13.1 The Blood Vessels

The cardiovascular system has three types of blood vessels: the **arteries** (and arterioles), which carry blood away from the heart to the capillaries; the **capillaries,** which permit exchange of material with the tissues; and the **veins** (and venules), which return blood from the capillaries to the heart.

The blood vessels require oxygen and nutrients just as do other tissues, and therefore the larger ones have blood vessels in their own walls.

The Arteries

The largest artery in the human body, the aorta, is about 25 mm wide. An arterial wall has three layers (Fig. 13.1*a*). The inner layer is a simple squamous epithelium called endothelium with a connective tissue basement membrane that contains elastic fibers. The middle layer is the thickest layer and consists of smooth muscle that can contract to regulate blood flow and blood pressure. The outer layer is fibrous connective tissue near the middle layer, but it becomes loose connective tissue at its periphery.

Smaller arteries branch into a number of arterioles. **Arterioles** are small arteries just visible to the naked eye, being under 0.5 mm in diameter. The middle layer of arterioles has some elastic tissue but is composed mostly of smooth muscle whose fibers encircle the arteriole. When these muscle fibers are contracted, the vessel has a smaller diameter (is constricted); when these muscle fibers are relaxed, the vessel has a larger diameter (is dilated). Whether arterioles are constricted or dilated affects blood pressure. The greater the number of vessels dilated, the lower the blood pressure.

The Capillaries

Arterioles branch into capillaries, which are extremely narrow—about 8–10 μm wide. Capillaries have one-cell-thick walls composed only of endothelium with a basement

