

CHAPTER 18

ANATOMY OF THE CARDIOVASCULAR SYSTEM

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KEY TERMS

anastomosis

arteriole

artery

atrium

capillary

endocardium

endothelium

epicardium

myocardium

pericardium

pulmonary circulation

systemic circulation

vein

ventricle

venule

The cardiovascular system is sometimes called, simply, the *circulatory system*. It consists of the heart, which is a muscular pumping device, and a closed system of vessels called *arteries*, *veins*, and *capillaries*. As the name implies, blood contained in the circulatory system is pumped by the heart around a closed circle or circuit of vessels as it passes again and again through the various circulations of the body (on p. 569).

As in the adult, survival of the developing embryo depends on the circulation of blood to maintain homeostasis and a favorable cellular environment. In response to this need, the cardiovascular system makes its appearance early in development and reaches a functional state long before any other major organ system. Incredible as it seems, the heart begins to beat regularly early in the fourth week after fertilization.

HEART

LOCATION OF THE HEART

The human heart is a four-chambered muscular organ, shaped and sized roughly like a person's closed fist. It lies in the mediastinum, or middle region of the thorax, just behind the body of the sternum between the points of attach-

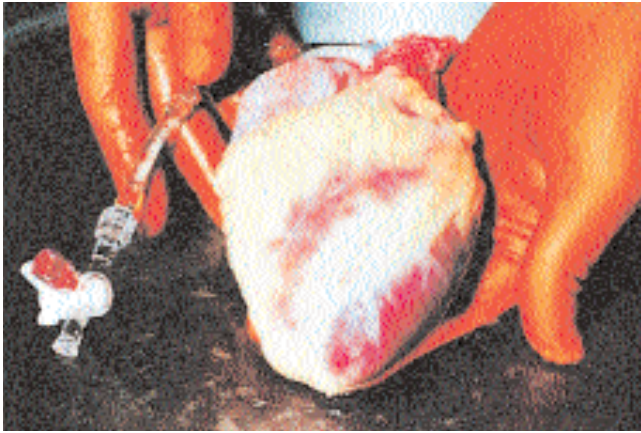


Figure 18-1 Appearance of the heart. This photograph shows a living human heart prepared for transplantation into a patient. Notice its size relative to the hands that are holding it.

ment of the second through the sixth ribs. Approximately two thirds of the heart's mass is to the left of the midline of the body and one third to the right.

Posteriorly the heart rests against the bodies of the fifth to the eighth thoracic vertebrae. Because of its placement between the sternum in front and the bodies of the thoracic vertebrae behind, it can be compressed by application of pressure to the lower portion of the body of the sternum using the heel of the hand. Rhythmic compression of the heart in this way can maintain blood flow in cases of cardiac arrest and, if combined with effective artificial respiration, the resulting procedure, called *cardiopulmonary resuscitation* (CPR), can be life saving.

The anatomical position of the heart in the thoracic cavity is shown in Figure 18-9. The lower border of the heart, which forms a blunt point known as the *apex*, lies on the diaphragm, pointing toward the left. To count the apical beat, one must place a stethoscope directly over the apex, that is, in the space between the fifth and sixth ribs (fifth intercostal space) on a line with the midpoint of the left clavicle.

The upper border of the heart, that is, its base, lies just below the second rib. The boundaries, which, of course, indicate its size, have considerable clinical importance, because a marked increase in heart size accompanies certain types of heart disease. Therefore when diagnosing heart disorders, the physician charts the boundaries of the heart. The “normal” boundaries of the heart are, however, influenced by such factors as age, body build, and state of contraction.

SIZE AND SHAPE OF THE HEART

At birth the heart is said to be transverse (wide) in type and appears large in proportion to the diameter of the chest cavity. In the infant, it is $\frac{1}{130}$ of the total body weight compared to about $\frac{1}{300}$ in the adult. Between puberty and 25 years of age the heart attains its adult shape and weight—about 310 g is average for the male and 225 g for the female.

In the adult the shape of the heart tends to resemble that of the chest. In tall, thin individuals the heart is frequently described as elongated, whereas in short, stocky individuals it has greater width and is described as transverse. In individuals of average height and weight it is neither long nor transverse but somewhat intermediate between the two (Figure 18-1). Its approximate dimensions are length, 12 cm ($4\frac{3}{4}$ inches); width, 9 cm ($3\frac{1}{2}$ inches); and depth, 6 cm ($2\frac{1}{2}$ inches). Figure 18-2 shows details of the heart and great vessels in a posterior view and in an anterior view.

COVERINGS OF THE HEART

Structure of the Heart Coverings

The heart has its own special covering, a loose-fitting inextensible sac called the *pericardium*. The pericardial sac, with the heart removed, can be seen in Figure 18-3. The *pericardium* consists of two parts: a fibrous portion and a serous portion (Figure 18-4). The sac itself is made of tough white fibrous tissue but is lined with smooth, moist serous membrane—the parietal layer of the serous pericardium. The same kind of membrane covers the entire outer surface of the heart. This covering layer is known as the *visceral layer* of the serous pericardium or as the *epicardium*. The fibrous sac attaches to the large blood vessels emerging from the top of the heart but not to the heart itself (see Figure 18-3). Therefore it fits loosely around the heart, with a slight space between the visceral layer adhering to the heart and the parietal layer adhering to the inside of the fibrous sac. This space is called the *pericardial space*. It contains (10 to 15 ml) of lubricating fluid secreted by the serous membrane and called *pericardial fluid*.

The structure of the pericardium can be summarized as follows:

- **Fibrous pericardium**—tough, loose-fitting, and inelastic sac around the heart
- **Serous pericardium**—consisting of two layers
 - *Parietal layer*—lining inside of the fibrous pericardium
 - *Visceral layer (epicardium)*—adhering to the outside of the heart; between visceral and parietal layers is a space, the pericardial space, which contains a few drops of pericardial fluid

Function of the Heart Coverings

The fibrous pericardial sac with its smooth, well-lubricated lining provides protection against friction. The heart moves easily in this loose-fitting jacket with no danger of irritation from friction between the two surfaces, as long as the serous pericardium remains normal and continues to produce lubricating serous fluid.



1. In anatomical terms, where is the heart located?
2. Name the layers of tissue that make up the pericardium.
3. What is the function of the pericardium?

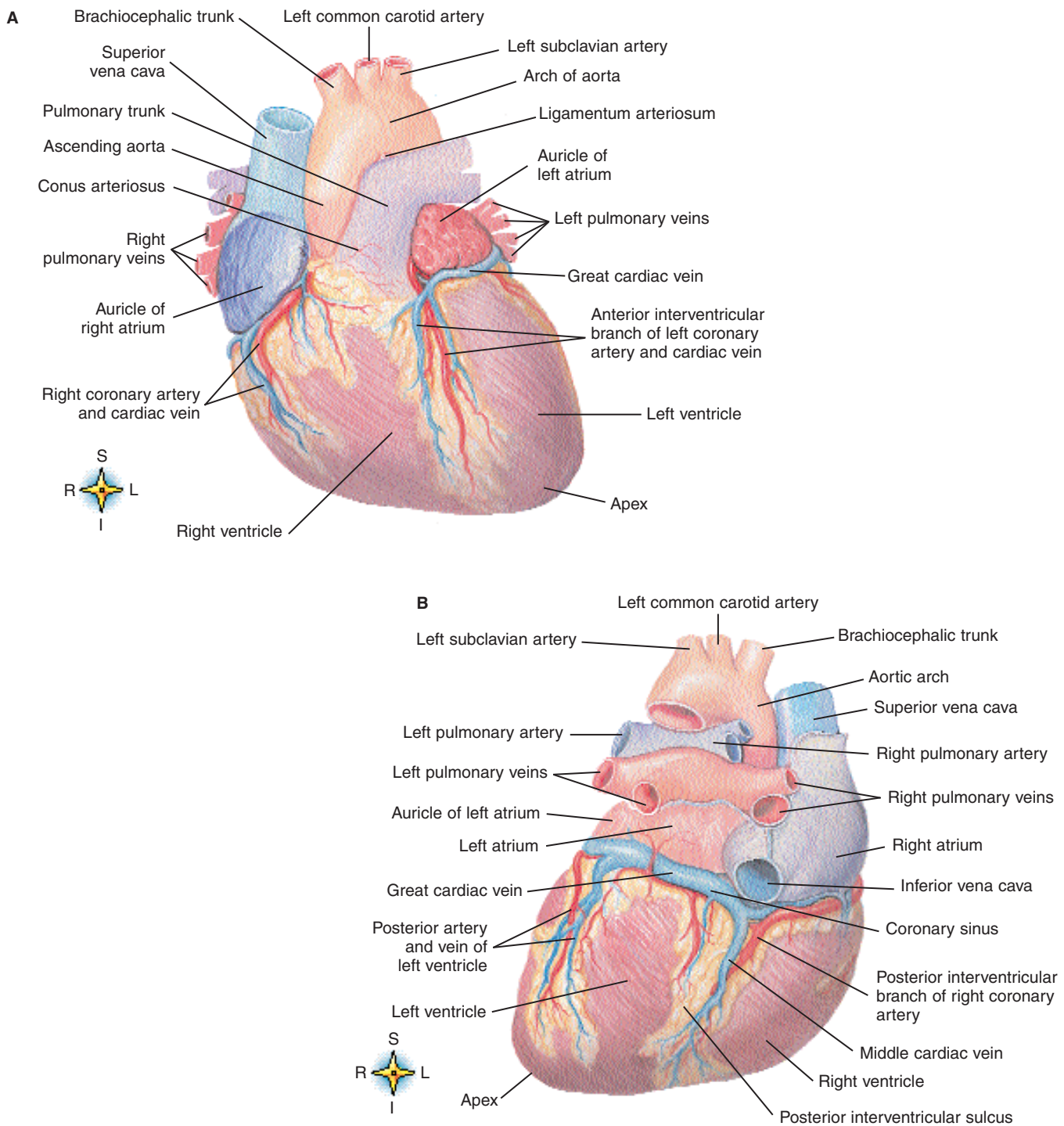


Figure 18-2 The heart and great vessels. A, Anterior view of the heart and great vessels. B, Posterior view of the heart and great vessels.

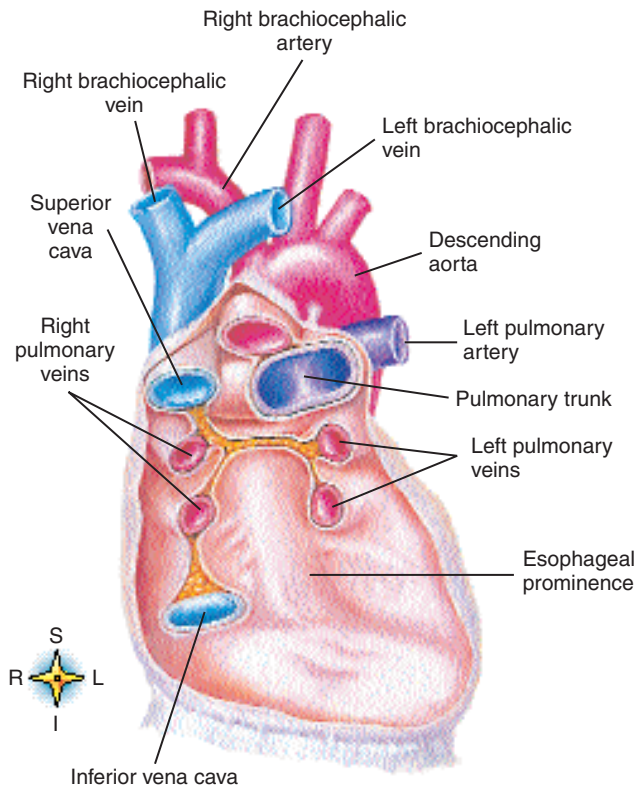


Figure 18-3 Pericardium. This frontal view shows the pericardial sac with the heart removed. Notice that the pericardial sac attaches to the large vessels that enter and exit the heart, not to the heart itself.

STRUCTURE OF THE HEART

Wall of the Heart

Three distinct layers of tissue make up the heart wall (see Figure 18-4) in both the atria and the ventricles: the epicardium, myocardium, and endocardium.

Epicardium. The outer layer of the heart wall is called the *epicardium*, a name that literally means “on the heart.” The epicardium is actually the visceral layer of the serous pericardium already described. In other words, the same structure has two different names: epicardium and serous pericardium.

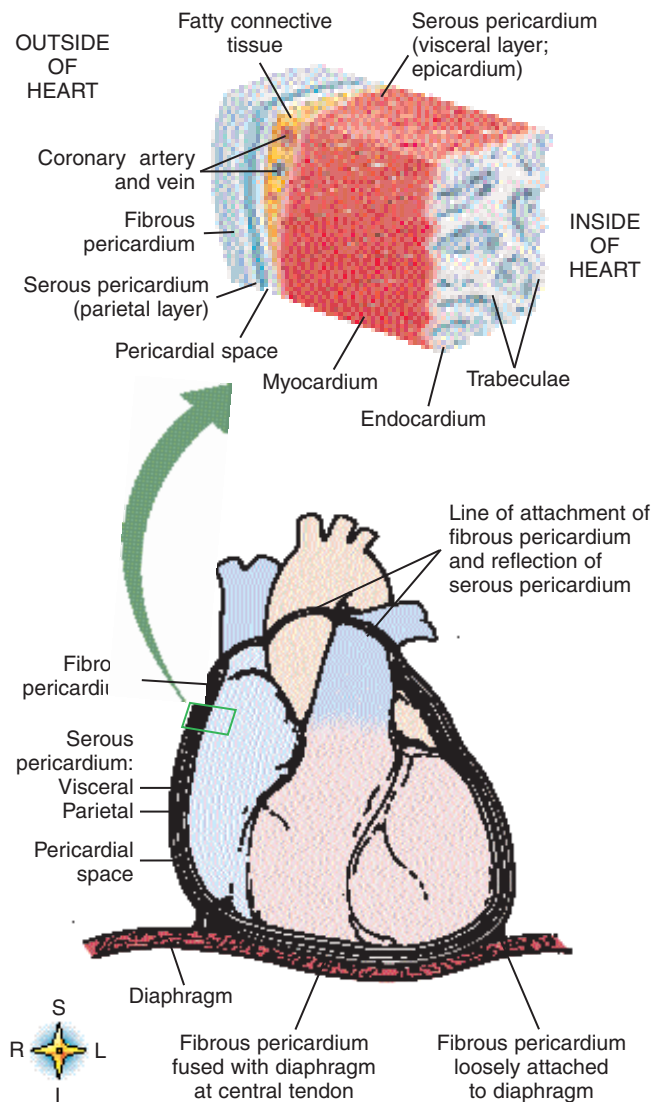


Figure 18-4 Wall of the heart. This section of the heart wall shows the fibrous pericardium, the parietal and visceral layers of the serous pericardium (with the pericardial space between them), the myocardium, and the endocardium. Notice that there is fatty connective tissue between the visceral layer of the serous pericardium (epicardium) and the myocardium. Notice also that the endocardium covers beamlike projections of myocardial muscle tissue, called trabeculae.

Myocardium. The bulk of the heart wall is the thick, contractile, middle layer of specially constructed and arranged cardiac muscle cells called the *myocardium*. The minute structure of cardiac muscle has been described in Chapters 5 and 11. Recall that cardiac muscle tissue is composed of many branching cells that are joined into a continuous mass by *intercalated disks* (Figure 18-5). Because each intercalated disk includes many gap junctions, large areas of cardiac muscle are electrically coupled into a single functional unit called a *syncytium* (meaning “joined cells”). Because they form a syncytium, muscle cells can pass an action potential along a large area of the heart wall, stimulating contraction

in each muscle fiber of the syncytium. Another advantage of the syncytium structure is that the cardiac fibers form a continuous sheet of muscle that wraps entirely around the cavities within the heart. Thus the encircling myocardium can compress the heart cavities, and the blood within them, with great force.

Recall also that cardiac muscles are *autorhythmic*, meaning that they can contract on their own in a slow, steady rhythm. As we explained in Chapter 11, cardiac muscle cells cannot summate contractions to produce tetanus and thus do not fatigue—a useful characteristic for muscle tissue that must maintain a continuous cycle of alternating contraction and relaxation for the entire span of life. Because the mus-

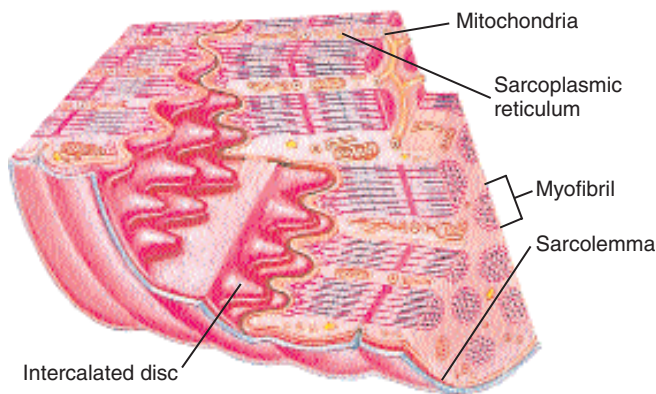


Figure 18-5 Cardiac muscle. This section of cardiac muscle tissue shows how cardiac muscle cells are joined to one another by intercalated disks. Compare this figure with Figure 11-19 on p. 329.

cular myocardium can contract powerfully and rhythmically, without fatigue, the heart is an efficient and dependable pump for blood.

Endocardium. The lining of the interior of the myocardial wall is a delicate layer of endothelial tissue known as the *endocardium*. *Endothelium* is the type of membranous tissue that lines the heart and blood vessels. Endothelium resembles simple squamous epithelium, except for the fact that during embryonic development endothelium arises from different tissue than does epithelium. Notice in Figure 18-4 that the endocardium covers beamlike projections of myocardial tissue. These muscular projections are called *trabeculae*. Specialized folds or pockets formed by the endocardium make up the functional components of the major valves that regulate the flow of blood through the chambers of the heart.

Chambers of the Heart

The interior of the heart is divided into four cavities, or heart chambers (Figure 18-6). The two upper chambers are called *atria* (singular, *atrium*), and the two lower chambers are called *ventricles*. The left chambers are separated from the right chambers by an extension of the heart wall called the *septum*.

Atria. The two superior chambers of the heart—the *atria*—are often called the “receiving chambers” because they receive blood from vessels called *veins*. Veins are the large blood vessels that return blood from various tissues to

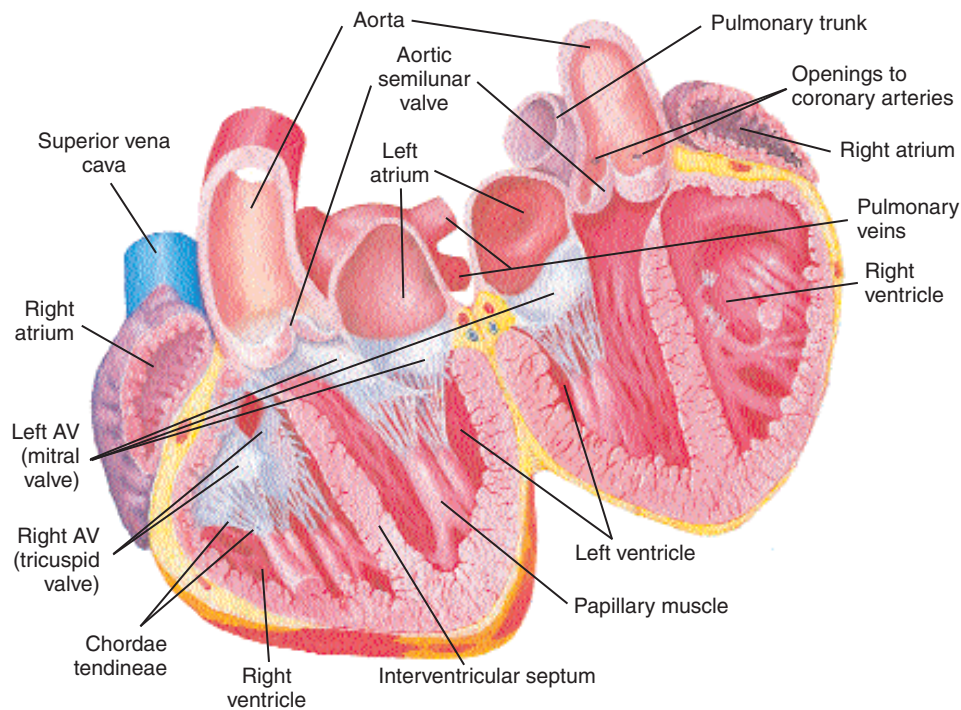


Figure 18-6 Interior of the heart. This illustration shows the heart as it would appear if it were cut along a frontal plane and opened like a book. The front portion of the heart lies to the reader's right; the back portion of the heart lies to the reader's left. The four chambers of the heart—two atria and two ventricles—are easily seen.

the heart so that the blood can be pumped out to tissues again. Figure 18-7 shows how the atria alternately relax and contract to receive blood, then push it into the lower chambers. Because the atria need not generate great pressure to move blood such a small distance, the myocardial wall of each atrium is not very thick.

If you look at Figure 18-2, A, you will notice that part of each atrium is labeled as an *auricle*. The term *auricle* (meaning “little ear”) refers to the earlike flap protruding from each atrium. Thus the auricles are *part of* the atria. The terms *auricle* and *atrium* should not be used synonymously.

Ventricles. The *ventricles* are the two lower chambers of the heart. Because the ventricles receive blood from the atria and pump blood out of the heart into arteries, the ventricles are considered to be the primary “pumping chambers” of the heart. Because more force is needed to pump blood such a distance, the myocardium of each ventricle is thicker than the myocardium of either atrium. The myocardium of the left ventricle is thicker than that of the right ventricle because the left ventricle pushes blood through most vessels of the body, whereas the right ventricle pushes blood only through the vessels that serve the gas exchange tissues of the lungs.

The pumping action of the heart chambers is summarized in Figure 18-7 and described further in Chapter 19.

