Circulatory System

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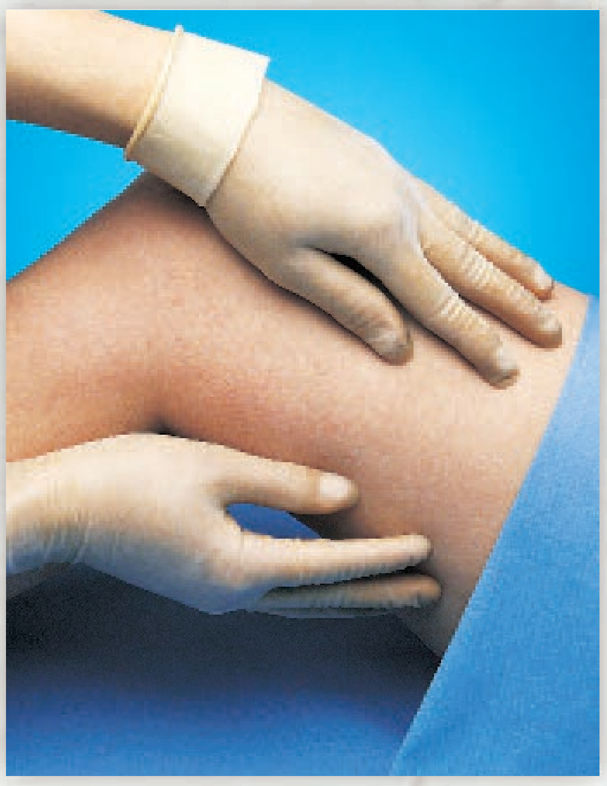


Clinical Case Study

A 65-year-old woman who had been discharged from the hospital following a myocardial infarction (heart attack) returned to the emergency room several weeks later because of the sudden onset of pain in her right lower extremity. The attending physician noticed that the patient's leg was also pale and cool from the knee down. Furthermore, he was unable to detect a pulse over the dorsal pedal and popliteal arteries. A good femoral pulse, however, was palpable in the inguinal region. Upon questioning, the patient stated that she was sent home with blood-thinning medication because tests had revealed that the heart attack had caused a blood clot to form within her heart. The doctors were worried, she added, that "a piece of the clot could break off and go to other parts of the body."

Explain how the patient's heart attack could have led to her current leg complaints. In which side of her heart (right or left) did the previously diagnosed blood clot most likely reside? Explain anatomically where the cause of her new problem is located and describe how it came to arrive there.

FIGURE: Observation and palpation are important diagnostic tools used to assess vascular problems. Blockage of blood flow may have serious consequences downstream from the point of occlusion.

FUNCTIONS AND MAJOR COMPONENTS OF THE CIRCULATORY SYSTEM

An efficient circulatory system is necessary for maintaining the life of complex multicellular organisms.

Objective 1 Describe the functions of the circulatory system.

Objective 2 Describe the major components of the circulatory system.

A unicellular organism can provide for its own maintenance and continuity by performing the wide variety of functions needed for life. By contrast, the complex human body is composed of trillions of specialized cells that demonstrate a division of labor. Cells of a multicellular organism depend on one another for the very basics of their existence. The majority of the cells of the body are firmly implanted in tissues and are incapable of procuring food and oxygen on their own, or even moving away from their own wastes. Therefore, a highly specialized and effective means of transporting materials within the body is needed.

The blood contained within vessels serves this transportation function. An estimated 60,000 miles of vessels throughout the body of an adult ensure that continued sustenance reaches each of the trillions of living cells. However, the blood can also transport disease-causing viruses, bacteria, and their toxins. As a safeguard, the circulatory system has defense mechanisms—the white blood cells and lymphatic system. In order to perform its various functions, the circulatory system works together with the respiratory, urinary, digestive, endocrine, and integumentary systems in maintaining homeostasis (fig. 16.1).

Functions of the Circulatory System

The many functions of the circulatory system can be grouped into two broad areas: transportation and protection.

1. **Transportation.** All of the substances involved in cellular metabolism are transported by the circulatory system. These substances can be categorized as follows:
   a. *Respiratory*. Red blood cells called **erythrocytes** (*ĕ-rith'rŏ-sīts*) transport oxygen to the tissue cells. In the lungs, oxygen from the inhaled air attaches to hemoglobin molecules within the erythrocytes and is trans-

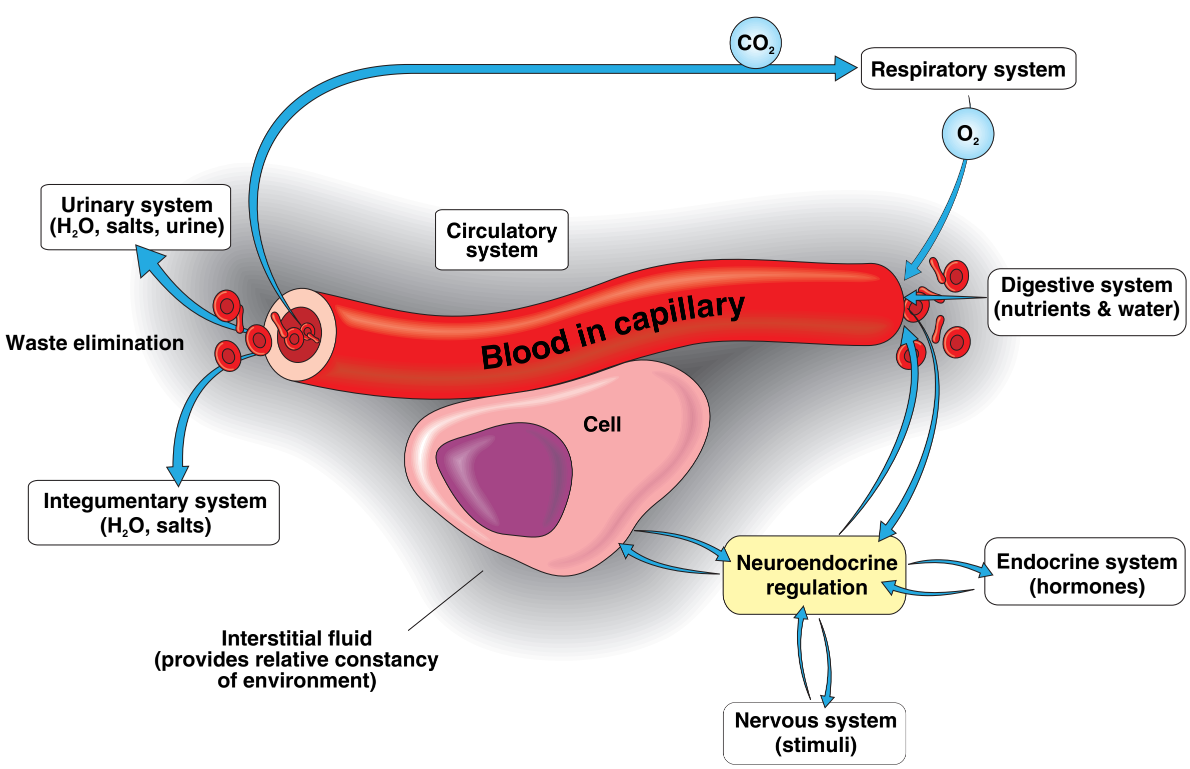


FIGURE 16.1 The relationship of the circulatory system to the other body systems in maintaining homeostasis.

ported to the cells for aerobic respiration. Carbon dioxide produced by cellular respiration is carried by the blood to the lungs for elimination in the exhaled air (fig. 16.2).

b. *Nutritive*. The digestive system is responsible for the mechanical and chemical breakdown of food to forms that can be absorbed through the intestinal wall into the blood and lymph vessels. The blood then carries these absorbed products of digestion through the liver to the cells of the body.

c. *Excretory*. Metabolic wastes, excess water and ions, as well as other molecules in plasma (the fluid portion of blood), are filtered through the capillaries of the kidneys into kidney tubules and excreted in urine.

d. *Regulatory*. The blood carries hormones and other regulatory molecules from their site of origin to distant target tissues.

2. **Protection.** The circulatory system protects against injury and foreign microbes or toxins introduced into the body. The clotting mechanism protects against blood loss when vessels are damaged, and white blood cells called **leukocytes** (*loo'kŏ-sīts*) render the body immune to many disease-causing agents. Leukocytes may also protect the body through phagocytosis (see fig. 3.12).

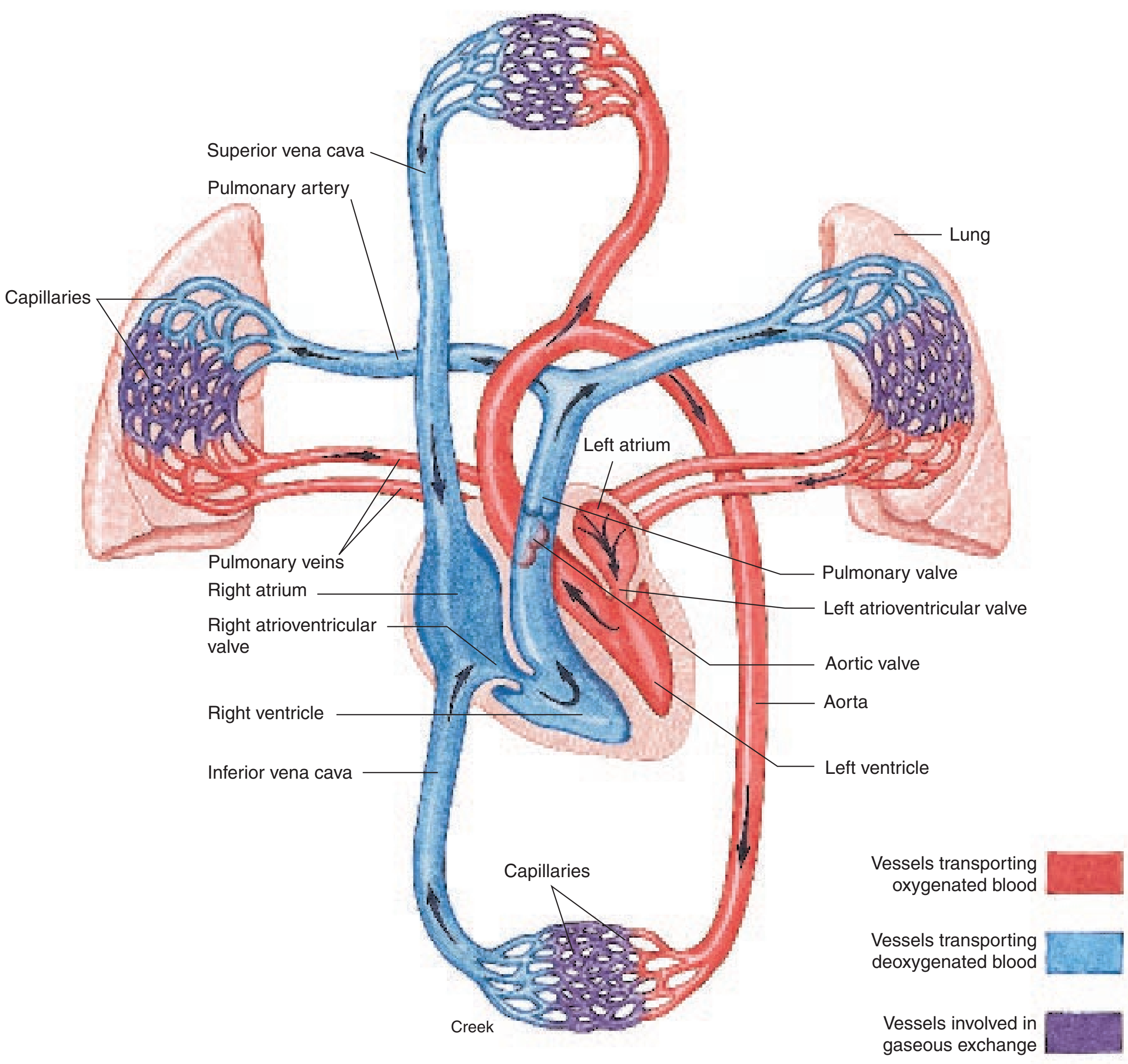


FIGURE 16.2 A schematic diagram of the circulatory system.

CHAPTER 16

Major Components of the Circulatory System

The circulatory system is frequently divided into the **cardiovascular system,** which consists of the heart, blood vessels, and blood, and the **lymphatic system,** which consists of lymphatic vessels and lymphoid tissues within the spleen, thymus, tonsils, and lymph nodes.

The **heart** is a four-chambered double pump. Its pumping action creates the pressure needed to push blood in the vessels to the lungs and body cells. At rest, the heart of an adult pumps about 5 liters of blood per minute. It takes only about a minute for blood to be circulated to the most distal extremity and back to the heart.

Blood vessels form a tubular network that permits blood to flow from the heart to all living cells of the body and then back to the heart. *Arteries* carry blood away from the heart, while *veins* return blood to the heart. Arteries and veins are continuous with each other through smaller blood vessels.

Arteries branch extensively to form a network of progressively smaller vessels. Those that are microscopic are called *arterioles* (*ar-te″re-o′lēz*). Conversely, microscopic-sized veins called *venules* (*ven′yoolz*) deliver blood to progressively larger vessels that empty into the large veins. Blood passes from the arterial to the venous system in *capillaries,* which are the thinnest and most numerous blood vessels. All exchanges of fluid, nutrients, and wastes between the blood and tissue cells occur across the walls of capillaries; thus, they are considered the basic functional units of the circulatory system.

Fluid derived from plasma passes out of capillary walls into the surrounding tissues, where it is called *interstitial fluid* or *tissue fluid.* Some of this fluid returns directly to capillaries and some enters into **lymphatic vessels** located in the connective tissues around the blood vessels. Fluid in lymphatic vessels is called *lymph.* This fluid is returned to the venous blood at particular sites. **Lymph nodes,** positioned along the way, cleanse the lymph prior to its return to the venous blood.

Endothermic (warm-blooded) animals, including humans, need an efficient circulatory system to transport oxygen-rich blood rapidly to all parts of the body. Of the vertebrates, only birds and mammals with their consistently warm body temperatures are considered endothermic, and only birds, mammals, and a few reptiles (crocodiles and alligators) have a four-chambered heart.

Knowledge Check

1. Name the components of the circulatory system that function in oxygen transport, in the transport of nutrients from the digestive system, and in protection.
2. Define the terms *artery, vein,* and *capillary* and describe the function of each of these vessels.
3. Define the terms *interstitial fluid* and *lymph.* How do these fluids relate to blood plasma?

BLOOD

Blood, a highly specialized connective tissue, consists of formed elements—erythrocytes, leukocytes, and platelets (thrombocytes)—that are suspended and carried in the blood plasma. The constituents of blood function in transport, immunity, and blood-clotting mechanisms.

Objective 3 List the different types of formed elements of blood; describe their appearance and explain their functions.

Objective 4 Describe the origin of erythrocytes, leukocytes, and platelets.

Objective 5 List the different types of substances found in blood plasma.

Objective 6 Describe the origin and function of the different categories of blood plasma proteins.

The total blood volume in the average-sized adult is about 5 liters, constituting about 8% of the total body weight. Blood leaving the heart is referred to as *arterial blood.* Arterial blood, with the exception of that going to the lungs, is bright red in color because of the high concentration of oxyhemoglobin (the combination of oxygen and hemoglobin) in the erythrocytes. *Venous blood* is blood returning to the heart. Except for the venous blood from the lungs, it contains less oxygen and is, therefore, a darker red than the oxygen-rich arterial blood. Blood has a viscosity that ranges between 4.5 and 5.5. This means that it is thicker than water, which has a viscosity of 1.0. Blood has a pH range of 7.35 to 7.45 and a temperature within the thorax of the body of about 38° C (100.4° F). When you donate blood, a "unit" (half a liter) is drained. This represents approximately a tenth of your total blood volume.

Blood is composed of a cellular portion, called **formed elements,** and a fluid portion, called **blood plasma.** When a blood sample is centrifuged, the heavier formed elements are packed into the bottom of the tube, leaving blood plasma at the top (fig. 16.3). The formed elements constitute approximately 45% of the total blood volume, a percentage known as the *hematocrit.* The blood plasma accounts for the remaining 55%. The hematocrit closely approximates the percentage of red blood cells per given volume of blood and is an important indicator of the oxygen-carrying capacity of blood.

Formed Elements of Blood

The formed elements of blood include **erythrocytes** (red blood cells, or RBCs); **leukocytes** (white blood cells, or WBCs); and **platelets** (thrombocytes). Erythrocytes are by far the most nu-

plasma: Gk. *plasma,* to form or mold
hematocrit: Gk. *haima,* blood; *krino,* to separate
erythrocytes: Gk. *erythros,* red; *kytos,* hollow (cell)
leukocytes: Gk. *leukos,* white; *kytos,* hollow (cell)

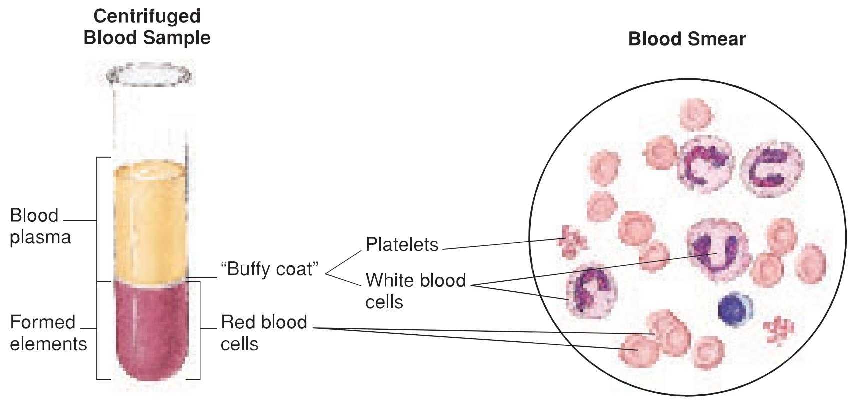


FIGURE 16.3 The formed elements (blood cells) become packed at the bottom of the test tube when whole blood is centrifuged, leaving the fluid blood plasma at the top of the tube. Red blood cells are the most abundant of the blood cells—white blood cells and platelets form only a thin, light-colored buffy coat at the interface of the packed red blood cells and the blood plasma.

merous of these three types. A cubic millimeter of blood contains 5.1 million to 5.8 million erythrocytes in males and 4.3 million to 5.2 million erythrocytes in females. By contrast, the same volume of blood contains only 5,000 to 10,000 leukocytes and 250,000 to 450,000 platelets.

Erythrocytes

Erythrocytes are biconcave discs—flattened, with a depressed center—about 7.5 µm in diameter and 2.5 µm thick. Their unique shape relates to their function of transporting oxygen; it provides an increased surface area through which gas can diffuse (fig. 16.4). Mature erythrocytes lack a nucleus and mitochondria (they obtain energy from anaerobic respiration). They have a circulating life span of only about 120 days, after which they are destroyed by phagocytic cells in the liver and spleen.

Oxygen molecules attached to *hemoglobin molecules* within erythrocytes give blood its red color. A hemoglobin molecule consists of four protein chains called *globins,* each of which is bound to one *heme,* a red-pigmented molecule. Each heme contains an atom of iron that can combine with one molecule of oxygen. Thus, the hemoglobin molecule as a whole can transport up to four molecules of oxygen. Considering that each erythrocyte contains approximately 280 million hemoglobin molecules, a single erythrocyte can transport over a billion molecules of oxygen. It is within the lungs that the oxygen molecules contained in inhaled air attach to the hemoglobin molecules and are transported via erythrocytes to the trillions of body cells.

Anemia refers to any condition in which there is an abnormally low hemoglobin concentration and/or erythrocyte count. The most common type is *iron-deficiency anemia,* which is due to a deficient intake or absorption of iron, or to excessive iron loss. Iron is an essential component of the hemoglobin molecule. In *pernicious anemia,* the production of red blood cells is insufficient because of lack of a substance needed for the absorption of vitamin B_{12} by intestinal cells. *Aplastic anemia* is anemia due to destruction of the red bone marrow, which may be caused by chemicals (including benzene and arsenic) or by radiation.

hemoglobin: Gk. *haima,* blood; *globus,* globe

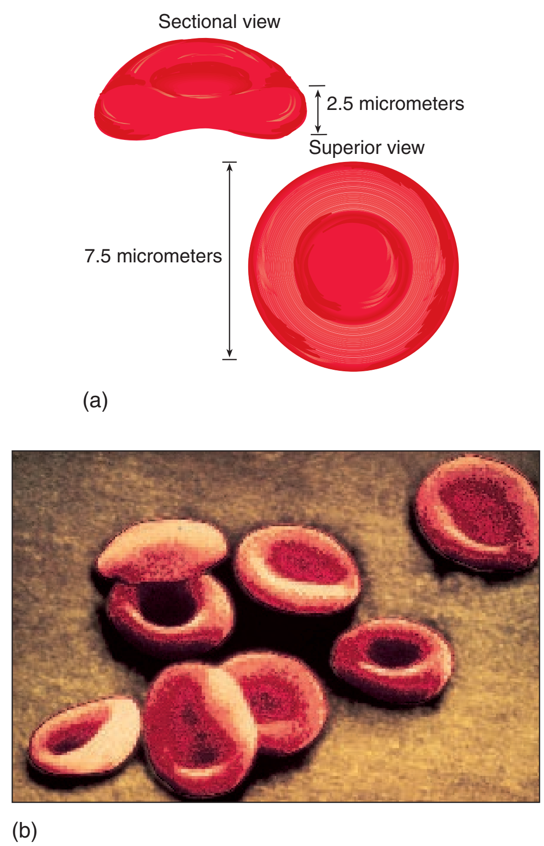


FIGURE 16.4 Erythrocytes. (*a*) A diagram and (*b*) a scanning electron micrograph.

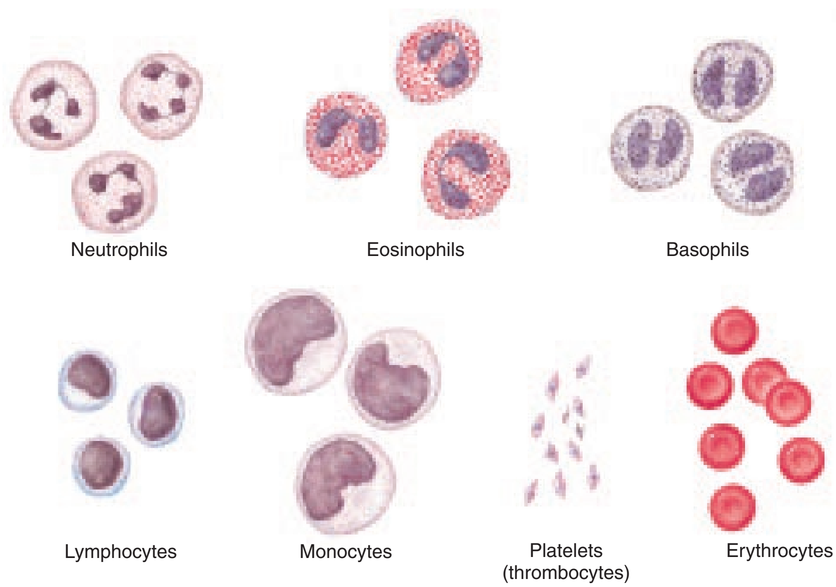


FIGURE 16.5 Types of formed elements in blood.

Leukocytes

Leukocytes are larger than erythrocytes and are different in other ways as well. Leukocytes contain nuclei and mitochondria and can move in an ameboid fashion (erythrocytes are not able to move independently). Because of their ameboid ability, leukocytes can squeeze through pores in capillary walls and move to an extravascular site of infection, whereas erythrocytes usually remain confined within blood vessels. The movement of leukocytes through capillary walls is called *diapedesis* (*di''ă-pĕ-de'sis*).

Leukocytes are almost invisible under the microscope unless they are stained; therefore, they are classified on the basis of their stained appearance. Those leukocytes that have granules in their cytoplasm are called **granular leukocytes.** Those with granules so small that they cannot be seen easily with the light microscope are called **agranular** (or nongranular) **leukocytes.** The granular leukocytes are also identified by their oddly shaped nuclei, which in some cases are contorted into lobes attached by thin strands. The granular leukocytes are therefore known as **polymorphonuclear** (*pol''e-mor''fo-noo'kle-ar*) **(PMN) leukocytes.**

The stain used to identify leukocytes is usually a mixture of a pink-to-red stain called *eosin* (*e'o-sin*) and a blue-to-purple (hematoxylin) stain called a "basic stain." Granular leukocytes with pink-staining granules are therefore called **eosinophils** (*e''ŏ-sin'ŏ-filz*) (fig. 16.5), and those with blue-staining granules are called **basophils.** Those with granules that have little affinity for either stain are **neutrophils.** Neutrophils are the most abundant type of leukocyte, constituting 54%–62% of the leukocytes in the blood.

The leukocytes of the agranular type include **monocytes** and **lymphocytes.** Monocytes are the largest cells found in the blood, and their large nuclei may vary considerably in shape. Lymphocytes have large nuclei surrounded by a relatively thin layer of cytoplasm.

Platelets

Platelets are the smallest of the formed elements and are actually fragments of large cells called **megakaryocytes** (*meg''ă-kar'e-ŏ-sīts*) found in red bone marrow. (This is why the term *formed elements* is used rather than *blood cells* to describe erythrocytes, leukocytes, and platelets.) The fragments that enter the circulation as platelets lack nuclei but, like leukocytes, are capable of ameboid movement. The platelet count per cubic millimeter of blood is 250,000 to 450,000. Platelets survive for about 5 to 9 days and then are destroyed by the spleen and liver.

Platelets play an important role in blood clotting. They constitute the major portion of the mass of the clot, and phospholipids in their cell membranes activate the clotting factors in blood plasma that result in threads of fibrin, which reinforce the platelet plug. Platelets that attach together in a blood clot also release a chemical called *serotonin,* which stimulates constriction of blood vessels, reducing the flow of blood to the injured area.

The appearance of the formed elements of the blood is shown in figures 16.5 and 16.6, and their characteristics are summarized in table 16.1.

Blood cell counts are an important source of information in assessing the health of a person. An abnormal increase in erythrocytes, for example, is termed *polycythemia* (*pol''e-si-the'me-ă*) and is indicative of several dysfunctions. As previously mentioned, an abnormally low red blood cell count is termed *anemia.* An elevated leukocyte count, called *leukocytosis,* is often associated with localized infection. A large number of immature leukocytes within a blood sample is diagnostic of the disease *leukemia.*

diapedesis: Gk. *dia,* through; *pedester,* on foot

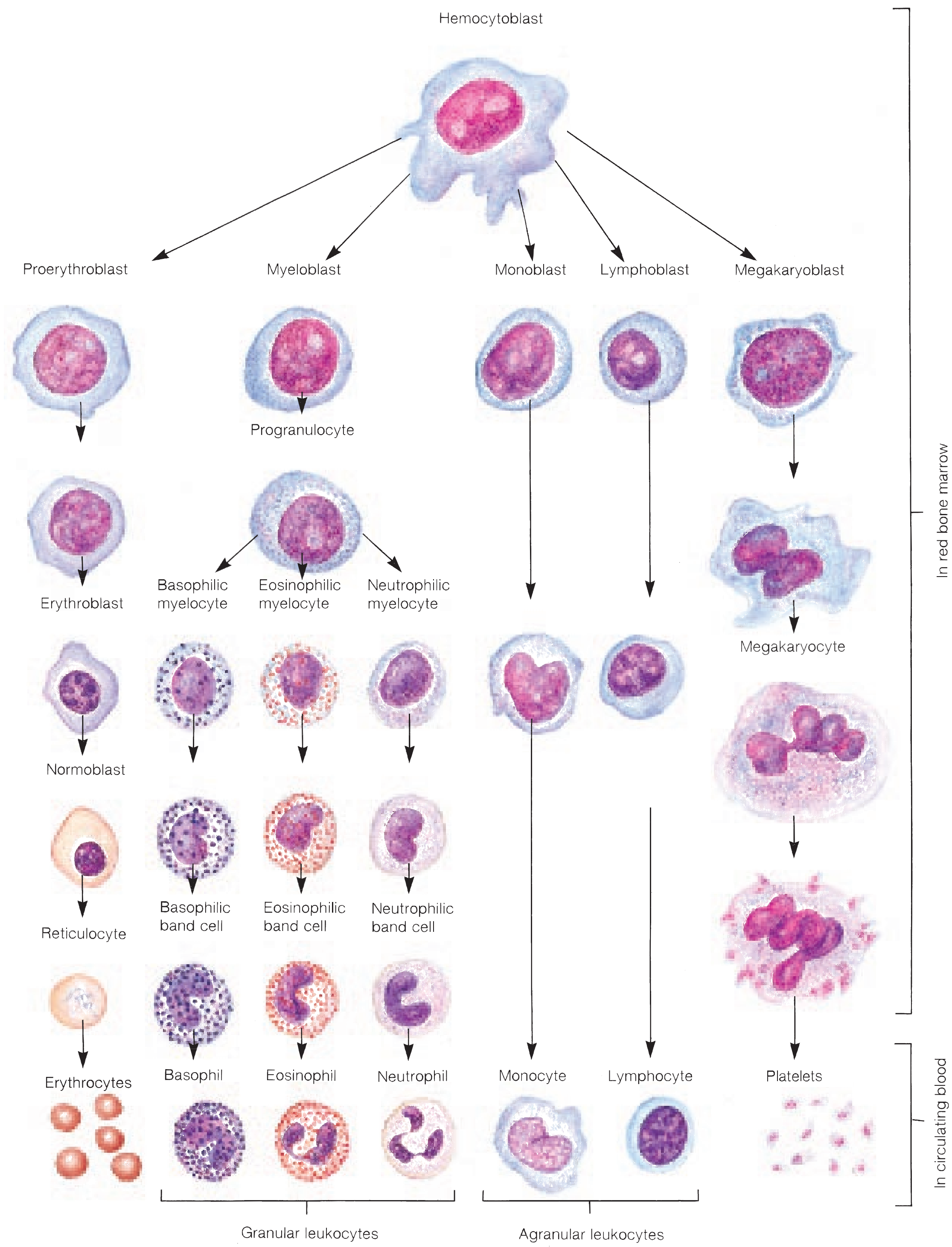


FIGURE 16.6 The processes of hemopoiesis. Formed elements begin as hemocytoblasts (stem cells) and differentiate into the various kinds of blood cells, depending on the needs of the body.

TABLE 16.1 Formed Elements of Blood

Component	Description	Number Present	Function
Erythrocyte (red blood cell)	Biconcave disc without nucleus; contains hemoglobin; survives 100 to 120 days red blood cells; large cytoplasmic granules; survive 12 hours to 3 days	4,000,000 to 6,000,000/mm^3	Transports oxygen and carbon dioxide
Leukocytes (white blood cells)		5,000 to 10,000/mm^3	Aid in defense against infections by microogranisms
Granulocytes	About twice the size of red blood cells; large cytoplasmic granules; survive 12 hours to 3 days		
1. Neutrophil	Nucleus with 2 to 5 lobes; cytoplasmic granules stain slightly pink	54% to 62% of white cells present	Phagocytic
2. Eosinophil	Nucleus bilobed; cytoplasmic granules stain red in eosin stain	1% to 3% of white cells present	Helps to detoxify foreign substances; secretes enzymes that break down clots
3. Basophil	Nucleus lobed; cytoplasmic granules stain blue in hematoxylin stain	Less than 1% of white cells present	Releases anticoagulant heparin
Agranulocytes	Cytoplasmic granules not visible; survive 100 to 300 days (some much longer)		
1. Monocyte	2 to 3 times larger than red blood cell; nuclear shape varies from round to lobed	3% to 9% of white cells present	Phagocytic
2. Lymphocyte	Only slightly larger than red blood cell; nucleus nearly fills cell	25% to 33% of white cells present	Provides specific immune response (including antibodies)
Platelet (thrombocyte)	Cytoplasmic fragment; survives 5 to 9 days	250,000 to 450,000/mm^3	Enables clotting; releases serotonin, which causes vasoconstriction

Hemopoiesis

Blood cells are constantly formed through a process called *hemopoiesis* (fig. 16.6). The term **erythropoiesis** (*ĕ-rith″ro-poi-e′sis*) refers to the formation of erythrocytes; **leukopoiesis** refers to the formation of leukocytes. These processes occur in two classes of tissues. **Myeloid tissue** is the red bone marrow of the humeri, femora, ribs, sternum, pelvis, and portions of the skull that produces erythrocytes, granular leukocytes, and platelets.

Lymphoid tissue—including the lymph nodes, tonsils, spleen, and thymus—produces the agranular leukocytes (monocytes and lymphocytes). During embryonic and fetal development, the hemopoietic centers are located in the yolk sac, liver, and spleen. After birth, the liver and spleen become the sites of blood cell destruction.

Erythropoiesis is an extremely active process. It is estimated that about 2.5 million erythrocytes are produced every second in order to replace the number that are continuously destroyed by the liver and spleen. (Recall that the life span of an erythrocyte is approximately 120 days.) During the destruction of erythrocytes, iron is salvaged and returned to the red bone marrow where it is used again in the formation of erythrocytes. Agranular leukocytes remain functional for 100 to 300 days under normal body conditions. Granular leukocytes, by contrast, have an extremely short life span of 12 hours to 3 days.

Hemopoiesis begins the same way in both myeloid and lymphoid tissues (fig. 16.6). Undifferentiated mesenchymal-like cells develop into stem cells called **hemocytoblasts.** These stem cells are able to divide rapidly. Some of the daughter cells become new stem cells (hence, the stem cell population is never depleted), whereas other daughter cells become specialized along different paths of blood cell formation. Hemocytoblasts, for example, may develop into **proerythroblasts** (*pro″ĕ-rith′rŏ-blasts*) which form erythrocytes; **myeloblasts,** which form granular leukocytes (neutrophils, eosinophils, and basophils); **lymphoblasts,** which form lymphocytes; **monoblasts,** which form monocytes; or **megakaryoblasts,** which form platelets.

