at home while relaxed to get a true reading. Box 15-2 explains how cardiac catheterization is used to measure blood pressure with high accuracy.



A



B

Figure 15-14 Measurement of blood pressure. (A) A sphygmomanometer, or blood pressure cuff. (B) Once the cuff is inflated, the examiner releases the pressure and listens for sounds in the vessels with a stethoscope. (A, Reprinted with permission from Bickley LS. *Bates' Guide to Physical Examination and History Taking*. 8th ed. Philadelphia: Lippincott Williams & Wilkins, 2003; B, reprinted with permission from Taylor C, Lillis C, LeMone P. *Fundamentals of Nursing*. 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

Checkpoint 15-17 What is the definition of blood pressure?

Checkpoint 15-18 What two components of blood pressure are measured?

Abnormal Blood Pressure Lower-than-normal blood pressure is called **hypotension** (hi-po-TEN-shun). Because of individual variations in normal pressure levels, however, what would be a low pressure for one person might be normal for someone else. For this reason, hypotension is best evaluated in terms of how well the body tissues are being supplied with blood. A person whose systolic blood pressure drops to below his or her normal range may experience fainting episodes because of inadequate blood flow to the brain. The sudden lowering of blood pressure to below a person's normal level is one

Box 15-2 Clinical Perspectives

Cardiac Catheterization: Measuring Blood Pressure From Within

Because arterial blood pressure decreases as blood flows further away from the heart, measurement of blood pressure with a simple inflatable cuff around the arm is only a reflection of the pressure in the heart and pulmonary arteries. Precise measurement of pressure in these parts of the cardiovascular system is useful in diagnosing certain cardiac and pulmonary disorders.

More accurate readings can be obtained using a catheter (thin tube) inserted directly into the heart and large vessels. One type commonly used is the pulmonary artery catheter (also known as the Swan-Ganz catheter), which has an inflatable balloon at the tip. This device is threaded into the right side of the heart through a large vein. Typically, the right internal jugular vein is used because it is the shortest

and most direct route to the heart, but the subclavian and femoral veins may be used instead. The catheter's position in the heart is confirmed by a chest X-ray and, when appropriately positioned, the atrial and ventricular blood pressures are recorded. As the catheter continues into the pulmonary artery, pressure in this vessel can be read. When the balloon is inflated, the catheter becomes wedged in a branch of the pulmonary artery, blocking blood flow. The reading obtained is called the **pulmonary capillary wedge (PCW) pressure**. It gives information on pressure in the heart's left side and on resistance in the lungs. Combined with other tests, cardiac catheterization can be used to diagnose cardiac and pulmonary disorders such as shock, pericarditis, congenital heart disease, and heart failure.

symptom of shock; it may also occur in certain chronic diseases and in heart block.

Hypertension (hi-per-TEN-shun), or high blood pressure, has received a great deal of attention in medicine. Hypertension normally occurs temporarily as a result of excitement or exertion. However, it may persist in a number of conditions, including the following:

- ▶ Kidney disease and uremia (excess nitrogenous waste in the blood) or other toxic conditions
- ▶ Endocrine disorders, such as hyperthyroidism and acromegaly
- ▶ Arterial disease, including hardening of the arteries (atherosclerosis), which reduces elasticity of the vessels
- ▶ Tumors of the adrenal gland's central portion (medulla) with the release of excess epinephrine

Hypertension that has no apparent medical cause is called **essential hypertension**. Excess of an enzyme called **renin** (RE-nin), produced in the kidney, appears to play a role in the severity of this kind of hypertension. Renin raises blood pressure by causing blood vessels to constrict and by promoting the kidney's retention of salt and water.

It is important to treat even mild hypertension because this condition can eventually:

- ▶ Weaken vessels and lead to saclike bulges (aneurysms) in vessel walls that are likely to rupture. In the brain, vessel rupture is one cause of stroke. Rupture of a vessel in the eye may lead to blindness.
- ▶ Stress the heart by causing it to work harder to pump blood into the arte-

rial system. In response to this greater effort, the heart enlarges, but eventually it weakens and becomes less efficient.