Valves of the Heart

The heart valves are mechanical devices that permit the flow of blood in one direction only. Four sets of valves are of importance to the normal functioning of the heart (Figure 18-8;

see Figure 18-7). Two of these, the **atrioventricular (AV) valves**, guard the openings between the atria and the ventricles (atrioventricular orifices). The atrioventricular valves are also called **cuspid valves**. The other two heart valves, the **semilunar (SL) valves**, are located where the pulmonary artery and the aorta arise from the right and left ventricles, respectively.

Atrioventricular Valves. The atrioventricular valve guarding the right atrioventricular orifice consists of three flaps (cusps) of endocardium. The free edge of each flap is anchored to the *papillary muscles* of the right ventricle by several cordlike structures called **chordae tendineae**. Because the right atrioventricular valve has three flaps, it is also called the **tricuspid valve**. The valve that guards the left atrioventricular orifice is similar in structure to the right atrioventricular valve, except that it has only two flaps and is therefore also called the **bicuspid** or, more commonly, the **mitral valve**.

The construction of both atrioventricular valves allows blood to flow from the atria into the ventricles but prevents it from flowing back up into the atria from the ventricles. Ventricular contraction forces the blood in the ventricles hard against the valve flaps, closing the valves and thereby ensuring the movement of the blood upward into the pulmonary artery and aorta as the ventricles contract (see Figure 18-7).

Semilunar Valves. The semilunar valves consist of half-moon-shaped flaps growing out from the lining of the pulmonary artery and aorta. The semilunar valve at the entrance of the pulmonary artery (pulmonary trunk) is called the *pulmonary semilunar valve*. The semilunar valve at the entrance

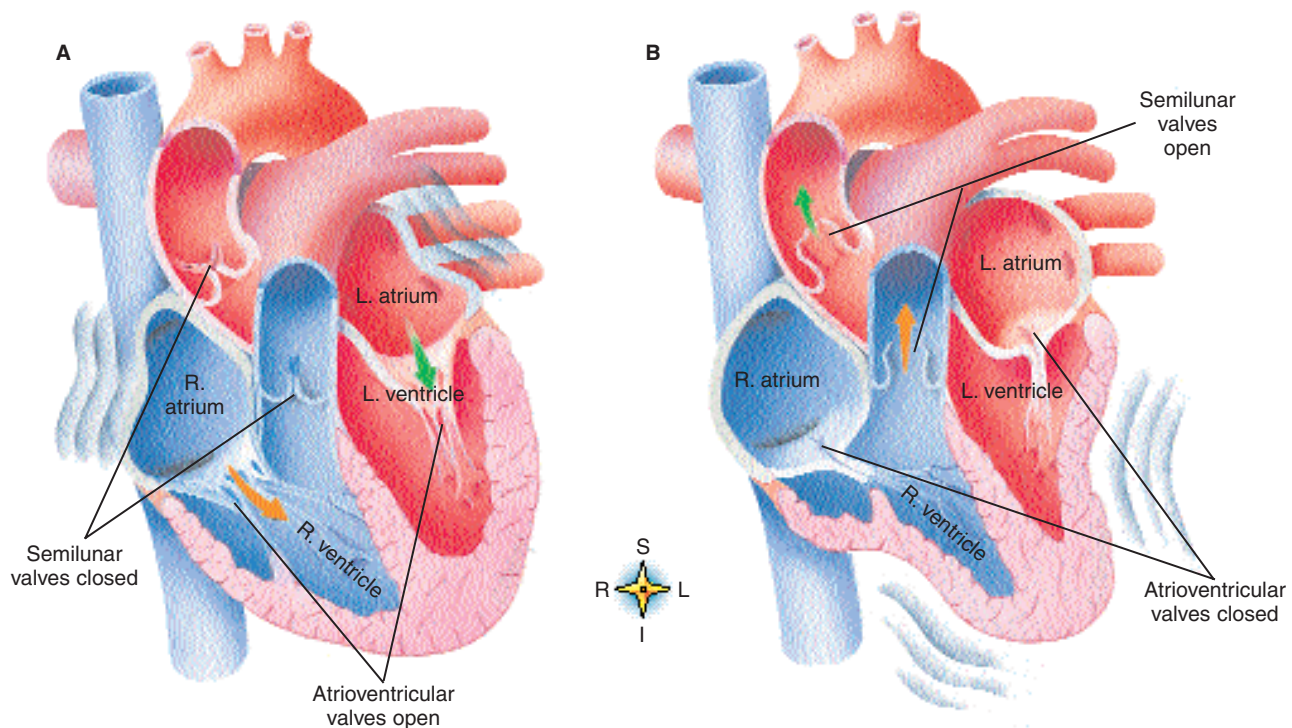


Figure 18-7 Chambers and valves of the heart. These illustrations depict the action of the heart chambers and valves when the atria contract (A) and when the ventricles contract (B).

of the aorta is called the *aortic semilunar valve*. When these valves are closed, as in Figures 18-7, *A*, and 18-8, *B*, blood fills the spaces between the flaps and the vessel wall. Each flap then looks like a tiny, filled bucket. Inflowing blood smooths the flaps against the blood vessel walls, collapsing the buckets and thereby opening the valves (see Figures 18-7, *B*, and 18-8, *C*). Closure of the semilunar valves, as of the atrioventricular valves, simultaneously prevents backflow and ensures forward flow of blood in places where there would otherwise be considerable backflow. Whereas the atrioventricular valves prevent blood from flowing back up into the atria from the ventricles, the semilunar valves prevent it from flowing back down into the ventricles from the aorta and pulmonary artery.

Skeleton of the Heart. Figure 18-8 shows the fibrous structure that is often called the *skeleton of the heart*. It is a

set of connected rings that serve as a semirigid support for the heart valves (on the inside of the rings) and for the attachment of cardiac muscle of the myocardium (on the outside of the rings). The skeleton of the heart also serves as an electrical barrier between the myocardium of the atria and the myocardium of the ventricles.

Surface Projection. When listening to the sounds of the heart on the body surface, as with a stethoscope, one must have an idea of the relationship between the valves of the heart and the surface of the thorax. Figure 18-9 indicates the surface relationship of the four heart valves and other features of the heart. It is important to remember, however, that considerable variation within the normal range makes a precise “surface projection” outline of the heart’s structure on the chest wall difficult.

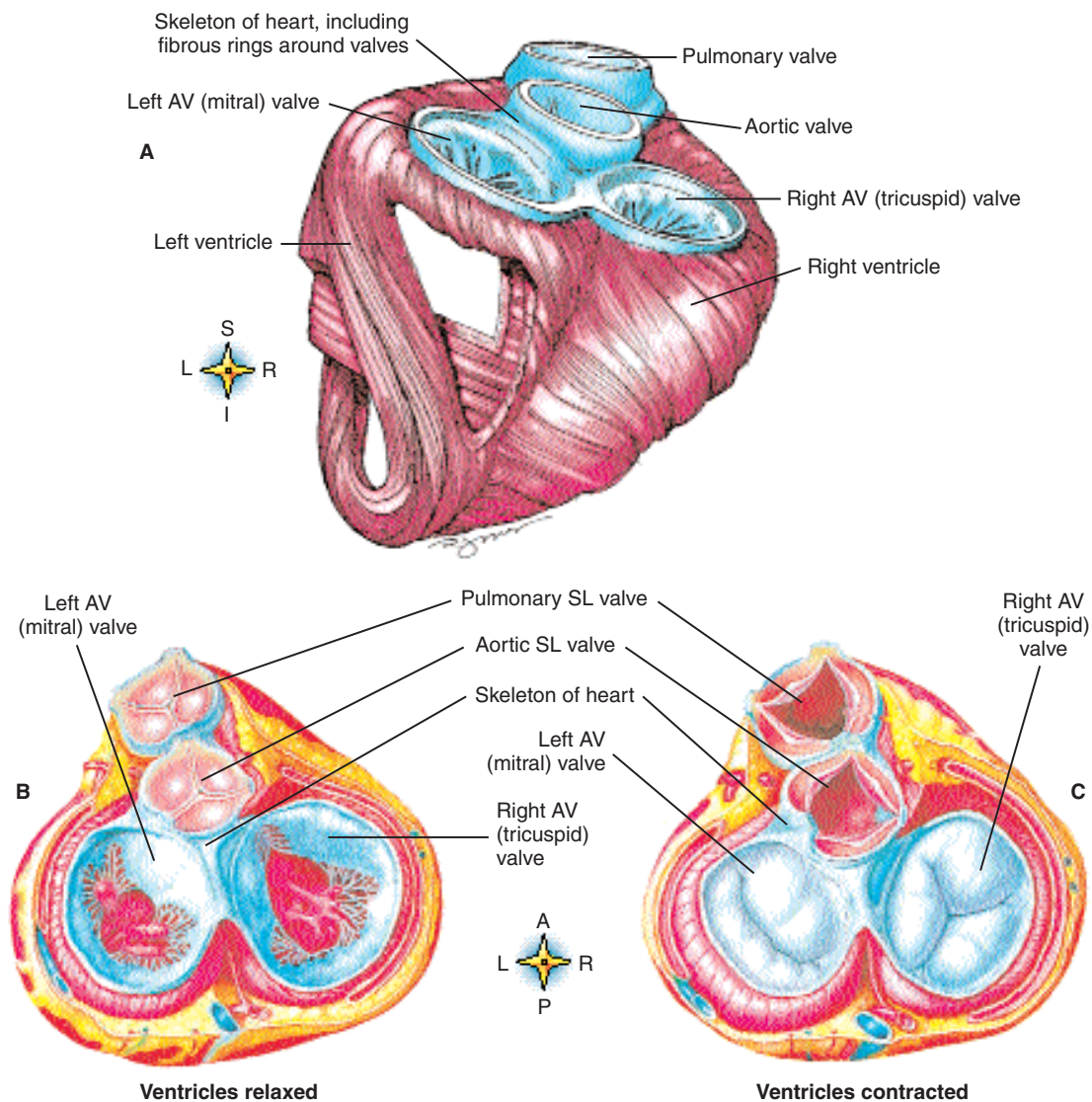


Figure 18-8 Structure of the heart valves. *A*, This posterior view shows part of the ventricular myocardium with the heart valves still attached. The rim of each heart valve is supported by a fibrous structure, called the skeleton of the heart, that encircles all four valves. *B*, This figure shows the heart valves as if the figure in *A* is viewed from above. Notice that the semilunar (SL) valves are closed and the atrioventricular (AV) valves are open, as when the atria are contracting (compare to Figure 18-7, *A*). *C*, This figure is similar to *B*, except that the semilunar valves are open and the atrioventricular valves are closed, as when the ventricles are contracting (compare to Figure 18-7, *B*).

Flow of Blood Through the Heart. To understand the functional anatomy of the heart and the rest of the cardiovascular system, one should be able to trace the flow of blood through the heart. As we take you through one complete pass through the right heart, then the left side of the heart, trace the path of blood flow with your finger, using Figure 18-7. We can trace the path of blood flow through the right side of the heart by beginning in the right atrium. From the right atrium, blood flows through the right atrioventricular (tricuspid) valve into the right ventricle. From the right ventricle, blood flows through the pulmonary semilunar valve into the first portion of the pulmonary artery, the pulmonary

trunk. The pulmonary trunk branches to form the left and right pulmonary arteries, which conduct blood to the gas exchange tissues of the lung. From there, blood flows through pulmonary veins into the left atrium.

We can begin to trace the path of blood flow through the left side of the heart from the left atrium. From the left atrium, blood flows through the left atrioventricular (mitral) valve into the left ventricle. From the left ventricle, blood flows through the aortic semilunar valve into the aorta. Branches of the aorta supply all the tissues of the body except the gas-exchange tissues of the lungs. Blood leaving the head and neck tissues empties into the superior vena cava, and blood leaving the lower body empties into the inferior vena cava. Both large vessels conduct blood into the right atrium, bringing us back to the point where we began.

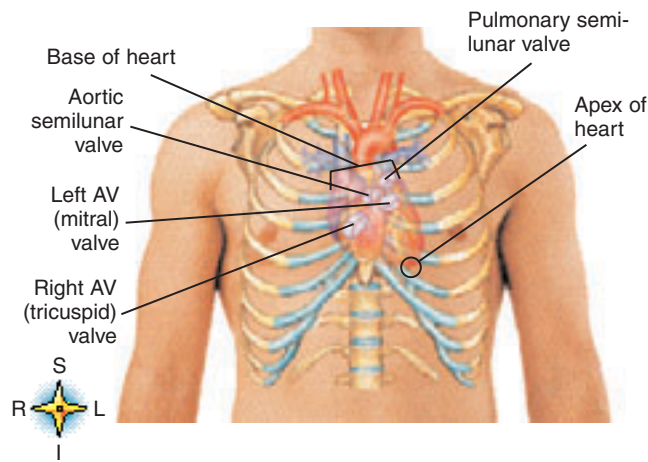


Figure 18-9 Relation of the heart to the anterior wall of the thorax. Valves of the heart are projected on the anterior thoracic wall.



1. Name the three layers of tissue that make up the wall of the heart. What is the function of each layer?
2. Name the four chambers of the heart and the valves associated with them.
3. How do atrioventricular valves differ from semilunar valves?

Blood Supply of Heart Tissue

Coronary Arteries. Myocardial cells receive blood by way of two small vessels, the right and left coronary arteries. Because the openings into these vitally important vessels lie behind flaps of the aortic semilunar valve, they come off of the aorta at its very beginning and are its first branches. Both right and left coronary arteries have two main branches, as shown in Figure 18-10, A.

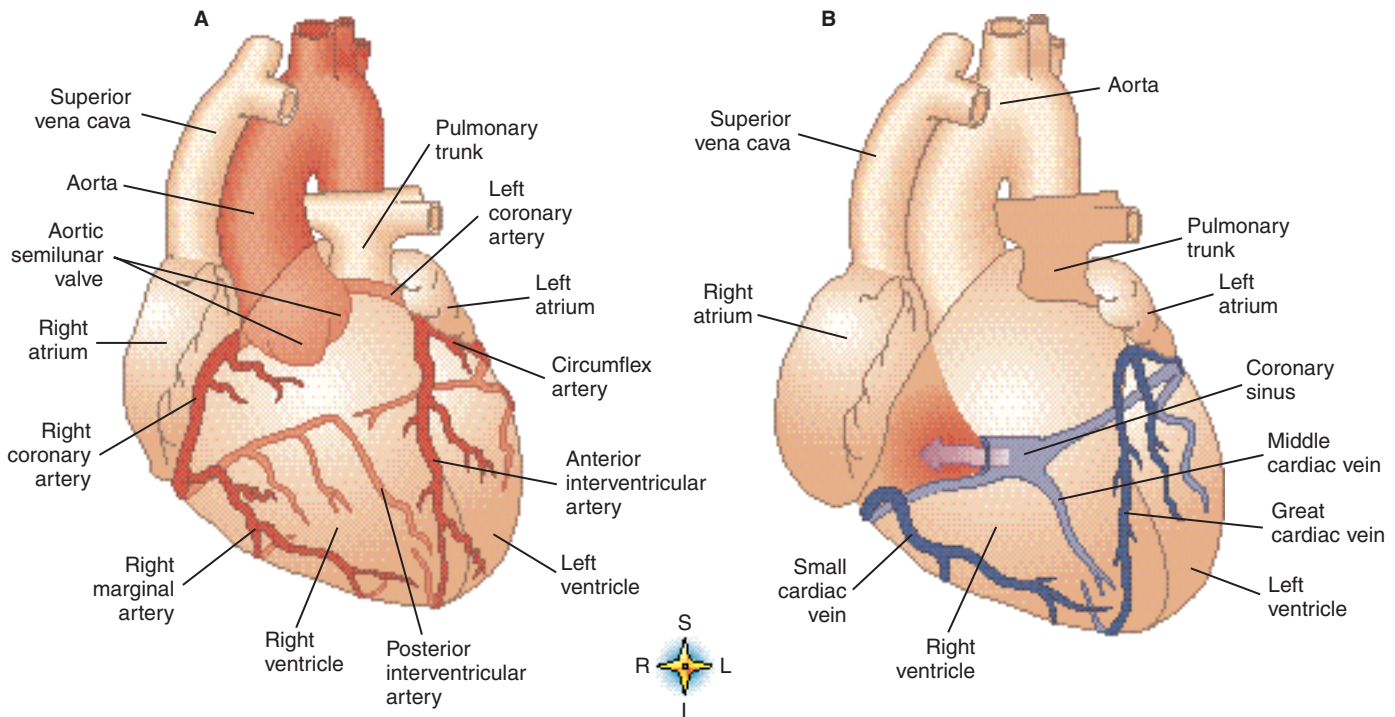


Figure 18-10 Coronary circulation. A, Arteries. B, Veins. Both illustrations are anterior views of the heart. Vessels near the anterior surface are more darkly colored than vessels of the posterior surface seen through the heart. (Clinicians often refer to the interventricular arteries as *descending* arteries. Thus the *left anterior descending artery* [LAD] is really the anterior interventricular artery.)

More than a half million Americans die every year from coronary disease, and another 3.5 million or more are estimated to suffer some degree of incapacitation. Knowledge about the distribution of coronary artery branches therefore has the utmost practical importance. Here, then, are some



Box 18-1 DIAGNOSTIC STUDY

Echocardiography

Echocardiography is a noninvasive technique for evaluating the internal structures and motions of the heart and great vessels. Ultrasound beams are directed into the patient's chest by a transducer. The transducer then acts as a receiver of the ultrasonic waves, or "echoes," to form images.

The images produced from the echoes are transmitted to a monitor. Echocardiography graphically demonstrates overall cardiac performance. It shows the internal dimensions of the chambers, size and motion of the intraventricular septum and posterior left ventricular wall, valve motion and anatomy, direction of blood flow, and presence of increased pericardial fluid, blood clots, and cardiac tumors.

Three echocardiographic techniques are used in clinical practice. All use a transducer that emits ultrasonic pulses through the chest wall and receives echoes from the cardiac structures.

- **M-mode (motion-mode) echocardiography** produces an "ice-pick" image of a narrow area within the ultrasonic beam. It shows the position and motion of cardiac structures.
- **Two-dimensional (2-D) echocardiography** produces a cross-sectional view and real time motion of cardiac structures. It allows the ultrasonic beam to move quickly, showing the structures and lateral movement. Together this shows the spatial relationship between the heart structures. Numerous views are possible with 2-D echocardiography.

Echocardiography is used to diagnose valvular heart disease, congenital heart disease, cardiomyopathy, congestive heart failure, pericardial disease, cardiac tumors, and intracardiac thrombi. It is also used to evaluate the function of the left ventricle after a myocardial infarction and the presence of pericardial fluid.

Doppler ultrasonography provides continuous waves but also uses a sound, or frequency ultrasound, to record the direction of blood flow through the heart. These sound waves are reflected off red blood cells as they pass through the heart, allowing the velocity of blood to be calculated as it travels through the heart chambers.

Color Doppler mapping is a variation that converts recorded flow frequencies into different colors. These color images are then superimposed on M-mode or 2-D echocardiograms, allowing more detailed evaluation of disorders.

principles about the heart's own blood supply that are worth noting:

- Both ventricles receive their blood supply from branches of the right and left coronary arteries.
- Each atrium, in contrast, receives blood only from a small branch of the corresponding coronary artery.
- The most abundant blood supply goes to the myocardium of the left ventricle—an appropriate amount, because the left ventricle does the most work and so needs the most oxygen and nutrients delivered to it.
- The right coronary artery is dominant in about 50% of all hearts; the left coronary artery is dominant in about 20%; and in about 30%, neither right nor left coronary artery dominates.

Another fact about the heart's own blood supply—one of life-and-death importance—is that only a few connections, or anastomoses, exist between the larger branches of the coronary arteries. An *anastomosis* consists of one or more branches from the proximal part of an artery to a more distal part of itself or of another artery. Thus anastomoses provide detours in which arterial blood can travel if the main route becomes obstructed. In short, they provide collateral circulation to a part. This explains why the scarcity of anastomoses between larger coronary arteries looms so large as a threat to life. If, for example, a blood clot plugs one of the larger coronary artery branches, as it frequently does in coronary thrombosis or embolism, too little or no blood can reach some of the heart muscle cells. They become ischemic, in other words. Deprived of oxygen, metabolic function is impaired and cell survival is threatened. **Myocardial infarction** (death of ischemic heart muscle cells) soon results. There is another anatomical fact, however, that brightens the picture somewhat: many anastomoses exist between very small arterial vessels in the heart, and, given time, new ones develop and provide collateral circulation to ischemic areas. In recent years, several surgical procedures have been devised to aid this process (see Figure 18-34, p. 585).



Box 18-2 DIAGNOSTIC STUDY

Cardiac Enzyme Studies

When the heart muscle is damaged, enzymes contained within the muscle cells are released into the bloodstream, causing increased serum levels. Studies of cardiac enzymes (CPK, AST, LDH) are useful in confirming a myocardial infarction (MI) when they are viewed in relation to other heart function tests and the complete medical examination. The rate of release and distribution of specific enzymes over time vary after an infarction. It is this pattern of enzyme elevation that is of diagnostic importance. Enzyme determinations are also useful in following the course of a myocardial infarction and in detecting an extension of it.

Cardiac Veins. After blood has passed through capillary beds in the myocardium, it enters a series of cardiac veins before draining into the right atrium through a common venous channel called the *coronary sinus*. Several veins that collect blood from a small area of the right ventricle do not end in the coronary sinus but instead drain directly into the right atrium. As a rule, the cardiac veins (see Figure 18-10) follow a course that closely parallels that of the coronary arteries.

Conduction System of the Heart

Four structures—the **sinoatrial node**, **atrioventricular node**, **atrioventricular bundle**, and **Purkinje fibers**—compose the conduction system of the heart. Each of these structures consists of cardiac muscle modified enough in structure to differ in function from ordinary cardiac muscle. The main specialty of ordinary cardiac muscle is contraction. In this, it is like all muscle, and like all muscle, ordinary cardiac muscle can also conduct impulses. However, conduction alone is the specialty of the modified cardiac muscle that composes the conduction system structures.

Sinoatrial Node. The sinoatrial node (SA node, or pacemaker) consists of hundreds of cells located in the right atrial wall near the opening of the superior vena cava (Figure 18-11).