Stem cells are currently being harvested from fetal organs (the placenta and umbilical cord) with the intent of promoting their differentiation into an array of adult cells, making up specific organs such as the brain and pancreas. It is hoped that differentiated stem cells will replace diseased cells in vital organs. Other research is focusing on utilizing stem cells from one's own red bone marrow and thus being more ethically acceptable and less likely to be rejected as foreign cells.

The major purpose of a bone marrow transplant is to provide competent hemopoietic hemocytoblasts to the recipient. If the bone marrow is returned to the same person, the procedure is called an *autotransplant.* If the donor and recipient are different people, it is termed an *allogenic transplant.*

hemopoiesis: Gk. *haima,* blood; *poiesis,* production
erythropoiesis: Gk. *erythros,* red; *poiesis,* production
leukopoiesis: Gk. *leukos,* white; *poiesis,* production

megakaryoblasts: Gk. *megas,* great; *karyon,* nut; *blastos,* germ

CHAPTER 16

TABLE 16.2 **Plasma Proteins**

Protein	Percentage of Total	Origin	Function
Albumin	60%	Liver	Gives viscosity to blood and assists in maintaining blood osmotic pressure
Globulin	36%		
Alpha globulins		Liver	Transport lipids and fat-soluble vitamins
Beta globulins		Liver	Transport lipids and fat-soluble vitamins
Gamma globulins		Lymphoid tissue	Constitute antibodies of immunity
Fibrinogen	4%	Liver	Assists platelets in the formation of clots

Blood Plasma

Blood plasma is the fluid portion, or *matrix,* of the blood. It can best be visualized when the formed elements are removed. Blood plasma constitutes approximately 55% of a given volume of blood. It is a straw-colored liquid, about 90% water. The remainder of the blood plasma consists of proteins, inorganic salts, carbohydrates, lipids, amino acids, vitamins, and hormones. The functions of blood plasma include transporting nutrients, gases, and vitamins; regulating electrolyte and fluid balances; and maintaining a consistent blood pH of between 7.35 and 7.45.

Plasma proteins constitute 7% to 9% of the blood plasma. These proteins remain within the blood and interstitial fluid and assist in maintaining body homeostasis. The three types of plasma proteins are albumins, globulins, and fibrinogen. **Albumins** (*al-byoo'minz*) account for about 60% of the plasma proteins and are the smallest of the three types. They are produced by the liver and provide the blood with carrier molecules and with the viscosity needed to maintain and regulate blood pressure. **Globulins** (*glob'yoo-linz*) make up about 36% of the plasma proteins. The three types of globulins are **alpha globulins, beta globulins,** and **gamma globulins.** The alpha and beta globulins are synthesized in the liver and function in transporting lipids and fat-soluble vitamins. Gamma globulins are produced by lymphoid tissues and are antibodies of immunity. The third type of plasma protein, **fibrinogen** (*fi-brin'ŏ-jen*), accounts for only about 4% of the protein content. Fibrinogens are large molecules that are synthesized in the liver and, together with platelets, play an important role in clotting the blood. When fibrinogen is removed from blood plasma, the remaining fluid is referred to as *serum.*

The plasma proteins of blood are summarized in table 16.2.

albumin: L. *albumen,* white
globulin: L. *globulus,* small globe
fibrinogen: L. *fibra,* fibrous

Knowledge Check

4. Describe erythropoiesis in terms of where it occurs, its rate, and the specific steps involved. What does a mature erythrocyte look like?
5. Describe the different types of leukocytes and explain where and how these different types are produced.
6. Explain how platelets are produced. How do they differ from other formed elements of blood?
7. List the different classes of plasma proteins and describe their origin and functions.
8. Explain how leukocytes get to the site of an infection.

HEART

The structure of the heart enables it to serve as a transport system pump that keeps blood continuously circulating through the blood vessels of the body.

Objective 7 Describe the location of the heart in relation to other organs of the thoracic cavity and their associated serous membranes.

Objective 8 Describe the structure and functions of the three layers of the heart wall.

Objective 9 Describe the chambers and valves of the heart and identify the grooves on its surface.

Objective 10 Trace the flow of blood through the heart and distinguish between the pulmonary and systemic circulations.

Objective 11 Describe the location of the conduction system components of the heart and trace the path of impulse conduction.

Location and General Description

The hollow, four-chambered, muscular **heart** is roughly the size of a clenched fist. It averages 255 grams in adult females and 310 grams in adult males. The heart contracts an estimated 42 million times a year, pumping 700,000 gallons of blood.

The heart is located in the thoracic cavity between the lungs in the mediastinum (fig. 16.7). About two-thirds of the heart is located left of the midline, with its *apex,* or cone-shaped end, pointing downward and resting on the diaphragm. The *base* of the heart is the broad superior end, where the large vessels attach.

The **parietal pericardium** (*per''ĭ-kar'de-um*) is a loose-fitting serous sac of dense fibrous connective tissue that encloses and protects the heart (fig. 16.7). It separates the heart

pericardium: Gk. *peri,* around; *kardia,* heart

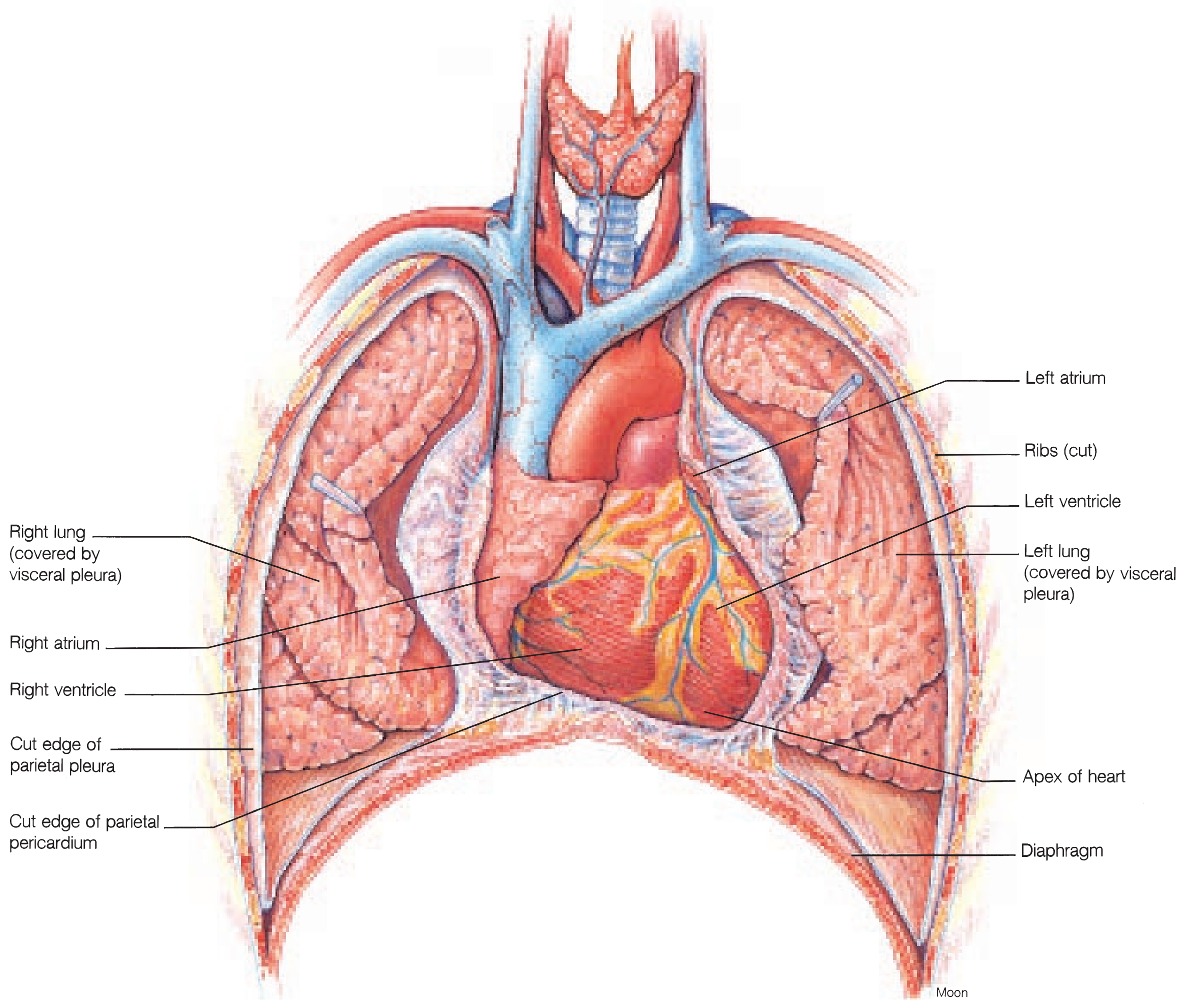


FIGURE 16.7 The position of the heart and associated serous membranes within the thoracic cavity.

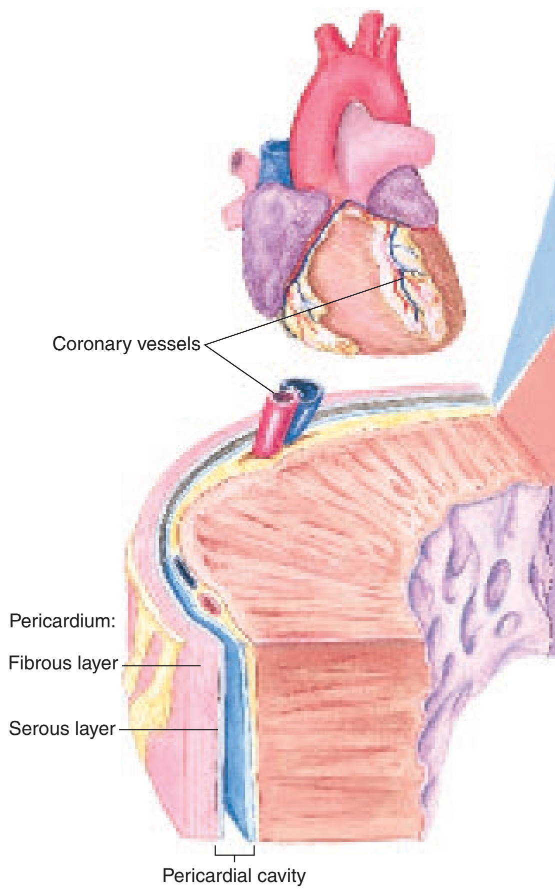
from the other thoracic organs and forms the wall of the *pericardial cavity* (table 16.3), which contains a watery, lubricating *pericardial fluid*. The parietal pericardium is actually composed of an outer *fibrous pericardium* and an inner *serous pericardium*. It is the serous pericardium that produces the lubricating pericardial fluid that allows the heart to beat in a kind of frictionless bath.

Pericarditis is an inflammation of the parietal pericardium that results in an increased secretion of fluid into the pericardial cavity. Because the tough, fibrous portion of the parietal pericardium is inelastic, an increase in fluid pressure impairs the movement of blood into and out of the chambers of the heart. Some of the pericardial fluid may be withdrawn for analysis by injecting a needle to the left of the xiphoid process to pierce the parietal pericardium.

Heart Wall

The wall of the heart is composed of three distinct layers (table 16.3). The outer layer is the **epicardium,** also called the *visceral pericardium*. The space between this layer and the parietal pericardium is the pericardial cavity, just described. The thick middle layer of the heart wall is called the **myocardium.** It is composed of cardiac muscle tissue (see chapter 4) and arranged in such a way that the contraction of the muscle bundles results in squeezing or wringing of the heart chambers. The thickness of the myocardium varies in accordance with the force needed to eject blood from the particular chamber. Thus, the thickest portion of the myocardium surrounds the left ventricle and the atrial walls are relatively thin. The inner layer of the wall, called the

TABLE 16.3 Layers of the Heart Wall



Layer	Characteristics	Function
Epicardium (visceral layer of serous pericardium)	Serous membrane including blood capillaries, lymph capillaries, and nerve fibers	Serves as lubricative outer covering
Myocardium	Cardiac muscle tissue separated by connective tissues and including blood capillaries, lymph capillaries, and nerve fibers	Provides muscular contractions that eject blood from the heart chambers
Endocardium	Endothelial tissue and a thick subendothelial layer of elastic and collagenous fibers	Serves as protective inner lining of the chambers and valves

endocardium, is continuous with the endothelium of blood vessels. The endocardium also covers the valves of the heart. Inflammation of the endocardium is called *endocarditis*.

Chambers and Valves

The interior of the heart is divided into four chambers: upper right and left **atria** (*a′tre-ă*—singular *atrium*) and lower right and left **ventricles.** The atria contract and empty simultaneously into the ventricles (fig. 16.8), which also contract in unison. The walls of the atria are reinforced with latticelike **pestinate muscles.** Contraction of these modified cardiac muscles ejects blood from the atria to the ventricles. Each atrium has an ear-shaped, expandable appendage called an **auricle** (*or′ĭ-kul*). The atria are separated from each other by the thin, muscular **interatrial septum;** the ventricles are separated from each other by the thick, muscular **interventricular septum. Atrioventricular valves** (*AV valves*) lie between the atria and ventricles, and **semilunar valves** are located at the bases of the two large vessels leaving the heart. Heart valves (see table 16.4) maintain a one-way flow of blood.

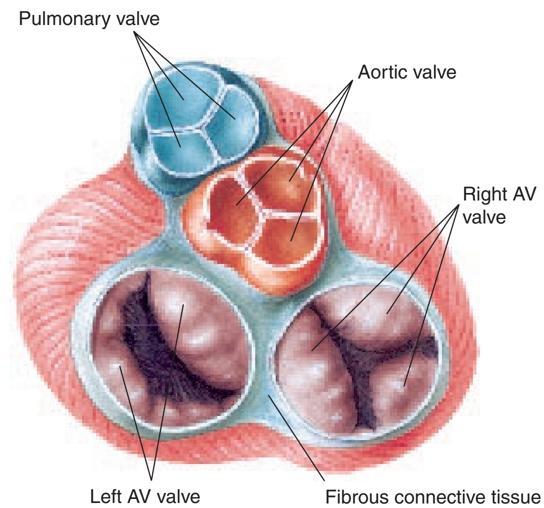
Grooved depressions on the surface of the heart indicate the partitions between the chambers and also contain **cardiac vessels** that supply blood to the muscular wall of the heart. The most prominent groove is the *coronary sulcus* that encircles the heart and marks the division between the atria and ventricles. The partition between the right and left ventricles is denoted by two (anterior and posterior) *interventricular sulci*.

atrium: L. *atrium*, chamber
ventricle: L. *ventriculus*, diminutive of *venter*, belly

auricle: L. *auricula*, a little ear

TABLE 16.4 Valves of the Heart

Valve	Location	Comments
Right atrioventricular valve	Between right atrium and right ventricle	Composed of three cusps that prevent a backflow of blood from right ventricle into right atrium during ventricular contraction
Pulmonary valve	Entrance to pulmonary trunk	Composed of three half-moon-shaped flaps that prevent a backflow of blood from pulmonary trunk into right ventricle during ventricular relaxation
Left atrioventricular (mitral) valve	Between left atrium and left ventricle	Composed of two cusps that prevent a backflow of blood from left ventricle to left atrium during ventricular contraction
Aortic valve	Entrance to ascending aorta	Composed of three half-moon-shaped flaps that prevent a backflow of blood from aorta into left ventricle during ventricular relaxation



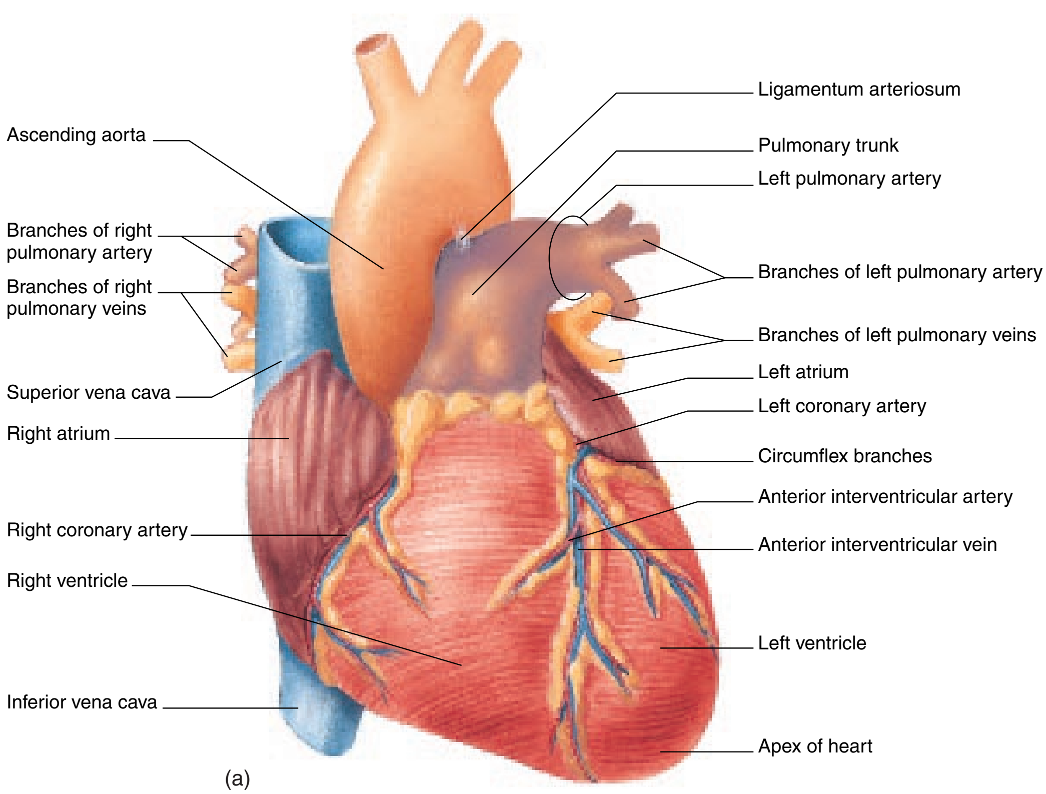


FIGURE 16.8 The structure of the heart. (*a*) An anterior view, (*b*) a posterior view, and (*c*) an internal view.

CHAPTER 16

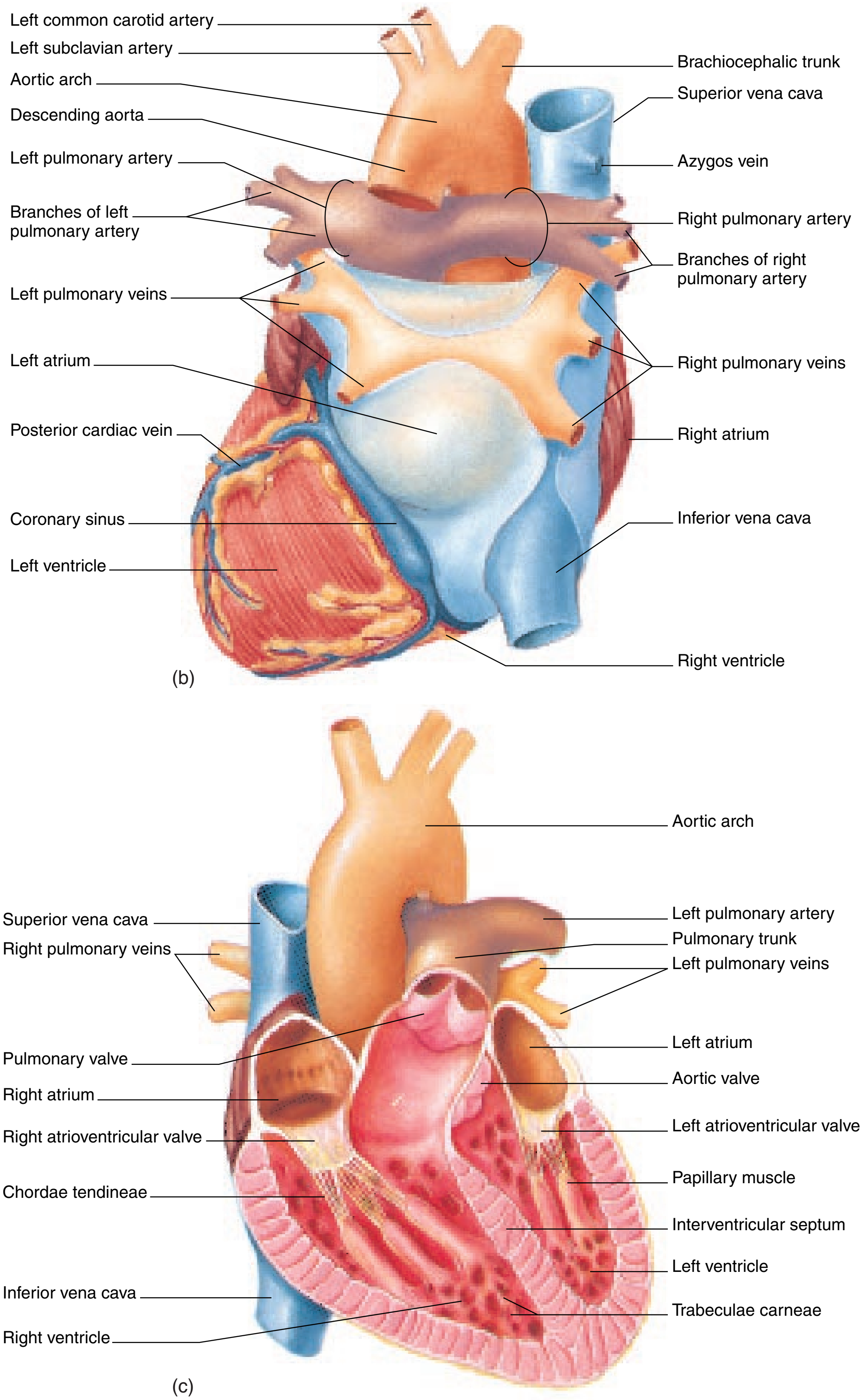


FIGURE 16.8 *Continued.*

The following discussion shows the sequence in which blood flows through the atria, ventricles, and valves. It is important to keep in mind that the right side of the heart (right atrium and right ventricle) receives deoxygenated blood (blood low in oxygen) and pumps it to the lungs. The left side of the heart (left atrium and left ventricle) receives oxygenated blood (blood rich in oxygen) from the lungs and pumps it throughout the body.

Right Atrium

The right atrium receives systemic venous blood from the **superior vena cava,** which drains the upper portion of the body, and from the **inferior vena cava,** which drains the lower portion (fig. 16.8). The *coronary sinus* is an additional opening into the right atrium that receives venous blood from the myocardium of the heart itself.

Right Ventricle

Blood from the right atrium passes through the **right atrioventricular (AV) valve** (also called the *tricuspid valve*) to fill the right ventricle. The right AV valve is characterized by three valve leaflets, or *cusps*. Each cusp is held in position by strong tendinous cords called **chordae tendineae** (*kor'de ten-din'e-e*). The chordae tendineae are secured to the ventricular wall by cone-shaped **papillary muscles.** These structures prevent the valves from everting, like an umbrella in a strong wind, when the ventricles contract and the ventricular pressure increases.

Ventricular contraction causes the right AV valve to close and the blood to leave the right ventricle through the **pulmonary trunk** and to enter the capillaries of the lungs via the **right** and **left pulmonary arteries.** The **pulmonary valve** (also called the *pulmonary semilunar valve*) lies at the base of the pulmonary trunk, where it prevents the backflow of ejected blood into the right ventricle.

Left Atrium

After gas exchange has occurred within the capillaries of the lungs, oxygenated blood is transported to the left atrium through two right and two left **pulmonary veins.**

Left Ventricle

The left ventricle receives blood from the left atrium. These two chambers are separated by the **left atrioventricular (AV) valve** (also called the *bicuspid valve* or *mitral valve*). When the left ventricle is relaxed, the valve is open, allowing blood to flow from the atrium into the ventricle; when the left ventricle contracts, the valve closes. Closing of the valve during ventricular contraction prevents the backflow of blood into the atrium.

The walls of the left ventricle are thicker than those of the right ventricle because the left ventricle bears a greater workload, pumping blood through the entire body. The endocardium of both ventricles is characterized by distinct ridges called **trabeculae carneae** (*tră-bek'yŭ-le kar'ne-e*) (fig. 16.8*c*). Oxygenated blood leaves the left ventricle through the **ascending portion of the aorta.** The **aortic valve** (also called the *aortic semilunar valve*), located at the base of the ascending portion of the aorta, closes as a result of the pressure of the blood when the left ventricle relaxes, and thus prevents the backflow of blood into the relaxed ventricle.

The valves are shown in figure 16.9, and their actions are summarized in table 16.4.

Cardiac catheterization is a procedure used in the diagnosis of certain heart disorders. A tube, or catheter, is inserted into a vein in the leg or the arm and threaded through the lumen of the vessel until it enters the heart. The location of the catheter can be monitored by means of a fluoroscope. When the catheter reaches the desired location within the heart, a radiopaque dye is released. The patient may then be radiographed, blood samples removed for analyses, or blood pressures monitored.

Circulatory Routes

The circulatory routes of the blood are illustrated in figure 16.2. The principal divisions of the circulatory blood flow are the *pulmonary* and *systemic circulations*.

The **pulmonary circulation** includes blood vessels that transport blood to the lungs for gas exchange and then back to the heart. It consists of the right ventricle that ejects the blood, the pulmonary trunk with its pulmonary valve, the pulmonary arteries that transport deoxygenated blood to the lungs, the pulmonary capillaries within each lung, the pulmonary veins that transport oxygenated blood back to the heart, and the left atrium that receives the blood from the pulmonary veins.

The **systemic circulation** involves all of the vessels of the body that are not part of the pulmonary circulation. It includes the right atrium, the left ventricle, the aorta with its aortic valve, all of the branches of the aorta, all capillaries other than those in the lungs involved with gas exchange, and all veins other than the pulmonary veins. The right atrium receives all of the venous return of oxygen-depleted blood from the systemic veins.

Coronary Circulation

The wall of the heart has its own supply of systemic blood vessels to meet its vital needs. The myocardium is supplied with blood by the **right** and **left coronary arteries** (fig. 16.10). These two vessels arise from the ascending part of the aorta, at the location of the aortic (semilunar) valve. The coronary arteries encircle the heart within the atrioventricular sulcus, the depression between the atria and ventricles. Two branches arise from both the right and left coronary arteries to serve the atrial and ventricular walls.

vena cava: L. *vena*, vein; *cava*, empty

chordae tendineae: L. *chorda*, string; *tendere*, to stretch

bicuspid: L. *bi*, two; *cuspis*, tooth point or spike

mitral: L. *mitra*, like a bishop's mitre

trabeculae carneae: L. *trabecula*, small beams; *carneus*, flesh

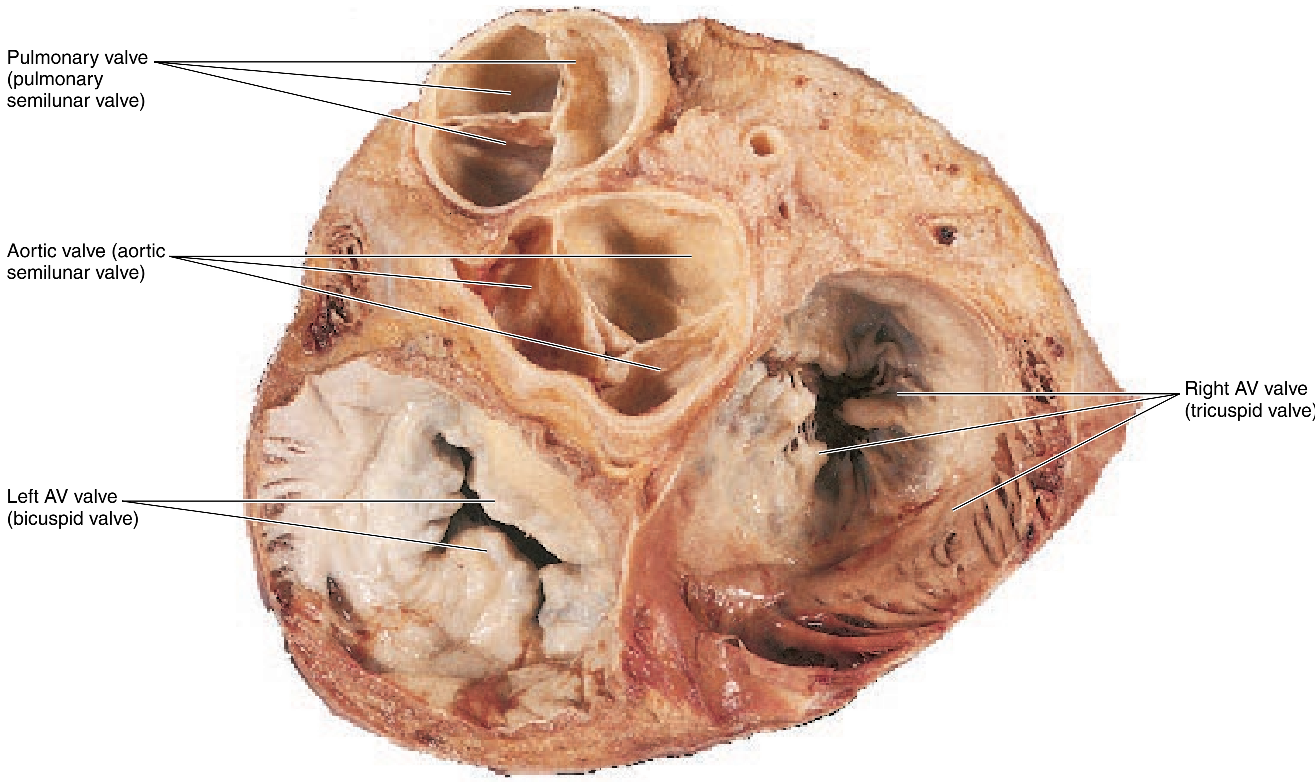


FIGURE 16.9 A superior view of the heart valves seen with the atria removed.

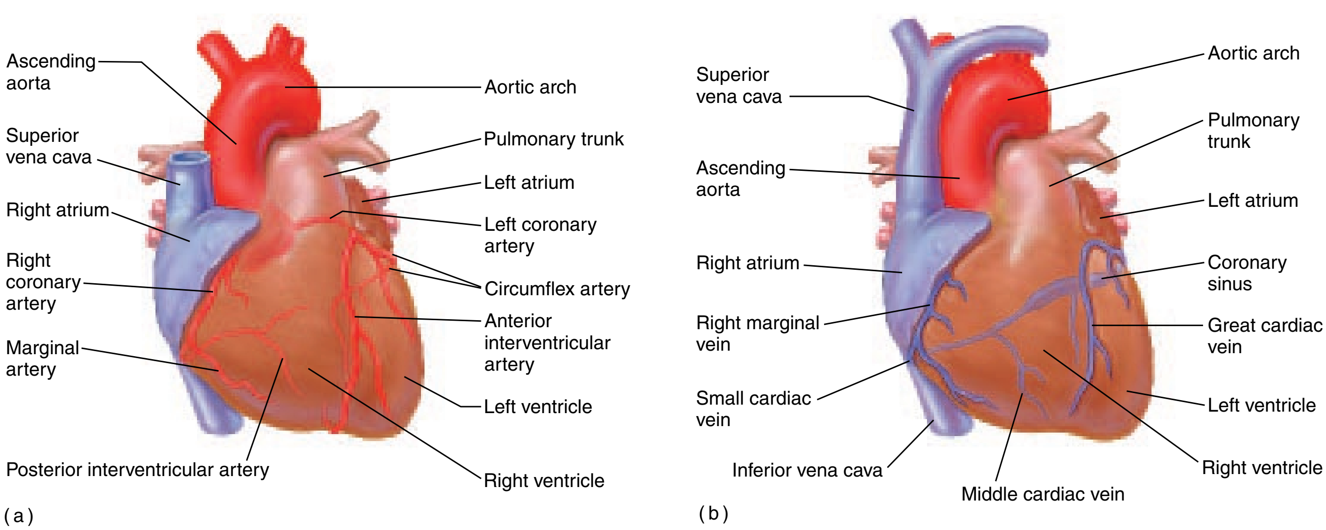


FIGURE 16.10 Coronary circulation. (*a*) An anterior view of the arterial supply to the heart and (*b*) an anterior view of the venous drainage.

The left coronary artery gives rise to the **anterior interventricular artery,** which courses within the anterior interventricular sulcus to serve both ventricles, and the **circumflex artery,** which supplies oxygenated blood to the walls of the left atrium and left ventricle. The right coronary artery gives rise to the **right marginal artery,** which serves the walls of the right atrium and right ventricle, and the **posterior interventricular artery,** which courses through the posterior interventricular sulcus to serve the two ventricles. The main trunks of the right and left coronaries anastomose (join together) on the posterior surface of the heart.

From the capillaries in the myocardium, the blood enters the **cardiac veins.** The course of these vessels parallels that of the coronary arteries. The cardiac veins, however, have thinner walls and are more superficial than the arteries. The two principal cardiac veins are the **anterior interventricular vein,** which returns blood from the anterior aspect of the heart, and the **posterior cardiac vein,** which drains the posterior aspect of the heart. These cardiac veins converge to form the **coronary sinus** channel on the posterior surface of the heart (figs. 16.8 and 16.10). The coronary venous blood then enters the heart through an opening into the right atrium.

Heart attacks are the leading cause of death in the United States. The most common type of heart attack involves an occlusion of a coronary artery, which reduces the delivery of oxygen to the myocardium. Several strategies are recommended to minimize the risk of heart attack: (1) reduce excess weight; (2) avoid hypertension through proper diet, stress reduction, or medication, if necessary; (3) avoid excessive saturated fats that may raise plasma cholesterol levels; (4) refrain from smoking; and (5) exercise regularly.