- ▶ Stress the kidneys and damage vessels in the kidneys.
- ▶ Damage the lining of vessels, predisposing to atherosclerosis

Although medical caregivers often place emphasis on the systolic blood pressure, in many cases, the diastolic pressure is even more important. The total fluid volume in the vascular system and the condition of small arteries may have a greater effect on diastolic pressure. **Table 15-1** lists degrees of hypertension as compared with normal blood pressure values.

Treatment of Hypertension Even though there is much individual variation in blood pressure, guidelines have been established for the diagnosis and treatment of hypertension. The first stage of hypertension begins at 140/90 mmHg. Treatment at this point should be based on diet, exercise, and weight loss, if necessary. Drug ther-

Table 15•1 Blood Pressure

BLOOD PRESSURE CLASSIFICATION (ADULTS)*		
CATEGORY	SYSTOLIC (mmHg)	DIASTOLIC (mmHg)
Optimal	<120	<80
Normal	<130	<85
High normal	130–139	85–89
Hypertension		
Stage 1 (mild)	140–159	90–99
Stage 2 (moderate)	160–179	100–109
Stage 3 (severe)	≥180	≥110

*When the systolic and diastolic pressures are in different categories, the higher category is used.

apy should be added to this regimen for people with pressure readings above 159/99 mmHg. Drugs used to treat hypertension include the following:

- ▶ Diuretics, which promote water loss
- ▶ Drugs that limit production of renin
- ▶ Drugs that relax blood vessels

Checkpoint 15-19 What is meant by *hypertension* and *hypotension*?

▶ Arterial Degeneration and Other Blood Vessels Disorders

As a result of age or other degenerative changes, materials may be deposited within the arterial walls. These deposits cause an irregular thickening of the wall at the expense of the lumen (space inside the vessel), as well as a loss of elasticity. In some cases, calcium salts and scar tissue may cause this hardening of the arteries, technically called **arteriosclerosis** (ar-te-re-o-skle-RO-sis). The most common form of this disorder is **atherosclerosis** (ath-er-o-skle-RO-sis) (Fig. 15-15), in which areas of yellow, fatlike material, called **plaque** (PLAK), accumulate in the vessels and separate the muscle and elastic connective tissue. Sometimes, the arterial lining is also damaged, leading to possible blood clot (thrombus) formation. The thrombus may partially or completely obstruct the vessel, as it sometimes does in coronary thrombosis. Box 15-3 provides information on how to prevent atherosclerosis.

A diet high in fats, particularly saturated fats, is known to contribute to atherosclerosis. Cigarette smoking also increases the extent and severity of this disorder. Arterial damage may be present for years without causing any noticeable symptoms. As the thickening of the wall continues and the lumen's diameter decreases, limiting

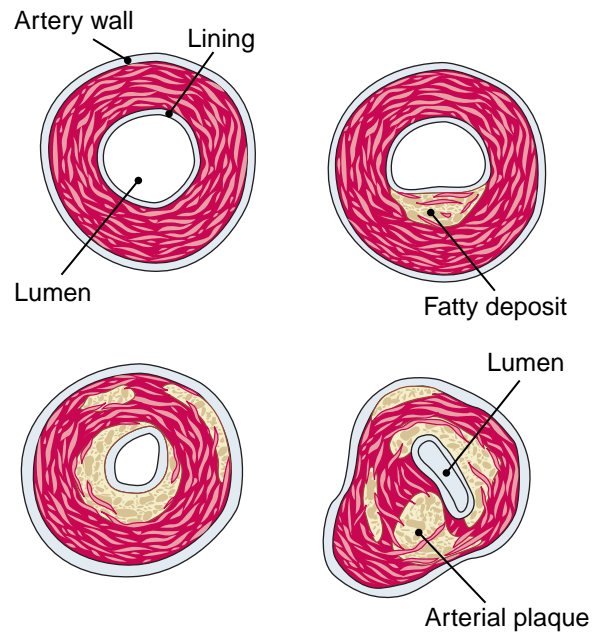


Figure 15-15 Stages in atherosclerosis.

blood flow, a variety of symptoms can appear. The nature of these disturbances varies with the parts of the body affected and with the extent of the arterial changes. Some examples are as follows:

