CHAPTER 13

Cardiovascular System

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Blood donations can help save the life of perhaps a family member or a friend.

Harry stretched out his arm and watched as the nurse slipped a needle into a vein at the crook of his arm. He was thinking about his friend who needed the blood that was now coursing through a plastic tube into a bag. Harry had the same blood type as his friend, who had been in an automobile accident. Blood, a vital fluid, carries oxygen from the lungs, and nutrients from the intestines to the cells. It also takes carbon dioxide to the lungs and wastes to the kidneys. Helping to fight infection, regulate body temperature, and coordinate the activity of body tissues are still other functions of blood. A severe loss of blood must be replaced by transfusion if life is to continue.

Humans have a closed cardiovascular system, in that the blood never runs free and is conducted to and from the tissues by blood vessels. Only the capillaries have walls thin enough to allow exchange of molecules with the tissues. The heart is the organ that keeps the blood moving through the vessels to the capillaries. Harry knew that if the heart fails to pump the blood for even a few minutes, the individual's life is in danger. The body has various mechanisms for ensuring that blood remains in the vessels and under a pressure that will maintain its transport function.

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

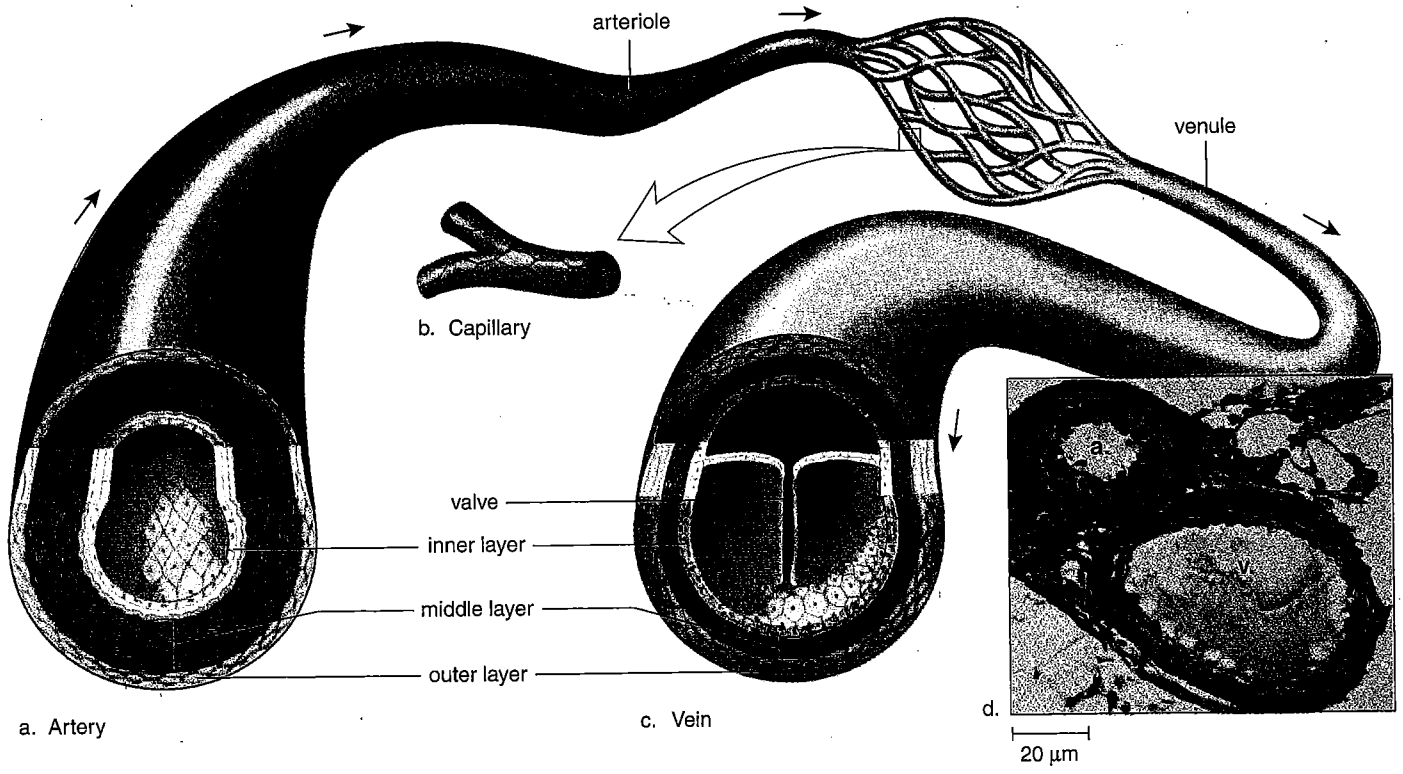

Figure 13.1 Blood vessels.
The walls of arteries and veins have three layers. The inner layer is composed largely of endothelium, with a basement membrane that has elastic fibers; the middle layer is smooth muscle tissue; the outer layer is connective tissue (largely collagen fibers). **a.** Arteries 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.