Conduction System of the Heart

Cardiac muscle has an intrinsic rhythmicity that allows the heartbeat to originate in and be conducted through the heart without extrinsic stimulation. Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the **conduction system.** The conduction system enables the **cardiac cycle,** which refers to the events surrounding the filling and emptying of the chambers of the heart. The conduction system consists of specialized tissues that generate and distribute electrical impulses through the heart. The components of the conduction system are the **sinoatrial node** (SA node), **atrioventricular node** (AV node), **atrioventricular bundle** (bundle of His [pronounced "hiss"]), and **conduction myofibers** (Purkinje [*pur-kin'jē*] fibers). None of these structures are macroscopic, but their locations can be noted (fig. 16.11*a*). The SA node, or *pacemaker,* is located in the posterior wall of the right atrium where the superior vena cava attaches to the heart. The SA node initiates the cardiac cycle by producing an electrical impulse that spreads over both atria, causing them to contract simultaneously and force blood into the ventricles. The basic depolarization rate of the SA node is 70 to 80 times per minute. The impulse then passes to the AV node, located in the inferior portion of the interatrial septum. From here, the impulse continues through the atrioventricular bundle, located at the top of the interventricular septum. The atrioventricular bundle divides into right and left bundle branches, which are continuous with the conduction myofibers within the ventricular walls. Stimulation of these fibers causes the ventricles to contract simultaneously.

Contraction of the ventricles is referred to as **systole** (*sis'tŏ-le*). Systole, together with the tension of the elastic fibers

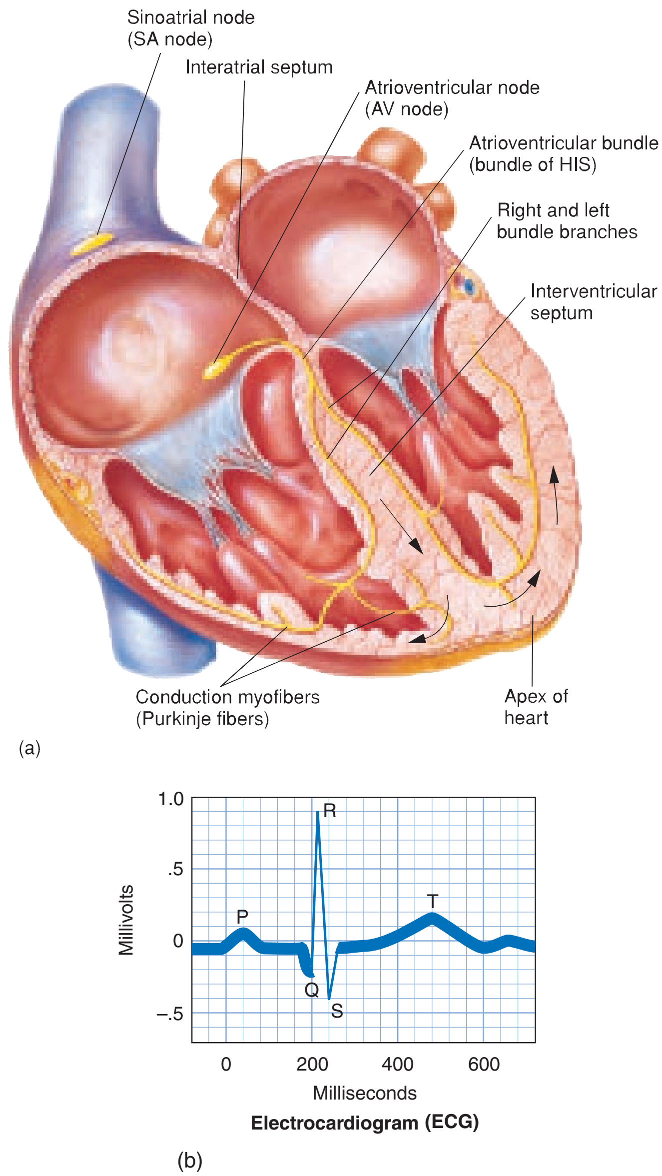


FIGURE 16.11 (*a*) The conduction system of the heart and (*b*) the electrocardiogram (ECG).

circumflex: L. *circum,* around; *flectere,* to bend

bundle of His: from Wilhelm His Jr., Swiss physician, 1863–1934

Purkinje fibers: from Johannes E. von Purkinje, Bohemian anatomist, 1787–1869

systole: Gk. *systole,* contraction

and contraction of smooth muscles within the systemic arteries, accounts for the systolic pressure within arteries. Ventricular relaxation is called **diastole** (*di-as′tŏ-le*). During diastole, the diastolic pressure within arteries can be recorded.

Variation in functioning within vital organs should be regarded as normal for a healthy adult. The heartbeat can vary by as much as 20 or 30 beats per minute in 24 hours, but the heart maintains an average of about 70 beats per minute during a day. Blood pressure recorded at 120 over 80 in the morning can rise to 140 over 100 by evening. The normal body temperature of 98.6° F will fluctuate between 97° and 99° F over a 24-hour period.

Although the heart does have an innate contraction pattern, it is also innervated by the autonomic nervous system in order to respond to the ever-changing physiological needs of the body (fig. 16.12). The SA and AV nodes have both sympathetic and parasympathetic innervation. Sympathetic stimulation accelerates the heart rate and dilates the coronary arteries, enabling the heart to meet its own increased metabolic demands as well as those of the rest of the body. Parasympathetic stimulation has the opposite effect. Sympathetic innervation is through fibers from the cervical and upper thoracic ganglia. Parasympathetic innervation is through branches of the vagus nerves. Branches from the right vagus innervate the SA node, and branches from the left vagus innervate the AV node.

Cardiac output is the volume of blood ejected by the heart into the systemic circulation each minute. It is determined by multiplying the stroke rate, or heart rate, by the stroke volume. The stroke volume is the amount of blood pumped from the heart into systemic circulation with each ventricular contraction, which amounts to about 70 ml of blood. A normal resting cardiac output ranges between 4.2 and 5.6 liters per minute. Exercise increases the heart rate, as do the hormones epinephrine and thyroxine. Atropine, caffeine, and camphor are drugs that have a stimulatory effect. Blood pressure and body temperature also have a profound effect on the heart rate.

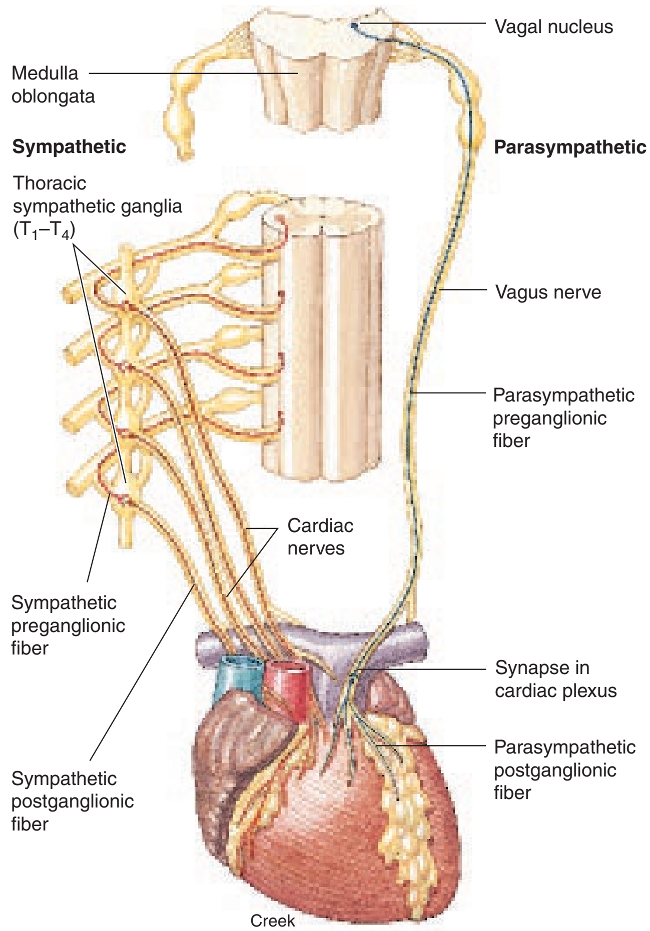


FIGURE 16.12 Innervation and feedback mechanisms of the heart.

Electrocardiogram

The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an *electrocardiogram* (ECG or EKG). The electrical changes result from depolarization and repolarization of cardiac muscle fibers and can be detected on the surface of the skin using an instrument called the *electrocardiograph*.

The principal aspects of an ECG are shown in figure 16.11*b*. The wave deflections, designated P, QRS, and T, are produced as specific events of the cardiac cycle occur. Any heart disease that disturbs the electrical activity will produce characteristic changes in one or more of these waves, so understanding the normal wave-deflection patterns is clinically important.

P Wave

Depolarization of the atrial fibers of the SA node produces the P wave. The actual contraction of the atria follows the P wave by a fraction of a second. The ventricles of the heart are in diastole during the expression of the P wave. A missing or abnormal P wave may indicate a dysfunction of the SA node.

P-R Interval

On the ECG recording, the P-R interval is the period of time from the start of the P wave to the beginning of the QRS complex. This interval indicates the amount of time required for the SA depolarization to reach the ventricles. A prolonged P-R interval suggests a conduction problem at or below the AV node.

QRS Complex

The QRS complex begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the depolarization of

diastole: Gk. *diastole*, prolonged or expansion

CHAPTER 16

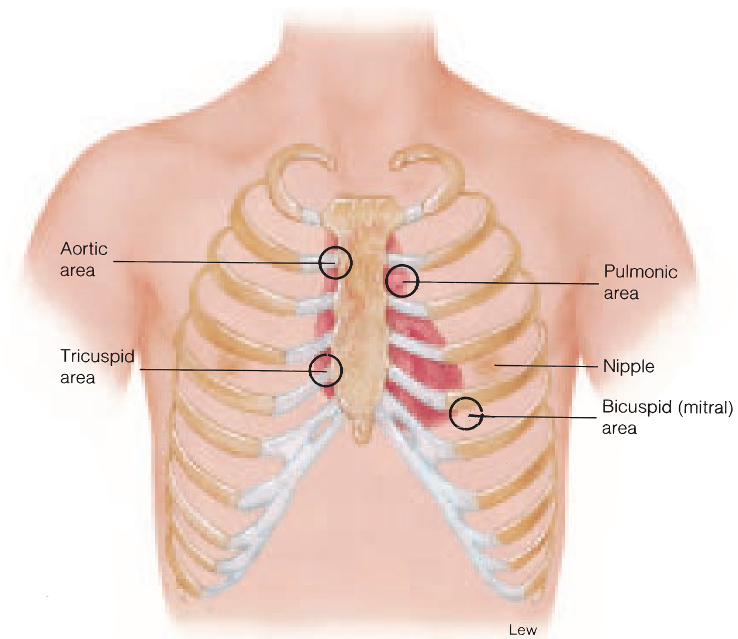


FIGURE 16.13 The valvular auscultatory areas are the standard stethoscope positions for listening to the heart sounds.

the ventricles. During this interval, the ventricles are in systole and blood is being ejected from the heart. It is also during this interval that the atria repolarize, but this event is obscured by the greater depolarization occurring in the ventricles. An abnormal QRS complex generally indicates cardiac problems of the ventricles. An enlarged R spike, for example, generally indicates enlarged ventricles.

S-T Segment

The time duration known as the S-T segment represents the period between the completion of ventricular depolarization and initiation of repolarization. The S-T segment is depressed when the heart receives insufficient oxygen; in acute myocardial infarction, it is elevated.

T Wave

The T wave is produced by ventricular repolarization. An arteriosclerotic heart will produce altered T waves, as will various other heart diseases.

Heart Sounds

Closing of the AV and semilunar valves produces sounds that can be heard at the surface of the chest with a stethoscope. These sounds are often verbalized as "lub-dub." The "lub," or **first sound,** is produced by the closing of the atrioventricular valves. The "dub," or **second sound,** is produced by the closing of the aortic and pulmonary valves. The first sound is thus heard when the ventricles contract at systole, and the second sound is heard when the ventricles relax at the beginning of diastole.

Heart sounds are of clinical importance because they provide information about the condition of the heart valves and may indicate heart problems. Abnormal sounds are referred to as *heart murmurs* and are caused by valvular leakage or restriction and the subsequent turbulence of the blood as it passes through the heart. In general, three basic conditions cause murmurs: (1) *valvular insufficiency,* in which the cusps of the valves do not form a tight seal; (2) *stenosis,* in which the walls surrounding a valve are roughened or constricted; and (3) a *functional murmur,* which is frequent in children and is caused by turbulence of the blood moving through the heart during heavy exercise. Functional murmurs are not pathological and are considered normal.

The valves of the heart are positioned directly deep to the sternum, which tends to obscure and dissipate valvular sounds. For this reason, a physician listening for heart sounds will place a stethoscope at locations designated as **valvular auscultatory areas.** These areas are named according to the valve that can be detected (fig. 16.13). The **aortic area** is immediately to the right of the sternum, at the second intercostal space. The **pulmonic area** is to the left of the sternum, almost directly across from the aortic area. The **tricuspid** and **bicuspid areas** are both near the fifth intercostal space, with the bicuspid (mitral) area more laterally placed. Surface landmarks are extremely important in identifying auscultatory areas. For example, in males and prepubescent females the biscuspid area is located just below the left nipple over the fifth intercostal space.

stenosis: Gk. *stenosis*, a narrowing

Knowledge Check

9. Distinguish between the pericardial and the thoracic cavities. Describe the serous membranes of the heart.
10. List the three layers of the heart wall and describe the structures associated with each layer.
11. List the valves that aid blood flow through the heart and describe their locations and functions.
12. Describe the flow of electrical impulses through the cardiac conduction system.

BLOOD VESSELS

The structure of arteries and veins allows them to transport blood from the heart to the capillaries and from the capillaries back to the heart. The structure of capillaries permits the exchange of blood plasma and dissolved molecules between the blood and surrounding tissues.

Objective 12 Describe the structure and function of arteries, capillaries, and veins.

Objective 13 Explain why capillaries are considered the functional units of the circulatory system.

Blood vessels form a closed tubular network that permits blood to flow from the heart to all the living cells of the body and then back to the heart. Blood leaving the heart passes through vessels of progressively smaller diameters referred to as **arteries, arterioles,** and **capillaries.** Capillaries are microscopic vessels that join the arterial flow to the venous flow. Blood returning to the heart from the capillaries passes through vessels of progressively larger diameters called **venules** and **veins.** In certain locations, such as surrounding the necks of the humerus and femur, there are converging arteries that form an *anastomosis* (*a-nas''tŏ-mo'sis*). This arrangement of vessels ensures a continuous supply of blood to these structures.

The walls of arteries and veins are composed of three layers, or tunics, as shown in figure 16.14.

- The **tunica externa,** or *adventitia*, the outermost layer, is composed of loose connective tissue.
- The **tunica media,** the middle layer, is composed of smooth muscle. The tunica media of arteries has variable amounts of elastic fibers.
- The **tunica interna,** the innermost layer, is composed of simple squamous epithelium and elastic fibers composed of *elastin*.

The layer of simple squamous epithelium is referred to as the **endothelium.** This layer lines the inner wall of all blood vessels. Capillaries consist of endothelium only, supported by a basement membrane.

Although arteries and veins have the same basic structure, there are some important differences between the two types of vessels. Arteries transport blood away from the heart; veins transport blood toward the heart. Arteries have more muscle in proportion to their diameter than do comparably sized veins. Also, arteries appear rounder than veins in cross section. Veins are usually partially collapsed because they are not usually filled to capacity. They can stretch when they receive more blood, and thus function as reservoirs or capacitance vessels. In addition, many veins have valves, which are absent in arteries.

Arteries

In the tunica media of large arteries, there are numerous layers of elastic fibers between the smooth muscle cells. Thus, the large arteries expand when the pressure of the blood rises as a result of ventricular contraction (systole); they recoil, like a stretched rubber band, when blood pressure falls during ventricular relaxation (diastole). This elastic recoil helps produce a smoother, less pulsatile flow of blood through the smaller arteries and arterioles.

Small arteries and arterioles are less elastic than the larger arteries and have a thicker layer of smooth muscle in proportion to their diameter. Unlike the larger *elastic arteries*, therefore, the smaller *muscular arteries* retain a relatively constant diameter as the pressure of the blood rises and falls during the heart's pumping activity. Because small muscular arteries and arterioles have narrow lumina, they provide the greatest resistance to blood flow through the arterial system.

Small muscular arteries that are 100 µm or less in diameter branch to form smaller arterioles (20–30 µm in diameter). In some tissues, blood from the arterioles enters the venules directly through **thoroughfare channels** (metarterioles) that form *vascular shunts* (fig. 16.15). In most cases, however, blood from arterioles passes into capillaries. Capillaries are the narrowest of blood vessels (7–10 µm in diameter), and serve as the functional units of the circulatory system. It is across their walls that exchanges of gases (O_2 and CO_2), nutrients, and wastes between the blood and the tissues take place.

Capillaries

The arterial system branches extensively to deliver blood to over 40 billion capillaries in the body. So extensive is this branching, that scarcely any cell in the body is more than a fraction of a millimeter away from any capillary; moreover, the tiny capillaries provide a total surface area of 1,000 square miles for exchanges between blood and interstitial (tissue) fluid.

Despite their large number, at any given time capillaries contain only about 250 ml of blood out of a total blood volume of about 5,000 ml (most blood is contained in the lumina of veins). The amount of blood flowing through a particular capillary bed is determined in part by the action of the **precapillary sphincter muscles** (fig. 16.15). These muscles allow only 5% to 10% of the

tunic: L. *tunica*, covering or coat

lumen: L. *lumen*, opening

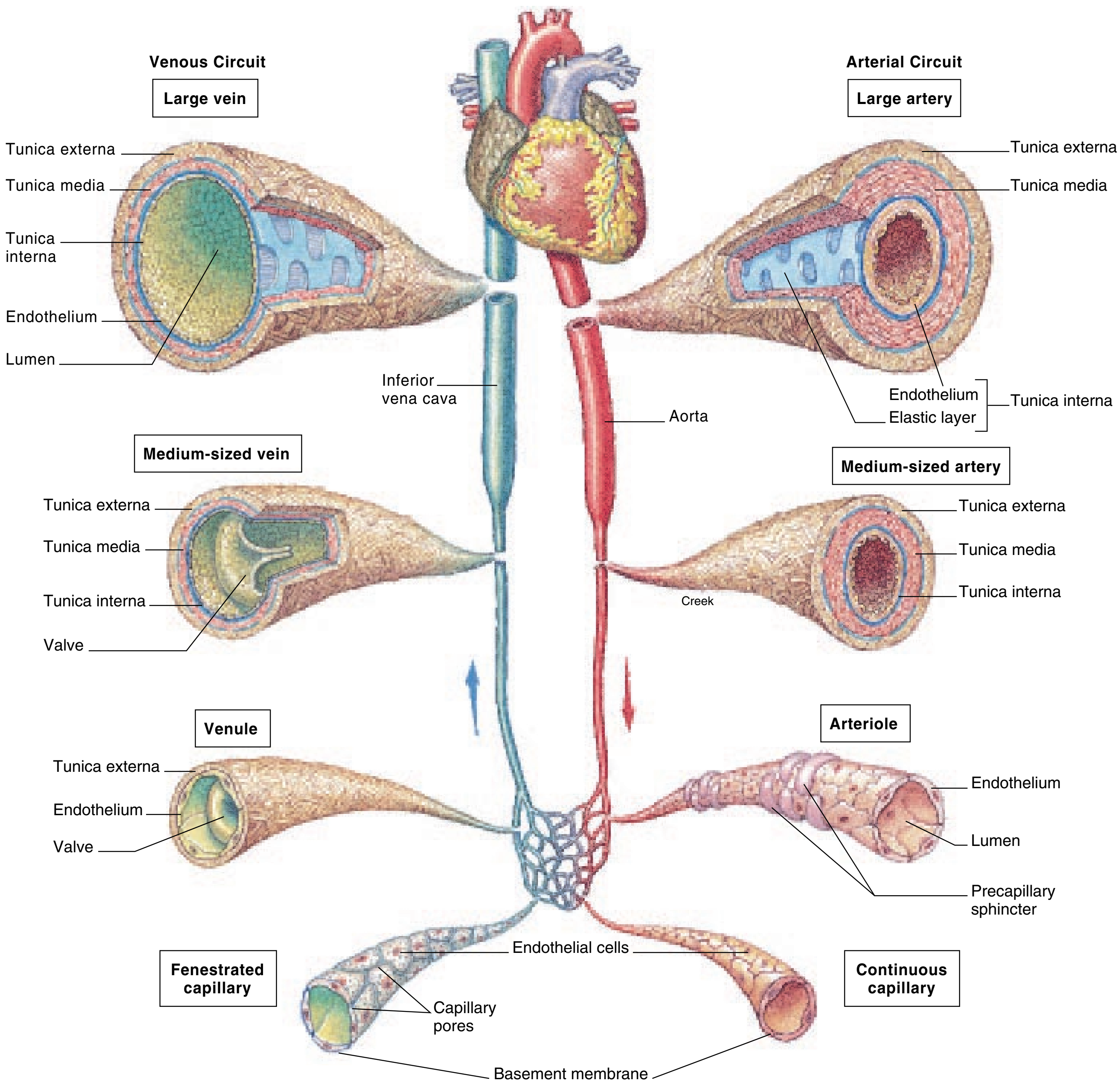


FIGURE 16.14 Relative thickness and composition of the tunics in comparable arteries and veins.

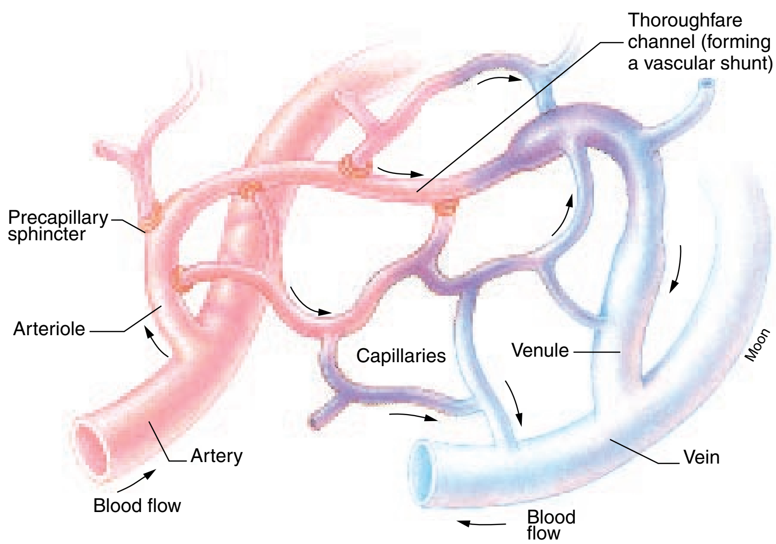


FIGURE 16.15 Microcirculation at the capillary level. Thoroughfare channels form vascular shunts, providing paths of least resistance between arterioles and venules. Precapillary sphincter muscles regulate the flow of blood through the capillaries.

capillary beds in skeletal muscles, for example, to be open at rest. Blood flow to an organ is regulated by the action of these precapillary sphincters and by the degree of resistance to blood flow provided by the small arteries and arterioles in the organ.

Unlike the vessels of the arterial and venous systems, the walls of capillaries are composed of just one cell layer—a simple squamous epithelium, or endothelium. The absence of smooth muscle and connective tissue layers allows for exchange of materials between the blood and the interstitial fluid.

Types of Capillaries

There are several different types of capillaries, distinguished by significant differences in structure. In terms of their endothelial lining, these capillary types include those that are *continuous*, those that are *discontinuous*, and those that are *fenestrated* (fig. 16.16).

Continuous capillaries are those in which adjacent endothelial cells are tightly joined together. These are found in muscles, lungs, adipose tissue, and in the central nervous system. The fact that continuous capillaries in the CNS lack intercellular channels contributes to the blood-brain barrier. Continuous capillaries in other organs have narrow intercellular channels (about 40–45Å wide) that permit the passage of molecules other than protein between the capillary blood and interstitial fluid.

The examination of endothelial cells with an electron microscope has revealed the presence of pinocytotic vesicles, which suggests that the intracellular transport of material may occur across the capillary walls. This type of transport appears to be the only available mechanism of capillary exchange within the central nervous system and may account, in part, for the selective nature of the blood-brain barrier (see fig. 11.8).

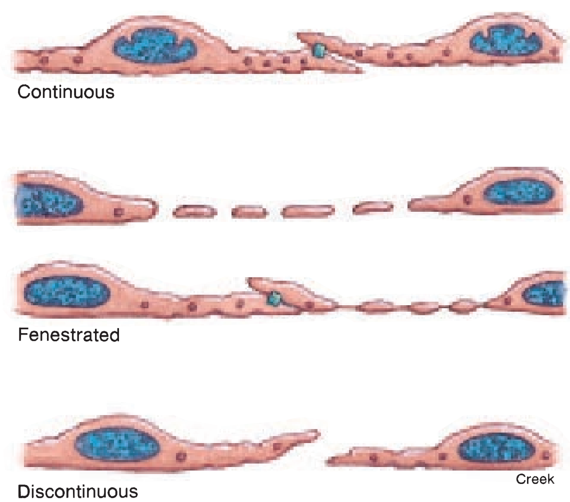


FIGURE 16.16 Diagrams of continuous, fenestrated, and discontinuous capillaries as they appear in the electron microscope. This classification is based on the continuity of the endothelium. (Dark circles in the cytoplasm indicate pinocytotic vesicles.)

Fenestrated (*fen'es-tra-tid*) **capillaries** occur in the kidneys, endocrine glands, and intestines. These capillaries are characterized by wide intercellular pores (800–1,000Å) that are covered by a layer of mucoprotein, which may serve as a diaphragm. **Discontinuous capillaries** are found in the bone marrow, liver, and spleen. The space between endothelial cells is so great that these capillaries look like little cavities (*sinusoids*) in the organ.

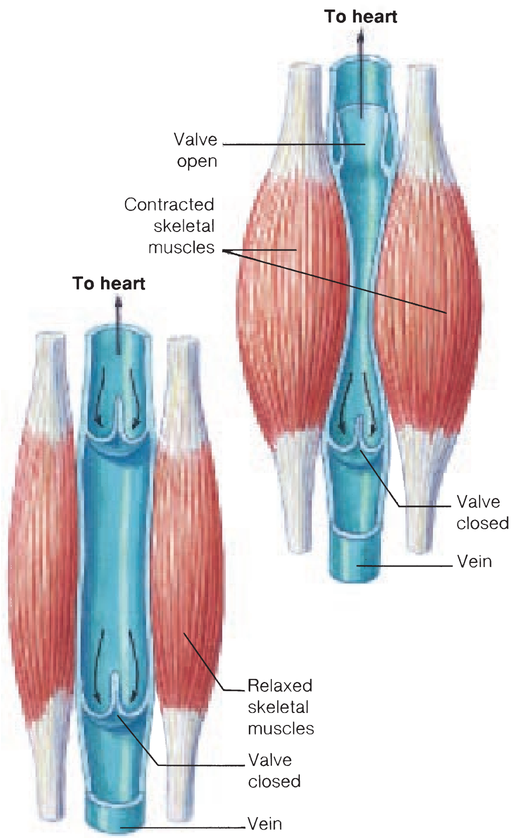


FIGURE 16.17 The action of the one-way venous valves. The contraction of skeletal muscles helps pump blood toward the heart, but the flow of blood away from the heart is prevented by closure of the venous valves.

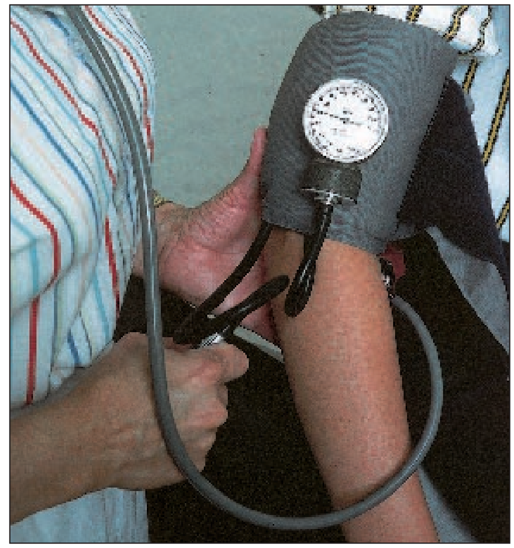


FIGURE 16.18 The use of a pressure cuff and a sphygmomanometer to measure blood pressure.

Veins

Veins are vessels that carry blood from capillaries back to the heart. The blood is delivered from microscopic vessels called **venules** into progressively larger vessels that empty into the large veins. The average pressure in the veins is only 2 mmHg, compared to a much higher average arterial pressure of about 100 mmHg. These pressures represent the hydrostatic pressure that the blood exerts on the walls of the vessels.

The low venous pressure is insufficient to return blood to the heart, particularly from the lower limbs. Veins, however, pass between skeletal muscle groups that provide a massaging action as they contract (fig. 16.17). As the veins are squeezed by contracting skeletal muscles, a one-way flow of blood to the heart is ensured by the presence of **venous valves.**

The effect of the massaging action of skeletal muscles on venous blood flow is often described as the *skeletal muscle pump*. The rate of venous return to the heart is dependent, in large part, on the action of skeletal muscle pumps. When these pumps are less active—for example, when a person stands still or is bedridden—blood accumulates in the veins and causes them to bulge. When a person is more active, blood returns to the heart at a faster rate and less is left in the venous system.

The accumulation of blood in the veins of the legs over a long period of time, as may occur in people with occupations that require standing still all day, can cause the veins to stretch to the point where the venous valves are no longer efficient. This can produce *varicose veins*. During walking, the movements of the foot activate the soleus muscle pump. This effect can be produced in bedridden people by extending and flexing the ankle joints.

Blood Pressure

Blood pressure is the force exerted by the blood against the inner walls of the vessels through which it flows. It plays its primary role in the arteries and arterioles, where the pressure is by far the highest. In capillaries and venules, blood pressure is considerably lower, and so the movement of blood is slower. In the veins, blood pressure plays only a minor role, because the action of the valves and skeletal muscle pumps provides most of the force needed to move blood to the heart. Along with measurements of pulse rate, rate of breathing, and body temperature, blood pressure is usually considered a vital sign.

Arterial blood pressure can be measured with a device called a *sphygmomanometer* (*sfig''mo-mă-nom'ĭ-ter*) (fig. 16.18). This instrument has an inflatable cuff that is used to constrict an artery at a pressure point (see fig. 16.33). Most commonly, the cuff is wrapped around the upper arm and a stethoscope is applied over

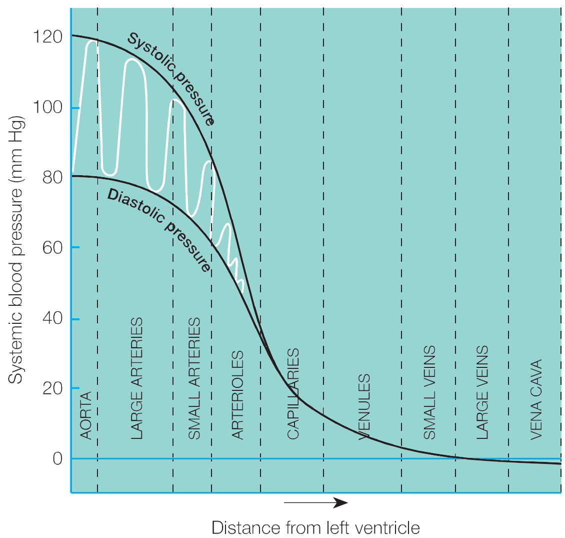


FIGURE 16.19 Blood pressure as recorded at various vascular sites.

the brachial artery, which is compressed against the humerus. As the blood pulsates through the constricted brachial artery, the pressure produced is indicated by the sphygmomanometer.

The normal blood pressure of an adult is about 120/80. This is an expression of the **systolic pressure** (120 mmHg) over the **diastolic pressure** (80 mmHg). The systolic pressure is created as blood is ejected from the heart during systole. When the ventricles relax during diastole, the arterial pressure drops and the diastolic pressure is recorded. For the most part, diastolic pressure results from contraction of the smooth muscles within the tunica media of the arterial walls. The difference between the systolic and diastolic pressure is called the **pulse pressure** and is generally about 40 mmHg.

Several factors influence the arterial blood pressure. Blood pressure decreases as the distance from the heart increases (fig. 16.19). An increased cardiac output (stroke volume × heart rate) increases blood pressure. Blood volume and blood viscosity both influence blood pressure, as do various drugs. Changes in the diameters of the vascular lumina through autonomic vasoconstriction or vasodilation have a direct bearing on blood pressure. Blood pressures are also greatly influenced by the general health of the cardiovascular system. Elevated blood pressure is referred to as *hypertension* and is potentially dangerous because of the added strain it puts on the heart.

One of the harmful effects of nicotine inhaled in cigarette smoke is vasoconstriction of arterioles. Nicotine also stimulates the adrenal medulla to secrete epinephrine, which is a heart stimulant and thus increases cardiac output. Both of these responses raise the blood pressure and increase the strain on the heart.

Knowledge Check

13. Describe the basic structural pattern of arteries and veins. Describe how arteries and veins differ in structure and how these differences contribute to the resistance function of arteries and the capacitance function of veins.
14. Describe the functional significance of the skeletal muscle pump and explain the action of venous valves.
15. Discuss the functions of capillaries and describe the structural differences between capillaries in different organs.
16. Describe the cardiovascular events that determine systolic and diastolic blood pressures.

PRINCIPAL ARTERIES OF THE BODY

The aorta ascends from the left ventricle to a position just above the heart, where it arches to the left and then descends through the thorax and abdomen. Branches of the aorta carry oxygenated blood to all of the cells of the body.

Objective 14 In the form of a flow chart, list the arterial branches of the ascending aorta and aortic arch.

Objective 15 Describe the arterial supply to the brain.

Objective 16 Describe the arterial pathways that supply the upper extremity.

Objective 17 Describe the major arteries serving the thorax, abdomen, and lower extremity.