- ▶ Leg cramps, pain, and sudden lameness while walking may be caused by insufficient blood supply to the lower extremities resulting from arterial damage.
- ▶ Headaches, dizziness, and mental disorders may be the result of cerebral artery sclerosis.
- ▶ Hypertension may result from a decrease in lumen size within many arteries throughout the body. Although hypertension may be present in young people with no

Box 15-3 • Health Maintenance

Preventing Atherosclerosis: Keeping Your Arteries Clean

Atherosclerosis and its complications (heart disease, stroke, and thrombosis) account for forty percent of all deaths in the United States! Atherosclerosis begins with microscopic damage to the endothelium of the arteries caused by direct contact with LDL (the “bad” cholesterol), oxidizing chemicals, such as free-radicals, and some proteins. Lipids begin to accumulate in the arterial wall, followed by aggregation of platelets and macrophages, and the formation of plaque. The arterial wall soon bulges into the lumen and obstructs blood flow. Arteries in the heart, brain, kidneys, and the extremities seem to be especially vulnerable to this process.

Certain risk factors associated with atherosclerosis, like age, gender, and genetic makeup cannot be changed, but others, like diet and lifestyle, can be controlled. To help slow this degenerative process, you should:

- ▶ Maintain a healthy weight and get plenty of exercise
- ▶ Limit intake of saturated fats, found mainly in foods from animal sources
- ▶ Eat adequate amounts of soluble fibers, such as oat bran and fruit fibers, which have been shown to decrease cholesterol levels in the blood
- ▶ Take in adequate amounts of vitamin E, vitamin C, folic acid, and calcium; each has been shown to have beneficial effects on the heart
- ▶ Consider adding vitamins B6 and B12 to your diet; both are thought to help the heart by lowering levels of an enzyme considered harmful
- ▶ Do not smoke
- ▶ Find ways to reduce stress

apparent arterial damage, and atherosclerosis may be present without causing hypertension, the two are often found together in elderly people.

- ▶ Palpitations, dyspnea (difficulty in breathing), paleness, weakness, and other symptoms may be the result of coronary artery arteriosclerosis. The severe pain of angina pectoris may follow the lack of oxygen and the myocardial damage associated with sclerosis of the vessels that supply the heart.
- ▶ An increase in the amount of urine with the appearance of albumin. Albumin is a normal plasma protein usually found in the urine only if there is kidney damage. Other symptoms referable to the kidneys may be caused by renal artery damage.
- ▶ Ulceration and tissue necrosis (death) as a result of ischemia (lack of blood supply), especially in the extremities. If the dead tissue is invaded by bacteria, the result is **gangrene** (GANG-grene). The arterial damage that is caused by diabetes, for example, often leads to gangrene in the extremities of elderly diabetic patients.

Treatment for Arterial Degeneration Balloon catheterization and bypass grafts used to treat arterial disease were discussed with reference to the heart in Chapter 14. Stents, small tubes inserted to keep vessels open, also discussed in relation to the heart, are used for other vessels as well. An additional treatment approach is **endarterectomy** (end-ar-ter-EK-to-me), removal of the thickened, atheromatous lining of a vessel. Common sites for this procedure are the carotid artery or vertebral artery leading to the brain and the common iliac or femoral arteries leading to the lower limbs. Surgeons can remove a blockage by direct incision of a vessel. More commonly, they use a cutting tool inserted with a catheter through the vessel opening to remove plaque.

Aneurysm An **aneurysm** (AN-u-rizm) is a bulging sac in the wall of a blood vessel caused by a localized weakness in that part of the vessel (Fig. 15-16). The aorta and vessels in the brain are common aneurysm sites. The damage to the wall may be congenital or a result of hardening of the arteries. Whatever the cause, the aneurysm may continue to grow in size. As it swells, it may cause some derangement of other structures, in which case definite symptoms are present. If undiagnosed, the walls of the weakened area eventually yield to the pressure, and the aneurysm bursts like a balloon, usually causing death. Surgical replacement of the damaged segment with a synthetic graft may be lifesaving.

Hemorrhage

A profuse escape of blood from the vessels is known as **hemorrhage** (HEM-or-ij), a word that means “a bursting forth of blood.” Such bleeding may be external or internal, from vessels of any size, and may involve any part of the body. Capillary oozing usually is stopped by the normal process of clot formation.