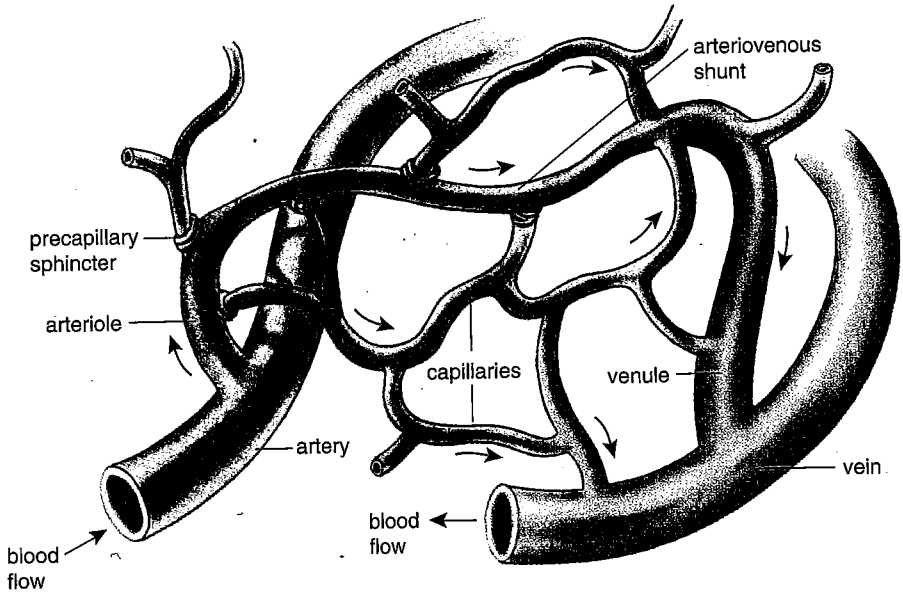

Figure 13.2 Anatomy of a capillary bed.
A capillary bed forms a maze of capillary vessels that lies between an arteriole and a venule. When sphincter muscles are relaxed, the capillary bed is open, and blood flows through the capillaries. When sphincter muscles are contracted, blood flows through a shunt 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).