Atrioventricular Node. The atrioventricular node (AV node or node of Tawara), a small mass of special cardiac muscle tissue, lies in the right atrium along the lower part of the interatrial septum.

Atrioventricular Bundle and Purkinje Fibers. The atrioventricular bundle (AV bundle or bundle of His) is a bundle of special cardiac muscle fibers that originate in the AV node and extend by two branches down the two sides of the interventricular septum. From there, they continue as the Purkinje fibers. The latter extend out to the lateral walls of the ventricles and papillary muscles. The functioning of the conduction system of the heart is discussed in Chapter 19.

Nerve Supply of the Heart

Both divisions of the autonomic nervous system send fibers to the heart. Sympathetic fibers (contained in the middle, superior, and inferior cardiac nerves) and parasympathetic fibers (in branches of the vagus nerve) combine to form cardiac plexuses located close to the arch of the aorta. From the cardiac plexuses, fibers accompany the right and left coronary arteries to enter the heart. Here most of the fibers terminate in the sinoatrial node, but some end in the atrioventricular node and in the atrial myocardium. Sympathetic nerves to the heart are also called *accelerator nerves*. Vagus fibers to the heart serve as *inhibitory* or *depressor nerves*.



1. Briefly describe the general structure and the function of the coronary circulation. Why is an understanding of the coronary circulation so critical to understanding major types of heart disease?

2. What is meant by the term *conduction system of the heart*?



Box 18-3 DIAGNOSTIC STUDY

Cardiac Nuclear Scanning

Cardiac nuclear scanning is a safe method of recognizing cardiac diseases. Basically, it is used to evaluate blood flow in coronary arteries or to evaluate ventricular function. The patient is given an intravenous (IV) injection of an appropriate radioactive substance. Shortly thereafter, a gamma-ray detector is placed over the heart while the patient is lying down. The detector records the image of the heart, and a Polaroid photograph of that image is taken. The only discomfort for the patient is the initial injection.

Cardiac scanning is used for various clinical situations, particularly the following: (1) screening, evaluation, and surveillance of adults for old and new myocardial infarctions; (2) evaluating chest pain or unusual results from other heart tests; and (3) evaluation of bypass surgery or therapy.

These studies are nearly free of complications. The era of noninvasive myocardial radioscanning is just beginning; these tests will undoubtedly be a vital part of the evaluation of many patients with myocardial disease.

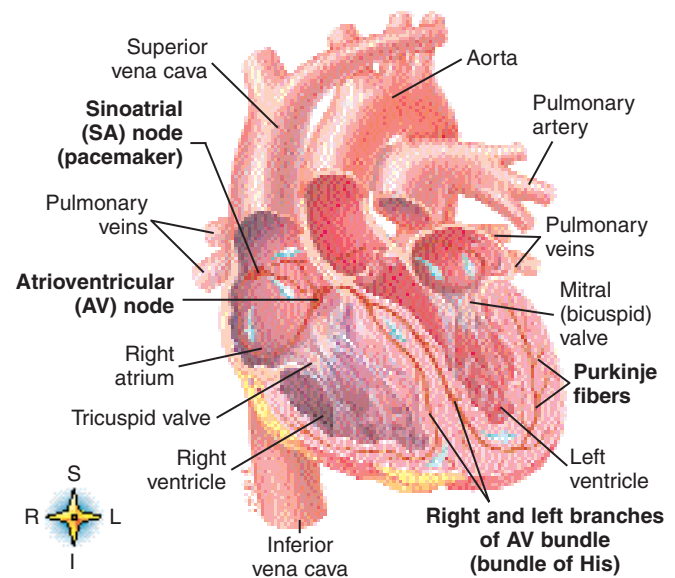


Figure 18-11 Conduction system of the heart. Specialized cardiac muscle cells in the wall of the heart rapidly conduct an electrical impulse throughout the myocardium. The signal is initiated by the SA node (pacemaker) and spreads to the rest of the atrial myocardium and to the AV node. The AV node then initiates a signal that is conducted through the ventricular myocardium by way of the AV bundle (of His) and Purkinje fibers.

BLOOD VESSELS

TYPES OF BLOOD VESSELS

There are three kinds of blood vessels: arteries, veins, and capillaries. An *artery* is a vessel that carries blood away from the heart. After birth all arteries except the pulmonary artery and its branches carry oxygenated blood. Small arteries are called *arterioles*.

A *vein*, on the other hand, is a vessel that carries blood toward the heart. All of the veins except the pulmonary veins contain deoxygenated blood. Small veins are called *venules*. Often, very large venous spaces are called *sinuses*. Both arteries and veins are macroscopic structures; that is, they can be seen without the aid of a microscope.

Capillaries are microscopic vessels that carry blood from small arteries to small veins, that is, from arterioles to venules. Irregular, microscopic spaces in the liver and a few other places in the body that take the place of capillaries are called sinusoids. Capillaries and sinusoids represented the “missing link” in the proof of circulation for many years—from the time William Harvey first declared that blood circulated from the heart through arteries to veins and back to

the heart until the time that microscopes made it possible to find these connecting vessels between arteries and veins. Many people rejected Harvey’s theory of circulation on the basis that there was no possible way for blood to get from arteries to veins. The discovery of the capillaries formed the final proof that the blood actually does circulate from the heart into arteries to arterioles, to capillaries, to venules, to veins, and back to the heart.

STRUCTURE OF BLOOD VESSELS

Outer Layer

The walls of the larger blood vessels, the arteries and veins, have three layers (Figure 18-12 and Table 18-1). The outermost layer is called the *tunica adventitia*. This Latin name literally means “coat that comes first,” referring to how it is found during the dissection of a vessel. The tunica adventitia is made of strong, flexible fibrous connective tissue. This layer helps hold vessels open and prevents tearing of the vessel walls during body movements. In veins, the tunica adventitia is the thickest of the three layers of the venous wall. In arteries, it is usually a little thinner than the middle layer of the arterial wall.

Table 18-1 Structure of Blood Vessels

Type of Vessel	Tunica Intima (Endothelium)	Tunica Media (Smooth Muscle; Elastic Connective Tissue)	Tunica Adventitia (Fibrous Type of Vessel Connective Tissue)
Arteries	Smooth lining	Allows constriction and dilation of vessels; thicker than in veins; muscle innervated by autonomic fibers	Provides flexible support that resists collapse or injury; thicker than in veins; thinner than tunica media
Veins	Smooth lining with semilunar valves to ensure one-way flow	Allows constriction and dilation of vessels; thinner than in arteries; muscle innervated by autonomic fibers	Provides flexible support that resists collapse or injury; thinner than in arteries; thicker than tunica media
Capillaries	Makes up entire wall of capillary; thinness permits ease of transport across vessel wall	(Absent)	(Absent)

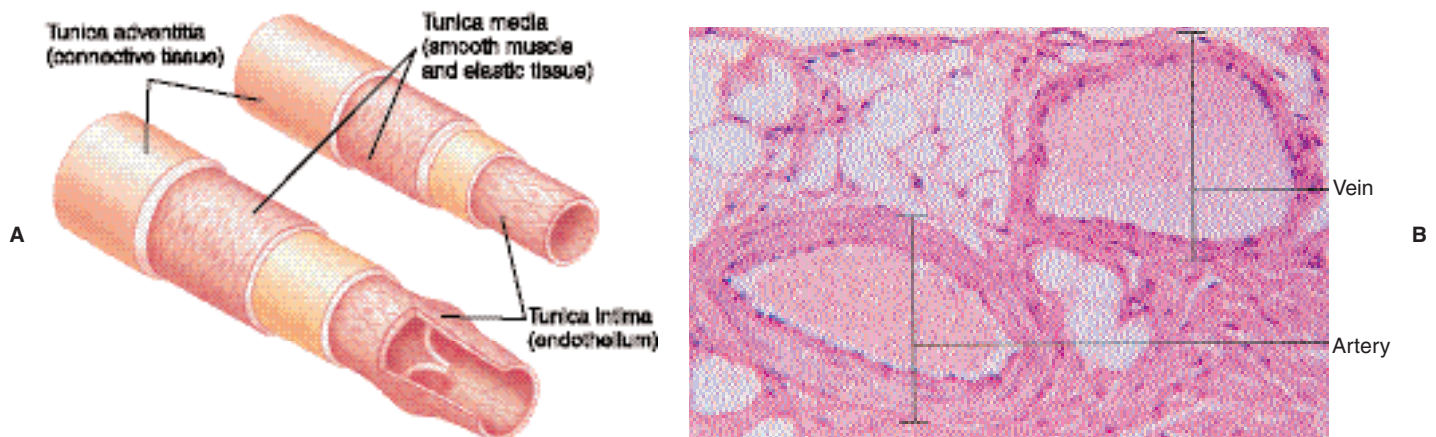


Figure 18-12 Structure of blood vessels. A, Drawings of a sectioned artery and vein show the three layers of large vessel walls. The outermost, *tunica adventitia*, is made of connective tissue; the middle, *tunica media*, is made of smooth muscle and elastic connective tissue; and the innermost, *tunica intima*, is made of endothelium. B, This light micrograph of a cross section of tissue contains an artery (left) and a vein (right). Note the prominence of the smooth muscle (*tunica media*) in the artery compared to the vein.

Middle Layer

The middle layer, or **tunica media** (Latin for “middle coat”), is made of a layer of smooth muscle tissue sandwiched together with a layer of elastic connective tissue. Some anatomists consider the elastic portion of the tunica media to be distinct enough to call it a separate *elastic layer* of the wall. The encircling smooth muscles of the tunica media permit changes in blood vessel diameter. The smooth muscle tissue of the tunica media is innervated by autonomic nerves and supplied with blood by tiny *vasa vasorum* (“vessels of vessels”). As a rule, arteries have a thicker layer of smooth muscle than do veins.

Inner Layer

The innermost layer of a blood vessel is called the *tunica intima*—Latin for “innermost coat.” The tunica intima is made up of endothelium that is continuous with the endothelium that lines the heart. In arteries, the endothelium provides a completely smooth lining. In veins, however, the endothelium also forms semilunar valves that help maintain the one-way flow of blood. As blood vessels decrease in diameter, the relative thickness of their walls also decreases. The smallest of the vessels, the capillaries, have only one thin coat: the endothelium. This structure is important because the thinness of the capillary wall allows for efficient exchange of materials between the blood plasma and the interstitial fluid of the surrounding tissues. In fact, the cells that make up the wall of some capillaries have numerous holes or *fenestrations* (Latin, “windows”) that permit the easy flow of fluid and solutes across the capillary wall. We will discuss the role of these fenestrated capillary walls as filtration membranes in more detail when we discuss the kidney in Chapter 28.

FUNCTIONS OF BLOOD VESSELS

The functions of the different types of blood vessels are determined by their structure. As you read through the following paragraphs, notice how the physical characteristics of each vessel type affect function.

Functions of Capillaries

The capillaries, although seemingly the most insignificant of the three kinds of blood vessels because of their diminutive size, nevertheless are the most important vessels functionally. Because the prime function of blood is to transport essential materials to and from the cells and because the actual delivery and collection of these substances take place in the capillaries, the capillaries must be regarded as the most important blood vessels.

Although capillaries are very tiny (on the average, only 1 mm long, or about $\frac{1}{25}$ inch), their numbers are so great as to be incomprehensible. Someone has calculated that if these microscopic tubes were joined end to end, they would extend almost 100,000 kilometers (62,000 miles), despite the fact that it takes 10 of them to reach a single centimeter. According to one estimate, 1 cubic centimeter of muscle tissue contains more than 100,000 of these important little vessels—that’s 1.5 million per cubic inch of tissue. None of the billions of cells composing the body lies very far removed from a capillary. The advantage of this lavish distribution of capillaries is, of course, apparent in view of their function of keeping the cells supplied with vital materials and rid of injurious wastes. As a matter of fact, capillaries are often called the *primary exchange vessels* of the cardiovascular system.

Yet another mechanism that promotes the efficient exchange between capillary blood and the surrounding tissue fluid is that capillaries are so numerous and so small that blood flows at its slowest rate while passing through the capillaries. Slow blood flow ensures the maximum contact time between blood and tissue. Add to this the thin-walled nature of the capillary, even the presence of fenestrations in some capillaries, and one can see how perfectly the structure of capillaries is suited to their function.

This flow of blood through the capillary bed is referred to as the **microcirculation**. Figure 18-13 shows the anatomical components of microcirculation: arterioles, capillaries, and venules.

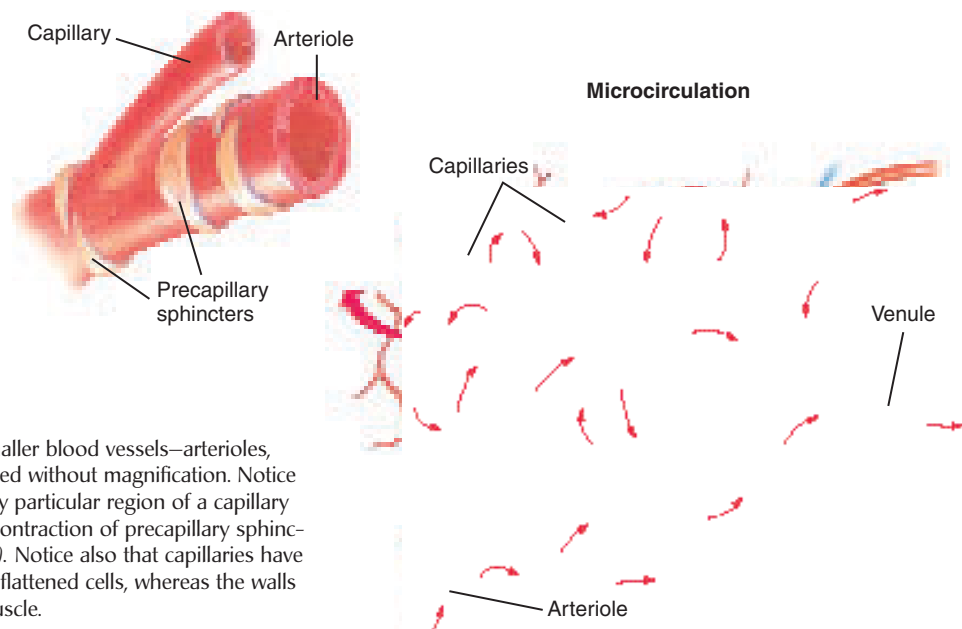


Figure 18-13 Microcirculation. The smaller blood vessels—arterioles, capillaries, and venules—cannot be observed without magnification. Notice that the control of blood flow through any particular region of a capillary network can be regulated by the relative contraction of precapillary sphincters in the walls of the arterioles (see inset). Notice also that capillaries have a wall composed of only a single layer of flattened cells, whereas the walls of the larger vessels also have smooth muscle.

Functions of Arteries

Arteries serve mainly as “distributors,” carrying the blood to the arterioles. Arterioles, too, serve as distributors, carrying blood from arteries to capillaries. But arterioles perform an additional function, one that is of great importance for maintaining normal blood pressure and circulation. They serve as the *resistance vessels* of the cardiovascular system.

Note in Figure 18-13 that the individual smooth muscle cells in the walls of arterioles act as **precapillary sphincters** near the point at which a capillary originates. These sphincters function as regulatory valves that reduce the flow of blood through a network of capillaries when they contract and constrict the arterioles. Precapillary sphincters increase the flow of blood through a tissue when they relax and dilate the arterioles. The concept of flow resistance and its relationship to blood vessel diameter are discussed further in Chapter 19.

Functions of Veins

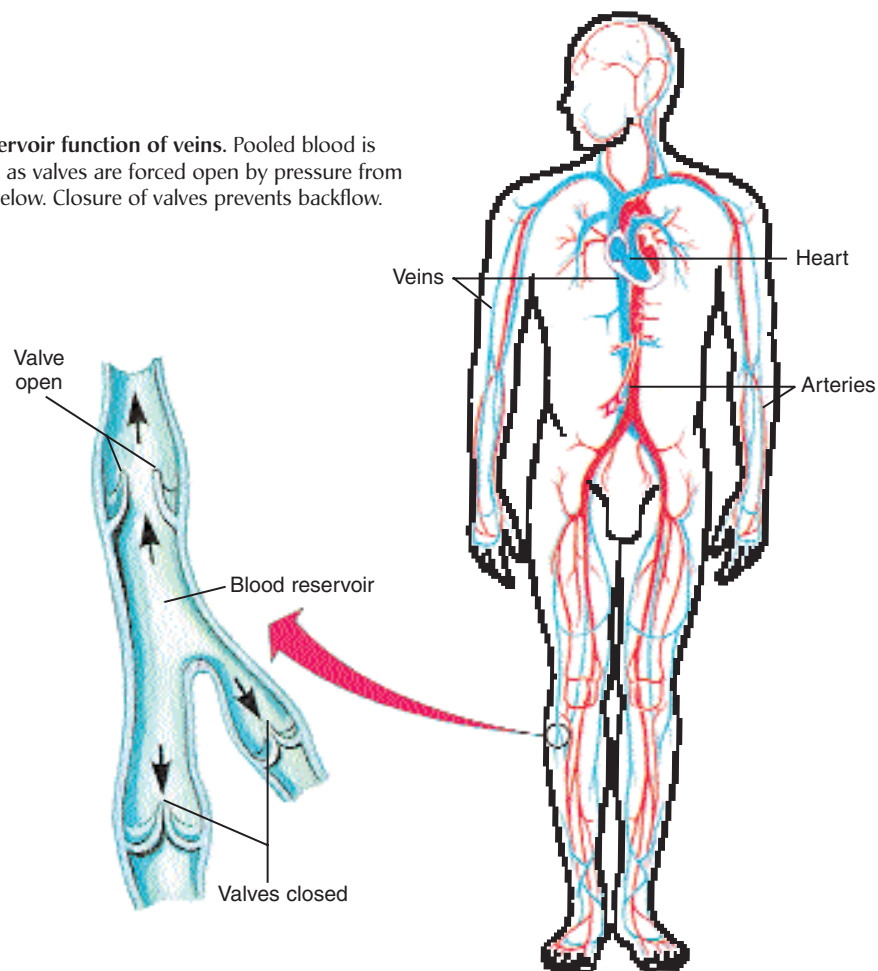
Veins function both as collectors and as reservoir vessels. They not only return blood from the capillaries to the heart, but they also can accommodate varying amounts of blood. The structural feature that allows them to accommodate varying amounts of blood, with almost no change in blood pressure,

is their great ability to stretch. Ease of stretch is also called **capacitance**, and for this reason the veins are often referred to as the *capacitance vessels* of the cardiovascular system. The reservoir function of veins, which we shall discuss later, plays an important part in maintaining normal circulation.

Figure 18-14 illustrates the potential for pooling of blood between valves in one segment of a vein. Pooled blood in each valved segment is moved toward the heart by the pressure from the moving volume of blood from below. The heart acts as the primary “pump,” keeping the blood moving through this circuit of vessels—arteries, arterioles, capillaries, venules, and veins. In short, the entire circulatory mechanism pivots around one essential function, that of keeping the capillaries supplied with an amount of blood adequate to the changing needs of the cells. All the factors governing circulation operate to maintain this function.

1. Name the three major types of blood vessels.
2. How does the structure of each major type of vessel differ from the other types?
3. How does the function of capillaries relate to the structure of their walls?

Figure 18-14 The reservoir function of veins. Pooled blood is moved toward the heart as valves are forced open by pressure from volume of blood from below. Closure of valves prevents backflow.



MAJOR BLOOD VESSELS

CIRCULATORY ROUTES

The term *circulation of blood* suggests its meaning, namely, blood flow through vessels arranged to form a circuit or circular pattern. Blood flow from the heart (left ventricle) through blood vessels to all parts of the body (except the lungs) and back to the heart (to the right atrium) is spoken of as *systemic circulation*. The left ventricle pumps blood into the ascending aorta. From here it flows into arteries that carry it into the various tissues and organs of the body. Within each structure, blood moves, as indicated in Figure 18-15 (see also Figure 18-13), from arteries to arterioles to capillaries. Here the vital two-way exchange of substances occurs between the blood and cells. Blood flows next out of each organ by way of its venules and then its veins to drain eventually into the inferior or superior vena cava. These two great veins of the body return venous blood to the heart (to the right atrium) to complete the systemic circulation. But the blood does not quite come full circle back to its starting point, the left ventricle. To do this and start on its way again, it must first flow through another circuit, the *pulmonary circulation*. Observe in Figure 18-15 that venous blood moves from the right atrium to the right ventricle to the pulmonary artery to lung arterioles and capillaries (see also Figure 18-7). Here, exchange of gases between blood and air takes place, converting deoxygenated

blood to oxygenated blood. This oxygenated blood then flows on through lung venules into four pulmonary veins and returns to the left atrium of the heart. From the left atrium it enters the left ventricle to be pumped again through the systemic circulation.

SYSTEMIC CIRCULATION

The systemic circulatory route includes most of the vessels of the body. The following paragraphs, tables, and illustrations outline some of the major vessels of the systemic circulation as well as tips for understanding this circulatory route.

Systemic Arteries

Locate the arteries listed in Table 18-2 (see also Figures 18-16 to 18-21). You may find it easier to learn the names of blood vessels and the relation of the vessels to each other from diagrams and tables than from narrative descriptions.