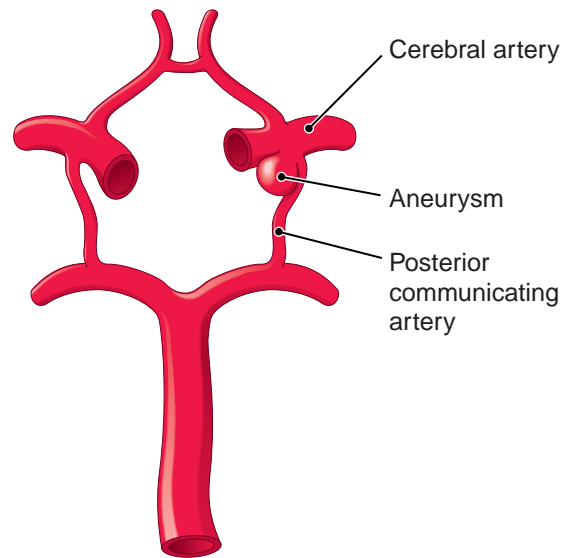


Figure 15-16 A cerebral aneurysm in the circle of Willis. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

First Aid for Hemorrhage The loss of a small amount of blood will cause no problem for a healthy adult, but loss of one liter or more of blood is life-threatening. The first step to control bleeding is the application of direct pressure to the wound using a clean cloth. An assisting person should wear gloves to protect from blood-borne diseases. A bleeding extremity should be elevated above the level of the heart. In cases of severe, persistent bleeding, application of pressure where a local artery can be pressed against a bone slows the bleeding. The most important of these “pressure points” are the following:

- ▶ The **facial artery**, which may be pressed against the lower jaw for hemorrhage around the nose, mouth, and cheek. One can feel the pulse of the facial artery in the depression about 1 inch anterior to the angle of the lower jaw.
- ▶ The **temporal artery**, which may be pressed against the side of the skull just anterior to the ear to stop hemorrhage on the side of the face and around the ear
- ▶ The **common carotid artery** in the neck, which may be pressed back against the spinal column for bleeding in the neck and the head. Avoid prolonged compression, which can result in lack of oxygen to the brain.
- ▶ The **subclavian artery**, which may be pressed against the first rib by a downward push with the thumb to stop bleeding from the shoulder or arm
- ▶ The **brachial artery**, which may be pressed against the humerus (arm bone) by a push inward along the natural groove between the two large muscles of the arm. This stops hand, wrist, and forearm hemorrhage.
- ▶ The **femoral artery** (in the groin), which may be pressed to avoid serious hemorrhage of the lower extremity.

It is important not to leave the pressure on too long, as this may cause damage to tissues supplied by arteries past the pressure point.

Shock

The word **shock** has a number of meanings. In terms of the circulating blood, it refers to a life-threatening condition in which there is inadequate blood flow to the body tissues. A wide range of conditions that reduce effective circulation can cause shock. The exact cause is often not known. However, a widely used classification is based on causative factors, the most important of which include the following:

- ▶ **Cardiogenic** (kar-de-o-JEN-ik) **shock**, sometimes called pump failure, is often a complication of heart muscle damage, as occurs in myocardial infarction. It is the leading cause of shock death.
- ▶ **Septic shock** is second only to cardiogenic shock as a cause of shock death. It is usually the result of an overwhelming bacterial infection.
- ▶ **Hypovolemic** (hi-po-vo-LE-mik) **shock** is caused by a decrease in the volume of circulating blood and may follow severe hemorrhage or burns.
- ▶ **Anaphylactic** (an-ah-fih-LAK-tik) **shock** is a severe allergic reaction to foreign substances to which the person has been sensitized (see Chapter 17 on Immunity).

When the cause is not known, shock is classified according to its severity.

In **mild shock**, regulatory mechanisms relieve the circulatory deficit. Symptoms are often subtle changes in heart rate and blood pressure. Constriction of small blood vessels and the detouring of blood away from certain organs increase the effective circulation. Mild shock may develop into a severe, life-threatening circulatory failure.