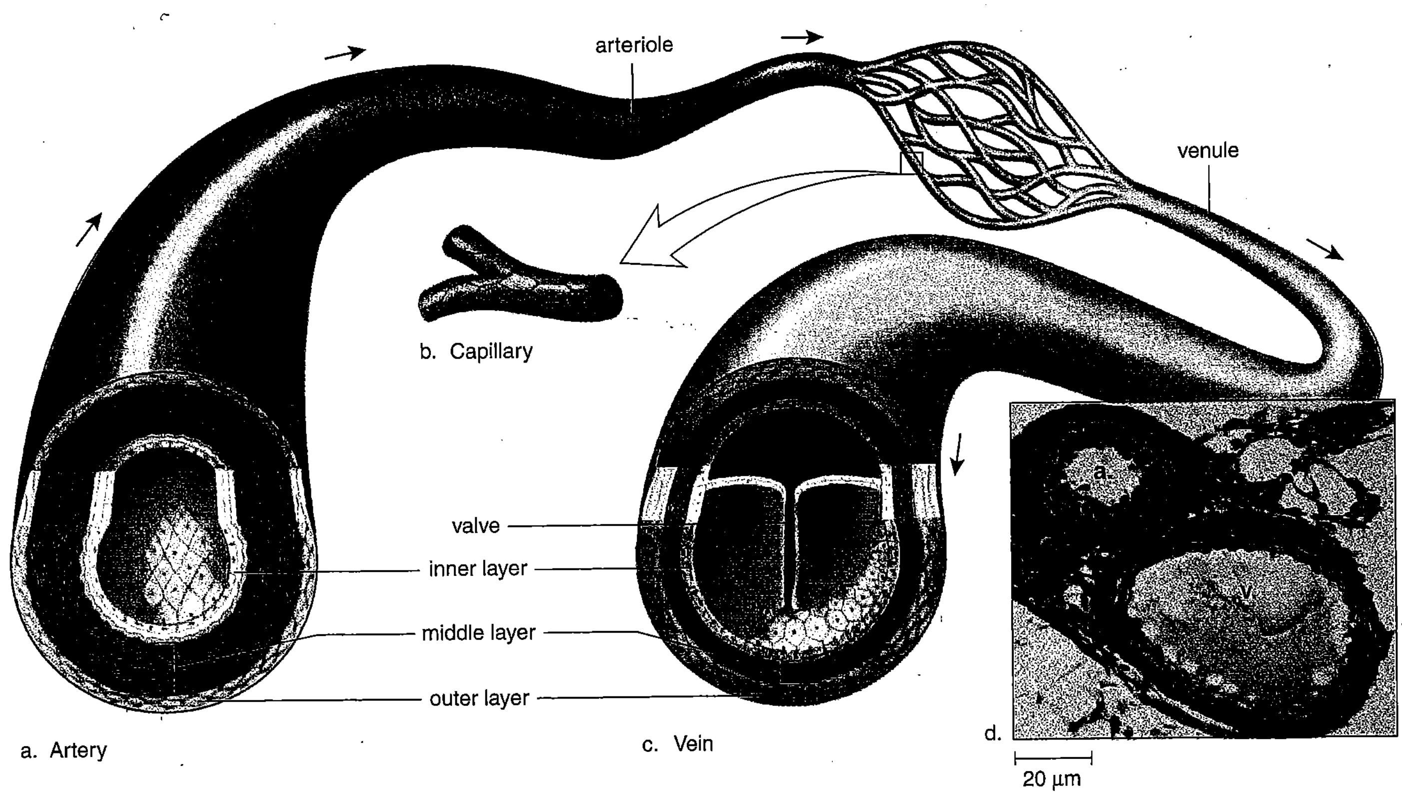

Figure 13.1 Blood vessels.
The walls of arteries and veins have three layers. The inner layer is composed largely of endothelium, with a basement membrane that has elastic fibers; the middle layer is smooth muscle tissue; the outer layer is connective tissue (largely collagen fibers). **a.** Arteries have a thicker wall than veins because they have a larger middle layer than veins. **b.** Capillary walls are one-cell-thick endothelium. **c.** Veins are larger in diameter than arteries, so that collectively veins have a larger holding capacity than arteries. **d.** Light micrograph of an artery (a) and a vein (v).

membrane. Although each capillary is small, they form vast networks; their total surface area in humans is about 6,000 square meters. Capillary beds (networks of many capillaries) are present in all regions of the body; consequently, a cut to any body tissue draws blood. Capillaries are a very important part of the human cardiovascular system because an exchange of substances takes place across their thin walls. Oxygen and nutrients, such as glucose, diffuse out of a capillary into the tissue fluid that surrounds cells. Wastes, such as carbon dioxide, diffuse into the capillary. Some water also leaves a capillary; any excess is picked up by lymphatic vessels, as discussed later in the chapter. The relative constancy of tissue fluid is absolutely dependent upon capillary exchange.

Since capillaries serve the cells, the heart and the other vessels of the cardiovascular system can be thought of as the means by which blood is conducted to and from the capillaries. Only certain capillaries are open at any given time. For example, after eating, the capillaries that serve the digestive system are open and those that serve the muscles are closed. Shunting of blood is possible because each capillary bed has an arteriovenous shunt that allows blood to go directly from the arteriole to the venule (Fig. 13.2). Contracted sphincter muscles prevent the blood from entering the capillary vessels.

The Veins

Veins and venules take blood from the capillary beds to the heart. First, the **venules** (small veins) drain blood from the capillaries and then join to form a vein. The walls of veins (and venules) have the same three layers as arteries, but there is less smooth muscle and connective tissue (Fig. 13.1*c*). Therefore, the wall of a vein is thinner than that of an artery. Also, veins often have **valves,** which allow blood to flow only toward the heart when open and prevent the backward flow of blood when closed. Valves are found in the veins that carry blood against the force of gravity, especially the veins of the lower extremities.

Since the walls of veins are thinner, they can expand to a greater extent (Fig. 13.1*d*). At any one time, about 70% of the blood is in the veins. In this way, the veins act as a blood reservoir. If blood is lost due to hemorrhaging, nervous stimulation causes the veins to constrict, providing more blood to the rest of the body.

Arteries and arterioles carry blood away from the heart toward the capillaries; capillaries join arterioles to venules; veins and venules return blood from the capillaries to the heart.