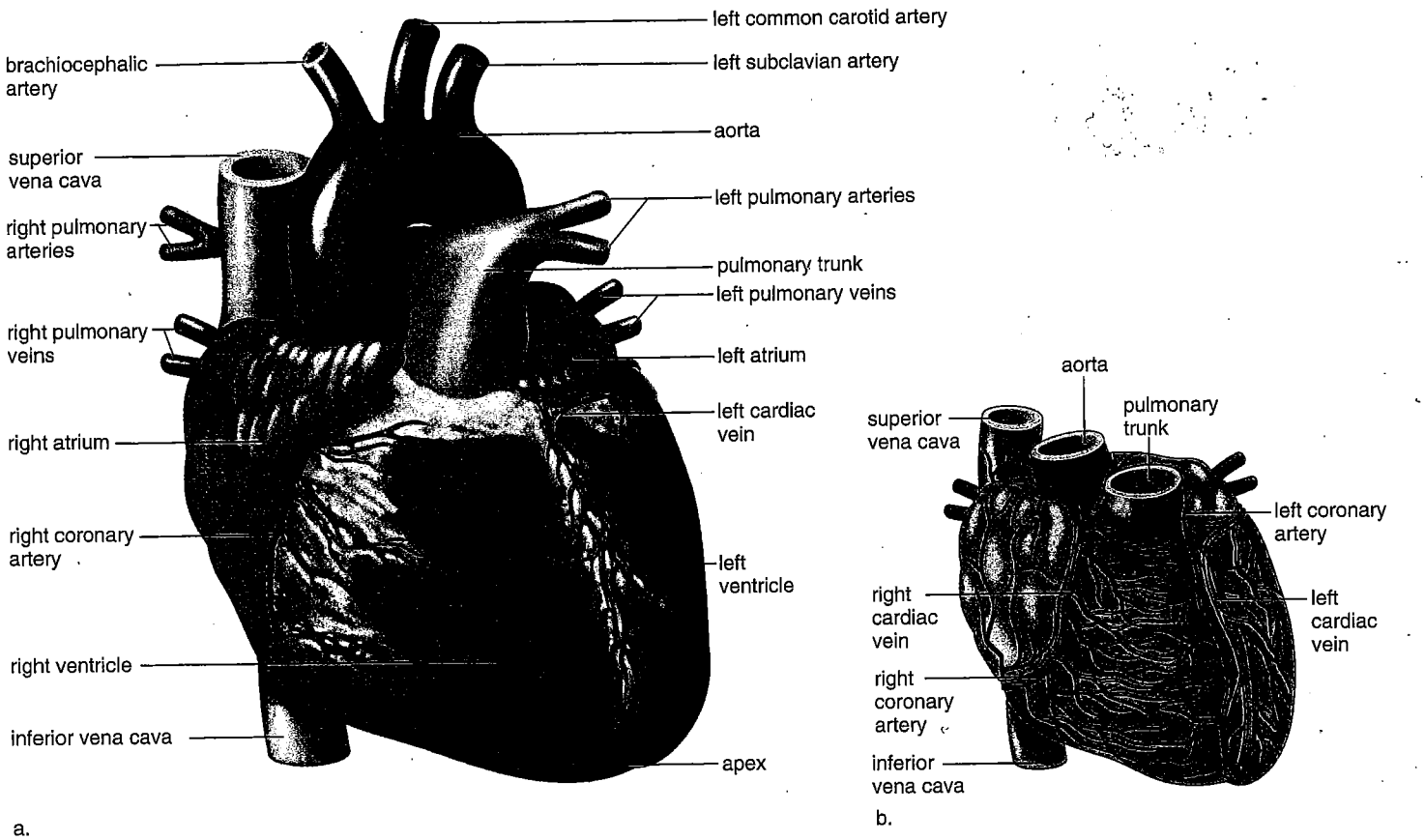

Figure 13.3 External heart anatomy.
a. The superior vena cava and the pulmonary trunk are attached to the right side of the heart. The aorta and pulmonary veins are attached to the left side of the heart. The right ventricle forms most of the ventral surface of the heart, and the left ventricle forms most of the dorsal surface. **b.** The coronary arteries and cardiac veins pervade cardiac muscle. The coronary arteries bring oxygen and nutrients to cardiac cells, which derive no benefit from blood coursing through the heart.

13.2 The Heart

The **heart** is a cone-shaped, muscular organ about the size of a fist. It is located between the lungs directly behind the sternum (breastbone) and is tilted so that the apex (the pointed end) is oriented to the left. The major portion of the heart, called the **myocardium,** consists largely of cardiac muscle tissue. The muscle fibers of the myocardium are branched and tightly joined to one another. The heart lies within the **pericardium,** a thick, membranous sac that secretes a small quantity of lubricating liquid. The inner surface of the heart is lined with endocardium, which consists of connective tissue and endothelial tissue.

The heart has four chambers. The two upper, thin-walled atria (sing., **atrium**) have wrinkled, protruding appendages called auricles. The two lower chambers are the thick-walled **ventricles,** which pump the blood (Fig. 13.3).

Internally, a wall called the septum separates the heart into a right side and a left side (Fig. 13.4*a*). The heart has four valves, which direct the flow of blood and prevent its backward movement. The two valves that lie between the atria and the ventricles are called the **atrioventricular valves.** These valves are supported by strong fibrous strings called **chordae tendineae.** The chordae, which are attached to muscular projections of the ventricular walls, support the valves and prevent them from inverting when the heart contracts. The atrioventricular valve on the right side is called the tricuspid valve because it has three flaps, or cusps. The atrioventricular valve on the left side is called the bicuspid (or mitral) valve because it has two flaps. The remaining two valves are the **semilunar valves,** whose flaps resemble half-moons, between the ventricles and their attached vessels. The pulmonary semilunar valve lies between the right ventricle and the pulmonary trunk. The aortic semilunar valve lies between the left ventricle and the aorta.

Humans have a four-chambered heart (two atria and two ventricles). A septum separates the right side from the left side.