Severe shock is characterized by poor circulation, which causes further damage and deepening of the shock. Symptoms of late shock include clammy skin, anxiety, low blood pressure, rapid pulse, and rapid, shallow breathing. Heart contractions are weakened, owing to the decrease in the heart's blood supply. The blood vessel walls also are weakened, so that the vessels dilate. The capillaries become more permeable and lose fluid, owing to the accumulation of metabolic wastes.

The victim of shock should first be placed in a horizontal position and covered with a blanket. If there is bleeding, it should be stopped. The patient's head should be kept turned to the side to prevent aspiration (breathing in) of vomited material, an important cause of death in shock cases. Further treatment of shock depends largely on treatment of the causative factors. For example, shock resulting from fluid loss, as in hemorrhage or burns, is best treated with blood products or plasma expanders (intravenous fluids). Shock caused by heart failure should be treated with drugs that improve heart muscle contractions. In any case, all measures are aimed at

supporting the circulation and improving the output of the heart. Oxygen is frequently administered to improve oxygen delivery to the tissues.

Checkpoint 15-20 With regard to the circulation, what is meant by shock?

Thrombosis

Formation of a blood clot in a vessel is **thrombosis** (throm-BO-sis). A blood clot in a vein, termed *deep venous thrombosis* (DVT), most commonly develops in the deep veins of the calf muscle, although it may appear elsewhere. Thromboses typically occur in people who are recovering from surgery, injury, or childbirth or those who are bedridden. Clot formation may also be associated with some diseases, with obesity, and with certain drugs, such as hormonal medications. Symptoms are pain and swelling, often with warmth and redness below or around the clot. Thrombosis can be diagnosed with ultrasound or with magnetic resonance imaging (MRI).

A dangerous complication of thrombosis is formation of an **embolus** (EM-bo-lus), a piece of the clot that becomes loose and floats in the blood. An embolus is carried through the circulatory system until it lodges in a vessel. If it reaches the lungs, sudden death from **pulmonary embolism** (EM-bo-lizm) may result. Prevention of infections, early activity to promote circulation after an injury or an operation, and the use of anticoagulant drugs when appropriate have greatly reduced the incidence of this condition.



Figure 15-17 Varicose veins. (Reprinted with permission from Bickley LS. Bates' Guide to Physical Examination and History Taking. 8th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.)

Phlebitis (fleh-BI-tis), inflammation of a vein, may contribute to clot formation, in which case the condition is called **thrombophlebitis** (throm-bo-fleh-BI-tis).

Varicose Veins

Varicose veins are superficial veins that have become swollen, distorted and ineffective. They may occur in the esophagus or rectum, but the veins most commonly in-

volved are the saphenous veins of the lower extremities (Fig. 15-17). This condition is found frequently in people who stand for long periods, such as salespeople, because blood tends to pool in the legs and put pressure on the veins. Pregnancy, with its accompanying pressure on the pelvic veins, may also be a predisposing factor. Varicose veins in the rectum are called **hemorrhoids** (HEM-o-royds), or *piles*. The general term for varicose veins is **varices** (VAR-ih-seze); the singular form is **varix** (VAR-iks).

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
Systemic Arteries		
brachi/o	arm	The <i>brachiocephalic</i> artery supplies blood to the arm and head on the right side.
cephal/o	head	See preceding example.
clav/o	clavicle	The <i>subclavian</i> artery extends under the clavicle on each side.
cost/o	rib	The <i>intercostal</i> arteries are between the ribs.
celi/o	abdomen	The <i>celiac</i> trunk branches to supply blood to the abdominal organs.
gastr/o	stomach	The <i>gastric</i> artery goes to the stomach.
splen/o	spleen	The <i>splenic</i> artery goes to the spleen.
hepat/o	liver	The <i>hepatic</i> artery supplies blood to the liver.
enter/o	intestine	The <i>mesenteric</i> arteries supply blood to the intestines.
phren/o	diaphragm	The <i>phrenic</i> artery supplies blood to the diaphragm.
ped/o	foot	The <i>dorsalis pedis</i> artery supplies blood to the foot.
stoma	mouth	An <i>anastomosis</i> is a communication between two vessels.
The Physiology of Circulation		
sphygm/o	pulse	A <i>sphygmomanometer</i> is used to measure blood pressure.
man/o	pressure	See preceding example.
Disorders Involving the Blood Vessels		
-ectomy	surgical removal	<i>Endarterectomy</i> is a procedure for removing plaque from the lining of a vessel.
phleb/o	vein	<i>Phlebitis</i> is inflammation of a vein.