Contraction of the left ventricle forces oxygenated blood into the arteries of the systemic circulation. The principal arteries of the body are shown in figure 16.20. They will be described by region and identified in order from largest to smallest, or as the blood flows through the system. The major systemic artery is the **aorta** (*a-or′tă*), from which all of the primary systemic arteries arise.

Aortic Arch

The systemic vessel that ascends from the left ventricle of the heart is called the **ascending portion of the aorta.** The **right** and **left coronary arteries,** which serve the myocardium of the heart with blood, are the only branches that arise from the ascending aorta. The aorta arches to the left and posteriorly over the pulmonary arteries as the **aortic arch** (fig. 16.21). Three vessels arise from the aortic arch: the **brachiocephalic** (*bra″ke-o-se-fal′ik*) **trunk,** the **left common carotid** (*kă-rot′id*) **artery,** and the **left subclavian artery.**

The brachiocephalic trunk is the first vessel to branch from the aortic arch and, as its name suggests, supplies blood to the structures of the shoulder, upper extremity, and head on the right

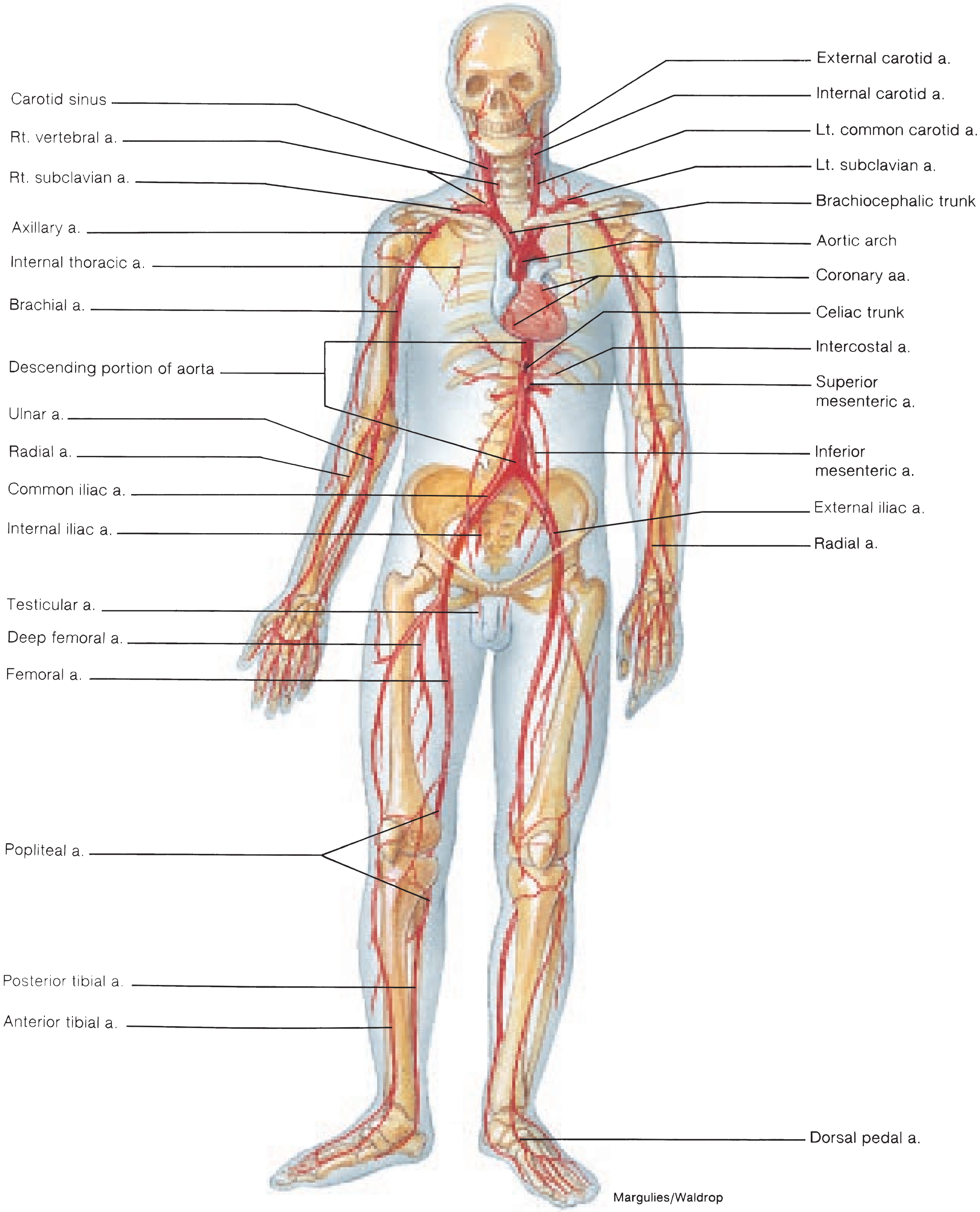


FIGURE 16.20 Principal arteries of the body (a. = artery; aa. = arteries).

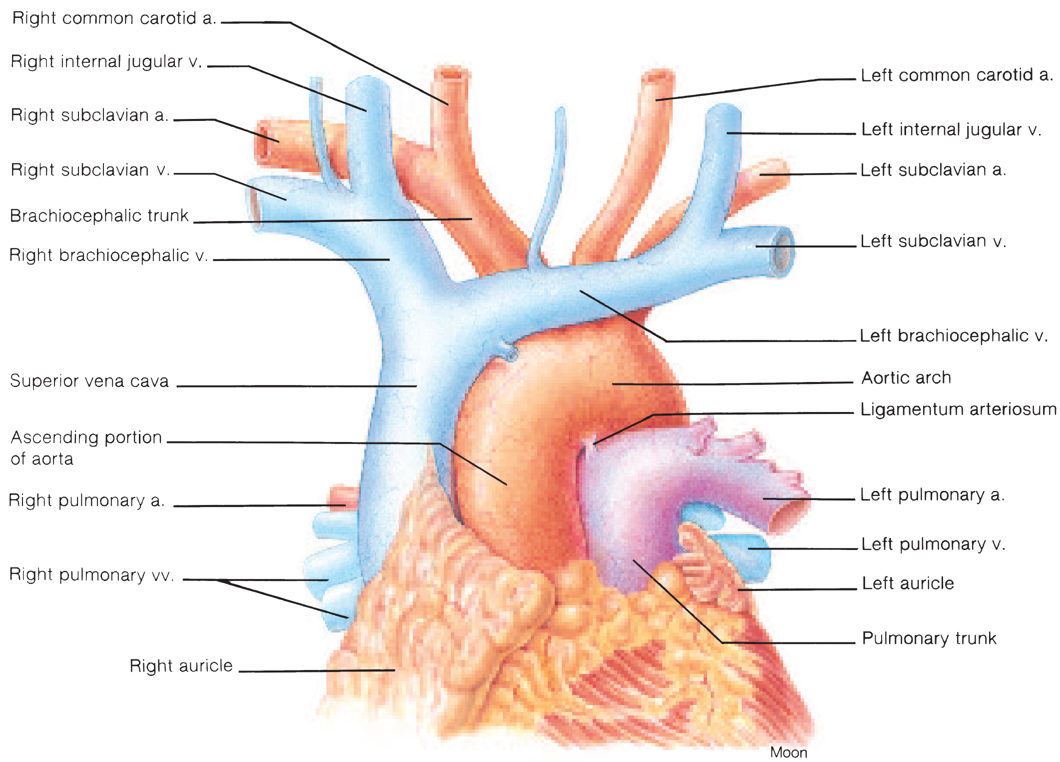


FIGURE 16.21 The structural relationship between the major arteries and veins to and from the heart (v. = vein; vv. = veins).

side of the body. It is a short vessel, rising superiorly through the mediastinum to a point near the junction of the sternum and the right clavicle. There it branches into the **right common carotid artery,** which extends to the right side of the neck and head, and the **right subclavian artery,** which carries blood to the right shoulder and upper extremity.

The remaining two branches from the aortic arch are the left common carotid and the left subclavian arteries. The left common carotid artery transports blood to the left side of the neck and head, and the left subclavian artery supplies the left shoulder and upper extremity.

Arteries of the Neck and Head

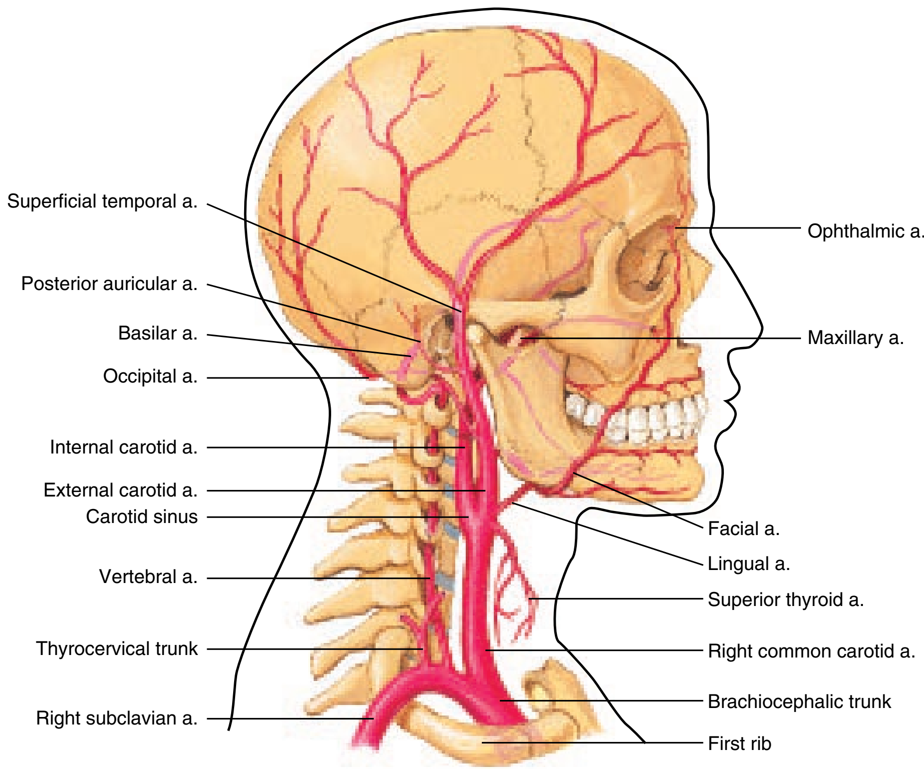
The common carotid arteries course upward in the neck along the lateral sides of the trachea (fig. 16.22). Each common carotid artery branches into the **internal** and **external carotid arteries** slightly below the angle of the mandible. By pressing gently in this area, a pulse can be detected (see fig. 16.33). At the base of the internal carotid artery is a slight dilation called the **carotid sinus.** The carotid sinus contains *baroreceptors,* which monitor blood pressure (see fig. 16.12). Surrounding the carotid sinus are the **carotid bodies,** small neurovascular organs that contain *chemoreceptors,* which respond to chemical changes in the blood.

Blood Supply to the Brain

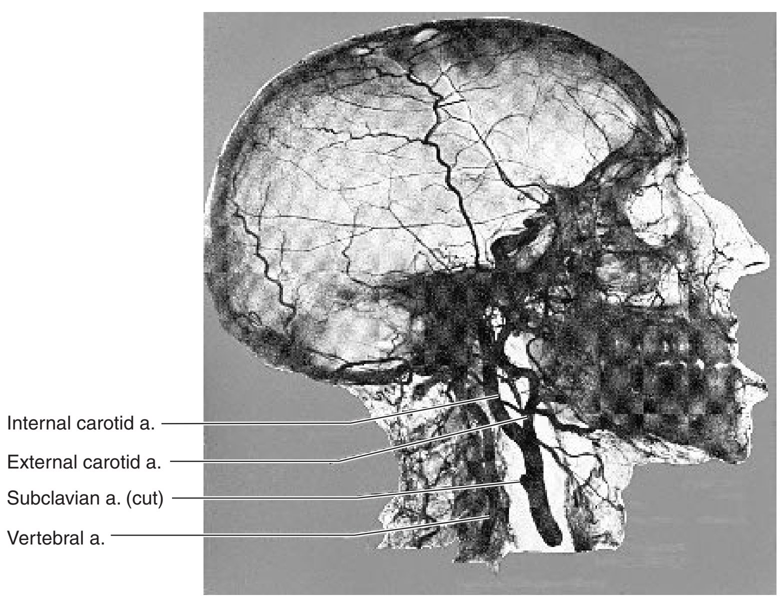
The brain is supplied with arterial blood that arrives through four vessels. These vessels eventually unite on the inferior surface of the brain in the area surrounding the pituitary gland (fig. 16.22). The four vessels are the paired *internal carotid arteries* and the paired *vertebral arteries*. The value of four separate vessels coming together at one location is that if one becomes occluded, the three alternate routes may still provide an adequate blood supply to the brain.

The **vertebral arteries** arise from the subclavian arteries at the base of the neck (fig. 16.22). They pass superiorly through the transverse foramina of the cervical vertebrae and enter the skull through the foramen magnum. Within the cranium, the two vertebral arteries unite to form the **basilar artery** at the level of the pons. The basilar artery ascends along the inferior surface of the brain stem and terminates by forming two **posterior cerebral arteries** that supply the posterior portion of the cerebrum (figs. 16.23 and 16.24). The **posterior communicating arteries** are branches that arise from the posterior cerebral arteries and participate in forming the **cerebral arterial circle** (*circle of Willis*) surrounding the pituitary gland.

circle of Willis: from Thomas Willis, English physician, 1621–75.



(a)



(b)

FIGURE 16.22 Arteries of the neck and head. (*a*) Major branches of the right common carotid and right subclavian arteries. (*b*) A radiograph of the head following a radiopaque injection of the arteries.

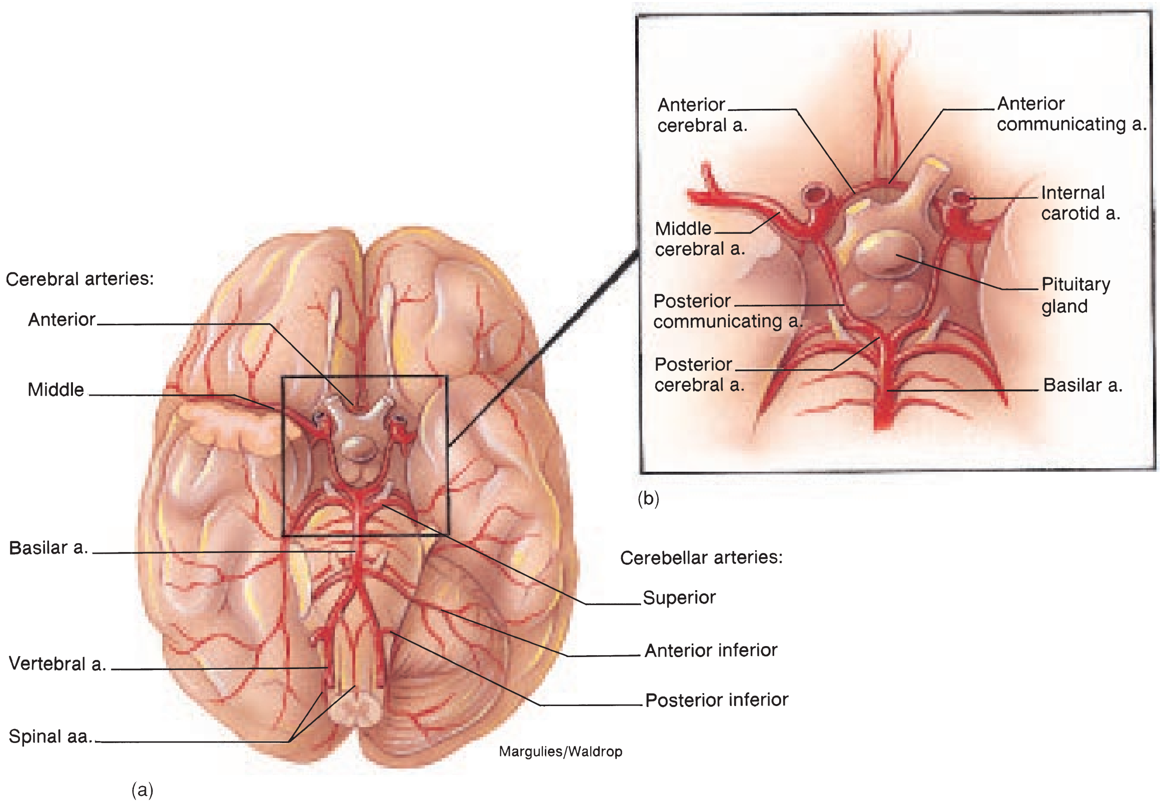


FIGURE 16.23 Arteries that supply blood to the brain. (*a*) An inferior view of the brain and (*b*) a close-up view of the region of the pituitary gland. The cerebral arterial circle (circle of Willis) consists of the arteries that ring the pituitary gland.

Each **internal carotid artery** arises from the common carotid artery and ascends in the neck until it reaches the base of the skull, where it enters the carotid canal of the temporal bone. Several branches arise from the internal carotid artery once it is on the inferior surface of the brain. Three of the more important ones are the **ophthalmic artery** (see fig. 16.22*a*), which supplies the eye and associated structures, and the **anterior** and **middle cerebral arteries,** which provide blood to the cerebrum. The internal carotid arteries are connected to the posterior cerebral arteries at the cerebral arterial circle.

Capillaries within the pituitary gland receive both arterial and venous blood. The venous blood arrives from venules immediately superior to the pituitary gland, which drain capillaries in the hypothalamus of the brain. This arrangement of two capillary beds in series—whereby the second capillary bed receives venous blood from the first—is called a *portal system.* The venous blood that travels from the hypothalamus to the pituitary contains hormones from the hypothalamus that help regulate pituitary hormone secretion.

External Carotid Artery

The external carotid artery gives off several branches as it extends upward along the side of the neck and head (see fig. 16.22*a*). The names of these branches are determined by the areas or structures they serve. The principal vessels that arise from the external carotid artery are the following:

- the **superior thyroid artery,** which serves the muscles of the hyoid region, the larynx and vocal folds, and the thyroid gland;
- the **ascending pharyngeal artery** (not shown), which serves the pharyngeal area and various lymph nodes;
- the **lingual artery,** which provides extensive vascularization to the tongue and sublingual gland;
- the **facial artery,** which traverses a notch on the inferior margin of the mandible to serve the pharyngeal area, palate, chin, lips, and nasal region—an important point in controlling bleeding from the face;
- the **occipital artery,** which serves the posterior portion of the scalp, the meninges over the brain, the mastoid process, and certain posterior neck muscles; and
- the **posterior auricular artery,** which serves the auricle of the ear and the scalp over the auricle.

The external carotid artery terminates at a level near the mandibular condyle by dividing into **maxillary** and **superficial temporal arteries.** The maxillary artery gives off branches to the

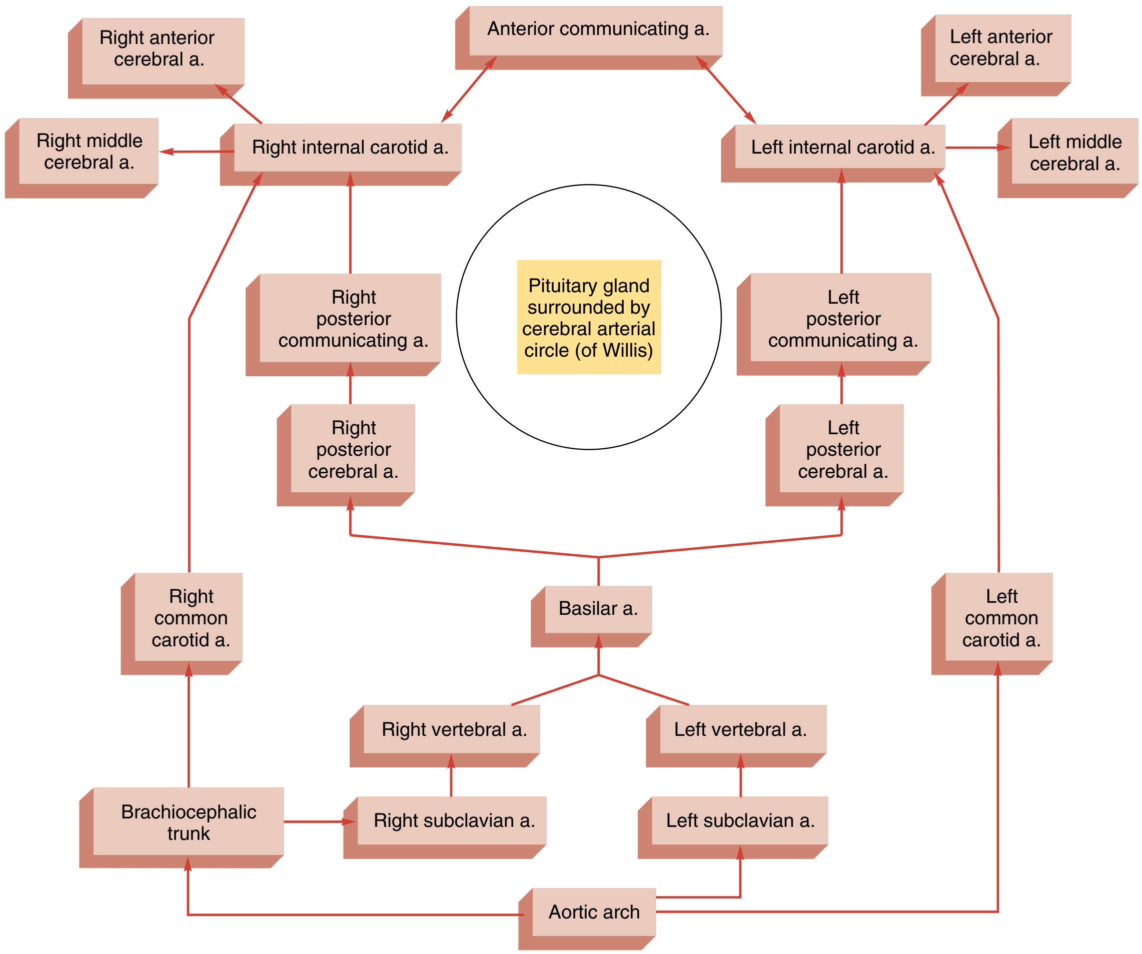


FIGURE 16.24 The path of arterial blood flow to the brain. (Note the ring of vessels surrounding the pituitary gland to form the cerebral arterial circle.)

teeth and gums, the muscles of mastication, the nasal cavity, the eyelids, and the meninges. The superficial temporal artery supplies blood to the parotid gland and to the superficial structures on the side of the head. Pulsations through the temporal artery can be easily detected by placing the fingertips immediately in front of the ear at the level of the eye (see fig. 16.33). This vessel is frequently used by anesthesiologists to check a patient's pulse rate during surgery.

Headaches are usually caused by vascular pressure on the sensitive meninges covering the brain. The two principal vessels serving the meninges are the meningeal branches of the occipital and maxillary arteries. Vasodilation of these vessels creates excessive pressure on the sensory receptors within the meninges, resulting in a headache.

Arteries of the Shoulder and Upper Extremity

As mentioned earlier, the **right subclavian artery** arises from the brachiocephalic trunk, and the **left subclavian artery** arises directly from the aortic arch (see fig. 16.21). Each subclavian artery passes laterally deep to the clavicle, carrying blood toward the arm (fig. 16.25). The pulsations of the subclavian artery can be detected by pressing firmly on the skin just above the medial portion of the clavicle (see fig. 16.33). From each subclavian artery arises a **vertebral artery** that carries blood to the brain (already described); a short **thyrocervical trunk** that serves the thyroid gland, trachea, and larynx; and an **internal thoracic artery**

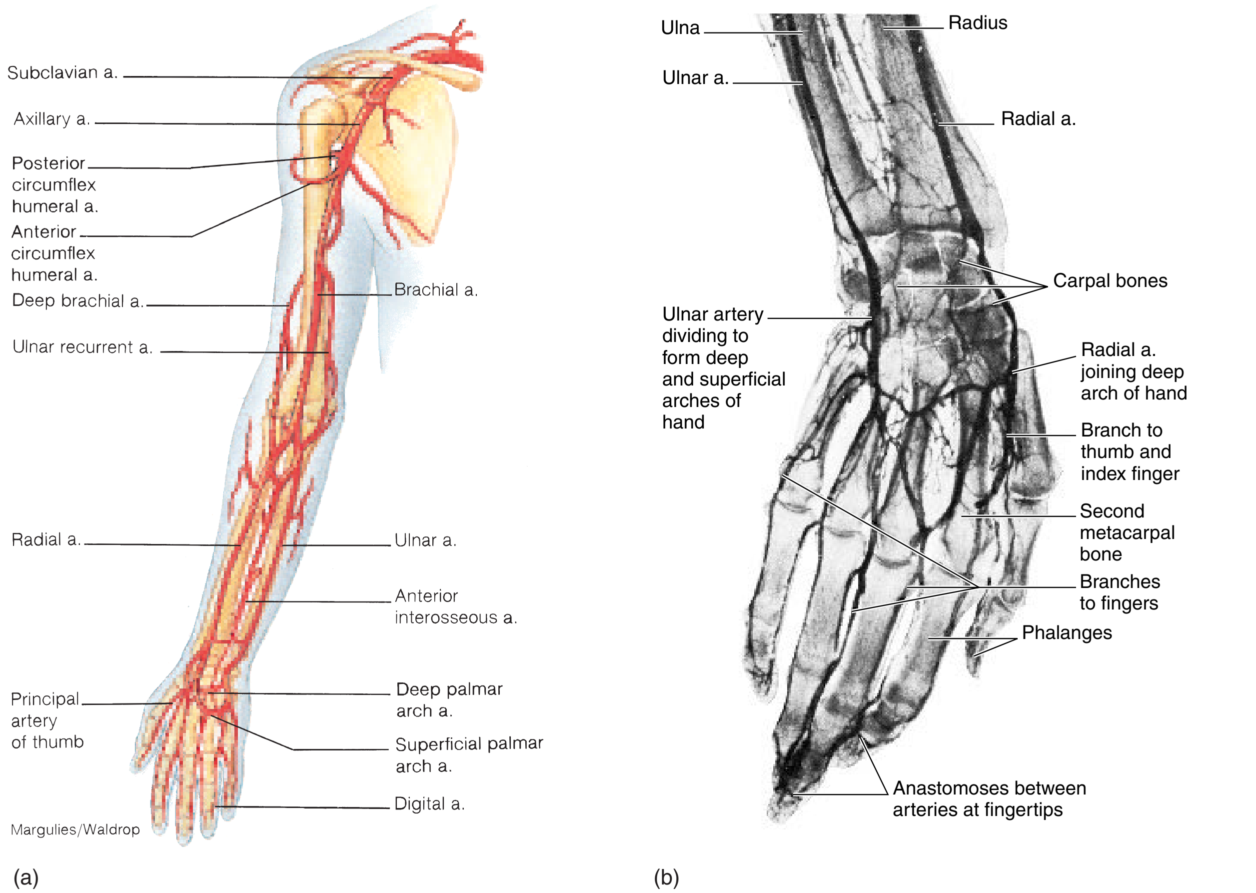


FIGURE 16.25 Arteries of the right upper extremity. (*a*) An anterior view of the major arteries, and (*b*) a radiograph of the forearm and hand following a radiopaque injection of the arteries.

that descends into the thorax to serve the thoracic wall, thymus, and pericardium. The **costocervical trunk** branches to serve the upper intercostal muscles, posterior neck muscles, and the spinal cord and its meninges. A branch of the internal thoracic artery supplies blood to the muscles and tissues (mammary glands) of the anterior thorax.

The **axillary** (*ak'sĭ-lar''e*) **artery** is the continuation of the subclavian artery as it passes into the axillary region (figs. 16.25 and 16.26). The axillary artery is that portion of the major artery of the upper extremity between the outer border of the first rib and the lower border of the teres major muscle. Several small branches arise from the axillary artery and supply blood to the tissues of the upper thorax and shoulder region.

The **brachial** (*bra'ke-al*) **artery** is the continuation of the axillary artery through the brachial region. The brachial artery courses on the medial side of the humerus, where it is a major pressure point and the most common site for determining blood pressure. A **deep brachial artery** branches from the brachial artery and curves posteriorly near the radial nerve to supply the triceps brachii muscle. Two additional branches from the brachial, the **anterior** and **posterior humeral circumflex arteries,** form a continuous ring of vessels around the proximal portion of the humerus.

Just proximal to the cubital fossa, the brachial artery branches into the **radial** and **ulnar arteries,** which supply blood to the forearm and a portion of the hand and digits. The radial artery courses down the lateral, or radial, side of the arm, where it sends numerous small branches to the muscles of the forearm. The **anterior interosseous artery** extends deep within the antebrachium between the radial and ulnar arteries. The **radial recurrent artery** serves the region of the elbow and is the first and largest branch of the radial artery. The radial artery is important as a site for recording the pulse near the wrist.

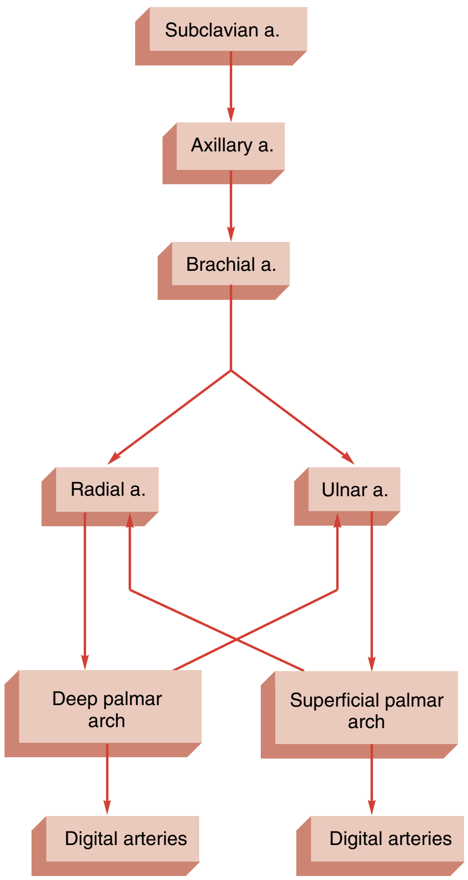


FIGURE 16.26 The path of arterial blood flow from the subclavian artery to the digital arteries of the fingers.

The ulnar artery extends down the medial, or ulnar, side of the forearm and gives off many small branches to the muscles on that side. It, too, has an initial large branch, the **ulnar recurrent artery,** which arises from the proximal portion near the elbow. At the wrist, the ulnar and radial arteries anastomose to form the **superficial** and **deep palmar arches.** The **metacarpal arteries** of the hand (not shown) arise from the deep palmar arch, and the **digital arteries** of the fingers arise from the superficial palmar arch.

Branches of the Thoracic Portion of the Aorta

The **thoracic portion of the aorta** is a continuation of the aortic arch as it descends through the thoracic cavity to the diaphragm. This large vessel gives off branches to the organs and muscles of the thoracic region. These branches include **pericardial arteries,** going to the pericardium of the heart; **bronchial arteries** for systemic circulation to the lungs; **esophageal** (*e-sof''ă-je'al*) **arteries,** going to the esophagus as it passes through the mediastinum; segmental **posterior intercostal arteries,** serving the intercostal muscles and structures of the wall of the thorax (fig. 16.27); and **superior phrenic** (*fren'ik*) **arteries,** supplying blood to the diaphragm. These vessels are summarized according to their location and function in table 16.5.

Branches of the Abdominal Portion of the Aorta

The **abdominal portion of the aorta** is the segment of the aorta between the diaphragm and the level of the fourth lumbar vertebra, where it divides into the **right** and **left common iliac arteries.** Small **inferior phrenic arteries** that serve the diaphragm are the first vessels to arise from the abdominal portion of the aorta. The next vessel is the short and thick **celiac** (*se'le-ak*) **trunk,** an unpaired vessel that divides immediately into three arteries: the **splenic,** going to the spleen; the **left gastric,** going to the stomach; and the **common hepatic,** going to the liver (figs. 16.28 and 16.29).

The **superior mesenteric artery** is another unpaired vessel. It arises anteriorly from the abdominal portion of the aorta, just below the celiac trunk. The superior mesenteric artery supplies blood to the small intestine (except for a portion of the duodenum), the cecum, the appendix, the ascending colon, and the proximal two-thirds of the transverse colon.

The next major vessels to arise from the abdominal portion of the aorta are the paired **renal arteries** that carry blood to the kidneys. Smaller **suprarenal arteries,** located just above the renal arteries, serve the adrenal (suprarenal) glands. The **testicular arteries** in the male and the **ovarian arteries** in the female are small paired vessels that arise from the abdominal portion of the aorta, just below the renal arteries. These vessels serve the gonads.

The **inferior mesenteric artery** is the last major branch of the abdominal portion of the aorta. It is an unpaired anterior vessel that arises just before the iliac bifurcation. The inferior mesenteric supplies blood to the distal one-third of the transverse colon, the descending colon, the sigmoid colon, and the rectum.

Several **lumbar arteries** branch posteriorly from the abdominal portion of the aorta throughout its length and serve the muscles and the spinal cord in the lumbar region. In addition, an unpaired **middle sacral artery** (fig. 16.30) arises from the posterior terminal portion of the abdominal portion of the aorta to supply the sacrum and coccyx.

Arteries of the Pelvis and Lower Extremity

The abdominal portion of the aorta terminates in the posterior pelvic area as it bifurcates into the right and left common iliac arteries. These vessels pass downward approximately 5 cm on their respective sides and terminate by dividing into the *internal* and *external iliac arteries*.