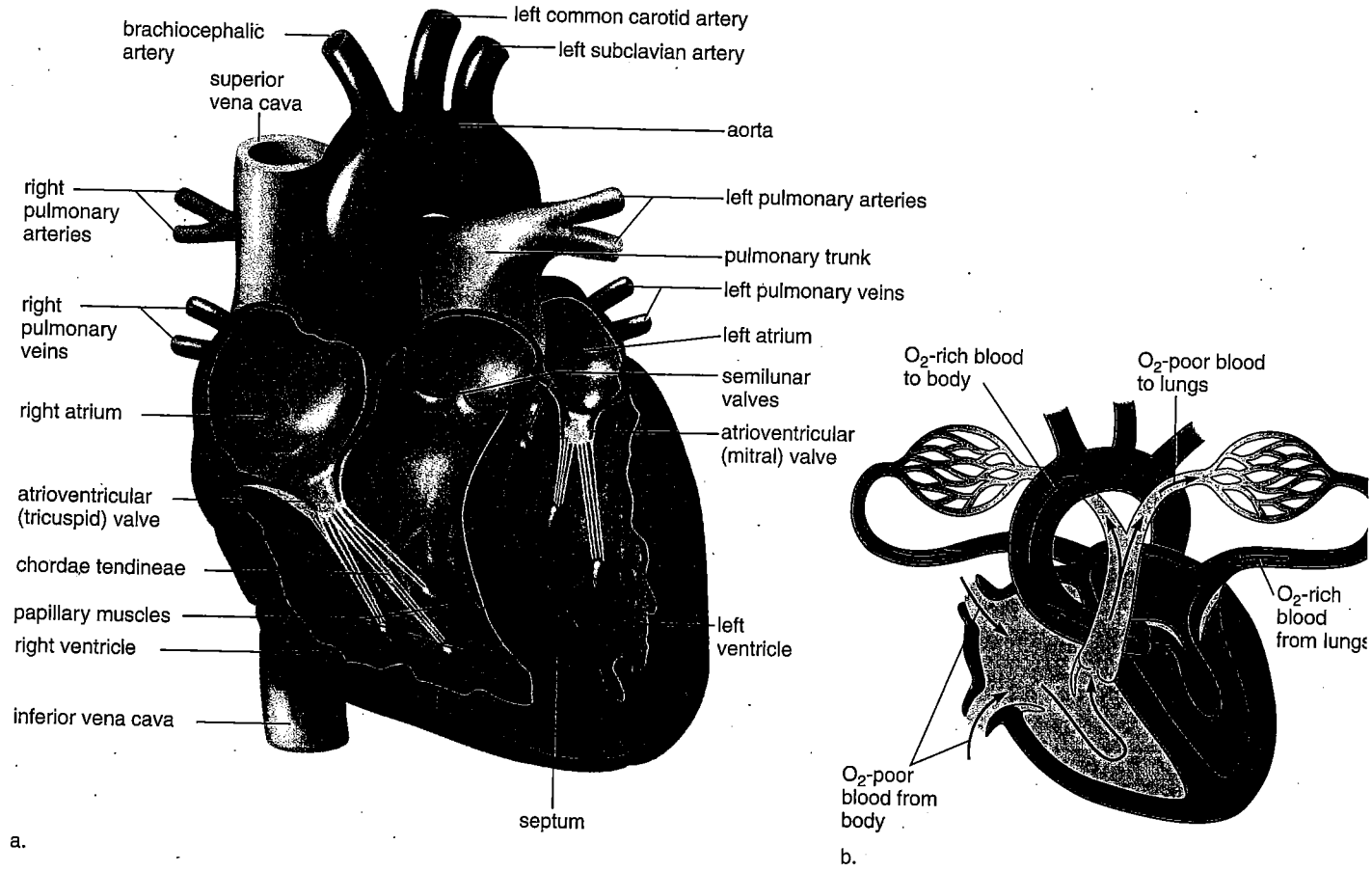

Figure 13.4 Internal view of the heart.
a. The heart has four valves. The atrioventricular valves allow blood to pass from the atria to the ventricles, and the semilunar valves allow bloo to pass out of the heart. **b.** This diagrammatic representation of the heart allows you to trace the path of the blood through the heart.

Passage of Blood Through the Heart

We can trace the path of blood through the heart (Fig. 13.4*b*) in the following manner:

- The superior vena cava and the inferior vena cava, which carry O_2-poor blood, enter the right atrium.
- The right atrium sends blood through an atrioventricular valve (the tricuspid valve) to the right ventricle.
- The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk. The pulmonary trunk divides into two **pulmonary arteries,** which go to the lungs.
- Four **pulmonary veins,** which carry O_2-rich blood, enter the left atrium.
- The left atrium sends blood through an atrioventricular valve (the bicuspid or mitral valve) to the left ventricle.
- The left ventricle sends blood through the aortic semilunar valve into the aorta to the body proper.

From this description, you can see that O_2-poor blo never mixes with O_2-rich blood and that blood must through the lungs in order to pass from the right side to t left side of the heart. In fact, the heart is a double pur because the right ventricle of the heart sends blood throu the lungs, and the left ventricle sends blood throughout t body. Since the left ventricle has the harder job of pum ing blood to the entire body, its walls are thicker than thc of the right ventricle, which pumps blood a relatively sh distance to the lungs.

The pumping of the heart sends blood out under pr sure into the arteries. Because the left side of the heart the stronger pump, blood pressure is greatest in the aor Blood pressure then decreases as the cross-sectional area arteries and then arterioles increases.

The right side of the heart pumps blood to the lungs, and the left side of the heart pumps blood throughout the body.