Summary

I. Blood vessels

- A. Arteries—carry blood away from heart
- B. Arterioles—small arteries
- C. Capillaries—allow for exchanges between blood and tissues, or blood and air in lungs; connect arterioles and venules
- D. Venules—small veins
- E. Veins—carry blood toward heart
 - 1. Blood circuits
 - A. Pulmonary circuit—carries blood to and from lungs
 - B. Systemic circuit—carries blood to and from rest of body
 - 1. Vessel structure
 - a. Artery walls—layers (tunics)
 - (1) Innermost—single layer of flat epithelial cells (endothelium)

- (2) Middle—thicker layer of smooth muscle and elastic connective tissue

- (3) Outer—connective tissue

- b. Arterioles—thinner walls, less elastic tissue, more smooth muscle
- c. Capillaries—only endothelium; single layer of cells
- d. Venules—wall slightly thicker than capillary wall
- e. Veins—all three layers; thinner walls than arteries, less elastic tissue

II. Systemic arteries

- A. The aorta and its parts
 - 1. Largest artery
 - 2. Divisions
 - a. Ascending aorta

- (1) Left and right coronary arteries
- b. Aortic arch
 - (1) Brachiocephalic artery—branches to arm and head on right
 - (2) Left common carotid artery—supplies left side of neck and the head
 - (3) Left subclavian artery—supplies left arm
- c. Descending aorta
 - (1) Thoracic aorta—branches to chest wall, esophagus, bronchi
 - (2) Abdominal aorta—supplies abdominal viscera
- B. Iliac arteries and their subdivisions
 - 1. Final divisions of aorta
 - 2. Branch to pelvis and legs
- C. Arteries that branch to the arm and head—common carotid, subclavian, brachial
- D. Anastomoses—communications between vessels

III. Systemic veins

- A. Superficial—near surface
- B. Deep—usually parallel to arteries with same names as corresponding arteries
 - 1. The venae cavae and their tributaries
 - a. Superior vena cava—drains upper part of body
 - (i) Jugular veins drain head and neck
 - (ii) Brachiocephalic veins empty into superior vena cava
 - b. Inferior vena cava—drains lower part of body
 - 2. Venous sinuses—enlarged venous channels
 - 3. Hepatic portal system—carries blood from abdominal organs to liver, where it is processed before returning to heart

IV. The physiology of circulation

- A. Capillary exchange
 - 1. Primary method—diffusion
 - 2. Medium—tissue fluid
 - 3. Blood pressure—drives fluid into tissues
 - 4. Osmotic pressure—pulls fluid into capillary
- B. Dynamics of blood flow
 - 1. Vasomotor activities
 - a. Vasodilation—increase in diameter of blood vessel
 - b. Vasoconstriction—decrease in diameter of blood vessel
 - c. Vasomotor center—in medulla; controls contraction and relaxation of smooth muscle in vessel wall
 - 2. Precapillary sphincter—regulates blood flow into capillary
 - 3. Return of blood to heart
 - a. Pumping action of heart
 - b. Pressure of skeletal muscles on veins
 - c. Valves in veins
 - d. Breathing—changes in pressure move blood toward heart

- C. The pulse
 - 1. Wave of pressure that travels along arteries as ventricles contract
 - 2. Rate affected by size, age, gender, activity, and other factors
- D. Blood pressure
 - 1. Force exerted by blood against vessel walls
 - 2. Factors
 - a. Cardiac output—stroke volume x heart rate
 - b. Resistance to blood flow—vessel diameter, vessel elasticity, blood viscosity, blood volume
 - 3. Measured in arm with sphygmomanometer
 - a. Systolic pressure
 - (1) Occurs during heart contraction
 - (2) Averages 120 mmHg
 - b. Diastolic pressure
 - (1) Occurs during heart relaxation
 - (2) Averages 80 mmHg
 - 4. Abnormal blood pressure
 - a. Hypotension—low blood pressure
 - b. Hypertension—high blood pressure
 - (1) Essential hypertension—has no apparent medical cause
 - (2) May involve renin, enzyme released from kidneys
 - (3) May lead to aneurysm, stroke, stress on heart and kidneys, atherosclerosis
 - 5. Treatment of hypertension—diuretics, reduction of renin, relaxation of blood vessels