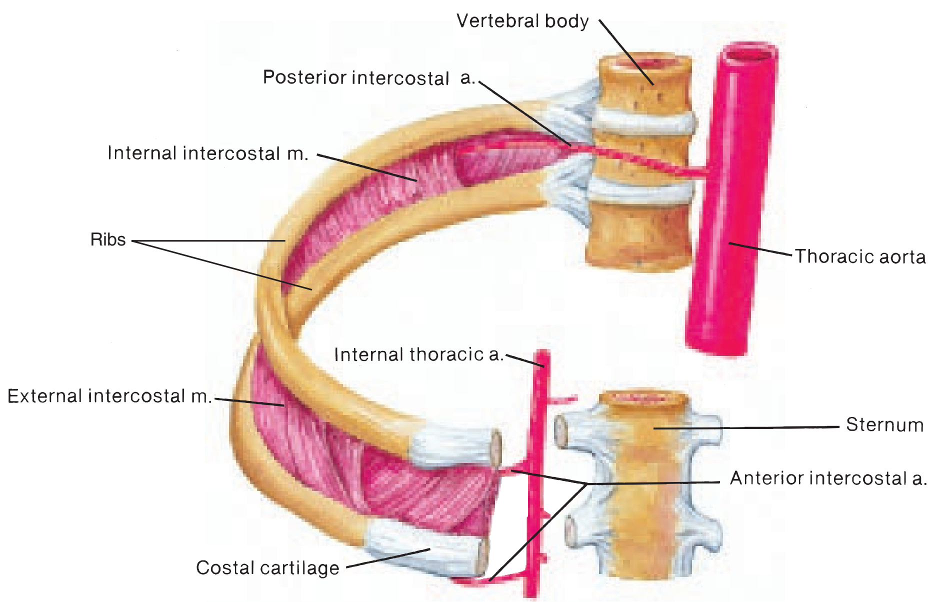


FIGURE 16.27 Arteries that serve the thoracic wall.

TABLE 16.5 Segments and Branches of the Aorta

Segment of Aorta	Arterial Branch	General Region or Organ Served
Ascending portion of aorta	Right and left coronary aa.	Heart
Aortic arch	Brachiocephalic trunk	
	Right common carotid a.	Right side of head and neck
	Right subclavian a.	Right shoulder and right upper extremity
	Left common carotid a.	Left side of head and neck
	Left subclavian a.	Left shoulder and left upper extremity
Thoracic portion of aorta	Pericardial aa.	Pericardium of heart
	Posterior intercostal aa.	Intercostal and thoracic muscles, and pleurae
	Bronchial aa.	Bronchi of lungs
	Superior phrenic aa.	Superior surface of diaphragm
	Esophageal aa.	Esophagus
Abdominal portion of aorta	Inferior phrenic aa.	Inferior surface of diaphragm
	Celiac trunk	
	Common hepatic a.	Liver, upper pancreas, and duodenum
	Left gastric a.	Stomach and esophagus
	Splenic a.	Spleen, pancreas, and stomach
	Superior mesenteric a.	Small intestine, pancreas, cecum, appendix, ascending colon, and transverse colon
	Suprarenal aa.	Adrenal (suprarenal) glands
	Lumbar aa.	Muscles and spinal cord of lumbar region
	Renal aa.	Kidneys
	Gonadal aa.	
	Testicular aa.	Testes
	Ovarian aa.	Ovaries
	Inferior mesenteric a.	Transverse colon, descending colon, sigmoid colon, and rectum
	Common iliac aa.	
	External iliac aa.	Lower extremities
	Internal iliac aa.	Genital organs and gluteal muscles

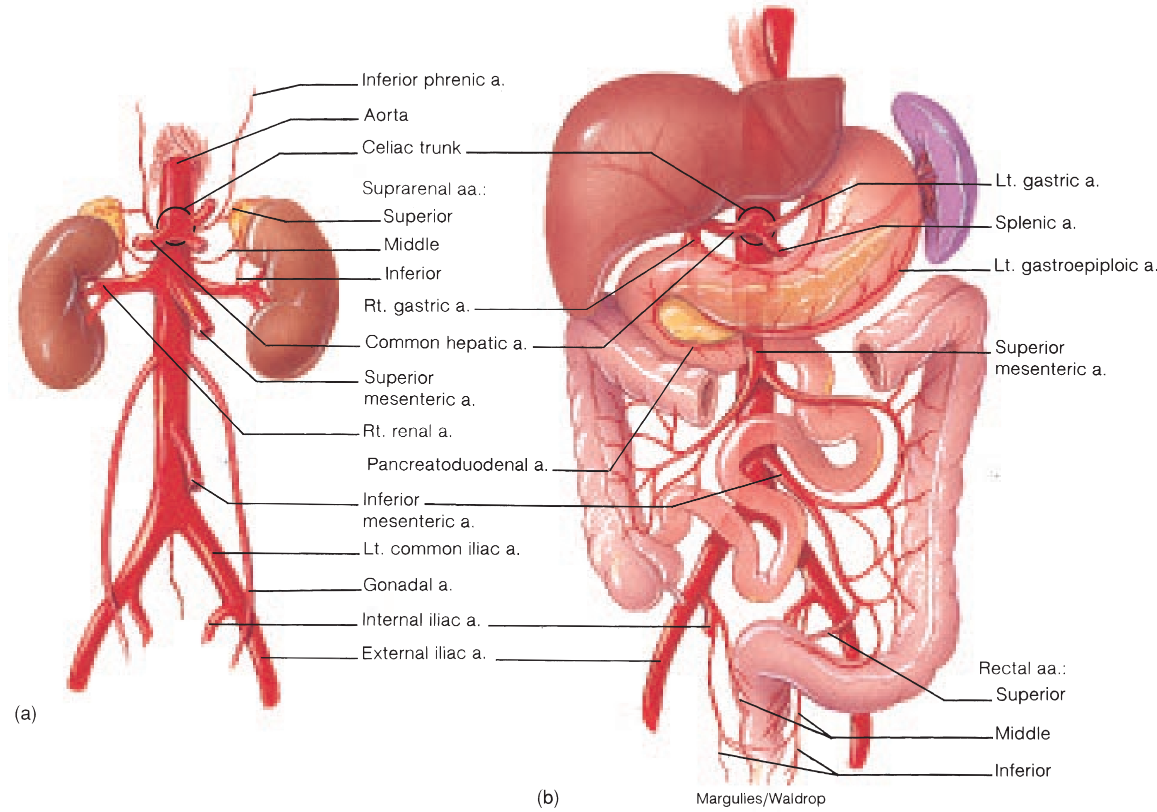


FIGURE 16.28 An anterior view of the abdominal aorta and its principal branches. In (*a*) the abdominal viscera have been removed; in (*b*) they are intact.

The *internal iliac artery* has extensive branches to supply arterial blood to the gluteal muscles and the organs of the pelvic region (fig. 16.30). The wall of the pelvis is served by the **iliolumbar** and **lateral sacral arteries.** The internal visceral organs of the pelvis are served by the **middle rectal** and the **superior, middle,** and **inferior vesicular arteries** to the urinary bladder. In addition, **uterine** and **vaginal arteries** branch from the internal iliac arteries to serve the reproductive organs of the female. The muscles of the buttock are served by the **superior** and **inferior gluteal arteries.** Some of the upper medial thigh muscles are supplied with blood from the **obturator artery.** The **internal pudendal artery** of the internal iliac artery serves the musculature of the perineum and the external genitalia. During sexual arousal it supplies the blood for vascular engorgement of the penis in the male and clitoris in the female.

The external iliac artery passes out of the pelvic cavity deep to the inguinal ligament (fig. 16.31) and becomes the **femoral** (*fem'or-al*) **artery.** Two branches arise from the external iliac artery, however, before it passes beneath the inguinal ligament. An **inferior epigastric artery** branches from the external iliac artery and passes superiorly to supply the skin and muscles of the abdominal wall. The **deep circumflex iliac artery** is a small branch that extends laterally to supply the muscles attached to the iliac fossa.

The femoral artery passes through an area called the **femoral triangle** on the upper medial portion of the thigh (figs. 16.31 and 16.32). At this point, it is close to the surface and its pulse can be palpated. Several vessels arise from the femoral artery to serve the thigh region. The largest of these, the **deep femoral artery,** passes posteriorly to serve the hamstring muscles. The **lateral** and **medial femoral circumflex arteries** encircle the proximal end of the femur and serve muscles in this region. The femoral artery becomes the **popliteal** (*pop''lĭ-te'al*) **artery** as it passes across the posterior aspect of the knee.

FIGURE 16.29 An anterior view of the principal arteries of the abdominal cavity from a dissected cadaver.

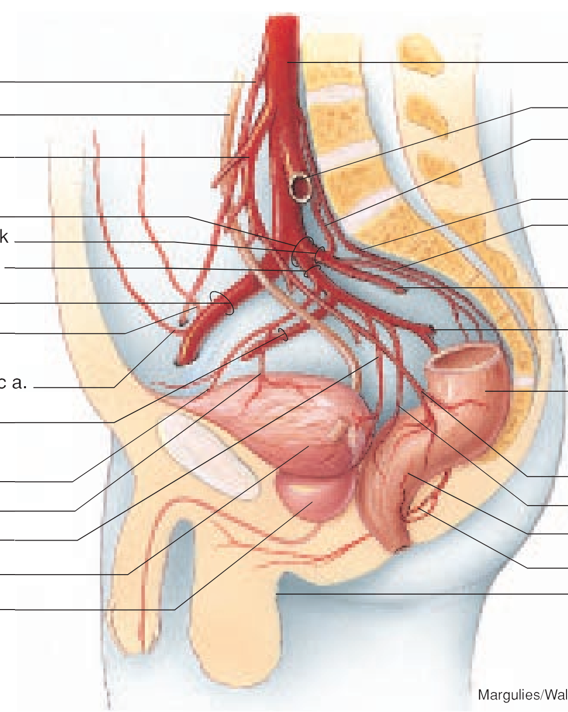


FIGURE 16.30 Arteries of the pelvic region.

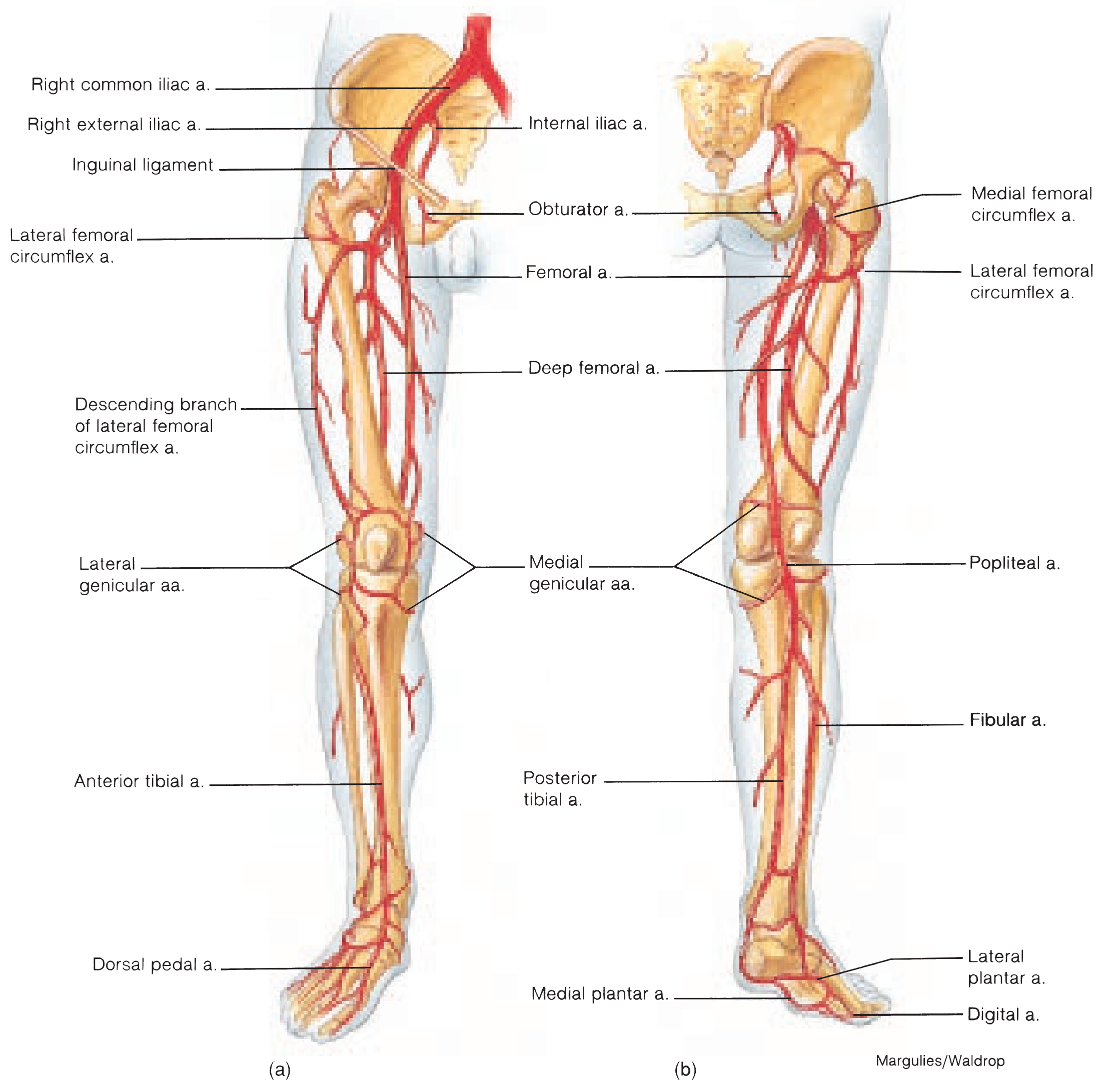


FIGURE 16.31 Arteries of the right lower extremity. (*a*) An anterior view and (*b*) a posterior view.

Hemorrhage can be a serious problem in many accidents. To prevent a victim from bleeding to death, it is important to know where to apply pressure to curtail the flow of blood (fig. 16.33). The pressure points for the appendages are the brachial artery on the medial side of the arm and the femoral artery in the groin. Firmly applied pressure to these regions greatly diminishes the flow of blood to traumatized areas below. A tourniquet may have to be applied if bleeding is severe enough to endanger life.

The popliteal artery supplies small branches to the knee joint, and then divides into an **anterior tibial artery** and a **posterior tibial artery** (fig. 16.31). These vessels traverse the anterior and posterior aspects of the leg, respectively, providing blood to the muscles of these regions and to the foot.

At the ankle, the anterior tibial artery becomes the **dorsal pedal artery** that serves the ankle and dorsum (superior portion) of the foot and then contributes to the formation of the **dorsal arch** of the foot. Clinically, palpation of the dorsal pedal artery can provide information about circulation to the foot; more important, it can provide information about the circulation in general because its pulse is taken at the most distal portion of the body.

The posterior tibial artery gives off a large **fibular,** or **peroneal, artery** to serve the peroneal muscles of the leg. At the ankle, the posterior tibial bifurcates into the **lateral** and **medial plantar arteries** that supply the sole of the foot. The lateral

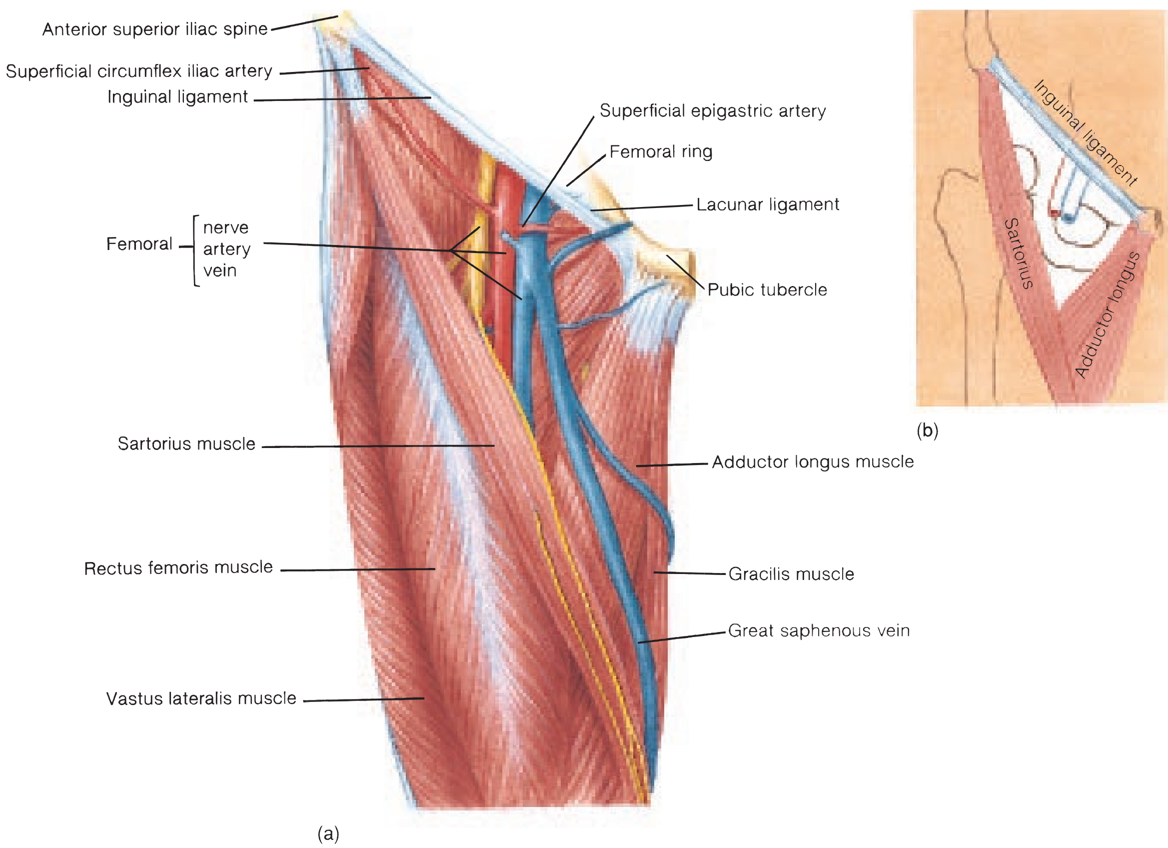


FIGURE 16.32 The femoral triangle. The structures within the femoral triangle are shown in (*a*); the boundaries of the triangle are shown in (*b*).

plantar artery anastomoses with the dorsal pedal artery to form the plantar arch, similar to the arterial arrangement in the hand. **Digital arteries** arise from the plantar arch to supply the toes with blood.

Knowledge Check

17. Describe the blood supply to the brain. Where is the cerebral arterial circle located and how is it formed?
18. Describe the clinical significance of the brachial and radial arteries.
19. Describe the arterial pathway from the subclavian artery to the digital arteries.
20. List the arteries that supply blood to the lower abdominal wall, the external genitalia, the hamstring muscles, the knee joint, and the dorsum of the foot.

PRINCIPAL VEINS OF THE BODY

After systemic blood has passed through the tissue, this oxygenated-poor blood is returned through veins of progressively larger diameters to the right atrium of the heart.

Objective 18 Describe the venous drainage of the head, neck, and upper extremity.

Objective 19 Describe the venous drainage of the thorax, lower extremities, and abdominal region.

Objective 20 Describe the vessels involved in the hepatic portal system.

In the venous portion of the systemic circulation, blood flows from smaller vessels into larger ones, so that a vein receives smaller tributaries instead of giving off branches as an artery

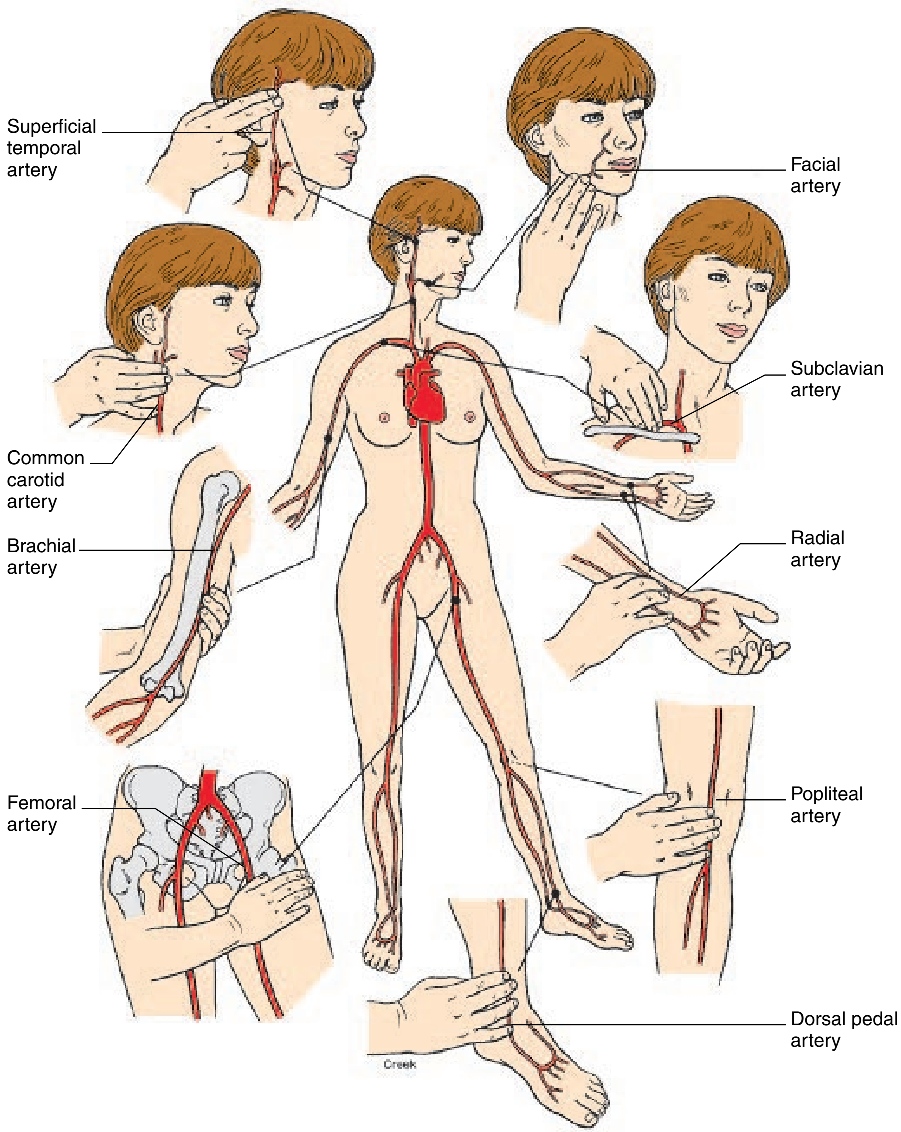


FIGURE 16.33 Important arterial pressure points and the locations at which arterial pulsations can best be detected.

does. The veins from all parts of the body (except the lungs) converge into two major vessels that empty into the right atrium: the **superior vena cava** (*ve'nă ka'vă*) and the **inferior vena cava** (fig. 16.34). Veins are more numerous than arteries and are both superficial and deep. Superficial veins generally can be seen just beneath the skin and are clinically important in drawing blood and giving injections. Deep veins are close to the principal arteries and are usually similarly named. As with arteries, veins are named according to the region in which they are found or the organ that they serve. (Note that when a vein serves an organ, it drains blood *away* from it.)

Veins Draining the Head and Neck

Blood from the scalp, portions of the face, and the superficial neck regions is drained by the **external jugular veins** (fig. 16.35). These vessels descend on the lateral sides of the neck, superficial to the sternocleidomastoid muscle and deep to the platysma muscle. They empty into the **right** and **left subclavian veins,** located just behind the clavicles.

jugular: L. *jugulum,* throat or neck

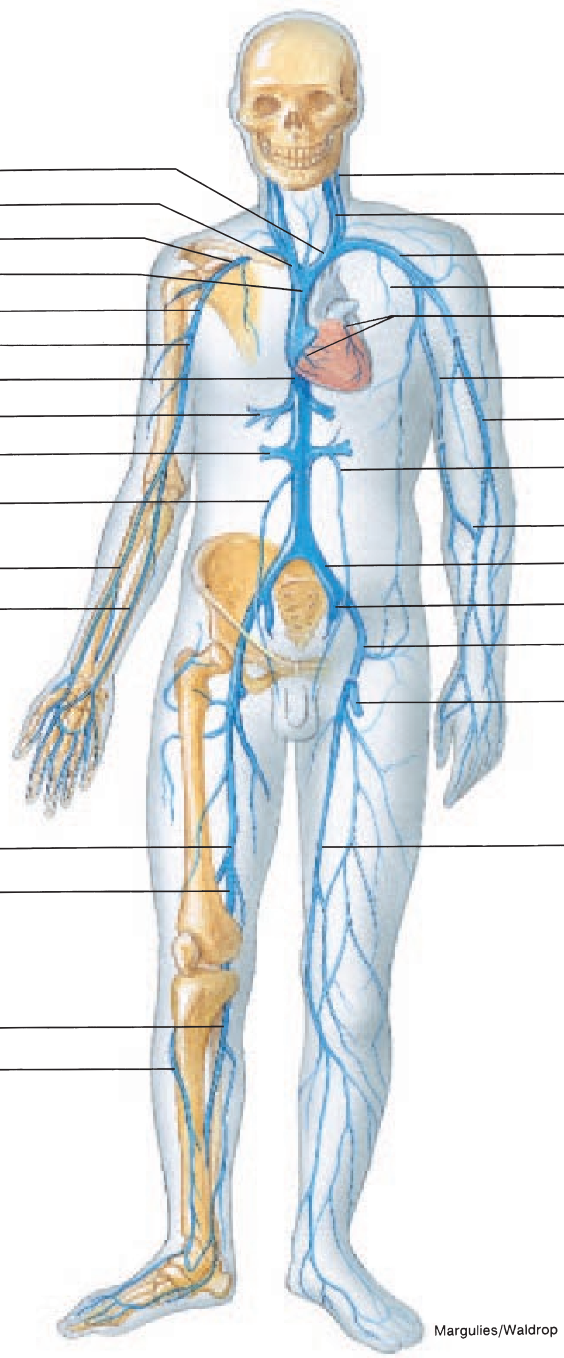


FIGURE 16.34 Principal veins of the body. Superficial veins are depicted in the left extremities and deep veins in the right extremities.

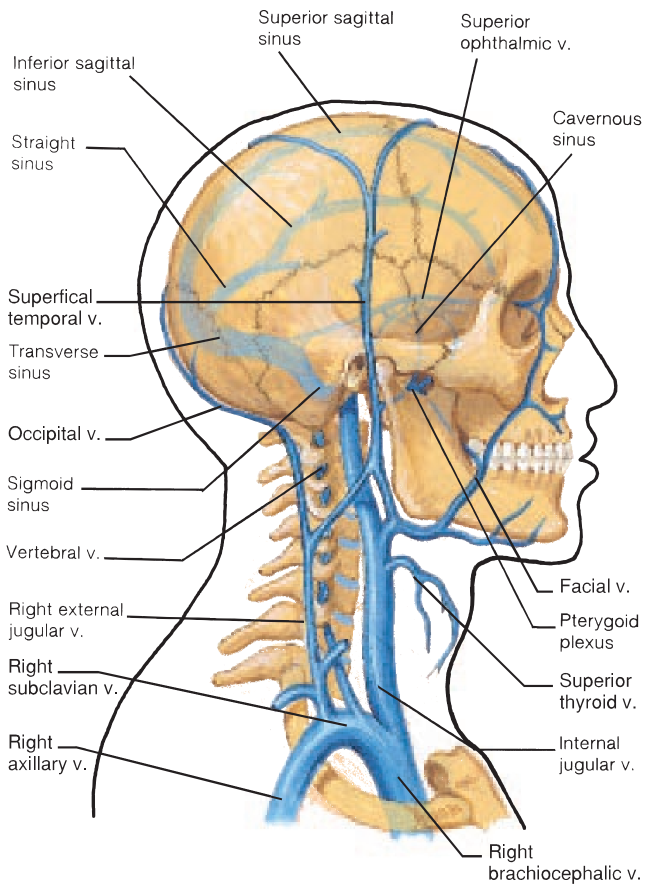


FIGURE 16.35 Veins that drain the head and neck. (Note the cranial venous sinuses that drain blood from the brain into the internal jugular vein.)

The paired **internal jugular veins** drain blood from the brain, meninges, and deep regions of the face and neck. The internal jugular veins are larger and deeper than the external jugular veins. They arise from numerous cranial **venous sinuses** (fig. 16.35), a series of both paired and unpaired channels positioned between the two layers of dura mater. The venous sinuses, in turn, receive venous blood from the **cerebral, cerebellar, ophthalmic** and **meningeal veins.**

The internal jugular vein passes inferiorly down the neck adjacent to the common carotid artery and the vagus nerve. All three of these structures are surrounded by the protective *carotid sheath* and are positioned beneath the sternocleidomastoid muscle. The convergence of the internal jugular vein with the subclavian vein forms a large **brachiocephalic** (*bra′′ke-o-sĕ-fal′ik*) **vein** on each side. The two brachiocephalic veins then merge to form the *superior vena cava*, which drains into the right atrium of the heart (see fig. 16.34).

The external jugular vein is the vessel that is seen on the side of the neck when a person is angry or wearing a tight collar. You can voluntarily distend this vein by performing *Valsalva's maneuver.* To do this, take a deep breath and hold it while you forcibly contract your abdominal muscles as in a forced exhalation. This procedure is automatically performed when lifting a heavy object or defecating. The increased thoracic pressure that results compresses the vena cavae and interferes with the return of blood to the right atrium. Thus, Valsalva's maneuver can be dangerous if performed by an individual with cardiovascular disease.

Veins of the Upper Extremity

The upper extremity has both superficial and deep venous drainage (fig. 16.36 and fig. 16.37). The superficial veins are highly variable

Valsalva's maneuver: from Antonio Valsalva, Italian anatomist, 1666–1723

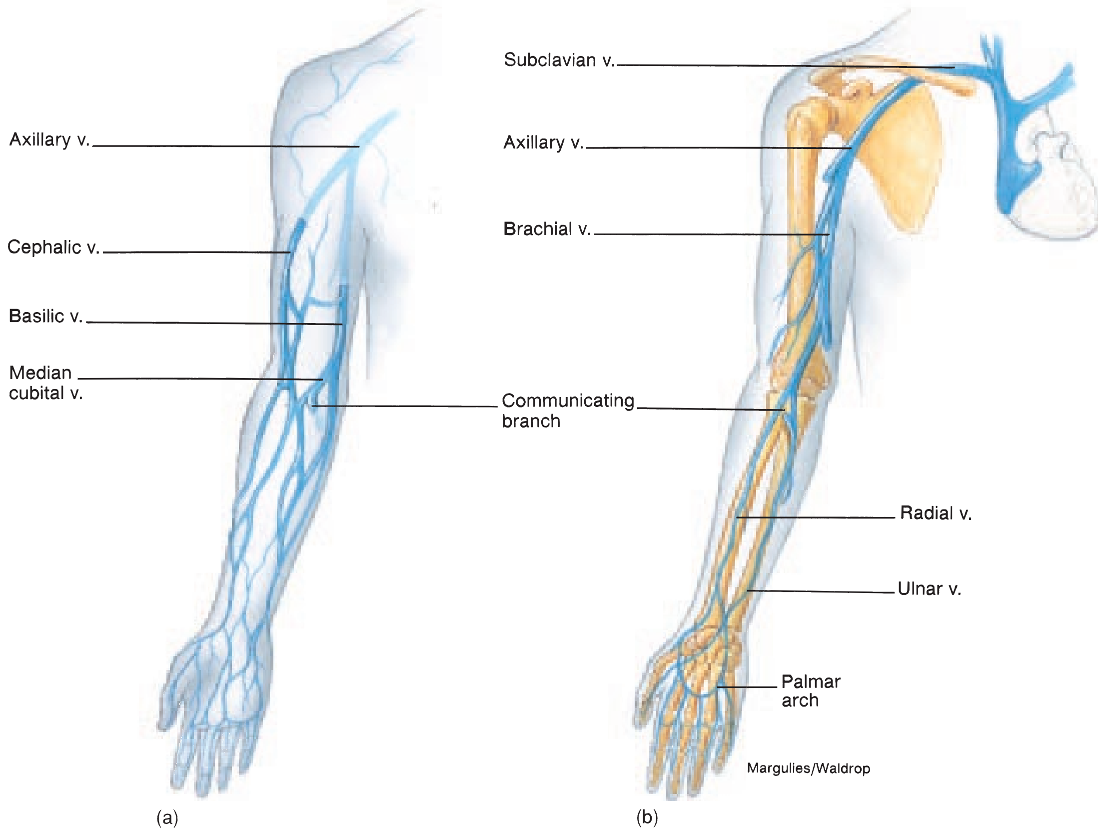


FIGURE 16.36 An anterior view of the veins that drain the upper right extremity. (*a*) Superficial veins and (*b*) deep veins.

and form an extensive network just below the skin. The deep veins accompany the arteries of the same region and bear similar names. The deep veins of the upper extremity will be described first.

Both the **radial vein** on the lateral side of the forearm and the **ulnar vein** on the medial side drain blood from the **deep** and **superficial palmar arches** of the hand. The radial and ulnar veins join in the cubital fossa to form the **brachial vein,** which continues up the medial side of the brachium.

The main superficial vessels of the upper extremity are the **basilic vein** and the **cephalic vein.** The basilic vein passes on the ulnar side of the forearm and the medial side of the arm. Near the head of the humerus, the basilic vein merges with the brachial vein to form the **axillary vein.**

The cephalic vein drains the superficial portion of the hand and forearm on the radial side, and then continues up the lateral side of the arm. In the shoulder region, the cephalic vein pierces the fascia and joins the axillary vein. The axillary vein then passes the first rib to form the subclavian vein, which unites with the internal jugular to form the brachiocephalic vein of that side.

Superficially, in the cubital fossa of the elbow, the **median cubital vein** ascends from the cephalic vein on the lateral side to connect with the basilic vein on the medial side. The median cubital vein is a frequent site for venipuncture to remove a sample of blood or add fluids to the blood.

Veins of the Thorax

The superior vena cava, formed by the union of the two brachiocephalic veins, empties venous blood from the head, neck, and upper extremities directly into the right atrium of the heart. These large vessels lack the valves that are characteristic of most other veins in the body.