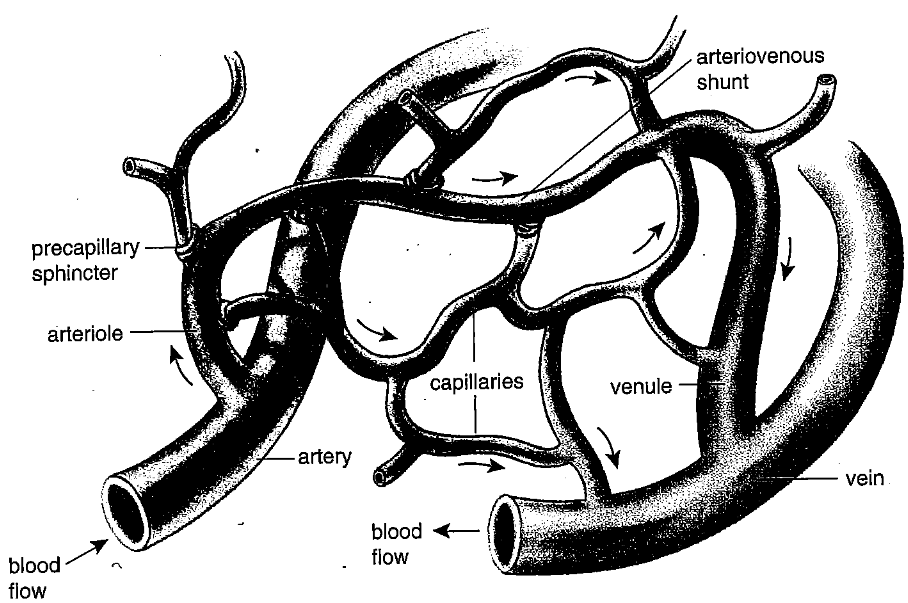

Figure 13.2 Anatomy of a capillary bed.
A capillary bed forms a maze of capillary vessels that lies between an arteriole and a venule. When sphincter muscles are relaxed, the capillary bed is open, and blood flows through the capillaries. When sphincter muscles are contracted, blood flows through a shunt that carries blood directly from an arteriole to a venule. As blood passes through a capillary in the tissues, it gives up its oxygen (O_2). Therefore, blood goes from being O_2-rich in the arteriole (red color) to being O_2-poor in the vein (blue color).

13.3 The Vascular Pathways

The cardiovascular system, which is represented in Figure 13.7, includes two circuits: the **pulmonary circuit,** which circulates blood through the lungs, and the **systemic circuit,** which serves the needs of body tissues. Both circuits, as we shall see, are necessary to homeostasis.

The Pulmonary Circuit

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

The pulmonary arteries take O_2-poor blood to the lungs, and the pulmonary veins return blood that is O_2-rich to the heart.

The Systemic Circuit

The systemic circuit includes all of the arteries and veins shown in Figure 13.8. The largest artery in the systemic circuit is the **aorta,** and the largest veins are the **superior** and **inferior venae cavae.** The superior vena cava collects blood from the head, the chest, and the arms, and the inferior vena cava collects blood from the lower body regions. Both enter the right atrium. The aorta and the venae cavae serve as the major pathways for blood in the systemic circuit.

The path of systemic blood to any organ in the body begins in the left ventricle, which