General Principles About Arteries. As you learn the names of the main arteries, keep in mind that these are only the major pipelines distributing blood from the heart to the various organs and that, in each organ, the main artery resembles a tree trunk in that it gives off numerous branches that continue to branch and rebranch, forming ever smaller vessels (arterioles), which also branch, forming microscopic vessels, the capillaries. In other words, most arteries eventu-

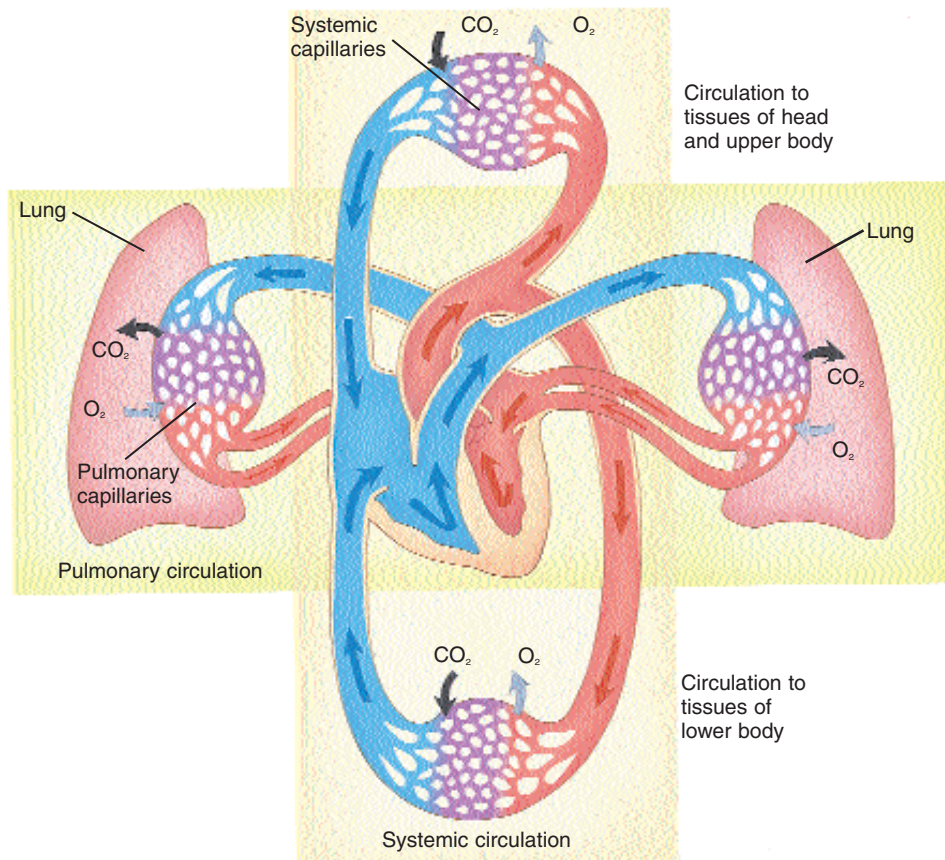


Figure 18-15 Blood flow through the circulatory system. In the pulmonary circulatory route, blood is pumped from the right side of the heart to the gas exchange tissues of the lungs. In the systemic circulation, blood is pumped from the left side of the heart to all other tissues of the body.

Table 18-2 Major Systemic Arteries

Artery*	Region Supplied	Artery*	Region Supplied
Ascending Aorta		Descending Abdominal Aorta	
Coronary arteries	Myocardium	Visceral branches	Abdominal viscera
Arch of Aorta		Celiac artery (trunk)	Abdominal viscera
Brachiocephalic (innominate)	Head and upper extremity	Left gastric	Stomach, esophagus
Right subclavian	Head, upper extremity	Common hepatic	Liver
Right vertebral†	Spinal cord, brain	Splenic	Spleen, pancreas, stomach
Right axillary (continuation of subclavian)	Shoulder, chest, axillary region	Superior mesenteric	Pancreas, small intestine, colon
Right brachial (continuation of axillary)	Arm and hand	Inferior mesenteric	Descending colon, rectum
Right radial	Lower arm and hand (lateral)	Suprarenal	Adrenal (suprarenal) gland
Right ulnar	Lower arm and hand (medial)	Renal	Kidney
Superficial and deep palmar arches (formed by anastomosis of branches of radial and ulnar)	Hand and fingers	Ovarian	Ovary, uterine tube, ureter
Digital	Fingers	Testicular	Testis, ureter
Right common carotid	Head and neck	Parietal branches	Walls of abdomen
Right internal carotid†	Brain, eye, forehead, nose	Inferior phrenic	Inferior surface of diaphragm, adrenal gland
Right external carotid†	Thyroid, tongue, tonsils, ear, etc.	Lumbar	Lumbar vertebrae and muscles of back
Left subclavian	Head and upper extremity	Median sacral	Lower vertebrae
Left vertebral†	Spinal cord, brain	Common iliac (formed by terminal branches of aorta)	Pelvis, lower extremity
Left axillary (continuation of subclavian)	Shoulder, chest, axillary region	External iliac	Thigh, leg, foot
Left brachial (continuation of axillary)	Arm and hand	Femoral (continuation of external iliac)	Thigh, leg, foot
Left radial	Lower arm and hand (lateral)	Popliteal (continuation of femoral)	Leg, foot
Left ulnar	Lower arm and hand (medial)	Anterior tibial	Leg, foot
Superficial and deep palmar arches (formed by anastomosis of branches of radial and ulnar)	Hand and fingers	Posterior tibial	Leg, foot
Digital	Fingers	Plantar arch (formed by anastomosis of branches of anterior and posterior tibial arteries)	Foot, toes
Left common carotid	Head and neck	Digital	Toes
Left internal carotid†	Brain, eye, forehead, nose	Internal iliac	Pelvis
Left external carotid†	Thyroid, tongue, tonsils, ear, etc.	Visceral branches	Pelvic viscera
Descending Thoracic Aorta		Middle rectal	Rectum
Visceral branches	Thoracic viscera	Vaginal	Vagina, uterus
Bronchial	Lungs, bronchi	Uterine	Uterus, vagina, uterine tube, ovary
Esophageal	Esophagus	Parietal branches	Pelvic wall and external regions
Parietal branches	Thoracic walls	Lateral sacral	Sacrum
Intercostal	Lateral thoracic walls (rib cage)	Superior gluteal	Gluteal muscles
Superior phrenic	Superior surface of diaphragm	Obturator	Pubic region, hip joint, groin
		Internal pudendal	Rectum, external genitals, floor of pelvis
		Inferior gluteal	Lower gluteal region, coccyx, upper thigh

*Branches of each artery are indented below its name.

†See text and/or figures for branches of the artery.

ally diverge into capillaries. Arteries of this type are called **end-arteries**. Important organs or areas of the body supplied by end-arteries are subject to serious damage or death in occlusive arterial disease. As an example, permanent blindness results when the central artery of the retina, an end-artery, is occluded. Therefore occlusive arterial disease such as atherosclerosis is of great concern in clinical medicine when it affects important organs having an end-arterial blood supply.

A few arteries open into other branches of the same or other arteries. Such a communication is termed an **arterial anastomosis**. Anastomoses, we have already noted, fulfill an important protective function in that they provide detour routes for blood to travel in the event of obstruction of a main artery. The incidence of arterial anastomoses increases as distance from the heart increases, and smaller arterial

branches tend to anastomose more often than larger vessels. Examples of arterial anastomoses are the palmar and plantar arches. Other examples are found around several joints, as well as in other locations.

Another general principle to remember as you study the systemic arteries is that the **aorta** is the major artery that serves as the main trunk of the entire systemic arterial system. Notice in Figures 18-16 and 18-17 that different seg-

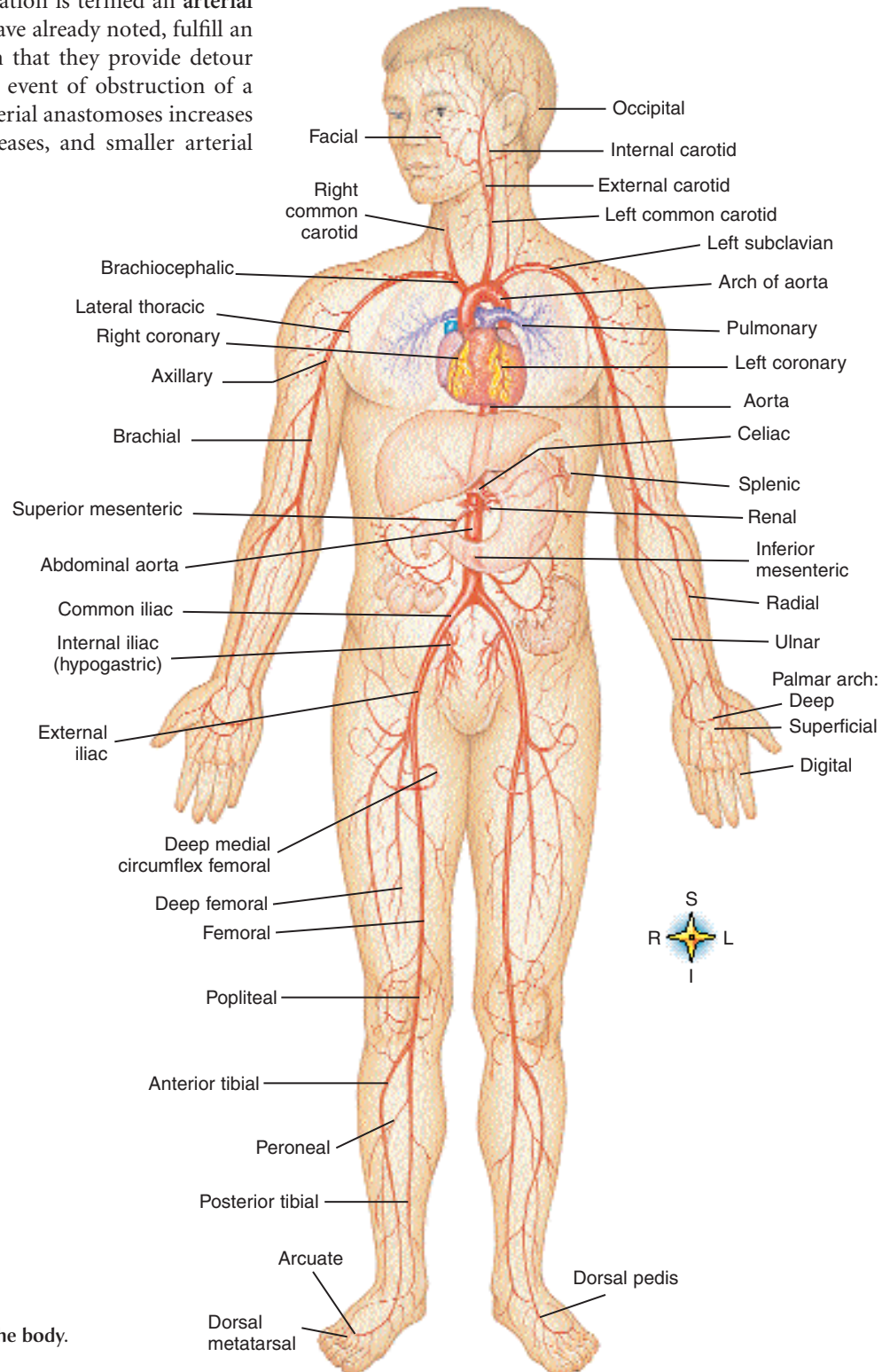


Figure 18-16 Principal arteries of the body.

ments of the aorta are known by different names. Because the first few centimeters of the aorta conduct blood upward out of the left ventricle, this region is known as the **ascending aorta**. The aorta then turns 180 degrees, forming a curved segment called the *arch of the aorta* or simply **aortic arch**. Arterial blood is conducted downward from the arch of the aorta through the **descending aorta**. The descending aorta passes through the thoracic cavity, where it is known as the **thoracic aorta**, to the abdominal cavity, where it is known as the **abdominal aorta**. If you check Table 18-2 or Figure 18-16 you will notice that all systemic arteries branch from the aorta or one of its branches.

Look again at Figures 18-16 and 18-17. Notice how the main branches from the arch of the aorta are different on the right compared to the left. The right side of the head and neck are supplied by the **brachiocephalic artery**, which

branches to become the **right subclavian artery** and **right common carotid artery**. On the left, however, the **left subclavian artery** and the **left common carotid artery** branch directly from the arch of the aorta—without an intervening brachiocephalic artery.

Arteries of the Head and Neck. Figure 18-18 shows the major arteries of the head, neck, and face. Trace the branching of arteries in the figure with your finger as you read through Table 18-2. Notice in this figure how the right and left vertebral arteries extend from their origin as branches of the subclavian arteries up the neck, through foramina in the transverse processes of the cervical vertebrae, through the foramen magnum and into the cranial cavity. Next, take a look at Figure 18-19, which shows the arteries at the base of the brain. Note how the vertebral arteries unite on the un-

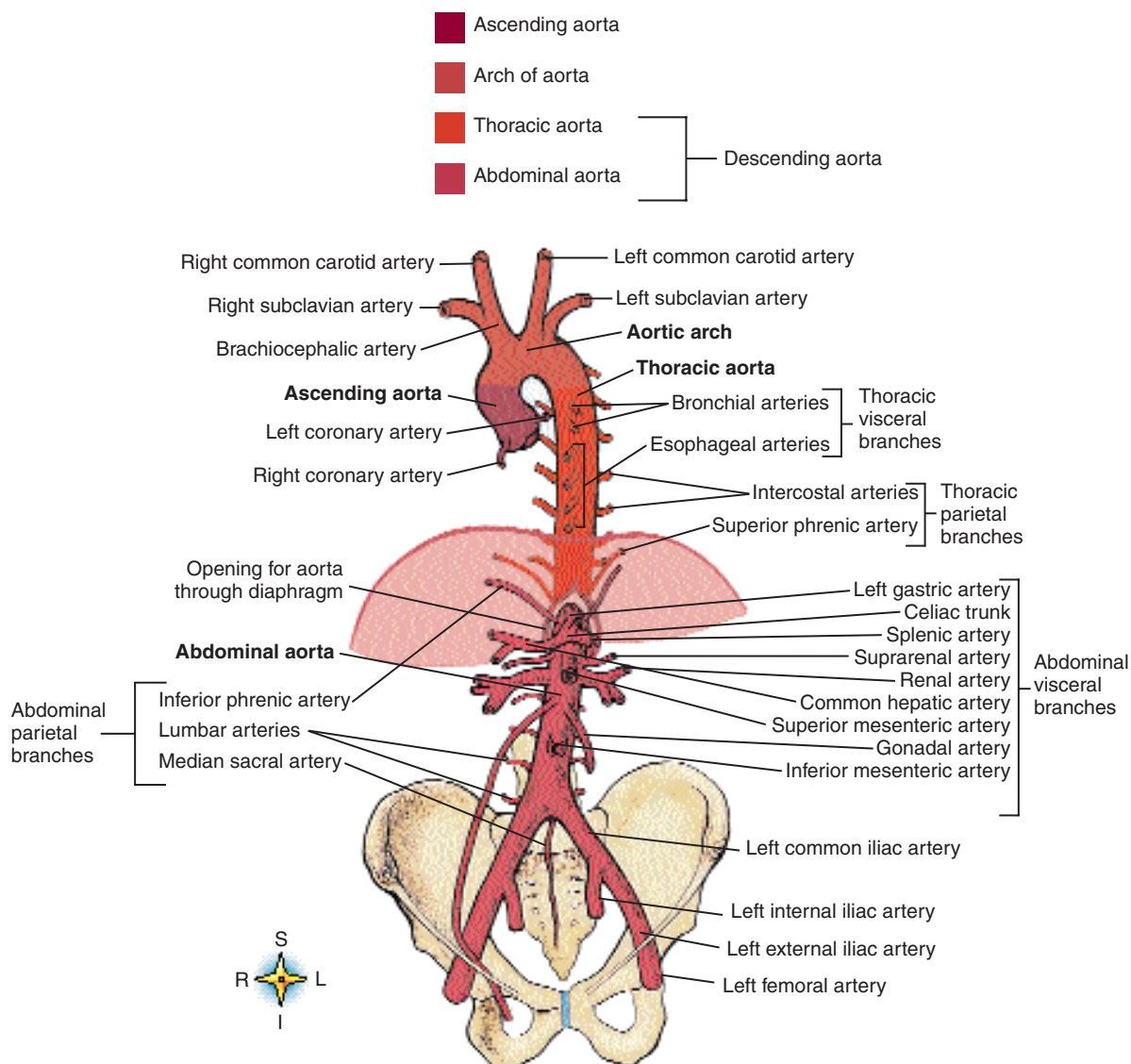


Figure 18-17 The aorta. The aorta is the main systemic artery, serving as a trunk from which other arteries branch. Blood is conducted from the heart first through the ascending aorta, then the arch of the aorta, then through the thoracic and abdominal segments of the descending aorta. See Table 18-2 for a more detailed outline of the arteries that branch from the aorta.

dersurface of the brainstem to form the *basilar artery*, which shortly branches into the right and left *posterior cerebral arteries* (Figure 18-19). The internal carotid arteries enter the cranial cavity in the midpart of the cranial floor, where they become known as the *arterial cerebral arteries*. Small vessels, the *communicating arteries*, join the anterior and posterior cerebral arteries in such a way as to form an arterial circle (*circle of Willis*) at the base of the brain, a good example of arterial anastomosis (Figure 18-19).

Arteries of the Extremities and Trunk. Next, take a look at Figure 18-20, which outlines the arteries of the upper extremity and Figure 18-21, which outlines the arteries of the lower extremity. Trace these arteries with your finger as you read through Table 18-2. Some of the major arteries that supply the thoracic and abdominopelvic regions can be seen in Figures 18-16 and 18-17.

Systemic Veins

Locate the veins listed in Table 18-3 (see also Figures 18-22 to 18-29). As with the arteries, you may find it easier to learn the

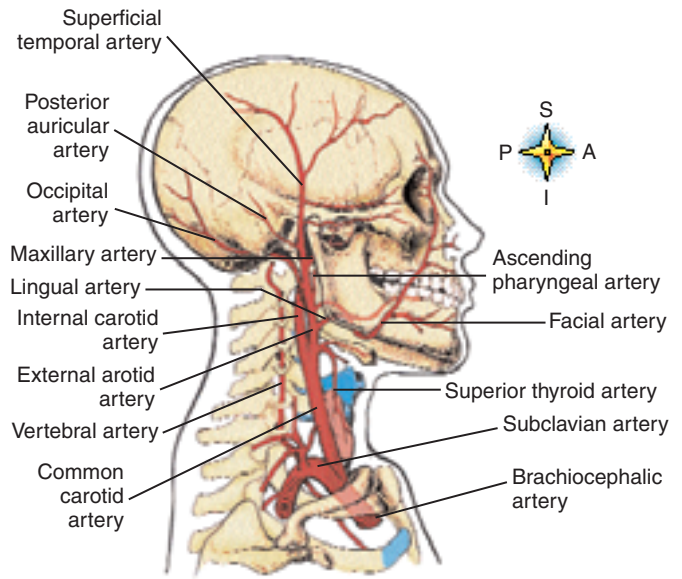


Figure 18-18 Major arteries of the head and neck. See Figure 18-20 for arteries inside the cranial cavity.

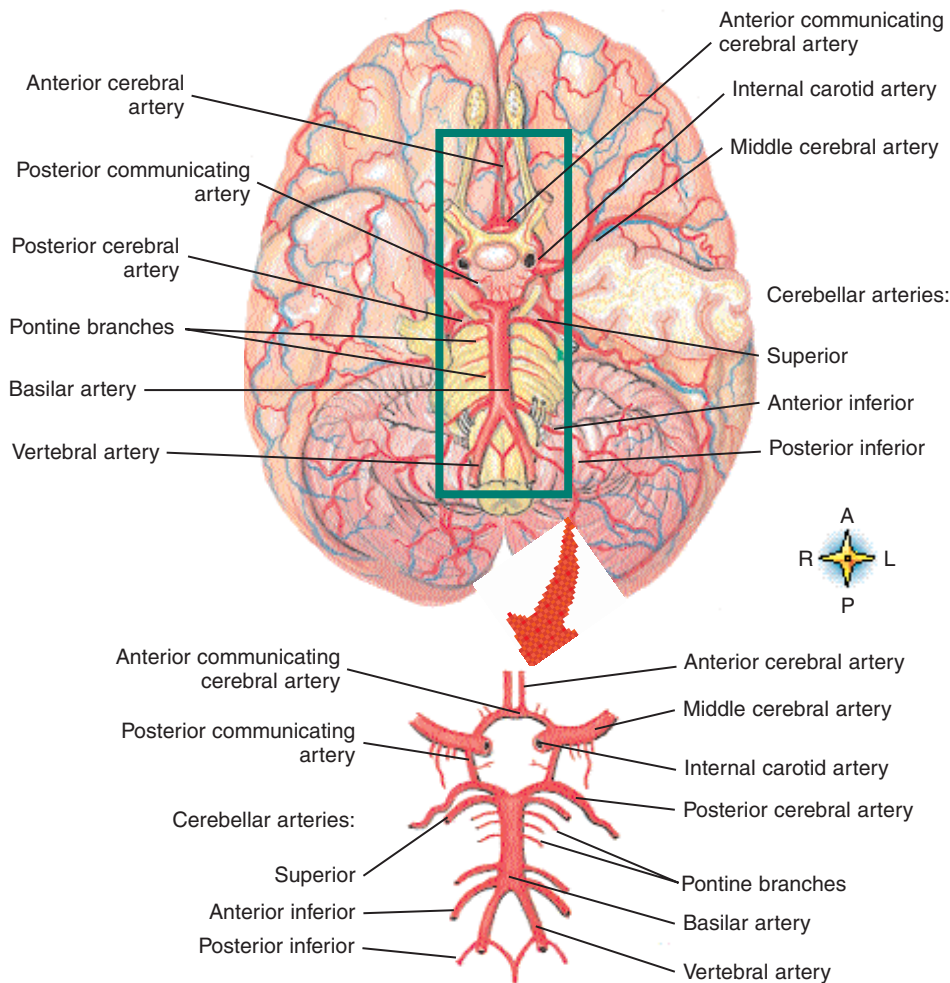


Figure 18-19 Arteries at the base of the brain. The arteries that compose the circle of Willis are the two anterior cerebral arteries joined to each other by the anterior communicating cerebral artery and to the posterior cerebral arteries by the posterior communicating arteries.