In addition to receiving blood from the brachiocephalic veins, the superior vena cava collects blood from the azygos system of veins arising from the posterior thoracic wall (figs. 16.38 and 16.39). The **azygos** (*az' ĭ-gos*) **vein** extends superiorly along

azygos: Gk. *a,* without; *zygon,* yoke

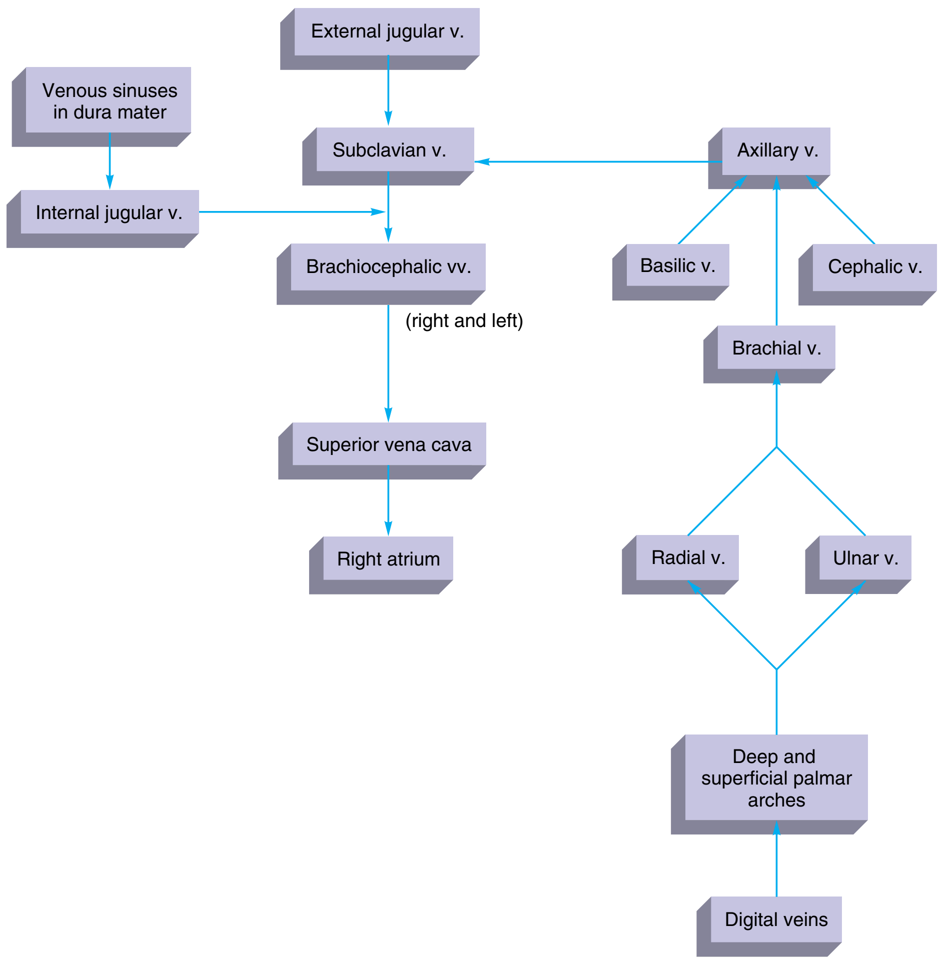


FIGURE 16.37 Venous return of blood from the head and the upper extremity to the heart.

the posterior abdominal and thoracic walls on the right side of the vertebral column. It ascends through the mediastinum to join the superior vena cava at the level of the fourth thoracic vertebra. Tributaries of the azygos include the **ascending lumbar veins,** (not illustrated) which drain the lumbar and sacral regions; **intercostal veins,** draining from the intercostal muscles; and the **accessory hemiazygos** (*hĕ'me-az-ĭ-gos*) and **hemiazygos veins,** which form the major tributaries to the left of the vertebral column.

Veins of the Lower Extremity

The lower extremities, like the upper extremities, have both a deep and a superficial group of veins (fig. 16.40). The deep veins accompany corresponding arteries and have more valves than do the superficial veins. The deep veins will be described first.

The **posterior** and **anterior tibial veins** originate in the foot and course upward behind and in front of the tibia to the back of the knee, where they merge to form the **popliteal vein.** The popliteal vein receives blood from the knee region. Just above the knee, this vessel becomes the **femoral vein.** The femoral vein in turn continues up the thigh and receives blood from the **deep femoral vein** near the groin. Just above this point, the femoral vein receives blood from the **great saphenous** (*să-fe-nus*) **vein** and then becomes the **external iliac vein** as it passes under the inguinal ligament. The external iliac curves upward to the level of the sacroiliac joint, where it merges with the **internal iliac vein** at the pelvic and genital regions to form the **common iliac vein.** At the level of the fifth lumbar vertebra, the right and left common iliacs unite to form the large inferior vena cava (fig. 16.40).

saphenous: L. *saphena*, the hidden one

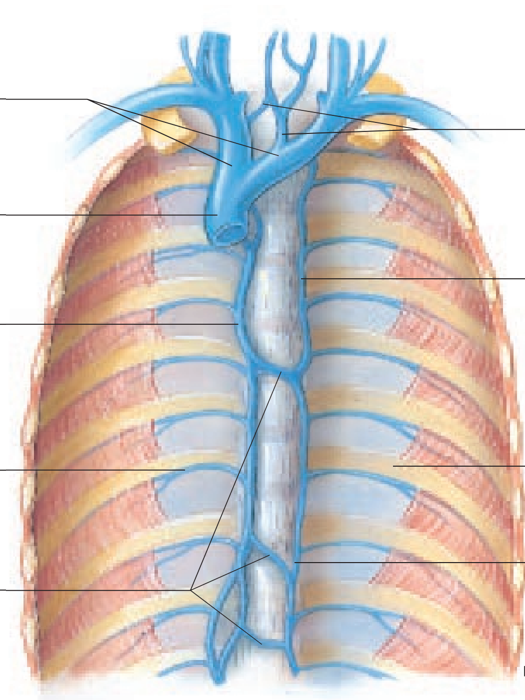
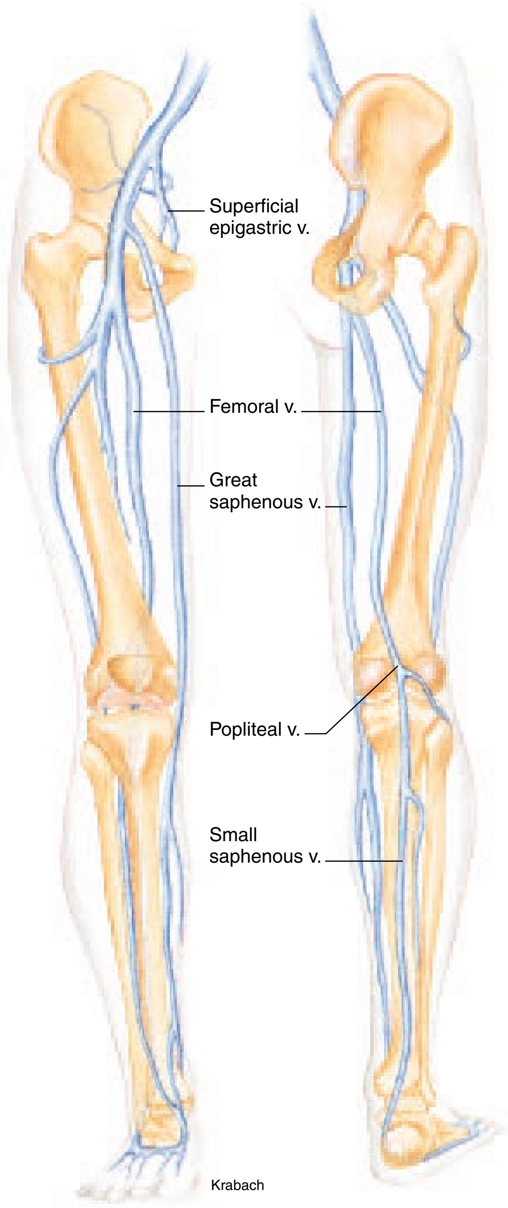
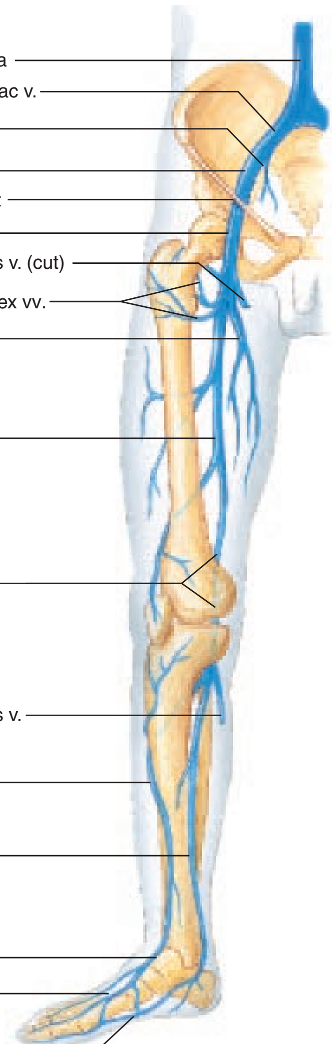


FIGURE 16.38 Veins of the thoracic region. (The lungs and heart have been removed.)

FIGURE 16.39 An anterior view of the deep thoracic veins from a dissected cadaver specimen.



(a)



(b)

FIGURE 16.40 Veins of the lower extremity. (*a*) Superficial veins, medial and posterior aspects, and (*b*) deep veins, a medial view.

The superficial veins of the lower extremity are the **small** and **great saphenous veins.** The small saphenous vein arises from the lateral side of the foot and ascends deep to the skin along the posterior aspect of the leg. It empties into the popliteal vein, posterior to the knee. The great saphenous vein is the longest vessel in the body. It originates from the medial side of the foot and ascends along the medial aspect of the leg and thigh before emptying into the femoral vein. The great saphenous vein is frequently excised and used as a coronary bypass vessel. If a superficial vein is removed, the venous return of blood from the appendage is through the remaining deep veins.

Veins of the Abdominal Region

The **inferior vena cava** parallels the abdominal aorta on the right side as it ascends through the abdominal cavity to penetrate the diaphragm and enter the right atrium (see fig. 16.34). It is the largest in diameter of the vessels in the body and is formed by the union of the two common iliac veins that drain the lower extremities. As the inferior vena cava ascends through the abdominal cavity, it receives tributaries from veins that correspond in name and position to arteries previously described.

Four paired **lumbar veins** (not shown) drain the posterior abdominal wall, the vertebral column, and the spinal cord. The **renal veins** drain blood from the kidneys and ureters into the inferior vena cava. The **right testicular vein** in males (or the **right ovarian vein** in females) drains the corresponding gonads, and the **right suprarenal vein** drains the right adrenal gland. These veins empty into the inferior vena cava. The **left testicular vein** (or **left ovarian vein**) and the **left suprarenal vein,** by contrast, empty into the left renal vein. The **inferior phrenic veins** receive blood from the inferior side of the diaphragm and empty into the inferior vena cava. **Right** and **left hepatic veins** originate from the capillary sinusoids of the liver and empty into the inferior vena cava immediately below the diaphragm.

Note that the inferior vena cava does not receive blood directly from the GI tract, pancreas, or spleen. Instead, the venous outflow from these organs first passes through capillaries in the liver.

Hepatic Portal System

A *portal system* is a pattern of circulation in which the vessels that drain one group of capillaries deliver blood to a second group of capillaries, which in turn are drained by more usual systemic veins that carry blood to the vena cavae and the right atrium of the heart. There are thus two capillary beds in series. The **hepatic** (*hĕ-pat′ik*) **portal system** is composed of veins that drain blood from capillaries in the intestines, pancreas, spleen, stomach, and gallbladder into capillaries in the liver (called *sinusoids*). The **right** and **left hepatic veins** that drain the venous blood from the liver and empty it into the inferior vena cava (fig. 16.41). As a consequence of the hepatic portal system, the absorbed products of digestion must first pass through the liver before entering the general circulation.

The **hepatic portal vein** is the large vessel that receives blood from the digestive organs. It is formed by a union of the **superior mesenteric vein,** which drains nutrient-rich blood from the small intestine, and the **splenic vein,** which drains the spleen. The splenic vein is enlarged because of a convergence of the following three tributaries: (1) the **inferior mesenteric vein** from the large intestine, (2) the **pancreatic vein** from the pancreas, and (3) the **left gastroepiploic** (*gas′′tro-ep′′ĭ-plo′ik*) **vein** from the stomach. The **right gastroepiploic vein,** also from the stomach, drains directly into the superior mesenteric vein.

Three additional veins empty into the hepatic portal vein. The **right** and **left gastric veins** drain the lesser curvature of the stomach and the **cystic vein** drains blood from the gallbladder.

One of the functions of the liver is to detoxify harmful substances, such as alcohol, that are absorbed into the blood from the small intestine. However, excessive quantities of alcohol cannot be processed during a single pass through the liver, and so a person becomes intoxicated. Eventually, the liver is able to process the alcohol as the circulating blood is repeatedly exposed to the liver sinusoids via the hepatic artery. Alcoholics may eventually suffer from *cirrhosis* of the liver as the normal liver tissue is destroyed.

In summary, it is important to note that the sinusoids of the liver receive blood from two sources. The hepatic artery supplies oxygen-rich blood to the liver, whereas the hepatic portal vein transports nutrient-rich blood from the small intestine for processing. These two blood sources become mixed in the liver sinusoids. Liver cells exposed to this blood obtain nourishment from it and are uniquely qualified (because of their anatomical position and enzymatic ability) to modify the chemical nature of the venous blood that enters the general circulation from the GI tract.

Knowledge Check

21. Using a flow chart, indicate the venous drainage from the head and neck to the superior vena cava. Point out the vein that may bulge in the side of the neck when a person performs Valsalva's maneuver and the vein that is commonly used as a site for venipuncture.
22. Describe the positions, sources, and drainages of the small and great saphenous veins.
23. Describe the hepatic portal system and comment on the functional importance of this system.

gastroepiploic: Gk. *gastros*, stomach; *epiplein*, to float on (referring to greater omentum)

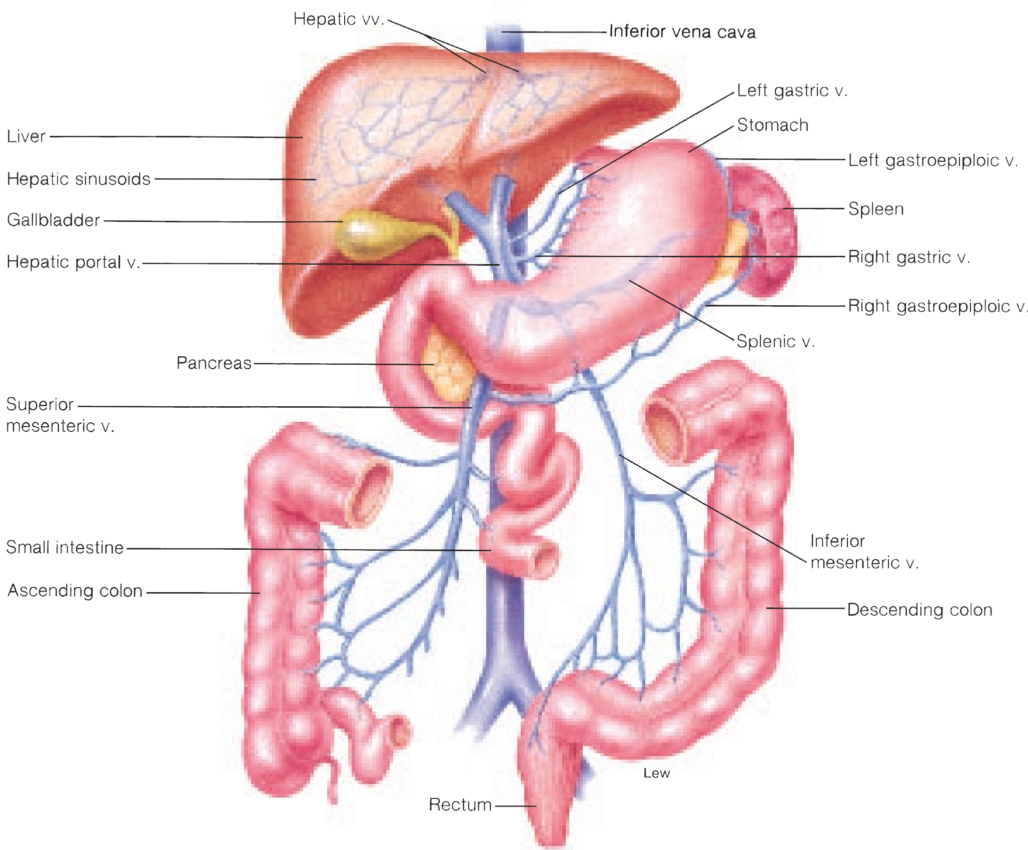


FIGURE 16.41 The hepatic portal system.

FETAL CIRCULATION

All of the respiratory, excretory, and nutritional needs of the fetus are provided for by diffusion across the placenta instead of by the fetal lungs, kidneys, and gastrointestinal tract. Fetal circulation is adaptive to these conditions.

Objective 21 Describe the fetal circulation to and from the placenta.

Objective 22 Describe the structure and function of the foramen ovale, ductus venosus, and ductus arteriosus.

The circulation of blood through a fetus is by necessity different from blood circulation in a newborn (fig. 16.42). Respiration, the procurement of nutrients, and the elimination of metabolic wastes occur through the maternal blood instead of through the organs of the fetus. The capillary exchange between the maternal and fetal circulation occurs within the **placenta** (*plă-sen'tă*) (see fig. 22.12). This remarkable structure, which includes maternal and fetal capillary beds, is discharged following delivery as the afterbirth.

The **umbilical cord** is the connection between the placenta and the fetal umbilicus. It includes one **umbilical vein** and two **umbilical arteries,** surrounded by a gelatinous substance. Oxygenated and nutrient-rich blood flows through the umbilical vein toward the inferior surface of the liver. At this point, the umbilical vein divides into two branches. One branch merges with the portal vein, and the other branch, called the **ductus venosus** (*ve-no'sus*) enters the inferior vena cava. Thus, oxygenated blood is mixed with venous blood returning from the lower extremities of the fetus before it enters the heart. The umbilical vein is the only vessel of the fetus that carries fully oxygenated blood.

The inferior vena cava empties into the right atrium of the fetal heart. Most of the blood passes from the right atrium into the left atrium through the **foramen ovale** (*fŏ-ra'men o-val'e*), an opening between the two atria. Here, it mixes with a small quantity of blood returning through the pulmonary circulation. The blood then passes into the left ventricle, from which it is pumped into the aorta and through the body of the fetus. Some blood entering the right atrium passes into the right ventricle and out of the heart via the pulmonary trunk. Because the lungs of the fetus are not functional, only a small portion of blood continues

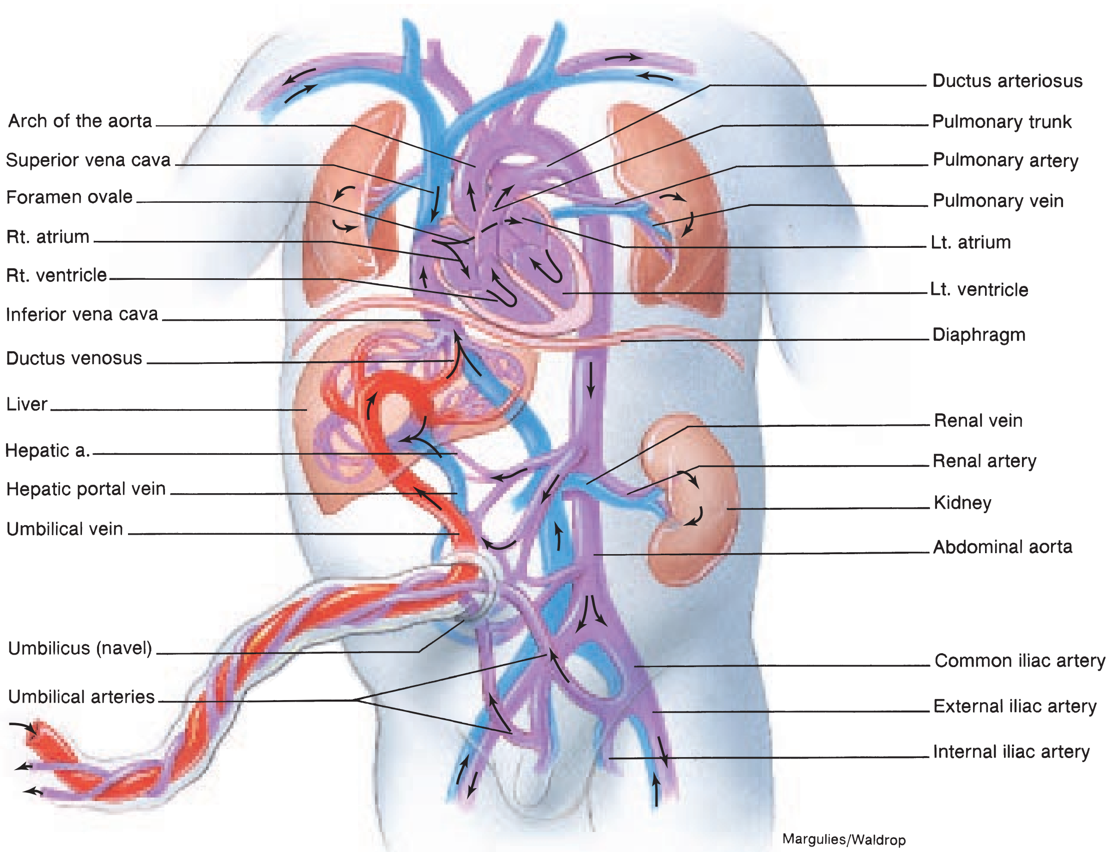


FIGURE 16.42 Fetal circulation. (Arrows indicate the direction of blood flow.)

through the pulmonary circulation (the resistance to blood flow is very high in the collapsed fetal lungs). Most of the blood in the pulmonary trunk passes through the **ductus arteriosus** (*ar-te''re-o'sus*) into the aortic arch, where it mixes with blood coming from the left ventricle. Blood is returned to the placenta by the two umbilical arteries that arise from the internal iliac arteries.

Notice that, in the fetus, oxygen-rich blood is transported by the inferior vena cava to the heart, and via the foramen ovale and ductus arteriosus to the systemic circulation.

Important changes occur in the cardiovascular system at birth. The foramen ovale, ductus arteriosus, ductus venosus, and the umbilical vessels are no longer necessary. The foramen ovale abruptly closes with the first breath of air because the reduced pressure in the right side of the heart causes a flap to cover the opening. This reduction in pressure occurs because the vascular resistance to blood flow in the pulmonary circulation falls far below that of the systemic circulation when the lungs fill with air. The pressure in the inferior vena cava and right atrium falls as a result of the loss of the placental circulation.

The constriction of the ductus arteriosus occurs gradually over a period of about 6 weeks after birth as the vascular smooth muscle fibers constrict in response to the higher oxygen concentration in the postnatal blood. The remaining structure of the ductus arteriosus gradually atrophies and becomes nonfunctional as a blood vessel. Transformation of the unique fetal cardiovascular system is summarized in table 16.6.

Knowledge Check

24. Trace the path of blood from the fetal heart through the placenta and back to the fetal heart.
25. Trace the path of oxygenated blood through the fetal circulation.
26. Describe the foramen ovale and ductus arteriosus and explain why blood flows the way it does through these structures in the fetal circulation.

TABLE 16.6 Cardiovascular Structures of the Fetus and Changes in the Neonate

Structure	Location	Function	Neonate Transformation
Umbilical vein	Connects the placenta to the liver; forms a major portion of the umbilical cord	Transports nutrient-rich oxygenated blood from the placenta to the fetus	Forms the round ligament of the liver
Ductus venosus	Venous shunt within the liver that connects the umbilical vein and the inferior vena cava	Transports oxygenated blood directly into the inferior vena cava	Forms the ligamentum venosum, a fibrous cord in the liver
Foramen ovale	Opening between the right and left atria	Acts as a shunt to bypass the pulmonary circulation	Closes at birth and becomes the fossa ovalis, a depression in the interatrial septum
Ductus arteriosus	Connects the pulmonary trunk and the aortic arch	Acts as a shunt to bypass the pulmonary circulation	Closes shortly after birth, atrophies, and becomes the ligamentum arteriosum
Umbilical arteries	Arise from internal iliac arteries and form a portion of the umbilical cord	Transport blood from the fetus to the placenta	Atrophy to become the lateral umbilical ligaments

LYMPHATIC SYSTEM

The lymphatic system, consisting of lymphatic vessels and various lymphoid tissues and organs, helps maintain fluid balance in tissues and absorb fats from the gastrointestinal tract. It also is part of the body's defense system against disease.

Objective 23 Describe the pattern of lymph flow from the lymphatic capillaries to the venous system.

Objective 24 Describe the general location, histological structure, and functions of the lymph nodes.

Objective 25 Describe the location and functions of the other lymphoid organs of the body.

The lymphatic system is closely related to the circulatory system, both structurally and functionally (fig. 16.43). A network of lymphatic vessels drains excess interstitial fluid (the approximate 15% that has not been returned directly to the capillaries) and returns it to the bloodstream in a one-way flow that moves slowly toward the subclavian veins. Additionally, the lymphatic system functions in fat absorption and in the body's defense against microorganisms and other foreign substances.

In short, the lymphatic system has three principal functions.

- It transports excess interstitial (tissue) fluid, which was initially formed as a blood filtrate, back to the blood.
- It serves as the route by which absorbed fats and some vitamins are transported from the small intestine to the blood.
- Its cells (called *lymphocytes*), located in lymphatic tissues, help provide immunological defenses against disease-causing agents.

Lymph and Lymphatic Vessels

The lymphatic network of vessels begins with the microscopic **lymphatic capillaries.** Lymphatic capillaries are closed-ended tubes that form vast networks in the intercellular spaces within most tissues. Within the villi of the small intestine, for example, lymphatic capillaries called *lacteals* (*lak'te-alz*), transport the products of fat absorption away from the GI tract. Because the walls of lymphatic capillaries are composed of endothelial cells with porous junctions, interstitial fluid, proteins, microorganisms, and absorbed fats (in the small intestine) can easily enter. Once fluid enters the lymphatic capillaries, it is referred to as **lymph** (*limf*). Adequate lymphatic drainage is needed to prevent the accumulation of interstitial fluid, a condition called *edema* (*ĕ-de'mă*).

From merging lymphatic capillaries, the lymph is carried into larger lymphatic vessels called **lymph ducts.** The walls of lymph ducts are much like those of veins. They have the same three layers and also contain valves to prevent backflow (fig. 16.44). The pressure that keeps the lymph moving comes from the massaging action produced by skeletal muscle contractions and intestinal movements, and from peristaltic contractions of some lymphatic vessels. The valves keep the lymph moving in one direction.

Interconnecting lymph ducts eventually empty into one of the two principal vessels: the **thoracic duct** and the **right lymphatic duct** (fig. 16.45). The larger thoracic duct drains lymph from the lower extremities, abdomen, left thoracic region, left upper extremity, and left side of the head and neck. The main trunk of this vessel ascends along the spinal column and drains into the left subclavian vein. In the abdominal area, there is a saclike enlargement of the thoracic duct called the **cisterna chyli** (*sis-ter'nă ki'le*), which collects lymph from the lower extremities and the intestinal region. The smaller right lymphatic duct drains lymphatic vessels from the right upper extremity, right thoracic region, and right side of the head and neck. The right lymphatic duct empties into the right subclavian vein near the internal jugular vein.

lacteal: L. *lacteus*, milk
lymph: L. *lympha*, clear water
edema: Gk. *edema*, a swelling
cisterna chyli: L. *cisterna*, box; Gk. *chylos*, juice

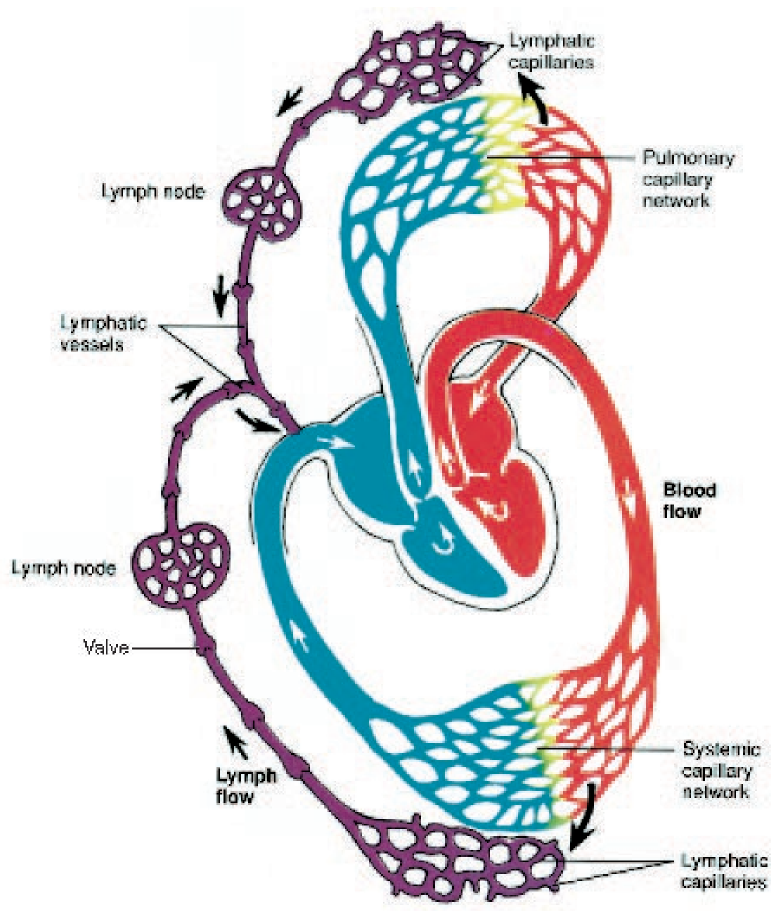


FIGURE 16.43 The schematic relationship between the circulatory and lymphatic systems. Interstitial (tissue) fluid is an extract of blood plasma formed at the pulmonary and systemic capillary networks. Lymph is the interstitial fluid that enters the lymphatic capillaries to be transported by lymphatic vessels to the venous bloodstream.

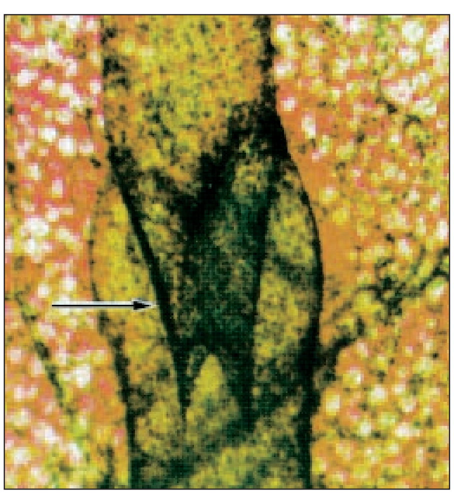


FIGURE 16.44 A photomicrograph of a valve (arrow) within a lymph vessel.

Lymph Nodes

Lymph filters through the reticular tissue (see fig. 4.18) of hundreds of **lymph nodes** clustered along the lymphatic vessels (fig. 16.46). The reticular tissue contains phagocytic cells that help purify the fluid. Lymph nodes are small bean-shaped bodies enclosed within fibrous connective tissue *capsules*. Specialized connective tissue bands called *trabeculae* (*tră-bek′yŭ-le*) divide the node. *Afferent lymphatic vessels* carry lymph into the node, where it is circulated through the *sinuses*, a series of irregular channels. Lymph leaves the node through the *efferent lymphatic vessel*, which emerges from the *hilum*—a depression on the concave side of the node. **Lymphatic nodules** within the node are the sites of lymphocyte production, and are thus important in the development of an immune response.