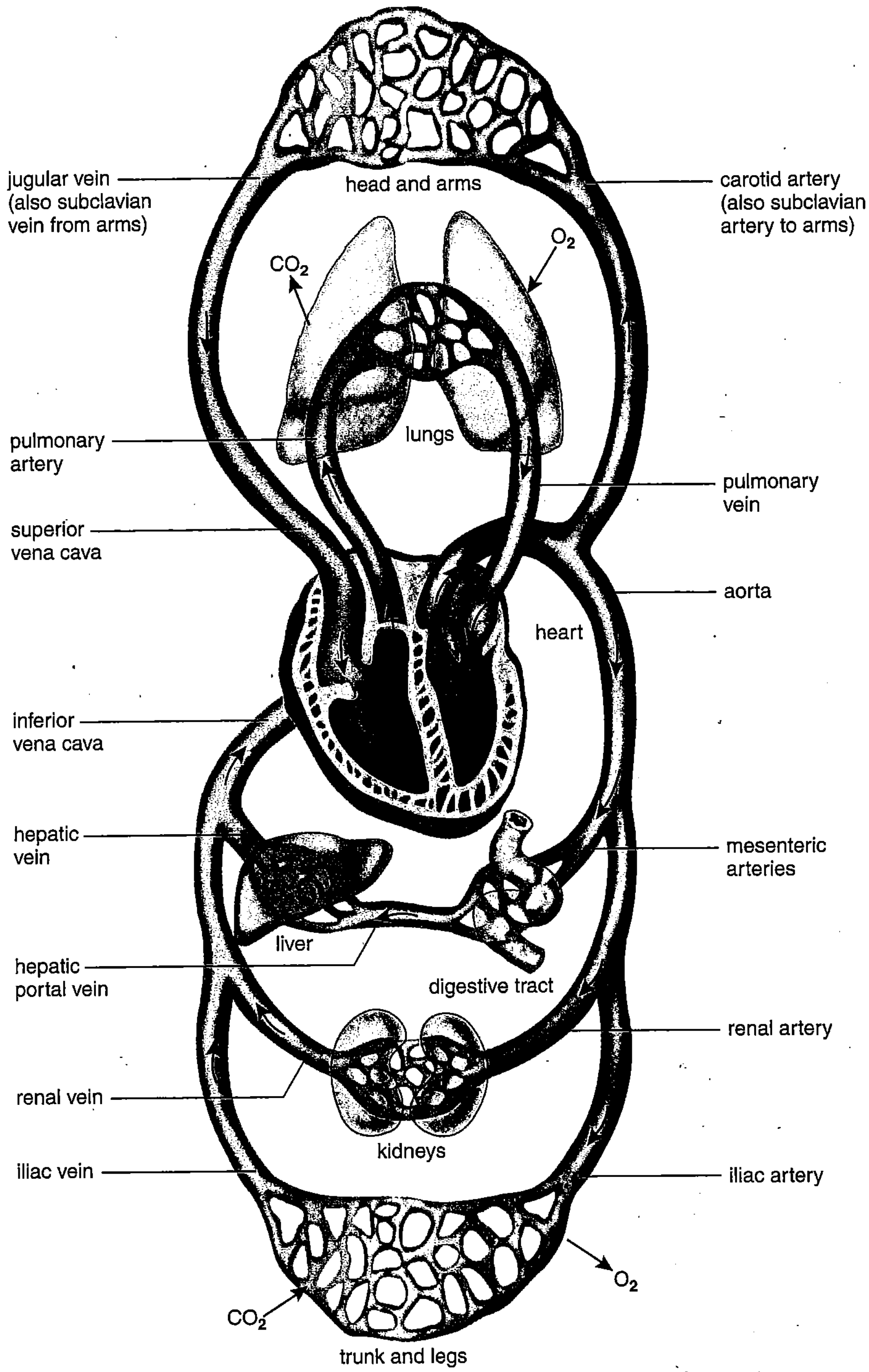

Figure 13.7 Cardiovascular system diagram.
The blue-colored vessels carry O_2-poor blood, and the red-colored vessels carry O_2-rich blood; the arrows indicate the flow of blood. Compare this diagram, useful for learning to trace the path of blood, to Figure 13.8 to realize that arteries and veins go to all parts of the body. Also, capillaries are present in all parts of the body, so no cell is located far from a capillary.