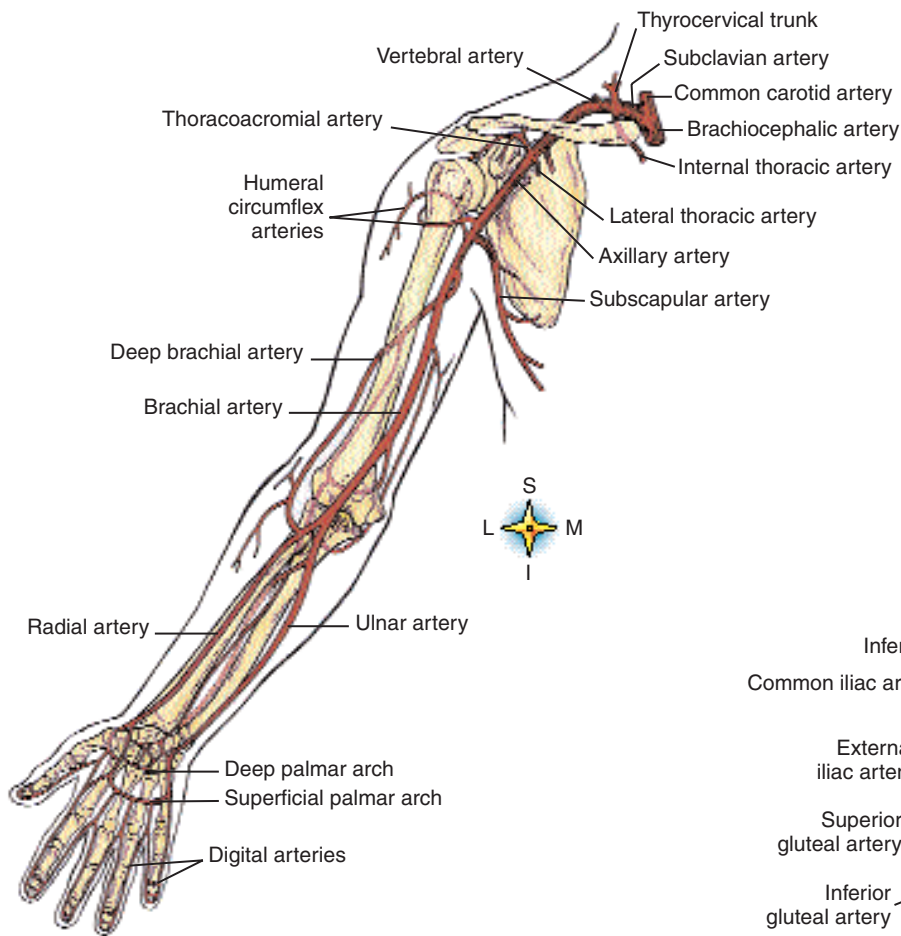


Figure 18-20 Major arteries of the upper extremity. Anterior view of the right shoulder and arm. The distal part of the radial artery is often used to assess a person's pulse (see Chapter 19 for a discussion of pulse waves).

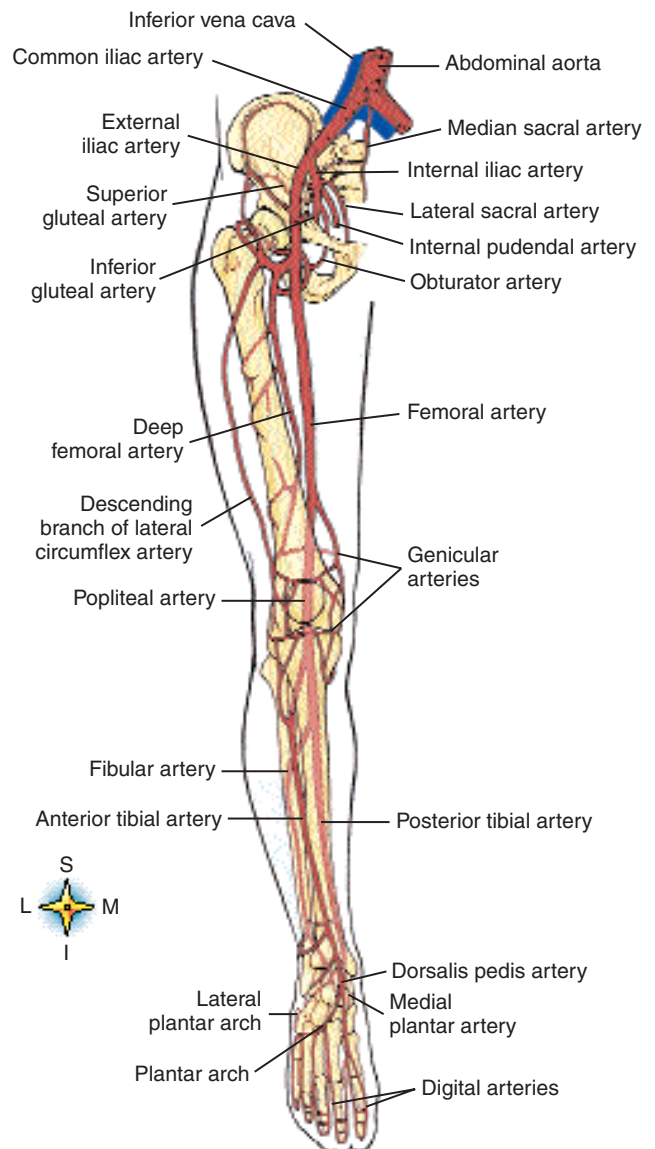


Figure 18-21 Major arteries of the lower extremity. Anterior view of the right hip and leg.

Table 18-3 Major Systemic Veins

Vein*	Region Drained	Vein*	Region Drained
Superior Vena Cava	Head, neck, thorax, upper extremity	Inferior Vena Cava	Lower trunk and extremity
Brachiocephalic (innominate)	Head, neck, upper extremity	Phrenic	Diaphragm
Internal jugular (continuation of sigmoid sinus)	Brain	Hepatic portal system	Upper abdominal viscera
Lingual	Tongue, mouth	Hepatic veins (continuations of liver venules and sinusoids and, ultimately, the hepatic portal vein)	Liver
Superior thyroid	Thyroid, deep face	Hepatic portal vein	Gastrointestinal organs, pancreas, spleen, gallbladder
Facial	Superficial face	Cystic	Gallbladder
Sigmoid sinus (continuation of transverse sinus/direct tributary of internal jugular)	Brain, meninges, skull	Gastric	Stomach
Superior and inferior petrosal sinuses	Anterior brain, skull	Splenic	Spleen
Cavernous sinus	Anterior brain, skull	Inferior mesenteric	Descending colon, rectum
Ophthalmic veins	Eye, orbit	Pancreatic	Pancreas
Transverse sinus (direct tributary of sigmoid sinus)	Brain, meninges, skull	Superior mesenteric	Small intestine, most of colon
Occipital sinus	Inferior, central region of cranial cavity	Gastroepiploic	Stomach
Straight sinus	Central region of brain, meninges	Renal	Kidneys
Inferior sagittal sinus	Central region of brain, meninges	Suprarenal	Adrenal (suprarenal) gland
Superior sagittal (longitudinal) sinus	Superior region of cranial cavity	Left ovarian	Left ovary
External jugular	Superficial, posterior head, neck	Left testicular	Left testis
Subclavian (continuation of axillary/direct tributary of brachiocephalic)	Axilla, lower extremity	Left ascending lumbar (anastomoses with hemiazygos)	Left lumbar region
Axillary (continuation of basilic/direct tributary of subclavian)	Axilla, lower extremity	Right ovarian	Right ovary
Cephalic	Lateral and lower arm, hand	Right testicular	Right testis
Brachial	Deep arm	Right ascending lumbar (anastomoses with azygos)	Right lumbar region
Radial	Deep lateral forearm	Common iliac (continuation of external iliac; common iliacs unite to form inferior vena cava)	Lower extremity
Ulnar	Deep medial forearm	External iliac (continuation of femoral/direct tributary of common iliac)	Thigh, leg, foot
Basilic (direct tributary of axillary)	Medial and lower arm, hand	Femoral (continuation of popliteal/direct tributary of external iliac)	Thigh, leg, foot
Median cubital (basilic) (formed by anastomosis of cephalic and basilic)	Arm, hand	Popliteal	Leg, foot
Deep and superficial palmar venous arches (formed by anastomosis of cephalic and basilic)	Hand	Posterior tibial	Deep posterior leg
Digital	Fingers	Medial and lateral plantar	Sole of foot
Azygos (anastomoses with right ascending lumbar)	Right posterior wall of thorax and abdomen, esophagus, bronchi, pericardium, mediastinum	Fibular (peroneal) (continuation of anterior tibial)	Lateral and anterior leg, foot
Hemiazygos (anastomoses with left renal)	Left inferior posterior wall of thorax and abdomen, esophagus, mediastinum	Anterior tibial	Anterior leg, foot
Accessory hemiazygos	Left superior posterior wall of thorax	Dorsal veins of foot	Anterior (dorsal) foot, toes
		Small (external, short) saphenous	Superficial posterior leg, lateral foot
		Great (internal, long) saphenous	Superficial medial and anterior thigh, leg, foot
		Dorsal veins of foot	Anterior (dorsal) foot, toes
		Dorsal venous arch	Anterior (dorsal) foot, toes
		Digital	Toes
		Internal iliac	Pelvic region

*Tributaries of each vein are indented below its name; deep veins are printed in dark blue and superficial veins are printed in light blue.

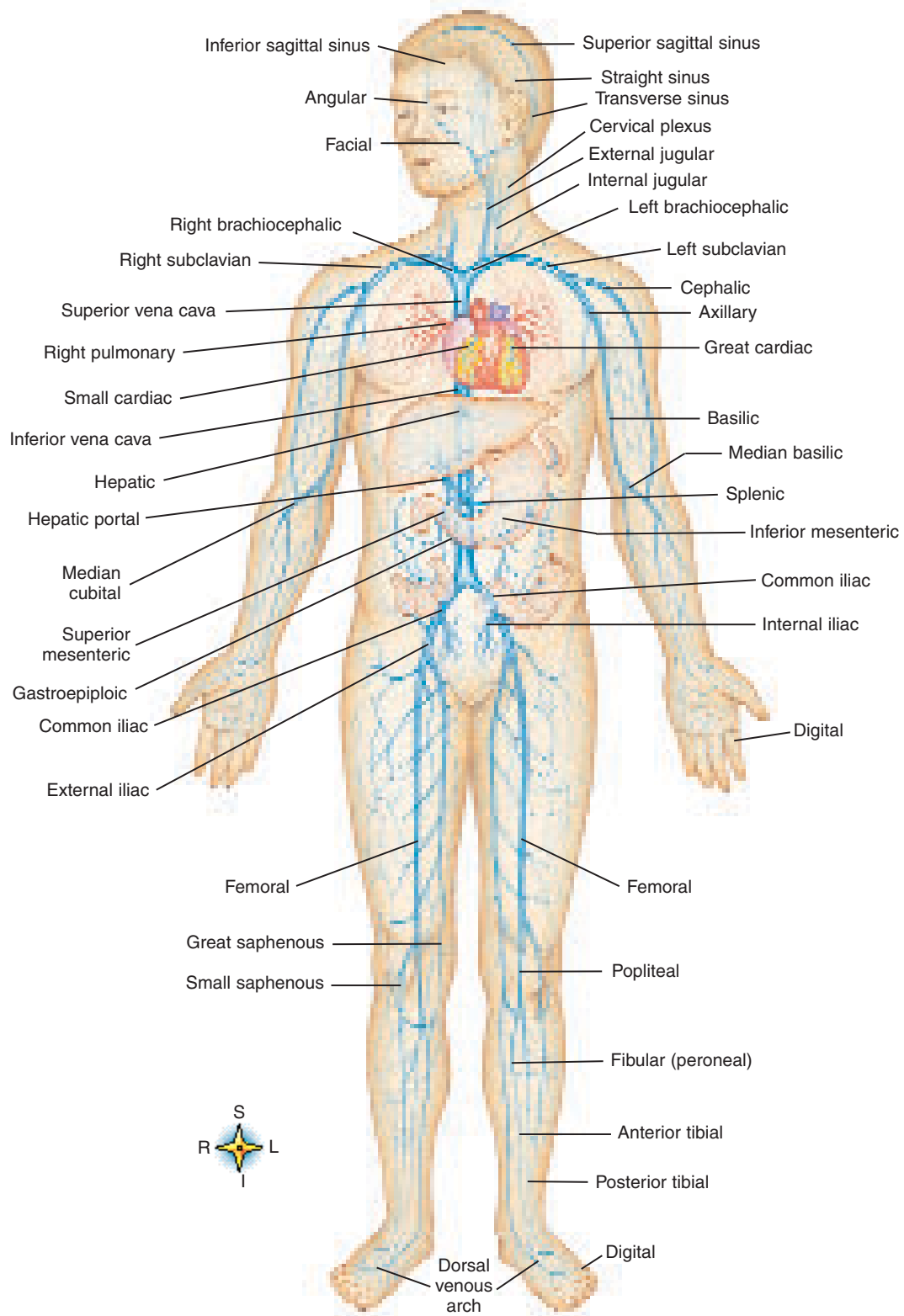


Figure 18-22 Principal veins of the body.



Box 18-4 HEALTH MATTERS

Clinical Importance of Venous Sinuses

Middle ear infections sometimes cause infection of the transverse sinuses with the formation of a thrombus. In such cases the internal jugular vein may be ligated (tied shut) to prevent the development of a fatal cardiac or pulmonary embolism.

Intravenous injections are perhaps most often given into the median basilic vein at the bend of the elbow. Blood that is to be used for various laboratory tests is also usually removed from this vein. In an infant, however, the longitudinal (superior sagittal) sinus is more often punctured (through the anterior fontanel) because the superficial arm veins are too tiny for the insertion of a needle.

names of veins and their anatomical relation to each other from diagrams and tables than from narrative descriptions.

General Principles About Veins. The following facts should be borne in mind while learning the names and locations of veins:

- Veins are the ultimate extensions of capillaries, just as capillaries are the eventual extensions of arteries. Whereas arteries branch into vessels of decreasing size to form arterioles and eventually capillaries, capillaries unite into vessels of increasing size to form venules and, eventually, veins.
- Although all vessels vary considerably in location and branches—and whether they are even present or not—the veins are especially variable. For example, the **median cubital vein** in the forearm is absent in many individuals.
- Many of the main arteries have corresponding veins bearing the same name and are located alongside or near the arteries (see Figure 18-14). These veins, like the arteries, lie in deep, well-protected areas, for the most part, close along the bones. Examples include the femoral artery and femoral vein, both located along the femur bone.
- Veins found in the deep parts of the body are called **deep veins** in contrast to **superficial veins**, which lie near the surface. The latter are the veins that can be seen through the skin.
- The large veins of the cranial cavity, formed by the dura mater, are not usually called veins but are instead called *dural sinuses*, or, simply, **sinuses** (Box 18-4). They should not be confused with the bony, air-filled sinuses of the skull.
- Veins communicate (anastomose) with each other in the same way as arteries. In fact, the venous portion of the systemic circulation has even more anastomoses than

the arterial portion. Such venous anastomoses provide for collateral return blood flow in cases of venous obstruction.

- Venous blood from the head, neck, upper extremities, and thoracic cavity, with the exception of the lungs, drains into the superior vena cava. Blood from the lower extremities and abdomen enters the inferior vena cava.

Table 18-3 identifies the major systemic veins. Locate each one as you read the table and trace them with your finger on Figures 18-22 to 18-29.

Veins of the Head and Neck. The deep veins of the head and neck lie mostly within the cranial cavity (Figure 18-23). These are mainly dural sinuses and other veins that drain into the **internal jugular vein**.

The superficial veins of the head and neck drain into the **right and left external jugular veins** in the neck. The external jugular veins receive blood from small superficial veins of face, scalp, and neck and terminate in **subclavian veins**. Small emissary veins connect veins of the scalp and face with blood sinuses of the cranial cavity, a fact of clinical interest as a possible avenue for infections to enter the cranial cavity.

Veins of the Upper Extremity. Deep veins of the upper extremity drain into the **brachial vein**, which in turn drain into the **axillary vein**, then the **subclavian vein** before joining the **brachiocephalic vein**, a major tributary of the **superior vena cava**. The major veins of the upper extremity are shown in Figure 18-24. At this point, it is interesting to note that the tributaries of the superior vena cava are more symmetrical from left to right than the nearby branches of the aorta. Compare Figures 18-16 and 18-22 to verify this point.

Superficial veins of the hand from the **palmar venous arches**, which, together with a complicated network of superficial veins of the lower arm, finally pour their blood into two large veins: the **cephalic vein** (thumb side) and **basilic vein** (little finger side). These two veins empty into the deep **axillary vein**.

Veins of the Thorax. Several small veins—such as the **bronchial, esophageal, pericardial veins**—return blood from thoracic organs (except gas exchange tissues in the lungs) directly into the **superior vena cava** or **azygos vein**. Refer to Figure 18-25 to see how these veins are arranged. The **azygos vein** lies to right of the spinal column and extends from the inferior vena cava (at level of first or second lumbar vertebra) through the diaphragm to the terminal part of the superior vena cava. The **hemiazygos vein** lies to the left of the spinal column, extending from the lumbar level of the inferior vena cava through the diaphragm to terminate in the **azygos vein**. The **accessory hemiazygos vein** connects some of the **superior intercostal veins** with the **azygos** or **hemiazygos vein**.

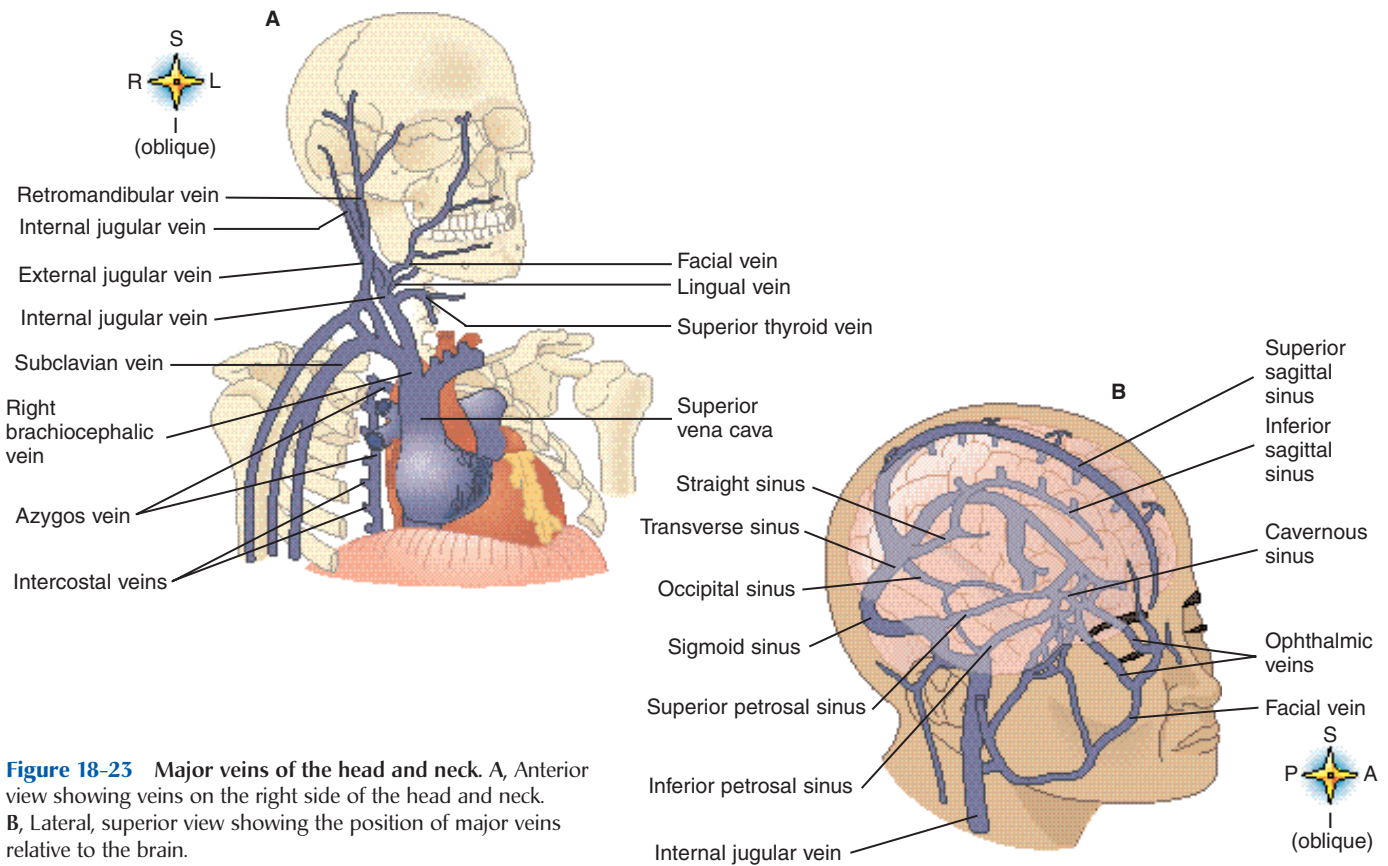


Figure 18-23 Major veins of the head and neck. **A**, Anterior view showing veins on the right side of the head and neck. **B**, Lateral, superior view showing the position of major veins relative to the brain.

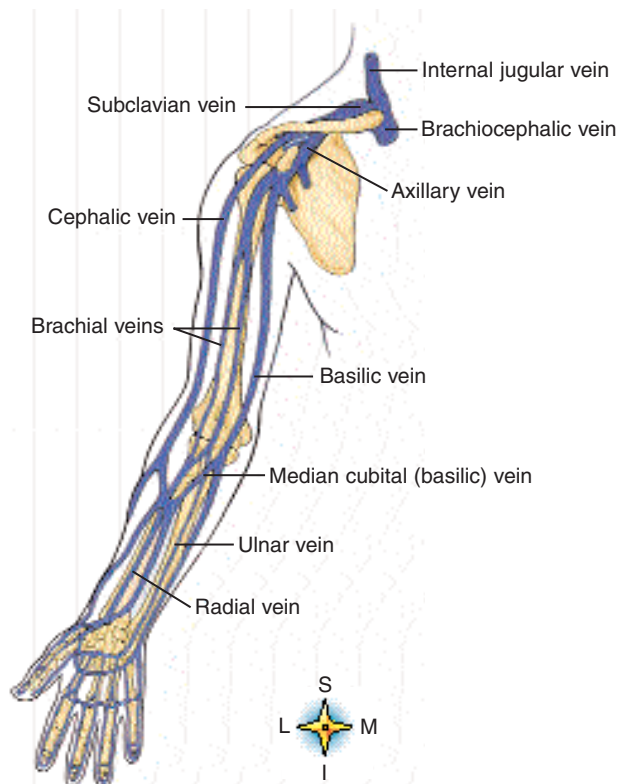


Figure 18-24 Major veins of the upper extremity. The median cubital (basilic) vein is commonly used for removing blood or giving intravenous infusions (anterior view).