V. Arterial degeneration and other blood vessel disorders

- A. Arteriosclerosis—hardening of arteries with scar tissue, calcium salts, or fatty deposits
 - 1. Atherosclerosis—deposits of fatty material (plaque) in vessels
 - 2. Possible results—pain, breathing problems, angina pectoris, thrombosis (blood clot), tissue necrosis, gangrene
- B. Aneurysm—weakness and bulging of a vessel; may burst
 - 1. Hemorrhage
 - a. Profuse loss of blood
 - b. First aid measures: direct pressure, elevation of limb, pressure on artery
 - 2. Shock—inadequate blood flow to tissues
 - 3. Thrombosis—formation of blood clot in a vessel
- C. Embolus—piece of a clot traveling in circulation
 - a. Pulmonary embolism—clot lodged in lung
- D. Phlebitis—inflammation of a vein; may lead to thrombophlebitis
 - 1. Varicose veins—swelling and loss of function in superficial veins, usually in legs and rectum (hemorrhoids)

Questions for Study and Review

Building Understanding

Fill in the blanks

1. Capillaries receive blood from vessels called _____.
2. The specific part of the brain that regulates blood pressure is the _____.
3. The flow of blood into an individual capillary is regulated by a(n) _____.
4. Lower-than-normal blood pressure is called _____.
5. Inflammation of a vein is called _____.

Matching

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

- | | |
|--|---------------|
| ___ 6. Lack of blood supply to a tissue or organ | a. embolus |
| ___ 7. Bulging sac in the wall of a vessel | b. thrombus |
| ___ 8. Loss of blood | c. ischemia |
| ___ 9. An immobile blood clot within a vessel | d. aneurysm |
| ___ 10. A mobile blood clot within a vessel | e. hemorrhage |

Multiple choice

- ___ 11. The innermost layer of a blood vessel is composed of
- smooth muscle
 - epithelium
 - connective tissue
 - nervous tissue
- ___ 12. The largest artery in the body is the
- aorta
 - brachiocephalic trunk
 - splenic artery
 - superior mesenteric artery
- ___ 13. The main process by which substances move between the cells and the capillary blood is
- endocytosis
 - exocytosis
 - osmosis
 - diffusion
- ___ 14. The stomach, spleen, and liver receive blood via the
- hepatic portal system
 - superior mesenteric artery
 - inferior mesenteric artery
 - celiac trunk
- ___ 15. The medical term describing the deposition of material within arterial walls is
- shock
 - gangrene
 - arteriosclerosis
 - stasis
- ___ 16. Differentiate between the terms in each of the following pairs:
- artery and vein
 - arteriole and venule
 - anastomosis and venous sinus
 - vasoconstriction and vasodilation
 - systolic and diastolic pressure
17. How does the structure of the blood vessels correlate with their function?
18. Trace a drop of blood from the left ventricle to the:
- right side of the head and neck
 - lateral surface of the left hand
 - right foot
 - liver
 - small intestine
19. Trace a drop of blood from capillaries in the wall of the small intestine to the right atrium. What is the purpose of going through the liver on this trip?
20. What physiological factors influence blood pressure?
21. Describe three mechanisms that promote the return of blood to the heart in the venous system.
22. What are some symptoms of arteriosclerosis and how are these produced?
23. What is shock and why is it so dangerous? Name some symptoms of shock and identify the types of shock based on (a) cause and (b) severity.

Conceptual Thinking

24. Kidney disease usually results in the loss of protein from the blood into the urine. One common sign of kidney disease is edema. Based on this information and your understanding of capillary exchange, explain why edema is often associated with kidney disease.
25. Cliff C., a 49-year-old self-described “couch potato,” has a blood pressure of 162/100 mmHg. What is Cliff’s diagnosis? What can this disorder lead to? If you were Cliff’s doctor, what treatments might you discuss with him?