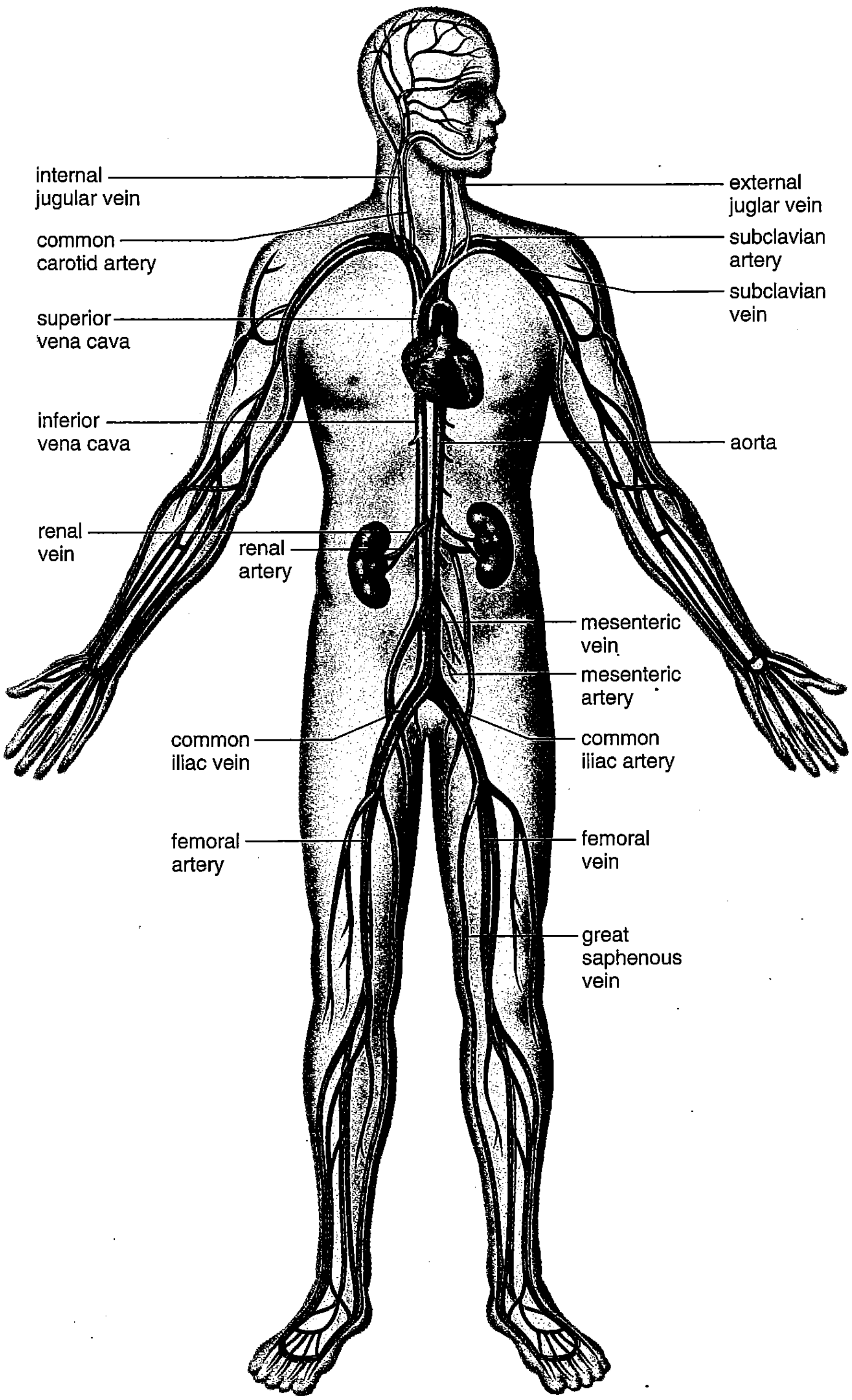

Figure 13.8 Major arteries and veins of the systemic circuit. A realistic representation of the major blood vessels of the systemic circuit shows how the systemic arteries and veins are arranged in the body. The superior and inferior venae cavae take their names from their relationship to which organ?

pumps blood into the aorta. Branches from the aorta go to the organs and major body regions. For example, this is the path of blood to and from the lower legs:

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

Notice that, when tracing blood, you need only mention the aorta, the proper branch of the aorta, the region, and the vein returning blood to the vena cava. In most instances, the artery and the vein that serve the same region are given the same name (Fig. 13.8). What happens when the blood reaches a particular region? Capillary exchange takes place, refreshing tissue fluid so that its composition stays relatively constant.

The **coronary arteries** (see Fig. 13.3) serve the heart muscle itself. (The heart is not nourished by the blood in its own chambers.) The coronary arteries are the first branches off the aorta. They originate just above the aortic semilunar valve, and they lie on the exterior surface of the heart, where they divide into diverse arterioles. Because they have a very small diameter, the coronary arteries may become clogged, as discussed on page 256. The coronary capillary beds join to form venules. The venules converge to form the cardiac veins, which empty into the right atrium.

The body has a portal system called the **hepatic portal system,** which is associated with the liver. A portal system begins and ends in capillaries; in this instance, the first set of capillaries occurs at the villi of the small intestine, and the second occurs in the liver. Blood passes from the capillaries of the intestinal villi into venules that join to form the **hepatic portal vein.** The hepatic portal vein connects the villi of the intestine with the liver, an organ that monitors the makeup of the blood. The **hepatic vein** leaves the liver and enters the inferior vena cava.

While Figure 13.7 is helpful in tracing the path of blood, remember that all parts of the body receive both arteries and veins, as illustrated in Figure 13.8.

The systemic circuit takes blood from the left ventricle of the heart, through the body proper, and back to the right atrium of the heart.

Blood Flow

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

Blood Flow in Arteries

Blood pressure is the pressure of blood against the wall of a blood vessel. Clinicians use a sphygmomanometer to measure blood pressure, usually in the brachial artery of the arm. The highest arterial pressure, called the **systolic pressure,** is reached during ejection of blood from the heart. The lowest arterial pressure, called the **diastolic pressure,** occurs while the heart ventricles are relaxing. Blood pressure in the brachial artery is typically 120 mm mercury (Hg) over 80 mm Hg, or simply 120/80. The higher number is the systolic pressure, and the lower number is the diastolic pressure.