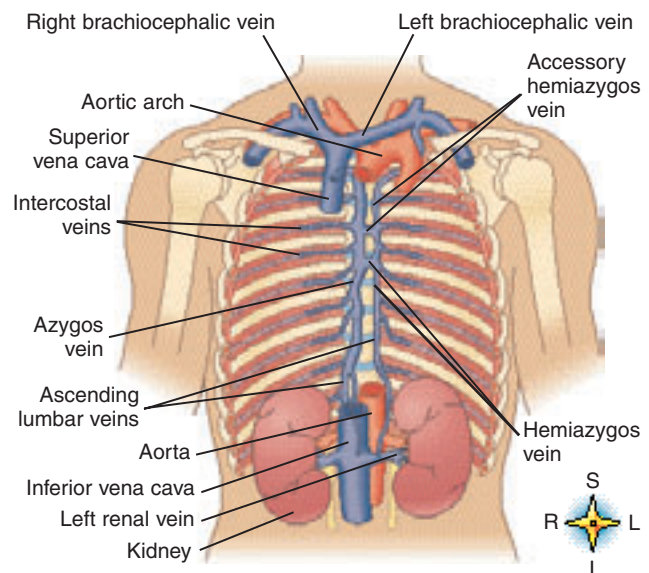


Figure 18-25 Principal veins of the thorax. Smaller veins of the thorax drain blood into the inferior vena cava or into the azygos vein—both are shown here. The hemiazygos vein and accessory hemiazygos vein on the left drain into the azygos vein on the right.

Veins of the Abdomen. The abdominal tributaries offer another opportunity to see a slight difference between the left and right portions of the systemic venous circulation. For example, Figure 18-26 shows that the **left spermatic vein** and **left suprarenal vein** usually drain into the **left renal vein** instead of into the **inferior vena cava**—as occurs on the right. For a description of the return of blood from the abdominal digestive organs, see the subsequent discussion of the **hepatic portal circulation**.

Hepatic Portal Circulation. Veins from the spleen, stomach, pancreas, gallbladder, and intestines do not pour their blood directly into the inferior vena cava, as do the veins from other abdominal organs. They send their blood to the liver by means of the hepatic portal vein. Here the blood mingles with the arterial blood in the capillaries and is eventually drained from the liver by the hepatic veins that join the inferior vena cava. Any arrangement in which venous blood flows through a second capillary network before returning to the heart is called a *portal* circulatory route. Portal comes from the Latin *porta*, meaning “gateway,” and is used here because the liver is a gateway through which blood returning from the digestive tract must pass before it returns to the heart.

There are several advantages of the detouring of blood from the digestive tract through the liver before it returns to the heart. Shortly after a meal, blood flowing through digestive organs begins absorbing glucose and other simple nutrients. The result is a tremendous increase in the blood glucose level. As the blood travels through the liver, however,

Box 18-5

How to Trace the Flow of Blood

To list the vessels through which blood flows in reaching a designated part of the body or in returning to the heart from a part, one must remember the following:

- Blood always flows in this direction: from left ventricle of heart to arteries, to arterioles, to capillaries of each body part, to venules, to veins, to right atrium, right ventricle, pulmonary artery, lung capillaries, pulmonary veins, left atrium, and back to left ventricle (Figure 18-27).
- When blood is in capillaries of abdominal digestive organs, it must flow through the hepatic portal system (see Figure 18-28) before returning to the heart.
- Names of main arteries and veins of body

For example, suppose glucose were instilled into the rectum. To reach the cells of the right little finger, the vessels through which it would pass after absorption from the intestinal mucosa into capillaries would be as follows: capillaries into venules of large intestine into inferior mesenteric vein, splenic vein, portal vein, capillaries of liver, hepatic veins, inferior vena cava, right atrium of heart, right ventricle, pulmonary artery, pulmonary capillaries, pulmonary veins, left atrium, left ventricle, ascending aorta, aortic arch, innominate artery, right subclavian artery, right axillary artery, right brachial artery, right ulnar artery, arteries of palmar arch, arterioles, and capillaries of right little finger.

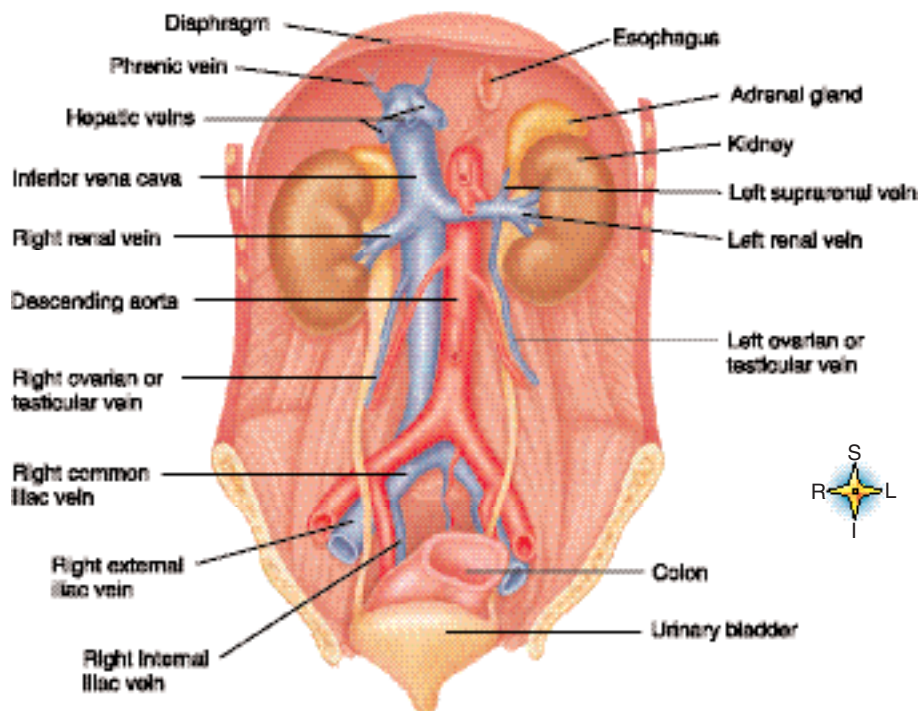


Figure 18-26 Inferior vena cava and its abdominopelvic tributaries. Anterior view of abdominopelvic cavity with many of the viscera removed. Note the close anatomical relationship between the inferior vena cava and the descending aorta.

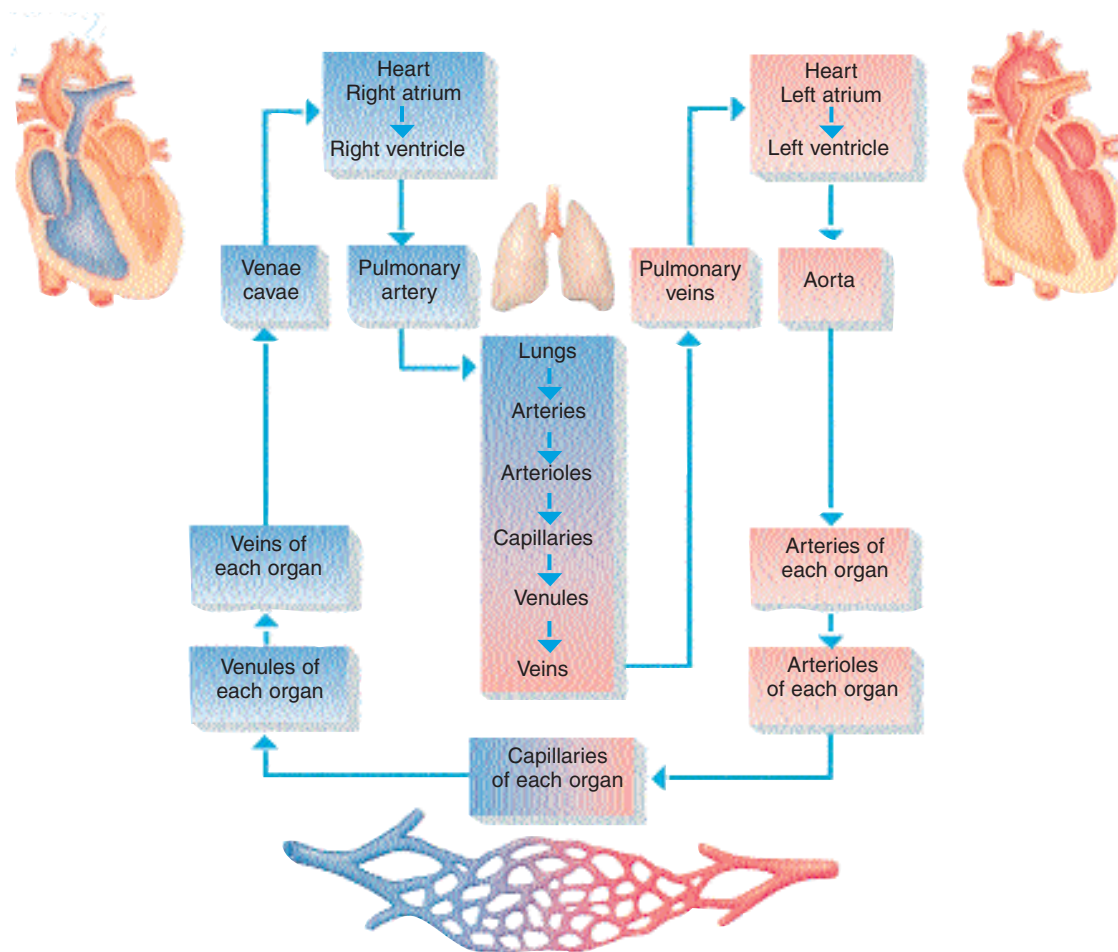


Figure 18-27 Blood flow in the body.

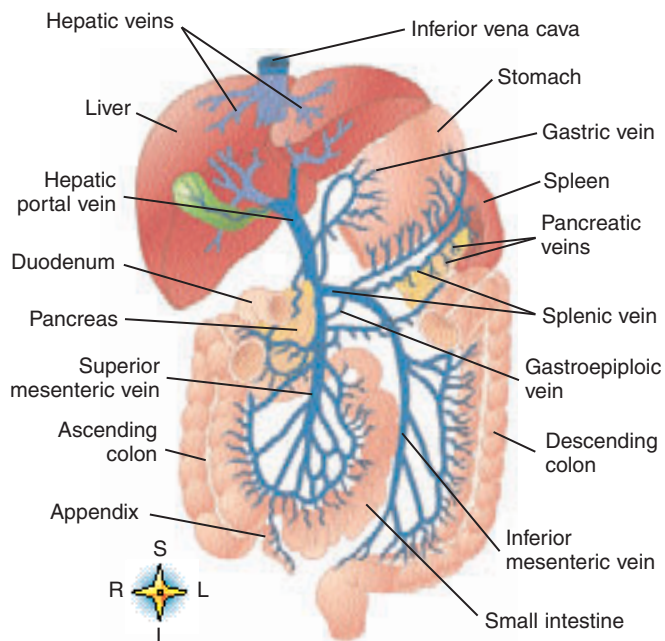


Figure 18-28 Hepatic portal circulation. In this unusual circulatory route, a vein is located between two capillary beds. The hepatic portal vein collects blood from capillaries in visceral structures located in the abdomen and empties it into the liver. Hepatic veins return blood to the inferior vena cava. (Organs are not drawn to scale.)

excess glucose is removed from the blood and stored in liver cells as glycogen. Thus blood returned to the heart carries only a moderate level of glucose. Many hours after food has yielded its nutrients, low-glucose blood coming from the digestive organs can pick up glucose released from the glycogen stores held in the liver cells before returning to the heart. Another advantage of the hepatic portal scheme is that toxic molecules such as alcohol can be partially removed or detoxified before the blood is distributed to the rest of the body. Additional information regarding the role of the liver, and the advantages of the portal circulation through the liver, is discussed in the chapters on the digestive system.

Figure 18-28 shows the plan of the hepatic portal system. In most individuals the hepatic portal vein is formed by the union of the splenic and superior mesenteric veins, but blood from the gastric, pancreatic, and inferior mesenteric veins drains into the splenic vein before it merges with the superior mesenteric vein.

If either hepatic portal circulation or venous return from the liver is interfered with (as often occurs in certain types of liver disease or heart disease), venous drainage from most of the other abdominal organs is necessarily obstructed also. The accompanying increased capillary pressure accounts, at least in part, for the occurrence of abdominal bloating, or *ascites* (ah-SITE-eez), under these conditions.

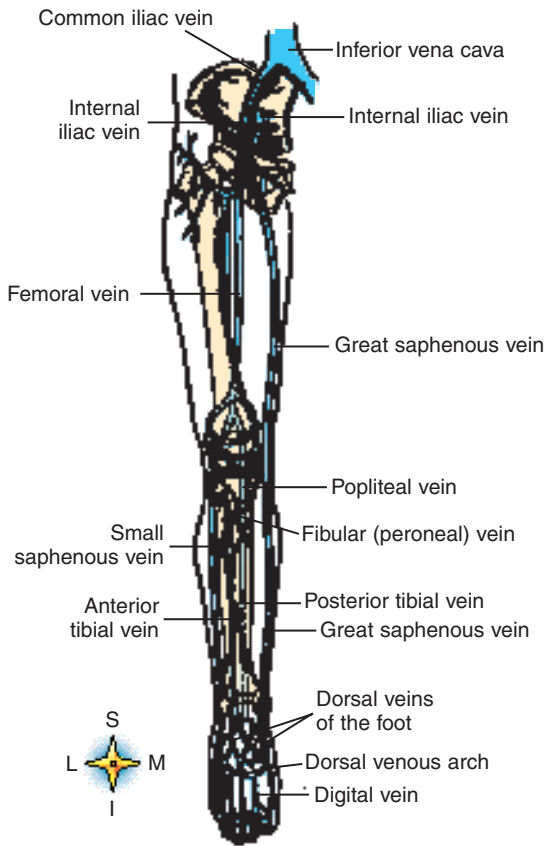


Figure 18-29 Major veins of the lower extremity (anterior view).

Veins of the Lower Extremity. As Figure 18-29 shows, deep veins of the lower leg drain from the **anterior tibial vein**, which continues as the **fibular (peroneal) vein**, and the **posterior tibial vein**. The fibular and posterior tibial veins join to form the **popliteal vein**, which runs behind the knee joint and continues up along the femur as the deep femoral vein. The **femoral vein** continues as the **external iliac vein**, draining into the common iliac vein and from there into the **inferior vena cava**.

Superficial veins of the lower extremity include the **small saphenous vein**, a tributary of the popliteal vein, and the **great saphenous vein**, which drains much of the superficial lower leg and foot. The name *saphenous* is from the Greek *saphenes*, a word that means “apparent”—an appropriate name for these visible, superficial veins.



1. What is the difference between the pulmonary circulation and the systemic circulation?
2. What is the function of arterial anastomoses? What is the function of venous anastomoses?
3. How are systemic arteries and veins usually named?
4. What are the advantages of a portal circulation through the liver?

Fetal Circulation

The Basic Plan of Fetal Circulation. Circulation in the body before birth necessarily differs from circulation after birth for one main reason—fetal blood secures oxygen and food from maternal blood instead of from fetal lungs and digestive organs. Obviously, then, there must be additional blood vessels in the fetus to carry the fetal blood into close approximation with the maternal blood and to return it to the fetal body. These structures are the two **umbilical arteries**, the **umbilical vein**, and the **ductus venosus**. Also, some structure must function as the lungs and digestive organs do postnatally, that is, a place where an interchange of gases, foods, and wastes between the fetal and maternal blood can take place. This structure is the *placenta* (Figure 18-30). The exchange of substances occurs without any actual mixing of maternal and fetal blood, because each flows in its own capillaries.

In addition to the placenta and umbilical vessels, three structures located within the fetus’ own body play an important part in fetal circulation. One of them (ductus venosus) serves as a detour by which most of the blood returning from the placenta bypasses the fetal liver. The other two (foramen ovale and ductus arteriosus) provide detours by which blood bypasses the lungs. A brief description of each of the six structures necessary for fetal circulation follows (Figure 18-31).

1. The two **umbilical arteries** are extensions of the internal iliac (hypogastric) arteries and carry fetal blood to the placenta.
2. The **placenta** is a structure attached to the uterine wall. Exchange of oxygen and other substances between maternal and fetal blood takes place in the placenta, although no mixing of maternal and fetal blood occurs.
3. The **umbilical vein** returns oxygenated blood from the placenta, enters the fetal body through the umbilicus, extends up to the undersurface of the liver where it gives off two or three branches to the liver, and then continues on as the ductus venosus. Two umbilical arteries and the umbilical vein together constitute the umbilical cord and are shed at birth along with the placenta.
4. The **ductus venosus** is a continuation of the umbilical vein along the undersurface of the liver and drains into the inferior vena cava. Most of the blood returning from the placenta bypasses the liver. Only a relatively small amount of blood enters the liver by way of the branches from the umbilical vein into the liver.
5. The **foramen ovale** is an opening in the septum between the right and left atria. A valve at the opening of the inferior vena cava into the right atrium directs most of the blood through the foramen ovale into the left atrium so that it bypasses the fetal lungs. A small percentage of the blood leaves the right atrium for the right ventricle and pulmonary artery. But most of this blood does not flow on into the lungs. Still another detour, the ductus arteriosus, diverts it.
6. The **ductus arteriosus** is a small vessel connecting the pulmonary artery with the descending thoracic aorta. It

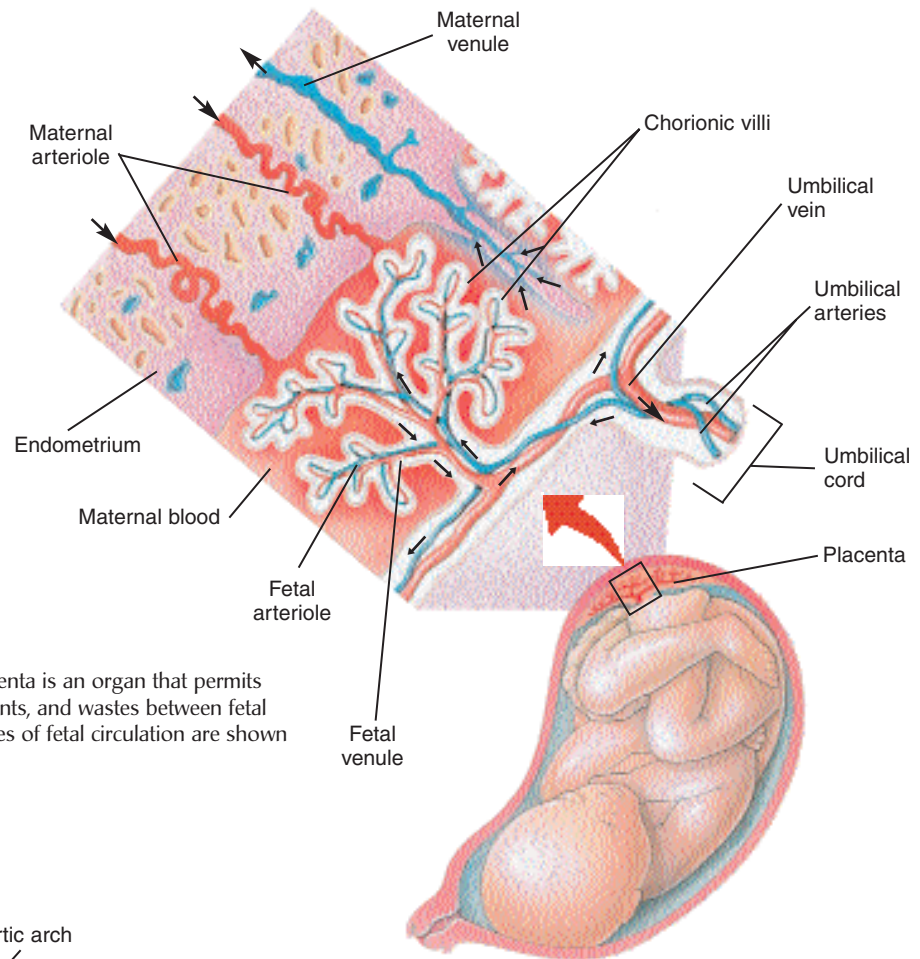


Figure 18-30 Placental circulation. The placenta is an organ that permits interchange of blood gases (O_2 and CO_2), nutrients, and wastes between fetal blood and maternal blood. Other special features of fetal circulation are shown in Figures 18-31 and 18-32.

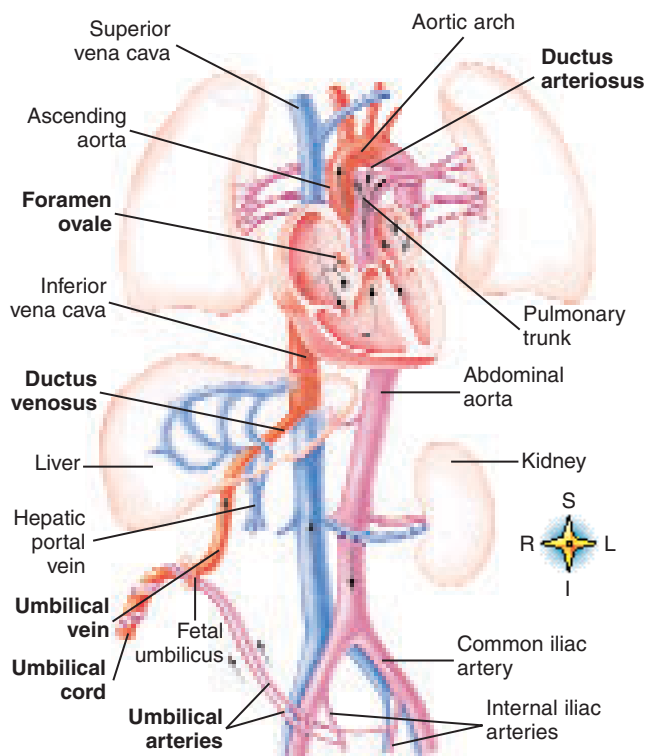


Figure 18-31 Plan of fetal circulation. Before birth, the human circulatory system has several special features that adapt the body to life in the womb. These features (*labeled in bold type*) include two umbilical arteries, one umbilical vein, ductus venosus, foramen ovale, and ductus arteriosus. The placenta, another essential feature of the fetal circulatory plan, is shown in Figure 18-30.

therefore enables another portion of the blood to detour into the systemic circulation without going through the lungs.