Lymph nodes usually occur in clusters in specific regions of the body (see fig. 16.45). Some of the principal groups of lymph nodes are the **popliteal** (not illustrated) and **inguinal nodes** of the lower extremity, the **lumbar nodes** of the pelvic region, the

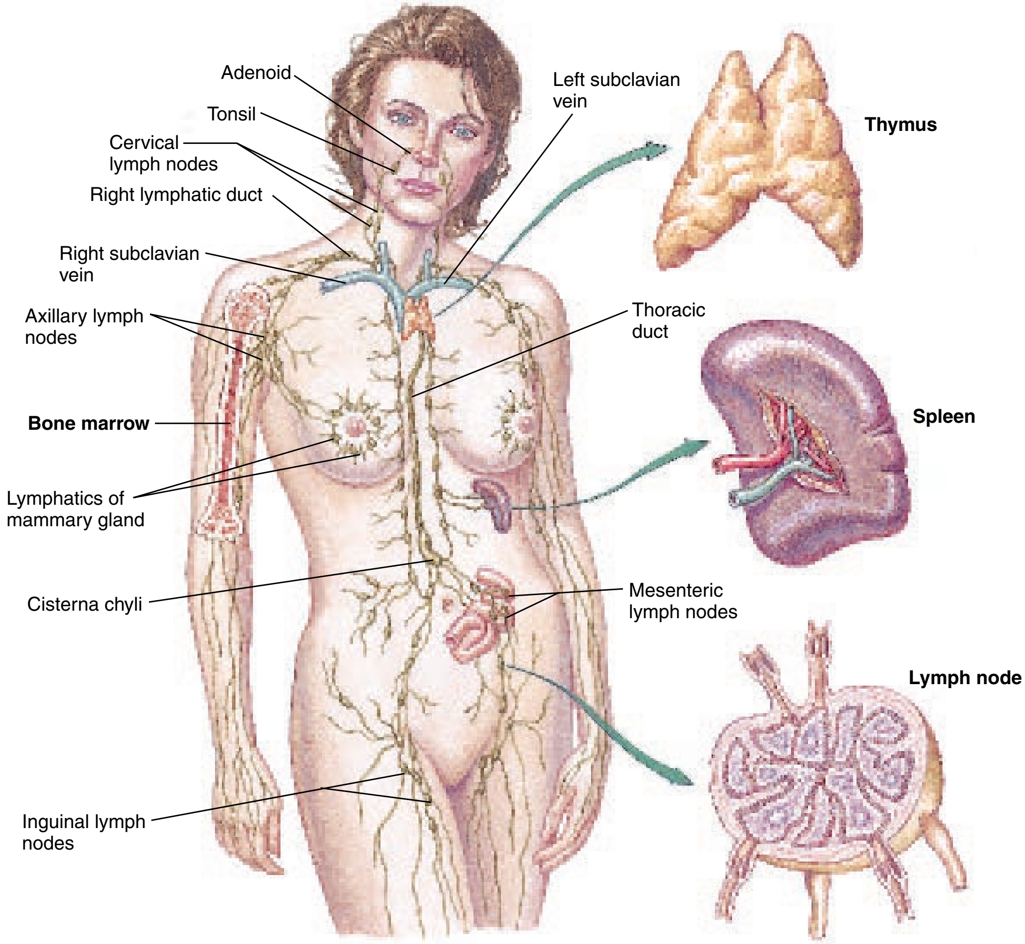


FIGURE 16.45 The lymphatic system showing the principal lymph nodes and other lymphoid organs. Lymph from the upper right extremity, the right side of the head and neck, and the right thoracic region drains through the right lymphatic duct into the right subclavian vein. Lymph from the remainder of the body drains through the thoracic duct into the left subclavian vein.

cubital and **axillary nodes** of the upper extremity, the **thoracic nodes** of the chest, and the **cervical nodes** of the neck. The submucosa of the small intestine contains numerous scattered lymphocytes and lymphatic nodules, and larger clusters of lymphatic tissue called **mesenteric** (Peyer's) **patches.**

Migrating cancer cells (metastases) are especially dangerous if they enter the lymphatic system, which can disperse them widely. On entering the lymph nodes, the cancer cells can multiply and establish secondary tumors in organs that are along the lymphatic drainage of the site of the primary tumor.

Peyer's patches: from Johann K. Peyer, Swiss anatomist, 1653–1712

Other Lymphoid Organs

In addition to the lymph nodes just described, the *tonsils*, *spleen*, and *thymus* are lymphoid organs. The **tonsils** form a protective ring of lymphatic tissue around the openings between the nasal and oral cavities and the pharynx (see fig. 17.3).

The tonsils, of which there are three pairs, combat infection of the ear, nose, and throat regions. Because of the persistent infections that some children suffer, the tonsils may become so overrun with infections that they, themselves, become a source of infections that spread to other parts of the body. A *tonsillectomy* may then have to be performed. This operation is not as common as it was in the past because of the availability of powerful antibiotics and because the functional value of the tonsils is appreciated to a greater extent.

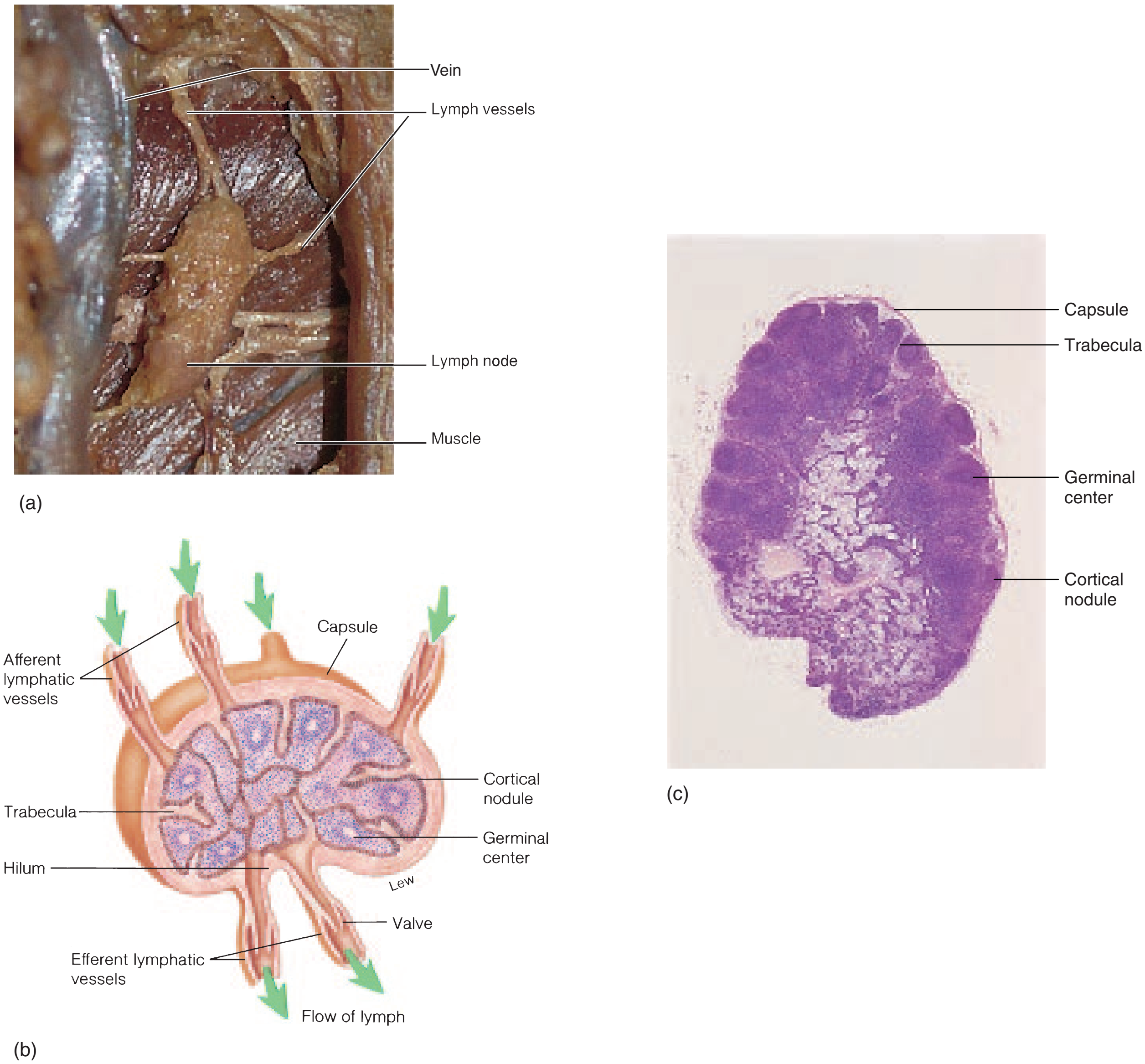


FIGURE 16.46 The structure of a lymph node. (*a*) A photograph of a lymph node positioned near a blood vessel, (*b*) a diagram of a sectioned lymph node and associated vessels, and (*c*) a photomicrograph of a lymph node.

The **spleen** (fig. 16.47) is located on the left side of the abdominal cavity, to the left of the stomach from which it is suspended. The spleen is not a vital organ in an adult, but it does assist other body organs in producing lymphocytes, filtering the blood, and destroying old erythrocytes. In an infant, the spleen is an important site for the production of erythrocytes. In an adult, it contains *red pulp*, which serves to destroy old erythrocytes, and *white pulp*, which contains germinal centers for the production of lymphocytes.

Of all of the abdominal organs, the spleen is the one most easily and frequently injured. Because it is highly vascular, extensive—sometimes massive—hemorrhage occurs when the spleen is ruptured. To prevent death from loss of blood, a *splenectomy* (removal of the spleen) is performed. Without immediate surgery for a ruptured spleen, the mortality rate is 90%.

spleen: L. *splen*, low spirits (thought to cause melancholy)

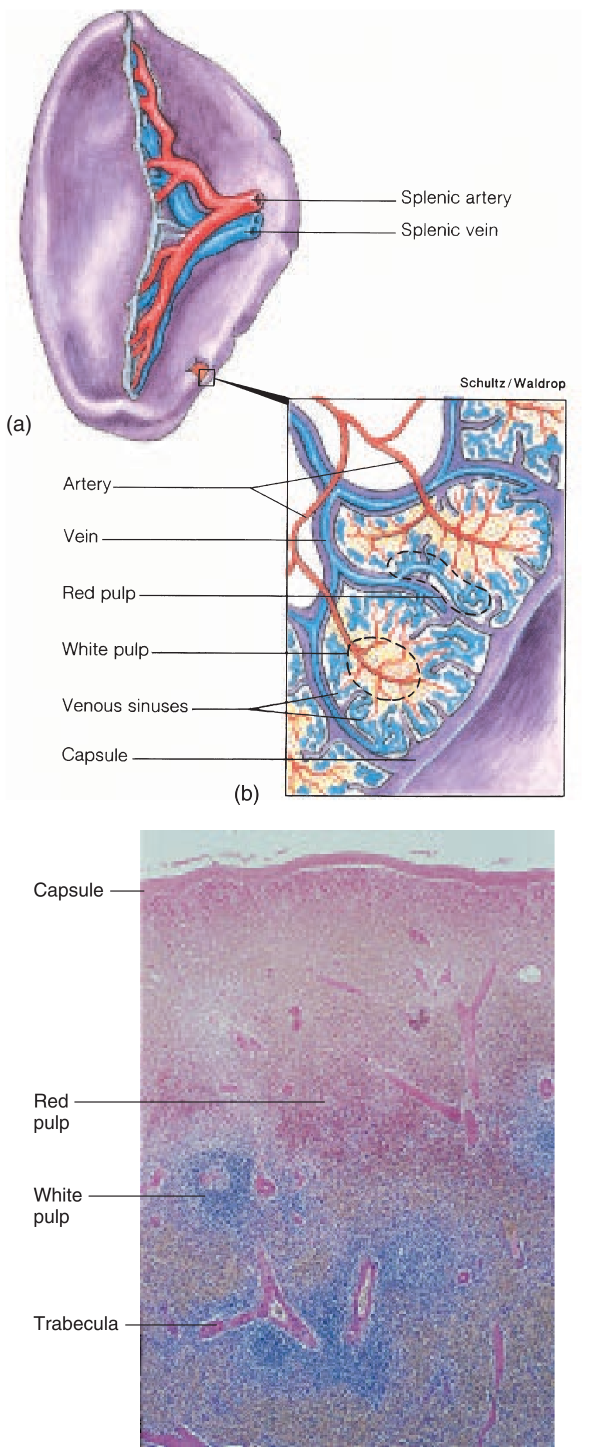


FIGURE 16.47 The structure of the spleen. (*a*) A medial view, (*b*) a diagram of the pulp, and (*c*) a photomicrograph (10×).

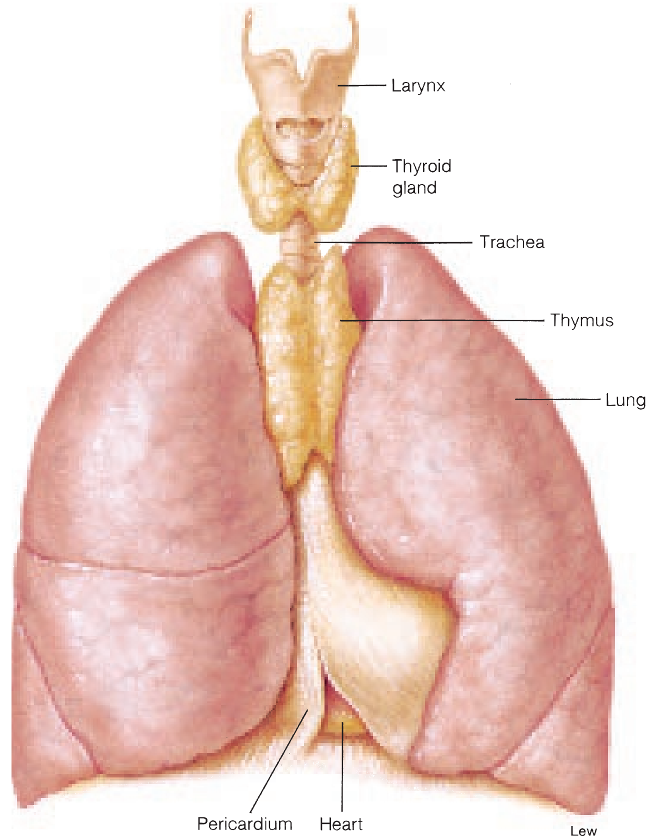


FIGURE 16.48 The thymus is located in the mediastinum, medial to the lungs.

The **thymus** is located in the anterior thorax, deep to the manubrium of the sternum (fig. 16.48). Because it regresses in size during puberty, it is much larger in a fetus and child than in an adult. The thymus plays a key role in the immune system.

The lymphoid organs are summarized in table 16.7.

Knowledge Check

27. Describe the relationship between lymph and blood in terms of their origin, composition, and fate.
28. List the two major lymph vessels of the body and describe their relationships to the vascular system.
29. Describe the structure, location, and function of the lymph nodes and identify the other lymphoid organs.

thymus: Gk. *thymos*, thyme (compared to the flower of this plant by Galen)

TABLE 16.7 Lymphoid Organs

Organ	Location	Function
Lymph nodes	In clusters or chains along the paths of larger lymphatic vessels	Sites of lymphocyte production; house T lymphocytes and B lymphocytes that are responsible for immunity; phagocytes filter foreign particles and cellular debris from lymph
Tonsils	In a ring at the junction of the oral cavity and pharynx	Protect against invasion of foreign substances that are ingested or inhaled
Spleen	In upper left portion of abdominal cavity, beneath the diaphragm and suspended from the stomach	Serves as blood reservoir; phagocytes filter foreign particles, cellular debris, and worn erythrocytes from the blood; houses lymphocytes
Thymus	Within the mediastinum, behind the manubrium	Important site of immunity in a child; houses lymphocytes; changes undifferentiated lymphocytes into T lymphocytes

CLINICAL CONSIDERATIONS

It has been said that as the circulatory system goes, so goes the rest of the body. The circulatory system is the lifeline to the other organs of the body. If the vital organs are deprived of the essentials for life, they will falter in their functions, ultimately resulting in body death. Some gerontologists believe that the first system of the body to show signs of aging is the circulatory system, and that this accelerates the aging process in the other systems.

The circulatory system is extremely important clinically because of the frequent irregularities and diseases that afflict it and the effect of its dysfunction on the maintenance of homeostasis. Given the confines of this text, it would not be practical to attempt a comprehensive discussion of the numerous clinical aspects of the cardiovascular system. However, some general comments will be made on cardiovascular assessment, on dysfunctions of the cardiovascular and lymphatic systems, and on the prevention and treatment of heart problems. In addition, first-aid treatment for victims of hemorrhage and shock will be discussed.

Cardiovascular Assessment

Cardiovascular assessment is an extremely important aspect of a physical examination. Several techniques are routinely used in gathering information. Auscultation of heart sounds with a **stethoscope** is not only important for detecting murmurs, but may help the physician evaluate general cardiac functioning or the progress of a patient with a cardiovascular problem.

An **electrocardiogram (ECG)** provides a "picture" of the electrical activity of the heart. The most important diagnostic use of the resting ECG is identifying abnormal cardiac rhythms. Injury to cardiac muscle, as in myocardial infarction, elevates or depresses the S-T segment while inverting and shortening the T wave.

Several diagnostic techniques, including **radiograms, CT scans,** and **ultrasound,** are employed for determining the size and position of the heart, the condition of the pericardial sac, and even the internal structure and condition of the vessels, chambers, and valves. The accumulation of fluids can be easily detected using these techniques. **Catheterization** of the heart in conjunction with a **fluoroscopic analysis** permits observation of the vessels, chambers, and valves of the heart. In addition, internal blood pressures can be recorded and samples of blood taken. Selective **arteriography** (*ar′′te-re-og′ră-fe*) enables a physician to study the wall of a particular vessel. An **angiocardiogram** (*an′′je-o-kar′de-ŏ-gram*) is a radiograph of the chambers of the heart and its vessels following an intravenous injection of a radiopaque dye.

Arterial blood pressure can be measured using a **sphygmomanometer** (see fig. 16.18). Blood pressure is indicative of the general health of the cardiovascular system. **Hypertension** is sustained high blood pressure and can result in mechanical damage to the cardiovascular system. Hypertension can be caused by resistance in the vessels from physiological actions (vasoconstriction) or by various vascular diseases (arteriosclerosis). Certain characteristics of the blood itself may cause hypertension.

Cardiac Arrhythmia

Arrhythmias, or abnormal heart rhythms, can be detected and described by the abnormal ECG patterns they produce. Because a heartbeat occurs whenever a normal QRS complex (see fig. 16.11*b*) is seen, and because the ECG chart paper moves at a known speed, its *x*-axis indicates time, and the cardiac rate (beats per minute) can easily be obtained from the ECG recording. A cardiac rate slower than 60 beats per minute indicates **bradycardia** (*brad′′ĭ-kar′de-ă*); a rate faster than 100 beats per minute is described as **tachycardia** (*tak′′ĭ-kar′de-ă*).

stethoscope: Gk. *stethos*, breast; *skopos*, watch, look at

sphygmomanometer: Gk. *sphygmos*, throbbing; *manos*, at intervals; L. *metrum*, measure

bradycardia: Gk. *bradys*, slow; *kardia*, heart

tachycardia: Gk. *tachys*, rapid; *kardia*, heart

Developmental Exposition

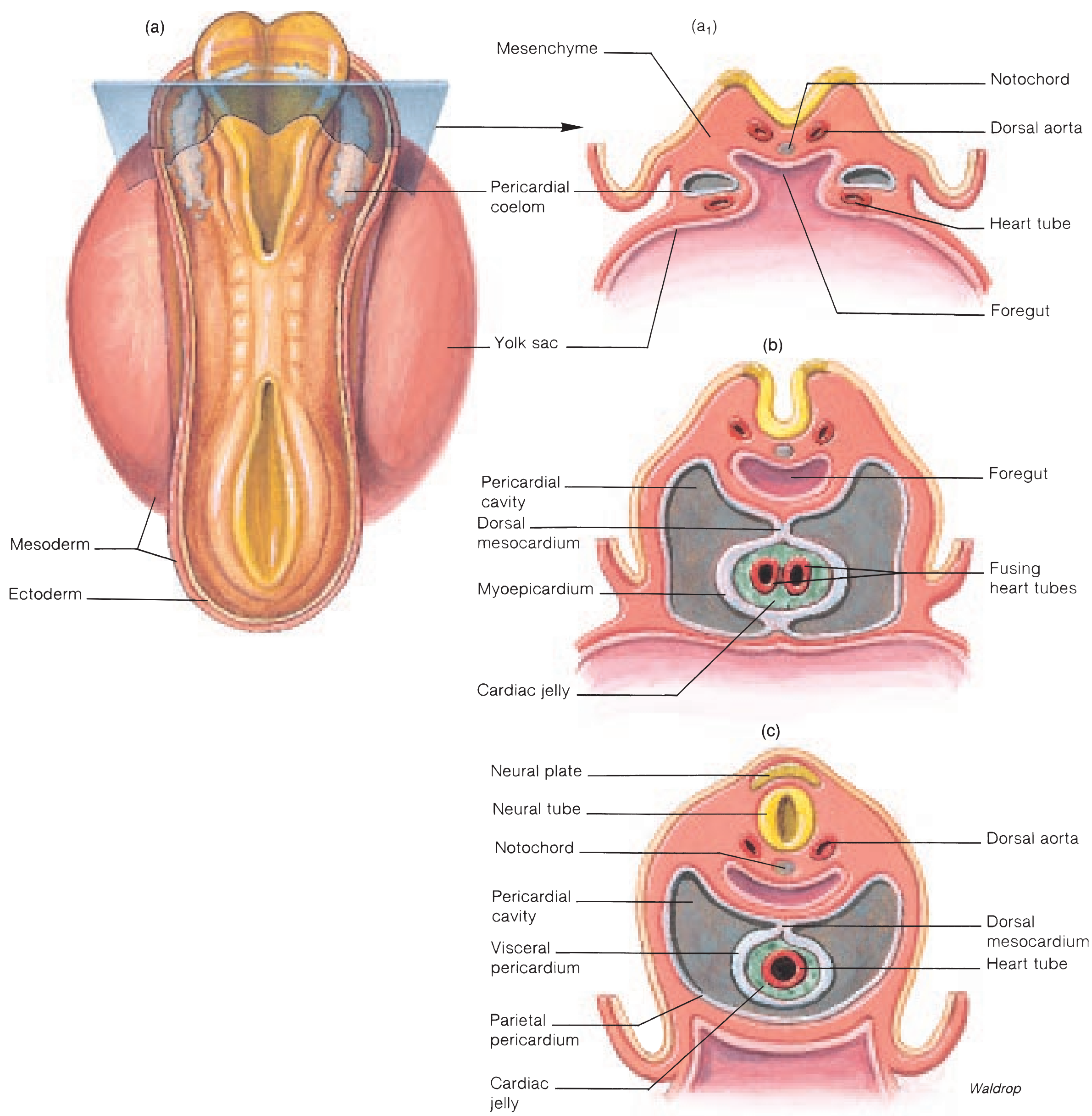


EXHIBIT I The early development of the heart from embryonic mesoderm. (*a*) A dorsal view of an embryo at day 20 showing the position of a transverse cut depicted in (a_1), (*b*), and (*c*). (a_1) At day 20, the heart tubes are formed from the heart cords. (*b*) By day 21, the medial migration of the heart tubes has brought them together within the forming pericardial cavity. (*c*) A single heart tube is completed at day 22 and is suspended in the pericardial cavity by the dorsal mesocardium.

The Circulatory System

EXPLANATION

The cardiovascular system is one of the first systems to form in the embryo, delivering nutrients to the mitotically active cells and disposing of waste products through its association with the maternal blood vessels in the placenta. Blood is formed and begins circulating through the vessels by the pumping action of the heart approximately 25 days after conception.

Throughout pregnancy, the fetus is dependent on the mother's circulatory system for exchange of nutrients, gases, and wastes. To accommodate this arrangement, some unique structures of the fetal circulatory system develop. The discussion that follows focuses on the development of the fetal heart and associated major vessels. The circulation of blood through the fetal cardiovascular system has already been discussed under the heading "Fetal Circulation."

DEVELOPMENT OF THE HEART

The development of the heart from two separate segments of mesoderm requires only 6 to 7 days. Heart development is first apparent at day 18 or 19 in the **cardiogenic** *(kar''de-o-jen'ik)* area of the mesoderm layer (exhibit I). A small paired mass of specialized cells called **heart cords** form here. Shortly after, a hollow center develops in each heart cord, and each structure is then referred to as a **heart tube.** The heart tubes begin to migrate toward each other on day 21 and soon fuse to form a single median heart tube. During this time, the heart tube undergoes dilations and constrictions, so that when fusion is completed during the fourth week, five distinct regions of the heart can be identified. These are the **truncus arteriosus, bulbus cordis, ventricle, atrium,** and **sinus venosus** (exhibit II).

After the fusion of the heart tubes and the formation of distinct dilations, the heart begins to pump blood. Partitioning of the heart chambers begins during the middle of the fourth week and is complete by the end of the fifth week. During this crucial time, many congenital heart problems develop.

Major changes occur in each of the five primitive dilations of the developing heart during the week-and-a-half embryonic period beginning in the middle of the fourth week. The truncus arteriosus differentiates to form a partition between the aorta and the pulmonary trunk. The bulbus cordis is incorporated in the formation of the walls of the ventricles. The sinus venosus forms the **coronary sinus** and a portion of the wall of the right atrium. The ventricle is divided into the right and left chambers by the growth of the **interventricular septum.** The atrium is partially partitioned into right and left chambers by the **septum secundum.** An opening between the two atria called the **foramen ovale** persists throughout fetal development. This opening is covered by a flexible valve that permits blood to pass from the right to the left side of the heart.

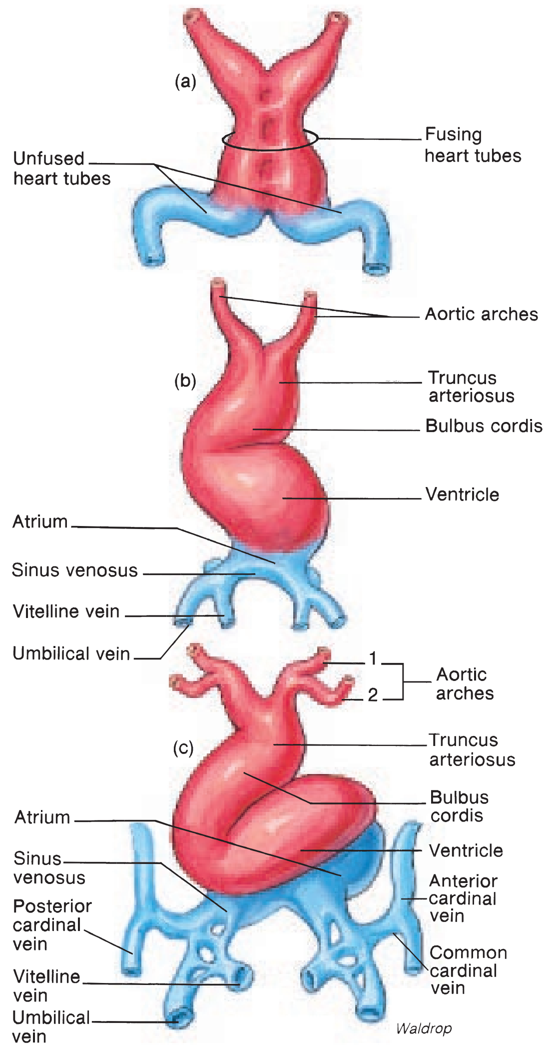


EXHIBIT II Formation of the heart chambers. (*a*) The heart tubes fuse during days 21 and 22. (*b*) The developmental chambers are formed during day 23. (*c*) Differential growth causes folding between the chambers during day 24, and vessels are developed to transport blood to and from the heart. The embryonic heart generally has begun rhythmic contractions and pumping of blood by day 25.

cardiogenic: Gk, *kardia,* heart; *genesis,* be born (origin)

TABLE 16.8 Structural Changes in the Development of the Heart

Primitive Cardiac Dilation	Developmental Fate
Truncus arteriosus	Differentiates to form the aorticopulmonary septum, which partitions the ascending aorta and the pulmonary trunk
Bulbus cordis	Incorporated into the walls of the ventricles
Sinus venosus	Differentiates to form the coronary sinus and a portion of the wall of the right atrium
Ventricle	Divided into right and left chambers by growth of the interventricular septum
Atrium	Partially partitioned into right and left chambers by the septum secundum. The opening in the partition, called the foramen ovale, persists throughout prenatal development.

TABLE 16.9 Derivatives of the Aortic Arches

Aortic Arch	Derivative
First pair	No derivative
Second pair	No derivative
Third pair	Proximal portions form the common carotid arteries. Distal portions form the external carotid arteries.
Fourth pair	Right arch forms the base of the right subclavian artery.
Fifth pair	Left arch forms a portion of the aortic arch.
Sixth pair	Right arch: proximal portion persists as proximal part of the right pulmonary artery; distal portion degenerates.
No derivative	Left arch: proximal portion forms the proximal part of the left pulmonary artery; distal part persists as the ductus arteriosus.

The development of the heart is summarized in table 16.8.

Congenital defects of the cardiac septa are a relatively common form of birth abnormality. Approximately 0.7% of live births and 2.7% of stillbirths show cardiac abnormalities. Ventricular septal defects are the most common of the cardiac defects. An infant with a congenital cardiac defect may suffer from inadequate oxygenation of blood and thus be termed a "blue baby."

DEVELOPMENT OF THE MAJOR ARTERIES

The formation of the major arteries occurs simultaneously with the development of the heart. The most complex and fascinating vascular formation is the development of the **aortic arches** associated with the pharyngeal pouches and branchial arches in the neck region (exhibit III). These aortic arches arise from the truncus arteriosus. Although six pairs of aortic arches develop, they are not all present at the same time, and none of them persists in entirety through fetal development.

The transformation of the six aortic arches into the basic adult arterial arrangement occurs between the sixth and eighth weeks of embryonic development. The first and second pairs of aortic arches disappear before the formation of the sixth. The third pair of aortic arches form the common carotid arteries and the external carotid arteries. The right fourth aortic arch forms the base of the right subclavian artery, and the left fourth arch contributes to part of the aortic arch. The first, second, and fifth pairs of aortic arches have no derivatives and soon atrophy. The right sixth aortic arch forms the proximal portion of the right pulmonary artery. The left sixth arch forms the proximal portion of the left pulmonary artery, and the distal portion of this arch persists as an embryonic shunt between the pulmonary trunk and the aorta called the **ductus arteriosus.**

The derivatives of the aortic arches are summarized in table 16.9.

Although the embryonic vessels that develop from the truncus arteriosus are called aortic arches, they should not be confused with the adult aortic arch; that is, the major systemic artery leaving the heart. Only the left fourth arch participates in the formation of the adult aortic arch.

An examination of the persisting aortic arches in the adults of different classes of vertebrates reveals interesting evolutionary relationships. Fish have six aortic arches persisting in the gill region. Reptiles have only one pair, a branch to the left and one to the right. All birds have a single right aortic arch, and all mammals have a single left aortic arch.

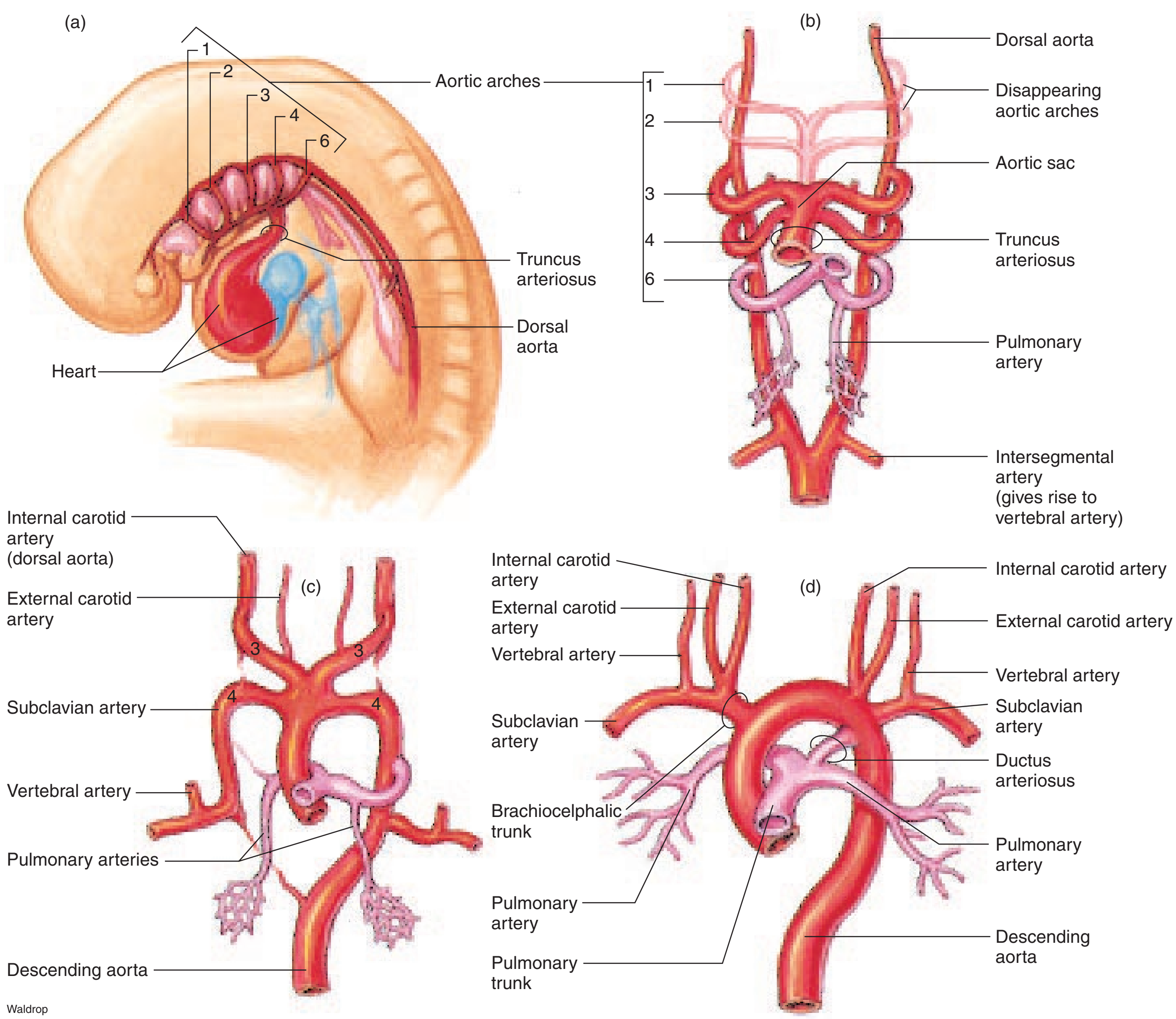


EXHIBIT III Formation of the aortic arch and major arteries of the thoracic region. (*a*) A schematic lateral view of the pharyngeal pouches and aortic arches within the neck region of a 28-day embryo. (Note that by this time arch 5 is no longer present.) (*b*) The aortic arches at 6 weeks. (Note that by this time arches 1 and 2 have largely disappeared.) (*c*) The aortic arches at 7 weeks. (*d*) The arterial configuration at 8 weeks.