Although the blood pressure in the brachial artery is typically about 120/80, blood pressure actually varies throughout the body. As already stated, blood pressure is highest in the aorta and lowest in the venae cavae. Blood pressure decreases with distance from the left ventricle because there are more arterioles than arteries, which increases the total cross-sectional area of the blood vessels. The decrease in blood pressure causes the blood velocity to gradually decrease as it flows toward the capillaries (Fig. 13.9).

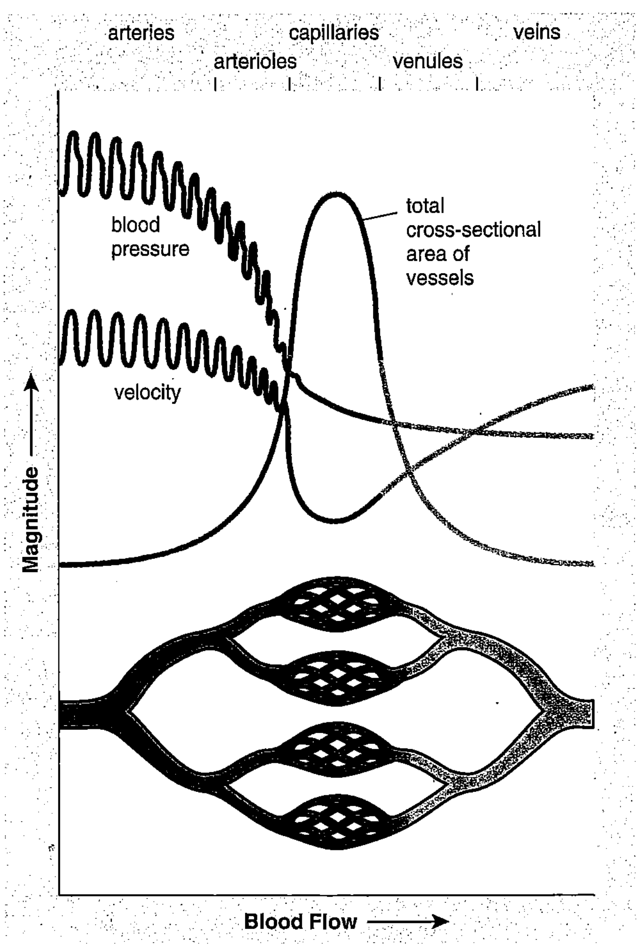

Figure 13.9 Cross-sectional area as it relates to blood pressure and blood velocity.
Blood pressure and blood velocity drop off in capillaries because capillaries have a greater cross-sectional area than arterioles.

Blood Flow in Capillaries

Because there are many more capillaries than arterioles, blood moves even more slowly through the capillaries. This slow progress allows time for substances to be exchanged between the blood in the capillaries and the surrounding tissues.

Blood Flow in Veins

Blood pressure is minimal in venules and veins (20–0 mm Hg). Instead of blood pressure, venous return depends upon three factors: skeletal muscle contraction, the presence of valves in veins, and respiratory movements. When the skeletal muscles contract, they compress the weak walls of the veins. This causes blood to move past the next valve. Once past the valve, blood cannot flow backward. The importance of muscle contraction in moving blood in the venous vessels can be demonstrated by forcing a person to stand rigidly still for an hour or so. Frequently, the person faints because blood has collected in the limbs, depriving the brain of needed blood flow and oxygen. In this case, fainting is beneficial because the resulting horizontal position aids in getting blood to the head.

When a person inhales, the thoracic pressure falls and abdominal pressure rises as the chest expands. This also aids the flow of venous blood back to the heart because blood flows in the direction of reduced pressure. Blood velocity increases slightly in the venous vessels due to a progressive reduction in the cross-sectional area as small venules join to form veins.

The backward pressure of blood can sometimes cause the valves to become weak and ineffective. The accumulation of blood in veins is commonly referred to as **varicose veins.** Varicose veins develop when the valves of veins become weak and ineffective due to the backward pressure of blood. Abnormal and irregular dilations are particularly apparent in the superficial (near the surface) veins of the lower legs. Crossing the legs or sitting in a chair so that its edge presses against the back of the knees can contribute to the development of varicose veins. Varicose veins also occur in the rectum, where they are called piles, or more properly, hemorrhoids. **Phlebitis,** an inflammation of a vein, is a more serious condition because it can lead to blood clots. If a clot is carried to a pulmonary vessel, death can result.

Blood pressure accounts for the flow of blood in the arteries and the arterioles. Skeletal muscle contraction, valves in veins, and respiratory movements account for the flow of blood in the venules and the veins.