Almost all fetal blood is a mixture of oxygenated and deoxygenated blood. Examine Figure 18-31 carefully to determine why this is so. What happens to the oxygenated blood returned from the placenta via the umbilical vein? Note that it flows into the inferior vena cava.

Changes in Circulation at Birth. Because the six structures that serve fetal circulation are no longer needed after birth, several changes take place (Figure 18-32). As soon as the umbilical cord is cut, the two umbilical arteries, the placenta, and the umbilical vein obviously no longer function. The placenta is shed from the mother's body as the afterbirth with part of the umbilical vessels attached. The sections of these vessels remaining in the infant's body eventually become fibrous cords, which remain throughout life (the umbilical vein becomes the round ligament of the liver). The ductus venosus, no longer needed to bypass blood around the liver, eventually becomes the ligamentum venosum of the liver. The foramen ovale normally becomes functionally closed soon after a newborn takes the first breath and full circulation through the lungs becomes established. Complete structural closure, however, usually requires 9 months

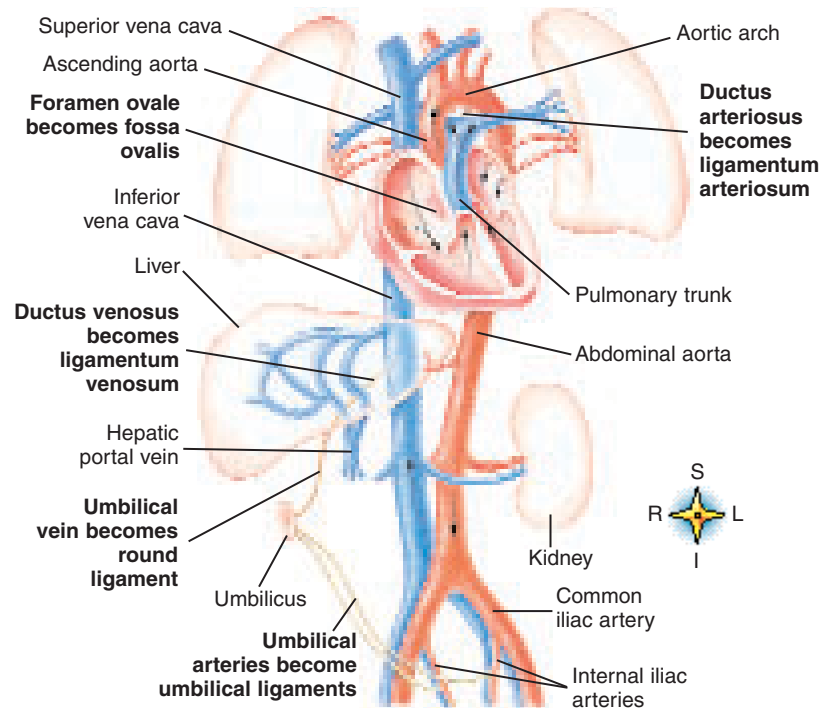


Figure 18-32 Changes in circulation after birth. Within the first year after the time of birth, certain changes in the circulatory plan occur to adapt the body to life outside the womb. The placenta and portions of the umbilical vessels outside the infant's body are removed or fall off at, or shortly after, the time of birth. The internal portion of the umbilical vein constricts and becomes fibrous, eventually forming the round ligament of the liver. Likewise, the internal umbilical arteries become umbilical ligaments, the ductus venosus becomes the ligamentum venosum, and the ductus arteriosus becomes the ligamentum arteriosum. The foramen ovale closes, forming a thin region of the atrial wall called the fossa ovalis.

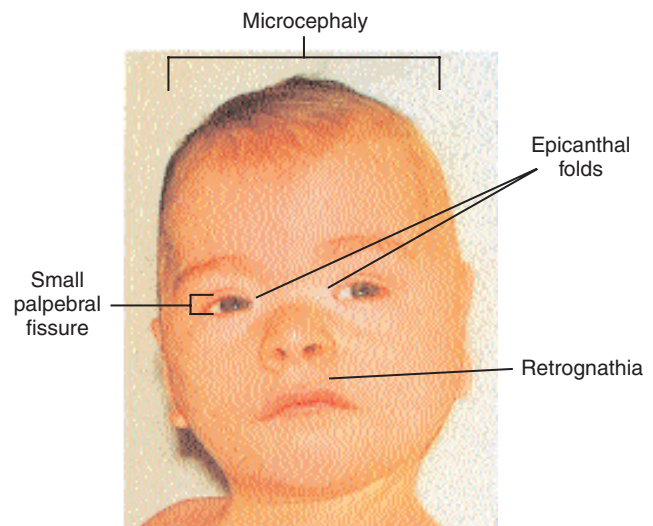
Box 18-6 HEALTH MATTERS

Fetal Alcohol Syndrome

Consumption of alcohol during pregnancy can have tragic effects on a developing fetus. Educational efforts to inform pregnant women about the dangers of alcohol are now receiving national attention. Even very limited consumption of alcohol during pregnancy poses significant hazards to the developing baby because alcohol can easily cross the placental barrier and enter the fetal bloodstream.

When alcohol enters the fetal blood, the potential result, called **fetal alcohol syndrome (FAS)**, can cause tragic congenital abnormalities such as “small head” or *microcephaly* (my-kro-SEF-ah-lee), low birth weight, cardiovascular defects, developmental disabilities such as physical and mental retardation, and even fetal death.

The photograph shows the small head, thinned upper lip, small eye openings (palpebral fissures), epicanthal folds, and receded upper jaw (retrognathia) typical of fetal alcohol syndrome.



or more. Eventually, the foramen ovale becomes a mere depression (fossa ovalis) in the wall of the right atrial septum. The ductus arteriosus contracts as soon as respiration is established. Eventually, it also turns into a fibrous cord, the ligamentum arteriosum. Compare the blood flow in Figures 18-31 and 18-32. Notice how separation of oxygenated and deoxygenated blood occurs *after* birth.



1. Name some of the structures of the fetal circulation that do not occur in the adult.
2. What is the function of the placenta and umbilical vessels?
3. What changes in the circulatory system occur at the time of birth?


CYCLE OF LIFE
Cardiovascular Anatomy

As with all body structures, the heart and blood vessels undergo profound anatomical changes during early development in the womb. At birth, the switch from a placenta-dependent system causes another set of profound anatomical changes. Throughout childhood, adolescence, and adulthood, the heart and blood vessels normally maintain their basic structure and function—permitting continued survival of the individual. Perhaps the only apparent normal changes in these structures occur as a result of regular exercise. The myocardium thickens and the supply of blood vessels in skeletal muscle tissues increases in response to increased oxygen and glucose use during prolonged exercise.

As we pass through adulthood, especially later adulthood, various degenerative changes can occur in the heart and blood vessels. For example, a type of “hardening of the arteries,” called *atherosclerosis*, can result in blockage or weakening of critical arteries—perhaps causing a myocardial infarction or stroke. The heart valves and myocardial tissues often degenerate with age, becoming hardened or fibrotic and less able to perform their functions properly. This reduces the heart’s pumping efficiency and therefore threatens homeostasis of the entire internal environment.


THE BIG PICTURE
Cardiovascular Anatomy and the Whole Body

In this chapter, we have briefly outlined the functional anatomy of many different structures: the heart, major arteries and veins, and even the tiny arterioles, venules, and capillaries.

In essence, we have described a complex, interconnected network of transport pipes for blood. Part of what you learned from this description is how each component of this blood-transporting network is constructed and just a little bit about how it works as an individual unit. Step back from this collection of facts for a moment and think about how each component of the heart works with the other components to keep blood flowing continuously through the heart. Broaden the picture now in your mind’s eye to include each of the other

components of the network: the arteries, the veins, and the capillaries. As you continue to study this chapter, keep this “big picture” in mind and add to it your deepening understanding of where each vessel and chamber gets its blood and where it delivers the blood. Before long, you will have a useful understanding of how the entire network functions as a system.

In the next chapter, we will build on your understanding of the functional anatomy of the cardiovascular system by discussing mechanisms of blood flow. In other words, all of the next chapter will deal with issues relating to the “big picture” function of cardiovascular function and its importance to survival.

MECHANISMS OF DISEASE**Disorders of the Cardiovascular System****Disorders of Heart Structure****Disorders Involving the Pericardium**

If the *pericardium* becomes inflamed, a condition called *pericarditis* results. Pericarditis may be caused by various factors: trauma, viral or bacterial infection, tumors, and other factors. The pericardial edema that characterizes this condition often causes the visceral and parietal layers of the serous pericardium to rub together—causing severe chest pain. Pericardial fluid, pus, or blood (in the case of an injury) may accumulate in the space between the two pericardial layers and impair the pumping action of the heart. This is termed *pericardial effusion* and may develop into a serious compression of the heart called **cardiac tamponade**.

Pericarditis may be acute or chronic, depending on the rate, severity, and duration of symptoms. Clinical manifestations include pericardial pain that increases with respirations or coughing, a “friction rub” (a grating, scratching sound heard over the left sternal border and upper ribs) resulting from movement together of the swollen pericardial

layers, difficulty breathing, restlessness, and an accumulation of pericardial fluid. Cardiac tamponade requires immediate pericardial drainage (pericardiocentesis). Antibiotics are usually prescribed to treat the causative organism and nonsteroidal antiinflammatory agents such as aspirin are prescribed to reduce the inflammation and thus control the symptoms.

Disorders Involving Heart Valves

Disorders of the cardiac valves can have several effects. For example, a congenital defect in valve structure can result in mild to severe pumping inefficiency. Incompetent valves leak, allowing some blood to flow back into the chamber from which it came. **Stenosed valves** are valves that are narrower than normal, slowing blood flow from a heart chamber.

Rheumatic heart disease results from a delayed inflammatory response to streptococcal infection that occurs most often in children. A few weeks after an improperly treated streptococcal infection, the cardiac valves and other tissues in the body may become inflamed—a condition called

rheumatic fever. If severe, the inflammation can result in stenosis or other deformities of the valves, chordae tendineae, or myocardium.

Mitral valve prolapse (MVP), a condition affecting the bicuspid or mitral valve, has a genetic basis in some cases but can result from rheumatic fever or other factors. A prolapsed mitral valve is one whose flaps extend back into the left atrium, causing incompetence (leaking) of the valve (Figure 18-33). Although this condition is common, occurring in up to 1 in every 20 people, most cases are asymptomatic. In severe cases, patients suffer chest pain and fatigue.

Aortic regurgitation is a condition in which blood not only ejects forward into the aorta but also regurgitates back into the left ventricle because of a leaky aortic semilunar valve. This causes a volume overload on the left ventricle, with subsequent hypertrophy and dilation of the left ventricle. The left ventricle attempts to compensate for the increased load by increasing its strength of contraction—which may eventually stress the heart to the point of causing myocardial ischemia.

Damaged or defective cardiac valves can often be replaced surgically—a procedure called *valvuloplasty*. Artificial valves made from synthetic materials, as well as valves taken from other mammals such as swine, are frequently used in these valve replacement procedures.

Disorders Involving the Myocardium

One of the leading causes of deaths in the United States is **coronary artery disease (CAD)**. This condition can result from many causes, all of which somehow reduce the flow of blood to the vital myocardial tissue. For example, in both coronary thrombosis and coronary embolism, a blood clot

occludes, or plugs, some part of a coronary artery. Blood cannot pass through the occluded vessel and so cannot reach the heart muscle cells it normally supplies. Deprived of oxygen, these cells soon die or are damaged. In medical terms, a **myocardial infarction (MI)**, or tissue death, occurs. A myocardial infarction (heart attack) is a common cause of death during middle and late adulthood. Recovery from a myocardial infarction is possible if the amount of heart tissue damaged was small enough that the remaining undamaged heart muscle can pump blood effectively enough to supply the needs of the rest of the heart, as well as the body.

Coronary arteries may also become blocked as a result of **atherosclerosis**, a type of “hardening of the arteries” in which lipids and other substances build up on the inside wall of blood vessels and eventually calcify, making the vessel wall hard and brittle. Mechanisms of atherosclerosis are discussed elsewhere in this chapter. Coronary atherosclerosis has increased dramatically over the last half century to become the leading cause of death in western countries. Many pathophysiologists believe this increase results from a change in lifestyle. They cite several important risk factors associated with coronary atherosclerosis: cigarette smoking, high-fat and high-cholesterol diets, and hypertension (high blood pressure).

The term **angina pectoris** is used to describe the severe chest pain that occurs when the myocardium is deprived of adequate oxygen. It is often a warning that the coronary arteries are no longer able to supply enough blood and oxygen to the heart muscle. **Coronary bypass surgery** is a frequent treatment for those who suffer from severely restricted coronary artery blood flow. In this procedure, veins are “harvested” from other areas of the body and used to bypass partial blockages in coronary arteries (Figure 18-34).

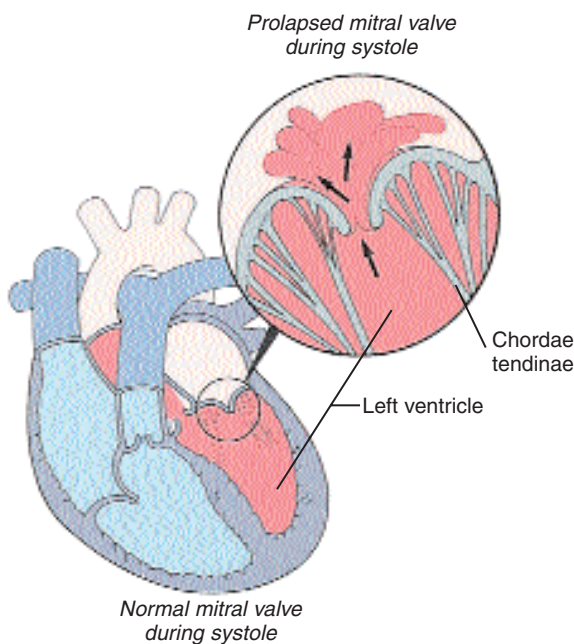


Figure 18-33 Mitral valve prolapse. The normal mitral valve (left) prevents backflow of blood from the left ventricle into the left atrium during ventricular systole (contraction). The prolapsed mitral valve (inset) permits leakage because the valve flaps billow backward, parting slightly.

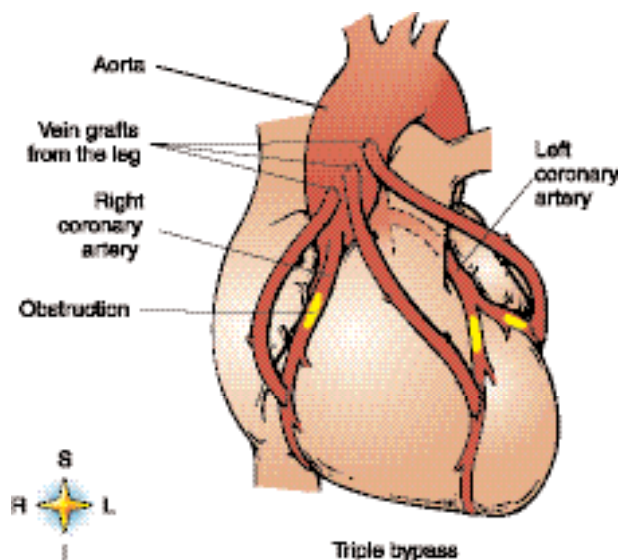


Figure 18-34 Coronary bypass. In coronary bypass surgery, blood vessels are “harvested” from other parts of the body and used to construct detours around blocked coronary arteries. Artificial vessels can also be used.

Congestive heart failure (CHF), or, simply, *left-side heart failure*, is the inability of the left ventricle to pump blood effectively. Most often, such failure results from myocardial infarction caused by coronary artery disease. It is called *congestive heart failure* because it decreases pumping pressure in the systemic circulation, which in turn causes the body to retain fluids. Portions of the systemic circulation thus become congested with extra fluid. As stated previously, left-side heart failure also causes congestion of blood in the pulmonary circulation, termed *pulmonary edema*—possibly leading to right heart failure.

Patients in danger of death because of heart failure may be candidates for heart *transplants* or heart *implants*. Heart transplants are surgical procedures in which healthy hearts from recently deceased donors replace the hearts of patients with heart disease. Unfortunately, a continuing problem with this procedure is the tendency of the body's immune system to reject the new heart as a foreign tissue. More details about the rejection of transplanted tissues are found in Chapter 21. Heart implants are artificial hearts that are made of biologically inert synthetic materials. After decades of false starts and cumbersome implants with external pumps, the era of the “artificial heart” seems to have finally arrived. On July 3, 2001, the first artificial heart was successfully implanted into Robert Tools by University of Louisville researchers. The one-kilogram (2 pound) AbioCor Implantable Replacement Heart is the first “artificial heart” to allow the patient to move about freely without any external pumps. Portable external battery packs are used to recharge the small internal battery that powers the internal pumping unit. The early success of the AbioCor unit gives hope that artificial hearts will one day be a commonplace and effective treatment for patients with severe heart disease.

Disorders of Blood Vessels

Disorders of Arteries

As mentioned earlier in this chapter, arteries contain blood that is maintained at a relatively high pressure. This means the arterial walls must be able to withstand a great deal of force or they will burst. The arteries must also stay free of obstruction; otherwise they cannot deliver their blood to the capillary beds (and thus the tissues they serve).

A common type of vascular disease that occludes (blocks) arteries and weakens arterial walls is called **arteriosclerosis**, or *hardening of the arteries*. Arteriosclerosis is characterized by thickening of arterial walls that progresses to hardening as calcium deposits form. The thickening and calcification reduce the flow of blood to the tissues. If the blood flow slows down too much, **ischemia** results. Ischemia, or decreased blood supply to a tissue, involves the gradual death of cells and may lead to complete tissue death—a condition called **necrosis**. If a large section of tissue becomes necrotic, it may begin to decay because of the action of decomposing bacteria. Necrosis that has progressed this far is called **gangrene**.

Because of the tissue damage involved, arteriosclerosis is not only painful—it is life threatening. As we have previ-

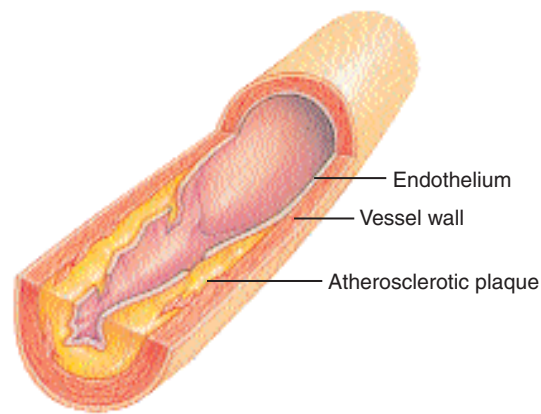


Figure 18-35 Partial blockage of an artery in atherosclerosis. Atherosclerotic plaque develops from the deposition of fats and other substances in the wall of the artery.

ously stated, ischemia of heart muscle can lead to *myocardial infarction* and death.

There are several types of arteriosclerosis, but perhaps the most well known is *atherosclerosis*—described earlier as the blockage of arteries by lipids and other matter (Figure 18-35). Eventually, the fatty deposits in the arterial walls become fibrous and perhaps calcified—resulting in sclerosis (hardening). High blood levels of triglycerides and cholesterol, which may be caused by a high-fat and high-cholesterol diet, smoking, and a genetic predisposition, are associated with atherosclerosis.

In general, arteriosclerosis develops with advanced age, diabetes, high-fat and high-cholesterol diets, hypertension (high blood pressure), and smoking. Arteriosclerosis can be treated by drugs, called *vasodilators*, that trigger the smooth muscles of the arterial walls to relax, thus causing the arteries to dilate (widen). Some cases of atherosclerosis are treated by mechanically opening the affected area of an artery, a type of procedure called **angioplasty**. In one procedure, a deflated balloon attached to a long tube, called a *catheter*, is inserted into a partially blocked artery and inflated (Figure 18-36). As the balloon inflates, the *plaque* (fatty deposits and tissue) is pushed outward, and the artery widens to allow near-normal blood flow. In a similar procedure, metal springs or mesh tubes, called *stents*, are inserted in affected arteries to hold them open. Other types of angioplasty use lasers, drills, or spinning loops of wire to clear the way for normal blood flow. Severely affected arteries can also be surgically bypassed or replaced.

Damage to arterial walls caused by arteriosclerosis or other factors may lead to the formation of an **aneurysm**. An aneurysm is a section of an artery that has become abnormally widened because of a weakening of the arterial wall. Aneurysms sometimes form a saclike extension of the arterial wall. One reason aneurysms are dangerous is because they, like atherosclerotic plaques, promote the formation of thrombi (abnormal clots). A thrombus may cause an embolism (blockage) in the heart or some other vital tissue. Another reason aneurysms are dangerous is their tendency to

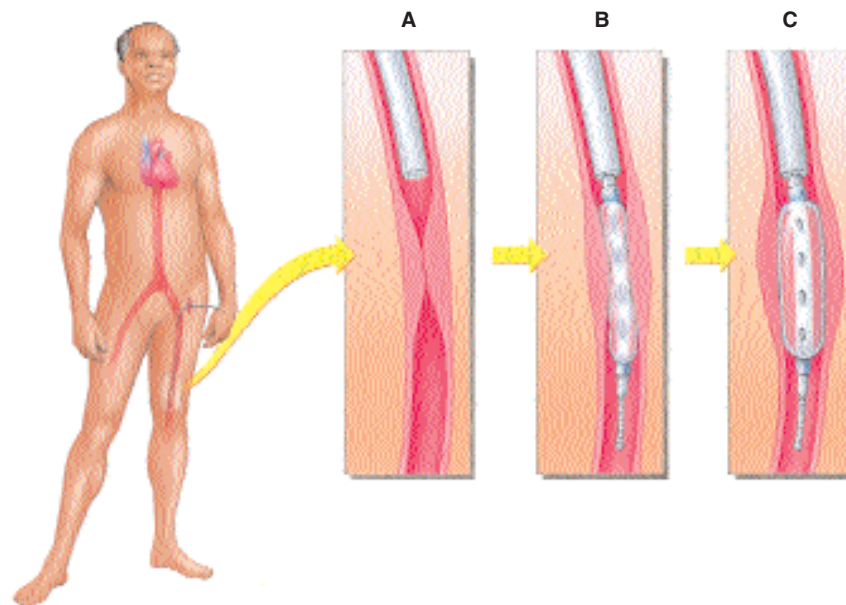


Figure 18-36 Balloon angioplasty. **A**, A catheter is inserted into the vessel until it reaches the affected region. **B**, A probe with a metal tip is pushed out the end of the catheter into the blocked region of the vessel. **C**, The balloon is inflated, pushing the walls of the vessel outward. Sometimes metal coils or tubes, called “stents,” are inserted to keep the vessel open. Newer drug-coated stents further reduce delayed scarring and re-clogging of arteries following angioplasty.

burst, causing severe hemorrhaging that may result in death. A brain aneurysm may lead to a *stroke*, or **cerebrovascular accident (CVA)**. A stroke results from ischemia of brain tissue caused by an embolism or ruptured aneurysm. Depending on the amount of tissue affected and the place in the brain the CVA occurs, effects of a stroke may range from hardly noticeable to crippling to fatal.

Disorders of Veins

Varicose veins are enlarged veins in which blood tends to pool rather than continue on toward the heart. Varicosities, also called **varices** (singular, *varix*), commonly occur in *superficial veins* near the surface of the body. The *great saphenous vein*, the largest superficial vein of the leg (see Figure 18-29), often becomes varicose in people who stand for long periods. The force of gravity slows the return of venous blood to the heart in such cases, causing blood-engorged veins to dilate. As the veins dilate, the distance between the flaps of venous valves widens—eventually making them incompetent (leaky) (Figure 18-37). Incompetence of valves causes even more pooling in affected veins—a positive-feedback phenomenon.

Hemorrhoids, or *piles*, are varicose veins in the anal canal. Excessive straining during defecation can create pressures that cause hemorrhoids. The unusual pressures of carrying a child during pregnancy predispose expectant mothers to hemorrhoids and other varicosities.

Varicose veins in some parts of the body can be treated by supporting the dilated veins from the outside. For instance, support stockings can reduce blood pooling in the great saphenous vein. Surgical removal of varicose veins can be

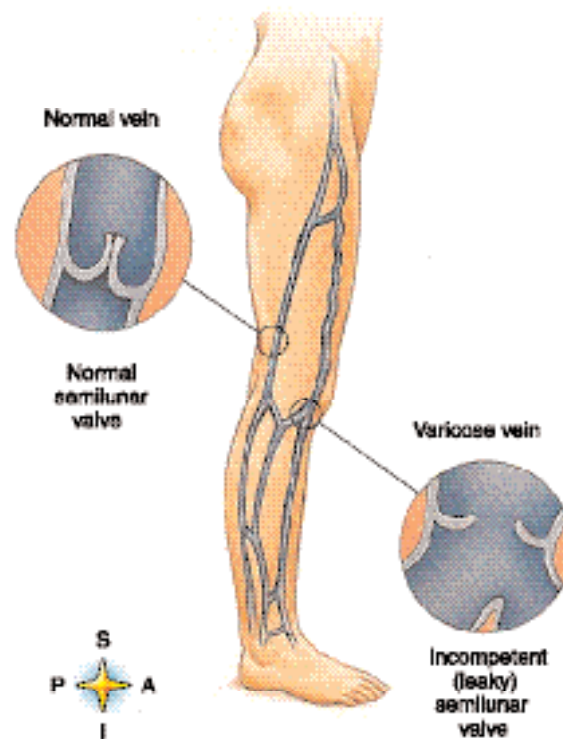


Figure 18-37 Varicose veins. Veins near the surface of the body—especially in the legs—may bulge and cause venous valves to leak.

performed in severe cases. Advanced cases of hemorrhoids are often treated by this type of surgery. Symptoms of milder cases of varicose veins can be relieved by removing the pressure that caused the condition.

Several factors can cause **phlebitis**, or vein inflammation. Irritation by an intravenous catheter, for example, is a common cause of vein inflammation. **Thrombophlebitis** is acute phlebitis caused by clot (thrombus) formation. Veins are more likely sites of thrombus formation than arteries because venous blood moves more slowly and is under less pressure. Thrombophlebitis is characterized by pain and discoloration of the surrounding tissue. If a piece of a clot breaks free, it may cause an embolism when it blocks a blood vessel. **Pulmonary embolism**, for example, could result when an embolus lodges in the circulation of the lung. Pulmonary

embolism can lead to death quickly if too much blood flow is blocked.

Heart Medications

Although numerous drugs are used in the treatment of heart disease, the following have proven to be basic tools of the cardiologist: *anticoagulants* prevent clot formation; *beta-adrenergic blockers* block norepinephrine receptors and thus reduce the strength and rate of heart beats; *calcium channel blockers* reduce heart contractions by preventing the flow of Ca^{++} into cardiac muscle cells; *digitalis* slows and increases the strength of cardiac contractions; *nitroglycerin* dilates coronary blood vessels and thus improves O_2 supply to myocardium; and *tissue plasminogen activator (TPA)* helps dissolve clots.

CASE STUDY

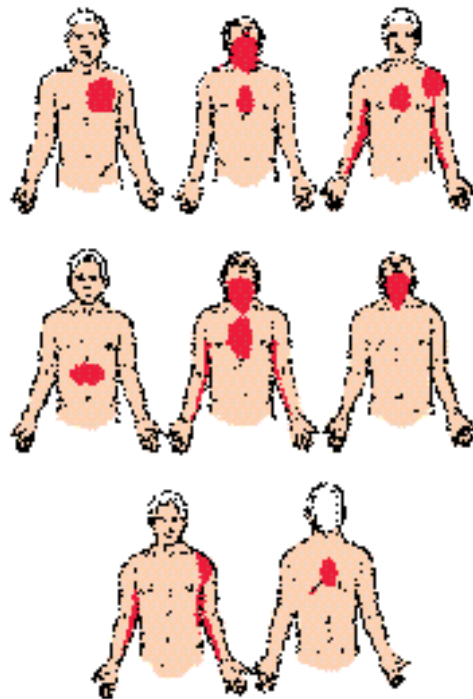
Clyde Banks, a 57-year-old black man who works in New York City as a taxi driver, is admitted to the critical care unit with chest pain. He has smoked two packs of cigarettes a day for 25 years. He has high blood pressure and type II diabetes mellitus. His father died of a heart attack at age 51. Other than bowling once a week, he leads a sedentary lifestyle. His typical food intake is high in fat and cholesterol.

Mr. Banks was bowling with friends when he felt pain in his chest. At first he ignored the pain but it became a crushing sensation in his sternal area that spread down his left arm. The pain continued even after he sat down for a while. His friends became concerned and called an ambulance.

On admission to the hospital, his physical examination reveals a height of 5 feet 11 inches and a weight of 230 lbs. His blood pressure is 110/60. He has a pulse of 110. His heart sounds irregular with an extra heart sound. He has crackling sounds at the bases of both lungs. His distal peripheral pulses are palpable but weak. His skin temperature is cool, and he is diaphoretic. The cardiac monitor shows irregular electrical activity. A 12-lead electrocardiogram indicates evidence of acute injury to the anterior myocardium. Cardiac enzymes are elevated in a pattern typical of myocardial infarction. High-density lipoprotein (HDL) levels are low and low-density lipoprotein (LDL) levels are high.

1. Which of Mr. Banks' risk factors for atherosclerosis are considered modifiable?
 1. Age
 2. Hypertension
 3. Smoking
 4. Family history
 5. Male sex
 6. Black race
 7. Cholesterol, HDL, and LDL levels
 8. Sedentary lifestyle
 9. High fat intake
 10. Body weight
 - A. 1, 2, 3, 8, 9, and 10
 - B. 2, 3, 7, 8, 9, and 10
 - C. 1, 2, 4, 5, 6, and 7
 - D. 2, 3, 5, 6, 7, and 10

2. Which of the following factors is the earliest pathological event leading to Mr. Banks' blocked coronary arteries?
 - A. Lipid deposition in the tunica intima
 - B. Ulceration of the tunica intima
 - C. Cellular proliferation of fatty streaks
 - D. Calcification of fibrous plaques
3. Based on the location of the infarcted tissues, which of the following coronary vessels is MOST likely to have atherosclerotic lesions?
 - A. Left coronary vein
 - B. Left coronary artery
 - C. Left subclavian artery
 - D. Right coronary vein
4. What was the primary cause of Mr. Banks' chest pain?
 - A. Myocardial ischemia
 - B. Pulmonary insufficiency
 - C. High cardiac output
 - D. Oliguria



LOCATIONS OF PAIN FROM MYOCARDIAL INFARCTION.

CHAPTER SUMMARY

HEART

- A. Location of the heart
 1. Lies in the mediastinum, behind the body of the sternum between the points of attachment of ribs two through six; approximately two thirds of its mass is to the left of the midline of the body and one third to the right
 2. Posteriorly the heart rests on the bodies of thoracic vertebrae five through eight
 3. Apex lies on the diaphragm, pointing to the left
 4. Base lies just below the second rib
 5. Boundaries of the heart are clinically important as an aid in diagnosing heart disorders
- B. Size and shape of the heart (Figures 18-1 and 18-2)
 1. At birth, transverse and appears large in proportion to the diameter of the chest cavity
 2. Between puberty and 25 years of age the heart attains its adult shape and weight

3. In adult, the shape of the heart tends to resemble that of the chest
- C. Coverings of the heart
 1. Structure of the heart coverings
 - a. Pericardium (Figure 18-3)
 - (1) Fibrous pericardium—tough, loose-fitting inextensible sac
 - (2) Serous pericardium—parietal layer lies inside the fibrous pericardium, and visceral layer (epicardium) adheres to the outside of the heart; pericardial space with pericardial fluid separates the two layers
 2. Function of the heart coverings—provides protection against friction
 - D. Structure of the heart
 1. Wall of the heart—made up of three distinct layers (Figure 18-4)
 - a. Epicardium—outer layer of heart wall
 - b. Myocardium—thick, contractile middle layer of heart wall; compresses the heart cavities, and the blood within them, with great force (Figure 18-5)
 - c. Endocardium—delicate inner layer of endothelial tissue
 2. Chambers of the heart—divided into four cavities with the right and left chambers separated by the septum (Figures 18-6 and 18-7)
 - a. Atria
 - (1) Two superior chambers, known as “receiving chambers,” because they receive blood from veins
 - (2) Atria alternately contract and relax to receive blood and then push it into ventricles
 - (3) Myocardial wall of each atrium is not very thick, because little pressure is needed to move blood such a small distance
 - (4) Auricle—earlike flap protruding from each atrium
 - b. Ventricles
 - (1) Two lower chambers, known as “pumping chambers,” because they push blood into the large network of vessels
 - (2) Ventricular myocardium is thicker than the myocardium of the atria, because great force must be generated to pump the blood a large distance; myocardium of left ventricle is thicker than the right, because it must push blood much further
 3. Valves of the heart—mechanical devices that permit the flow of blood in one direction only (Figure 18-8)
 - a. Atrioventricular (AV) valves—prevent blood from flowing back into the atria from the ventricles when the ventricles contract
 - (1) Tricuspid valve (right AV valve)—guards the right atrioventricular orifice; free edges of three flaps of endocardium are attached to papillary muscles by chordae tendineae
 - (2) Bicuspid, or mitral, valve (left AV valve)—similar in structure to tricuspid valve except only two flaps
 - b. Semilunar (SL) valves—half-moon-shaped flaps growing out from the lining of the pulmonary artery and aorta; prevents blood from flowing back into the ventricles from the aorta and pulmonary artery
 - (1) Pulmonary semilunar valve—valve at entrance of the pulmonary artery
 - (2) Aortic semilunar valve—valve at entrance of the aorta
 - c. Skeleton of the heart
 - (1) Set of connected rings that serve as a semi-rigid support for the heart valves and for the attachment of cardiac muscle of the myocardium
 - (2) Serves as an electrical barrier between the myocardium of the atria and that of the ventricles
 - d. Surface projection (review Figure 18-9)
 - e. Flow of blood through heart (review Figure 18-7)
 4. Blood supply of heart tissue (Figure 18-10)
 - a. Coronary arteries—myocardial cells receive blood from the right and left coronary arteries
 - (1) First branches to come off the aorta
 - (2) Ventricles receive blood from branches of both right and left coronary arteries
 - (3) Each ventricle receives blood only from a small branch of the corresponding coronary artery
 - (4) Most abundant blood supply goes to the myocardium of the left ventricle
 - (5) Right coronary artery is dominant in approximately 50% of all hearts and the left in about 20%; in approximately 30%, neither coronary artery is dominant
 - (6) Few anastomoses exist between the larger branches of the coronary arteries
 - b. Veins of the coronary circulation
 - (1) As a rule, veins follow a course that closely parallels that of coronary arteries
 - (2) After going through cardiac veins, blood enters the coronary sinus to drain into the right atrium
 - (3) Several veins drain directly into the right atrium
 5. Conduction system of the heart—comprising the sinoatrial (SA) node, atrioventricular (AV) node, AV bundle, and Purkinje fibers; made up of modified cardiac muscle (Figure 18-11)
 - a. Sinoatrial node (SA node or pacemaker)—hundreds of cells in the right atrial wall near the opening of the superior vena cava
 - b. Atrioventricular node (AV node or node of Tawara)—small mass of special cardiac muscle in right atrium along the lower part of interatrial septum

- c. Atrioventricular bundle (AV bundle or bundle of His) and Purkinje fibers
 - (1) AV bundle originates in AV node, extends by two branches down the two sides of the inter-ventricular septum, and continues as Purkinje fibers
 - (2) Purkinje fibers extend out to the papillary muscles and lateral walls of ventricles
- 6. Nerve supply of the heart
 - a. Cardiac plexuses—located near the arch of the aorta, made up of the combination of sympathetic and parasympathetic fibers
 - b. Fibers from the cardiac plexus accompany the right and left coronary arteries to enter the heart
 - c. Most fibers end in the SA node, but some end in the AV node and in the atrial myocardium
 - d. Sympathetic nerves—accelerator nerves
 - e. Vagus fibers—inhibitory, or depressor, nerves

BLOOD VESSELS

- A. Types of blood vessels
 - 1. Artery—vessel that carries blood away from the heart; small artery is an arteriole
 - 2. Vein—vessel that carries blood toward the heart; small vein is a venule
 - 3. Capillary—microscopic vessel that carries blood from arterioles to venules
- B. Structure of blood vessels (Figure 18-12)
 - 1. Arteries and veins have three layers
 - a. Tunica adventitia—outermost layer; made of strong, flexible fibrous connective tissue; helps hold vessels open; prevents tearing of vessels during body movements; in veins, thickest layer; in arteries, thinner than middle layer
 - b. Tunica media—middle layer; made of smooth muscle tissue sandwiched together with a layer of elastic connective tissue; permits changes in blood vessel diameter; artery tunica media thicker than that of vein
 - c. Tunica intima—innermost layer; made of endothelium; in arteries, completely smooth lining; in veins, forms semilunar valves
 - 2. Capillaries—have only one layer, the endothelium so the capillary wall is thin enough to allow effective exchanges of material between the plasma and interstitial fluid
- C. Functions of blood vessels
 - 1. Capillaries—most important vessels functionally because they allow the delivery and collection of substances; called the exchange vessels (Figure 18-13)
 - 2. Arteries—carry blood to arterioles
 - 3. Arterioles—carry blood from arteries to capillaries; also serve as resistance vessels
 - 4. Veins—act as collectors and as reservoir vessels; called the capacitance vessels (Figure 18-14)

MAJOR BLOOD VESSELS

- A. Circulatory routes (Figure 18-15)
 - 1. Systemic circulation—blood flows from the left ventricle of the heart through blood vessels to all parts of the body (except gas exchange tissues of lungs) and back to the right atrium
 - 2. Pulmonary circulation—venous blood moves from right atrium to right ventricle to pulmonary artery to lung arterioles and capillaries where gases are exchanged; oxygenated blood returns to left atrium via pulmonary veins; from left atrium, blood enters the left ventricle
- B. Systemic circulation
 - 1. Systemic arteries (review Table 18-2 and Figures 18-16 to 18-21)
 - a. Main arteries give off branches, which continue to rebranch, forming arterioles and then capillaries
 - b. End-arteries—arteries that eventually diverge into capillaries
 - c. Arterial anastomosis—arteries that open into other branches of the same or other arteries; incidence of arterial anastomoses increases as distance from the heart increases
 - 2. Systemic veins (review Figures 18-22 to 18-29)
 - a. Veins are the ultimate extensions of capillaries; unite into vessels of increasing size to form venules and then veins
 - b. Large veins of the cranial cavity are called dural sinuses
 - c. Veins anastomose the same as arteries
 - d. Venous blood from the head, neck, upper extremities, and thoracic cavity (except lungs) drains into superior vena cava
 - e. Venous blood from thoracic organs drains directly into superior vena cava or azygos vein
 - f. Hepatic portal circulation (Figure 18-28)
 - (1) Veins from the spleen, stomach, pancreas, gallbladder, and intestines send their blood to the liver via the hepatic portal vein
 - (2) In the liver the venous blood mingles with arterial blood in the capillaries and is eventually drained from the liver by hepatic veins that join the inferior vena cava
 - g. Venous blood from the lower extremities and abdomen drains into inferior vena cava
- C. Fetal circulation
 - 1. The basic plan of fetal circulation—additional vessels needed to allow fetal blood to secure oxygen and nutrients from maternal blood at the placenta (Figure 18-31)
 - a. Two umbilical arteries—extensions of the internal iliac arteries; carry fetal blood to the placenta
 - b. Placenta—attached to uterine wall; where exchange of oxygen and other substances between the separated maternal and fetal blood occurs (Figure 18-30)

- c. Umbilical vein—returns oxygenated blood from the placenta to the fetus; enters body through the umbilicus and goes to the undersurface of the liver where it gives off two or three branches and then continues as the ductus venosus
 - d. Ductus venosus—continuation of the umbilical vein and drains into inferior vena cava
 - e. Foramen ovale—opening in septum between the right and left atria
 - f. Ductus arteriosus—small vessel connecting the pulmonary artery with the descending thoracic aorta
2. Changes in circulation at birth (compare Figures 18-31 and 18-32)
 - a. When umbilical cord is cut, the two umbilical arteries, the placenta and umbilical vein, no longer function
 - b. Umbilical vein within the baby's body becomes the round ligament of the liver
 - c. Ductus venosus becomes the ligamentum venosum of the liver
 - d. Foramen ovale—functionally closed shortly after a newborn's first breath and pulmonary circulation is established; structural closure takes approximately 9 months
 - e. Ductus arteriosus—contracts with establishment of respiration, becomes ligamentum arteriosum

CYCLE OF LIFE: CARDIOVASCULAR ANATOMY

- A. Birth—change from placenta-dependent system
- B. Heart and blood vessels maintain basic structure and function from childhood through adulthood
 1. Exercise thickens myocardium and increases the supply of blood vessels in skeletal muscle tissue
- C. Adulthood through later adulthood—degenerative changes
 1. Atherosclerosis—blockage or weakening of critical arteries
 2. Heart valves and myocardial tissue degenerate—reduces pumping efficiency

REVIEW QUESTIONS

1. Discuss the size, position, and location of the heart in the thoracic cavity.
2. Describe the pericardium, differentiating between the fibrous and serous portions.
3. Exactly where is pericardial fluid found? Explain its function.

4. Define the following terms: *intercalated disks*, *syncytium*, *autorhythmic*.
5. Name and locate the chambers and valves of the heart.
6. Trace the flow of blood through the heart.
7. Identify, locate, and describe the functions of each of the following structures: SA node, AV node, AV bundle.
8. Identify the vessels that join to form the hepatic portal vein.
9. Describe the six unique structures necessary for fetal circulation.
10. Explain how the separation of oxygenated and deoxygenated blood occurs after birth.
11. Explain the purpose of echocardiography.
12. Identify the clinical significance of cardiac enzymes.
13. Why is the internal jugular vein sometimes ligated as a result of middle ear infection?
14. Briefly define the following terms: *aneurysm*, *atherosclerosis*, *phlebitis*.
15. Identify possible causes of coronary artery disease.
16. Define congestive heart failure.
17. Explain how hemorrhoids develop.

CRITICAL THINKING QUESTIONS

1. How is CPR accomplished? What is the significance of the placement of the heart in the thoracic cavity and successful CPR?
2. What would result if there were a lack of anastomosis in the arteries of the heart?
3. The general public thinks the most important structure in the cardiovascular system is the heart. Anatomists know it is the capillary. What information would you use to support this view?
4. Compare and contrast arterial blood in systemic circulation and arterial blood in pulmonary circulation.
5. Can you make the distinction between an occlusion of an end-artery and the occlusion of other small arteries?
6. Determine which of the following veins drain into the superior vena cava and which drain into the inferior vena cava: longitudinal sinus, great saphenous, basilic, internal jugular, azygos, popliteal, and hepatic portal.
7. How can you describe the functional advantage of a portal system?
8. Can you make use of the vessels and organs to trace the path taken by a single RBC? Begin at the right atrium and proceed to the left great toe and return to the right atrium.
9. Can you explain what happens to the cardiovascular system during the normal cycle of one's life?