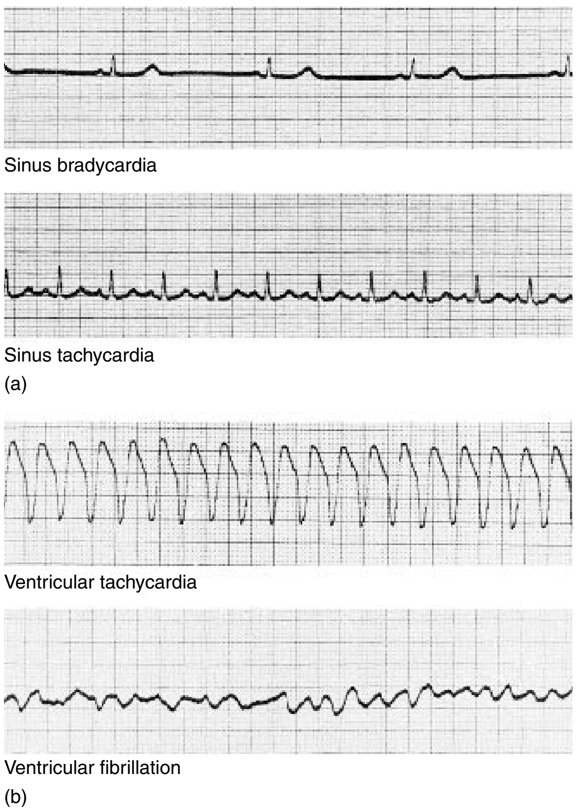


FIGURE 16.49 In (*a*) the heartbeat is paced by the normal pacemaker—the SA node (hence the name *sinus rhythm*). This can be abnormally slow (bradycardia—46 beats per minute in this example) or fast (tachycardia—136 beats per minute in this example). Compare the pattern of tachycardia in (*a*) with the tachycardia in (*b*). Ventricular tachycardia is produced by an ectopic pacemaker in the ventricles. This dangerous condition can quickly lead to ventricular fibrillation, also shown in (*b*).

Both bradycardia and tachycardia can occur normally (fig. 16.49*a*). Endurance-trained athletes, for example, commonly have a slower heart rate than the general population. This *athlete's bradycardia* occurs as a result of higher levels of parasympathetic inhibition of the SA node and is a beneficial adaptation. Activation of the sympathetic division of the ANS during exercise or emergencies causes a normal tachycardia to occur.

An abnormal bradycardia may be caused by a heart block, various drugs, shock, or increased intracranial pressure. An abnormal tachycardia occurs if the heart rate increases when a person is at rest. This may result from abnormally fast pacing by the atria because drugs or of the development of abnormally fast *ectopic pacemakers*—cells located outside the SA node that assume a pacemaker function. This abnormal atrial tachycardia thus differs from normal "sinus" (SA node) tachycardia. *Ventricular tachycardia* results when abnormally fast ectopic pacemakers in the ventricles cause them to beat rapidly and independently of the atria (fig. 16.49*b*). This is very dangerous because it can quickly degenerate to a lethal condition known as *ventricular fibrillation* (*fib''rĭ-la'shun*).

Ventricular Fibrillation

Fibrillation is caused by a continuous recycling of electrical waves through the myocardium. Because the myocardium enters a refractory period simultaneously at all regions, this recycling is normally prevented. If some cells emerge from their refractory periods before others, however, electrical waves can be continuously regenerated and conducted. The recycling of electrical waves along continuously changing pathways produces uncoordinated contraction and an impotent pumping action. These effects can be the result of damage to the myocardium.

Fibrillation can sometimes be stopped by a strong electric shock delivered to the chest—a procedure called **electrical defibrillation.** The electric shock depolarizes all the myocardial cells at the same time, causing them to enter a refractory state. The conduction of random recirculating impulses thus stops, and the SA node can begin to stimulate contraction in a normal fashion. Although this does not correct the initial problem that caused the abnormal electrical patterns, it can keep a person alive long enough to take other corrective measures.

Blood Disorders

Because blood is the functional component of the circulatory system, and because the circulatory system works in such close association with other body systems, blood analysis is perhaps the most informative part of a physical exam. Peripheral arterial pulsations, usually obtained at the radial artery, provide information about blood flow. Capillary filling, following **blanching,** is an indicator of peripheral arterial circulation and is generally tested at the nail bed. This is done by firmly pressing the thumbnail against the patient's toenail or fingernail and then quickly releasing the pressure. If the pinkish color returns quickly to the whitened (blanched) area, circulation is considered normal. Lack of peripheral coloration indicates vascular insufficiency.

Certain cardiovascular and blood abnormalities are expressed through the skin. **Cyanosis** (*si-ă-no'sis*) is characterized by a bluish coloration of the skin resulting from decreased oxygen concentration. **Anemia** is characterized by a pallor of the skin because of a deficiency of erythrocytes or hemoglobin. **Jaundice** is a condition in which the skin is yellowed because of excessive bile pigment (bilirubin) in the blood. **Edema** (*ĕ-de'mă*) is an excessive accumulation of interstitial (tissue) fluid, causing a swelling of a portion of the body. **Erythema** (*er''ĭ-the'mă*) is a redness of the skin usually caused by an infection, inflammation, toxic reaction, sunburn, or a lesion. None of these conditions are themselves diseases, but each is symptomatic of problems that may involve the cardiovascular system.

Blood analysis is an essential part of any thorough physical examination. Blood cell counts are used to determine the percentage of formed elements in the blood. An excess of red blood

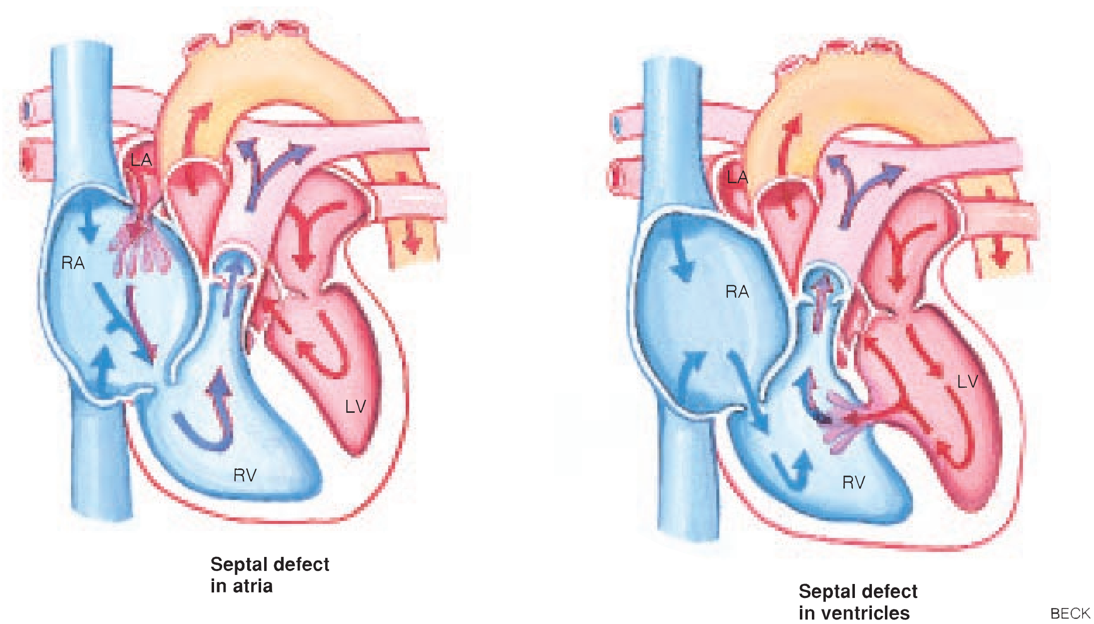


FIGURE 16.50 Abnormal patterns of blood flow as a result of septal defects.

cells, called **polycythemia** (*pol''e-si-the'me-ă*) (more than 6 million/mm^3), may indicate certain bone diseases. Excessive leukocyte production, called **leukocytosis,** is generally diagnostic of infections or diseases within the body. **Leukopenia** is a decrease in leukocyte count. The disease **leukemia** causes the unrestricted reproduction of immature leukocytes, which depresses erythrocyte and platelet formation and causes anemia and a tendency to bleed. Coagulation time, blood sedimentation rates, prothrombin time, and various serum analyses are other blood tests that provide specific information about body function or dysfunction.

Several blood diseases are distinguished by their rate of occurrence. **Sickle-cell anemia** is an autosomal recessive disease that occurs almost exclusively in blacks. Although about 10% of American blacks have the sickle-cell trait, fortunately fewer than 1% have sickle-cell disease. The distorted shape of the diseased cells reduces their capacity to transport oxygen, resulting in an abnormally high destruction of erythrocytes. With the decrease in erythrocytes, the patient becomes anemic. **Mononucleosis** is an infectious disease that is transmitted by a virus in saliva, and is therefore commonly called the "kissing disease." Mononucleosis is characterized by atypical lymphocytes. It affects primarily adolescents, causing fever, sore throat, enlarged lymph glands, and fatigue.

Heart Diseases

Heart diseases can be classified as congenital or acquired. **Congenital heart problems** result from abnormalities in embryonic development and may be attributed to heredity, nutritional problems (poor diet) of the pregnant mother, or viral infections. Congenital heart diseases occur in approximately 3 of every 100 births and account for about 50% of early childhood deaths. Many congenital heart defects can be corrected surgically, however, and others are not of a serious nature.

Heart murmurs can be congenital or acquired. Generally, they are of no clinical significance; nearly 10% of all people have heart murmurs, ranging from slight to severe. A **septal defect** is the most common type of congenital heart problem (fig. 16.50). An **atrial septal defect,** or **patent foramen ovale,** is a failure of the fetal foramen ovale to close at the time of birth. A **ventricular septal defect** is caused by an abnormal development of the interventricular septum. This condition may interfere with closure of the atrioventricular valves and may be indicated by cyanosis and abnormal heart sounds. **Pulmonary stenosis** is a narrowing of the opening into the pulmonary trunk from the right ventricle. It may lead to a pulmonary embolism and is usually recognized by extreme lung congestion.

The **tetralogy of Fallot** is a combination of four defects in a newborn that immediately causes a cyanotic condition. The four characteristics of this condition are (1) a ventricular septal defect, (2) an overriding aorta, (3) pulmonary stenosis, and (4) right ventricular hypertrophy (fig. 16.51). The pulmonary stenosis obstructs blood flow to the lungs and causes hypertrophy of the right ventricle. In an overriding aorta, the ascending portion arises midway between the right and left ventricles. Open-heart surgery is necessary to correct tetralogy of Fallot, and the overall mortality rate is about 5%.

tetralogy of Fallot: from Étienne-Louis A. Fallot, French physician, 1850–1911

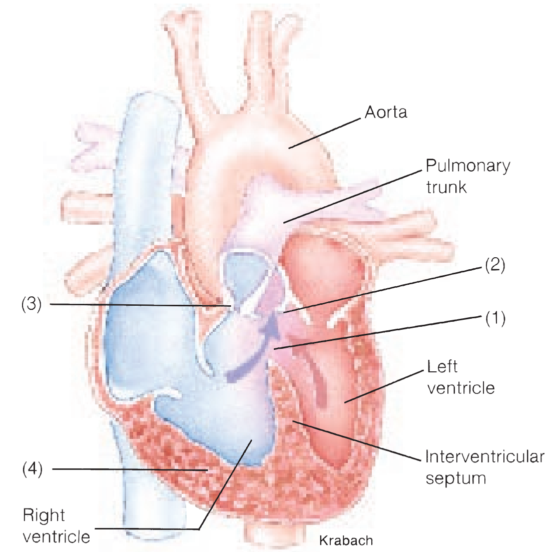


FIGURE 16.51 The tetralogy of Fallot. The four defects of this anomaly are (1) a ventricular septal defect, (2) an overriding aorta, (3) pulmonary stenosis (constriction), and (4) right ventricular hypertrophy (enlargement). (The arrows indicate the possible abnormal flow of blood with this condition.)

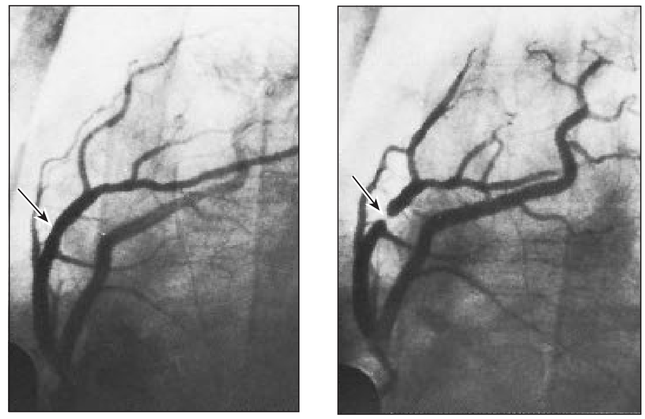


FIGURE 16.52 An arteriogram of the left coronary artery in a patient (*a*) when the ECG was normal and (*b*) when the ECG showed evidence of myocardial ischemia. Notice that a coronary artery spasm (see arrow in [*b*]) appears to accompany the ischemia.

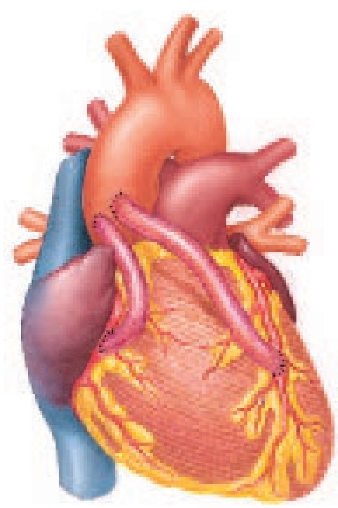


FIGURE 16.53 A double coronary artery bypass surgery. Several vessels may be used in the autotransplant, including the internal thoracic artery and the great saphenous vein.

Acquired heart disease may develop suddenly or gradually. Heart attacks are included in this category and are the leading cause of death in the United States. It is estimated that one in five individuals over the age of 60 will succumb to a heart attack. The immediate cause of a heart attack is generally one of the following: inadequate coronary blood supply, an anatomical disorder, or conduction disturbances.

Other types of acquired heart diseases affect the layers of the heart. **Bacterial endocarditis** is a disease of the lining of the heart, especially the cusps of the valves. It is caused by infectious organisms that enter the bloodstream. **Myocardial disease** is an inflammation of the heart muscle followed by cardiac enlargement and congestive heart failure. **Pericarditis** causes an inflammation of the pericardium—the covering membrane of the heart. Its distinctive feature is pericardial friction rub, a transitory scratchy sound heard during auscultation.

A tissue is said to be **ischemic** (*ĭ-ske'mik*) when it receives an inadequate supply of oxygen because of an inadequate blood flow. The most common cause of myocardial ischemia is atherosclerosis of the coronary arteries. The adequacy of blood flow is relative—it depends on the metabolic requirements of the tissue for oxygen. An obstruction in a coronary artery, for example, may allow sufficient blood flow at rest but may produce ischemia when the heart is stressed by exercise or emotional factors (fig. 16.52). In patients with this condition, angioplasty or coronary artery bypass surgery may be performed (fig. 16.53).

Myocardial ischemia is associated with increased concentrations of blood lactic acid produced by anaerobic respiration of the ischemic tissue. This condition often causes substernal pain, which also may be referred to the left shoulder and arm, as well as to other areas. This referred pain is called **angina pectoris** (*an-ji'nă pek'tor'is*). People with angina frequently take nitroglycerin or related drugs that help relieve the ischemia and pain. These drugs are effective because they stimulate vasodilation, which improves circulation to the heart and decreases the work that the heart must perform to eject blood into the arteries.

Myocardial cells are adapted to respire aerobically and cannot respire anaerobically for more than a few minutes. If ischemia and anaerobic respiration continue for more than a few

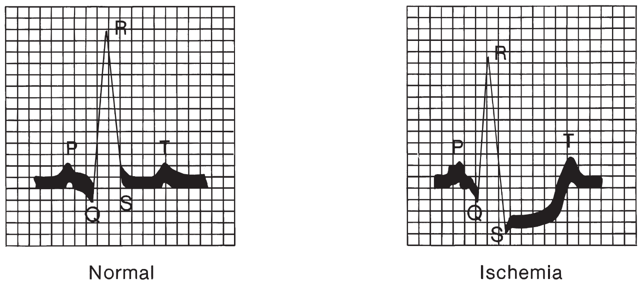


FIGURE 16.54 Depression of the S-T segment of the electrocardiogram as a result of myocardial ischemia.

minutes, *necrosis* (cellular death) may occur in the areas most deprived of oxygen. A sudden, irreversible injury of this kind is called a **myocardial infarction,** or **MI.**

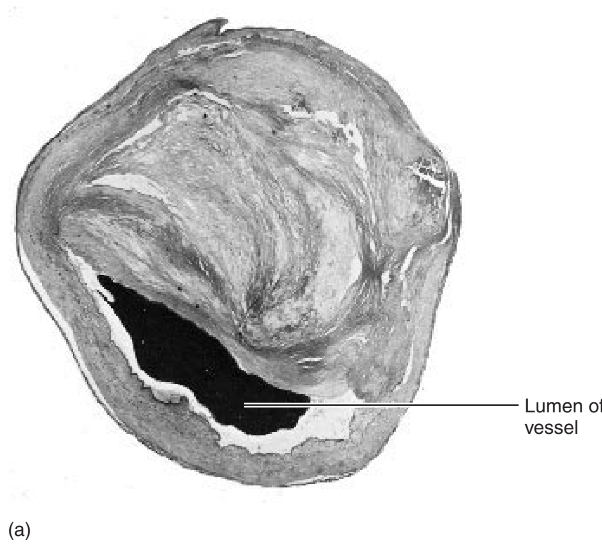
Myocardial ischemia may be detected by characteristic changes in the ECG (fig. 16.54). The diagnosis of myocardial infarction is aided by examining the blood concentration of various enzymes that are released from the damaged cells.

Vascular Disorders

Hypertension, or high blood pressure, is the most common type of vascular disorder. In hypertension, the resting systolic blood pressure exceeds 140 mmHg and the diastolic exceeds 90 mmHg. An estimated 22 million adult Americans are afflicted by hypertension. About 15% of the cases are the result of other body problems, such as kidney diseases, adrenal hypersecretion, or arteriosclerosis, and are diagnosed as secondary hypertension. Primary hypertension is more common and cannot be attributed to any particular body dysfunction. If hypertension is not controlled by diet, exercise, or drugs that reduce the blood pressure, it can damage various vital body organs, such as the heart or kidneys.

Arteriosclerosis (*ar-te''re-o-sklĕ-ro'sis*), or hardening of the arteries, is a generalized degenerative vascular disorder that results in loss of elasticity and thickening of the arteries. **Atherosclerosis** (*ath''er-o-sklĕ-ro'sis*) is a type of arteriosclerosis in which plaque material, called **atheroma** (*ath''er-o-mă*), forms on the tunica intima, narrowing the lumina of the arteries and prohibiting the normal flow of blood (fig. 16.55). In addition, an atheroma often creates a rough surface that can initiate the formation of a blood clot called a **thrombus.** An **embolism,** or **embolus,** is a detached thrombus that travels through the bloodstream and lodges so as to obstruct or occlude a blood vessel. An embolism lodged in a coronary artery is called a *coronary embolism;* in a vessel of the lung it is a *pulmonary embolism;* and in the brain it is a *cerebral embolism,* which could cause a **stroke.**

arteriosclerosis: Gk. *arterio,* artery; *skleros,* hard
atheroma: Gk. *athere,* mush; *oma,* tumor
thrombus: Gk. *thrombos,* a clot
embolism: Gk. *embolos,* a plug



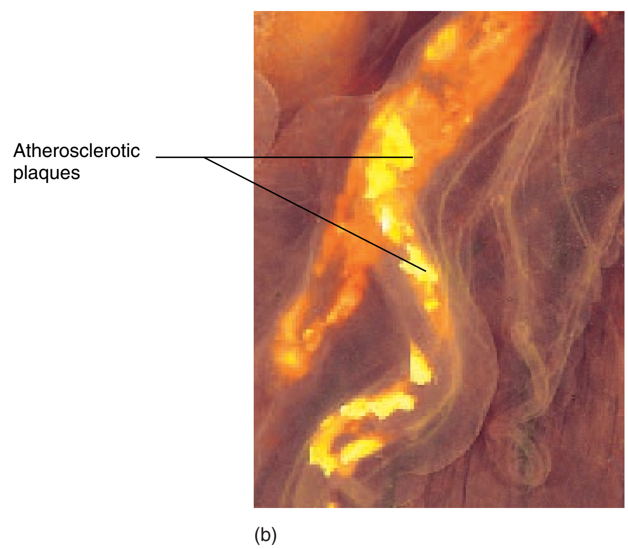


FIGURE 16.55 Atherosclerosis. (*a*) The lumen of a coronary artery is almost completely blocked by an atheroma. (*b*) A close-up view of the cleared left anterior descending coronary artery containing calcified atherosclerotic plaques. The heart is that of an 85-year-old female.

The causes of atherosclerosis are not well understood, but the disease seems to be associated with improper diet, smoking, hypertension, obesity, lack of exercise, and heredity.

Aneurysms, coarctations, and varicose veins are all types of vascular disfigurations. An **aneurysm** (*an'yă-riz-em*) is an expansion or bulging of the heart, aorta, or any other artery (fig. 16.56). Aneurysms are caused by weakening of the tunicas and may rupture or lead to embolisms. A **coarctation** is a constriction of a segment of a vessel, usually the aorta, and is frequently caused by tightening of remnant of the ductus arteriosus around the vessel. **Varicose veins** are weakened veins that become stretched and

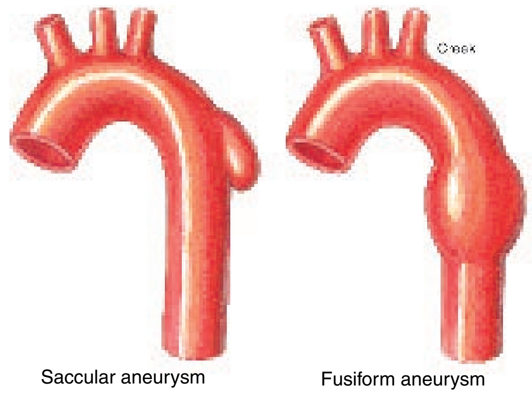


FIGURE 16.56 An aneurysm is an outpouching of the vascular wall. (*a*) A diagram of two types of aortic aneurysms and (*b*) an angiograph of a saccular aneurysm (see arrow) of the middle cerebral artery.

swollen. They are most common in the legs because the force of gravity tends to weaken the valves and overload the veins. Varicose veins can also occur in the rectum, in which case they are called **hemorrhoids.** *Vein stripping* is the surgical removal of superficial weakened veins. **Phlebitis** (*flĕ-bi'tis*) is inflammation of a vein. It may develop as a result of trauma or as an aftermath of surgery. Frequently, however, it appears for no apparent reason. Phlebitis interferes with normal venous circulation.

Disorders of the Lymphatic System

Infections of the body are generally accompanied by a swelling and tenderness of lymph nodes near the infection. An inflammation of lymph nodes is referred to as **lymphadenitis** (*lĭm-fad''en-i'tis*). In prolonged lymphadenitis, an **abscess** usually forms in the nodal tissue. An abscess is a localized pocket of pus formed by tissue destruction. If an infection is not contained by localized lymph nodes, **lymphangitis** may ensue. In this condition, red streaks can be seen through the skin extending proximally from the infected area. Lymphangitis is potentially dangerous because the uncontained infection may cause **septicemia** (*sep-tĭ-se'me-ă*) (blood poisoning).

The term **lymphoma** is used to describe primary malignancies within lymphoid tissues. Lymphomas are generally classified as **Hodgkin's disease lymphomas** or **non-Hodgkin's lymphomas.** Hodgkin's disease manifests itself as swollen lymph nodes in the neck and then progresses to involve the spleen, liver, and bone marrow. The prognosis for Hodgkin's disease is good if it is detected early. Non-Hodgkin's lymphomas include an array of specific and more obscure lymphatic cancers.

The lymphatic system is also frequently infected by metastasizing carcinomas. Fragmented cells from the original tumor may enter the lymphatic ducts with the lymph and travel to the lymph nodes, where they may cause secondary cancerous growths. Breast cancer will typically do this. The surgical treatment involves the removal of the infected nodes, along with some of the healthy nodes downstream to ensure that the cancer is eliminated.

Trauma to the Circulatory System

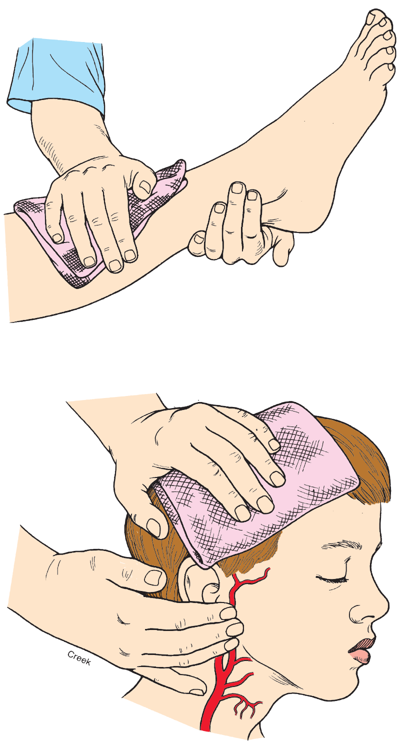
Hemorrhage and shock are two clinical considerations that directly involve the circulatory system. Knowledge of how to treat a victim experiencing these conditions is of paramount importance in administering first aid. Techniques to control bleeding and to administer first aid to victims experiencing shock are presented in the next two sections. Also review the important arterial pressure points presented in figure 16.33.

Control of Bleeding

Because serious bleeding is life threatening, the principal first-aid concern is to stop the loss of blood. The following are recommended steps in treating a victim who is hemorrhaging.

1. To reduce the chance that the victim will faint, lay the person down on a blanket (if available) and slightly elevate his or her legs. If possible, elevate the site of bleeding above the level of the trunk. To minimize the chance of shock, cover the victim with a blanket.
2. Without causing further trauma, carefully remove any dirt or debris from the wound. *Do not remove any impaling objects.* This should be done at the hospital by trained personnel.
3. Apply direct pressure to the wound with a sterile bandage, clean cloth, or an article of clothing (fig. 16.57).

septicemia: Gk. *seprikas,* septic; *haima,* blood
Hodgkin's disease: from Thomas Hodgkin, English physician, 1798–1866



(a)

(b)

FIGURE 16.57 Control of bleeding. (*a*) Direct pressure and (*b*) direct pressure and compression at an arterial pressure point.

FIGURE 16.58 Treatment of a victim experiencing shock.

4. Maintain direct pressure until the bleeding stops. Dress the wound with clean bandages or cloth lightly bound in place.
5. If the bleeding does not stop and continues to seep through the dressing, *do not remove the dressing*. Rather, place additional absorbent material on top of it and continue to apply direct pressure.
6. If direct pressure does not stop the bleeding, the pressure point to the wound site may need to be compressed. In the case of a severe wound to the hand, for example, compress the brachial artery against the humerus. This should be done while pressure continues to be applied to the wound itself.
7. Once the bleeding has stopped, leave the bandage in place and immobilize the injured body part. Get the victim to the hospital or medical treatment center at once.

Recognizing and Treating Victims of Shock

Shock is the medical condition that occurs when body tissues do not receive enough oxygen-carrying blood. It is often linked with crushing injuries, heat stroke, heart attacks, poisoning, severe burns, and other life-threatening conditions. Symptoms of patients experiencing shock include the following.

- **Skin.** The skin is pale or gray, cool, and clammy.
- **Pulse.** The heartbeat is weak and rapid. Blood pressure is reduced, frequently to below measurable values.
- **Respiration.** The respiratory rate is hurried, shallow, and irregular.
- **Eyes.** The eyes are staring and lusterless, possibly with dilated pupils.
- **State of being.** The victim may be conscious or unconscious. If conscious, he or she is likely to feel faint, weak, and confused. Frequently, the victim is anxious and excited.

Most trauma victims will experience some degree of shock, especially if there has been considerable blood loss. Immediate first-aid treatment for shock is essential and includes the following steps.

1. Get the victim to lie down (fig. 16.58). Lay the person on his or her back with the feet elevated. This position maintains blood flow to the brain and may relieve faintness and mental confusion. Keep movement to a minimum. If the victim has sustained an injury in which raising the legs causes additional pain, leave the person flat on his or her back.
2. Keep the victim warm and comfortable. If the weather is cold, place a blanket under and over the person. If the weather is hot, position the person in the shade on top of a blanket. Loosen tight collars, belts, or other restrictive clothing. *Do not give the person anything to drink,* even if he or she complains of thirst.

3. Take precautions for internal bleeding or vomiting. If the victim has blood coming from the mouth, or if there is indication that the victim may vomit, position the person on his or her side to prevent choking or inhaling the blood or vomitus.
4. Treat injuries appropriately. If the victim is bleeding, treat accordingly (see arterial pressure points [fig. 16.33] and control of bleeding [fig. 16.57]). Immobilize fractures and sprains. Always be alert to the possibility of spinal injuries and take the necessary precautions.
5. See that hospital care is provided as soon as possible.

Clinical Case Study Answer

Mural thrombus (a blood clot adherent to the inner surface of one of the heart's chambers) is a fairly common complication of myocardial infarction. Once a thrombus forms within the heart, a piece may break off and travel throughout the body. This is the most likely cause of the symptoms in the right leg of our patient. Because the embolus traveled and lodged in the systemic circulation (as opposed to the pulmonary circulation), the mural thrombus was probably located in the left side of the heart. The embolus traveled to a point in the femoral artery and lodged there, thus occluding blood flow to the popliteal artery and its branches. The route of travel was as follows: left side of the heart → ascending aorta → descending thoracic aorta → abdominal aorta → right common iliac artery → right external iliac artery → femoral artery.

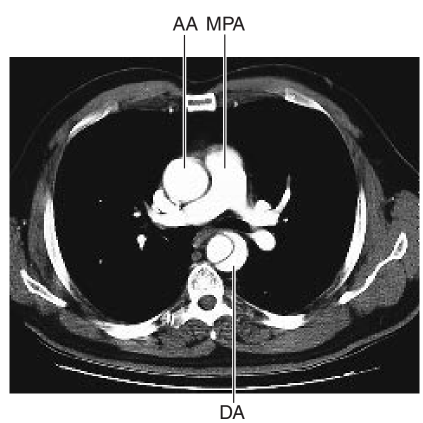
The standard treatment for this problem is emergency surgery to extract the clot from the leg. Anticoagulation (blood-thinning) therapy is then continued or instituted.

CLINICAL PRACTICUM 16.1

A 75-year-old male with a long history of hypertension presents to the emergency room with complaints of stabbing chest pain that goes through to his back. On physical exam, the patient's lungs are clear, and heart sounds are also normal with regular rate and rhythm. An electrocardiogram is also normal. Because of his symptoms, you suspect an aortic dissection and order a CT scan. (MPA = main pulmonary artery, AA = ascending aorta, DA = descending aorta.)

QUESTIONS

1. What is the dark line noted within the contrast-filled aorta?
2. Which portions of the aorta are involved?
3. You also note that the patient has a difference in blood pressure between the left and right arm, with the left arm having a significantly lower blood pressure. What could be the cause?

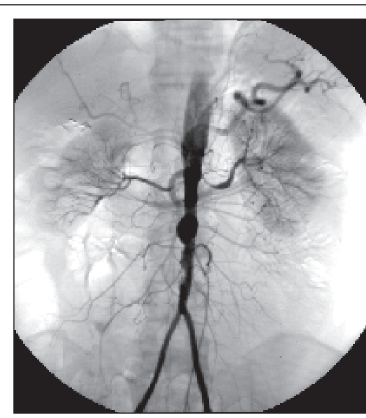


CLINICAL PRACTICUM 16.2

A previously healthy 65-year-old female complains of muscle weakness. Her blood pressure is markedly elevated today, and in looking at her chart you notice that blood pressures are trending upward on her previous two visits. Physical examination reveals a repeating abdominal noise heard with the stethoscope, which corresponds to her heartbeat. Lab work shows very low serum potassium. You suspect the weakness is due to the low potassium, so you start her on potassium supplementation. This measure proves effective in correcting her muscle weakness. To work up the new onset high blood pressure, you request an angiogram of her abdominal arteries.

QUESTIONS

1. Explain the abdominal noise.
2. How can the renal artery stenosis (narrowing) seen in the adjacent angiogram cause high blood pressure?
3. Discuss the impact that this condition may have on the opposite renal artery and kidney.



Chapter Summary

Functions and Major Components of the Circulatory System (pp. 538–540)

1. The circulatory system transports oxygen and nutritive molecules to the tissue cells and carbon dioxide and other wastes away from tissue cells; it also carries hormones and other regulatory molecules to their target organs.
2. Leukocytes and their products help protect the body from infection, and platelets function in blood clotting.
3. The components of the circulatory system are the heart, blood vessels, and blood, which constitute the cardiovascular system, and the lymphatic vessels and lymphoid tissue and organs of the lymphatic system.

Blood (pp. 540–545)

1. Blood, a highly specialized connective tissue, consists of formed elements (erythrocytes, leukocytes, and platelets) suspended in a watery fluid called plasma.
2. Erythrocytes are disc-shaped cells that lack nuclei but contain hemoglobin. There are approximately 4 million to 6 million erythrocytes per cubic millimeter of blood, and they are functional for about 120 days.
3. Leukocytes have nuclei and are classified as granular (eosinophils, basophils, and neutrophils) or agranular (monocytes and lymphocytes). Leukocytes defend the body against infections by microorganisms.
4. Platelets, or thrombocytes, are cytoplasmic fragments that assist in the formation of clots to prevent blood loss.
5. Erythrocytes are formed through a process called erythropoiesis; leukocytes are formed through leukopoiesis.
6. Prenatal hemopoietic centers are the yolk sac, liver, and spleen. In the adult, red bone marrow and lymphoid tissues perform this function.

Heart (pp. 545–555)

1. The heart is enclosed within a pericardial sac. The wall of the heart consists of the epicardium, myocardium, and endocardium.
   (a) The right atrium receives blood from the superior and inferior venae cavae, and the right ventricle pumps blood through the pulmonary trunk into the pulmonary arteries.
   (b) The left atrium receives blood from the pulmonary veins, and the left ventricle pumps blood into the ascending aorta.
   (c) The heart contains right and left atrioventricular valves (the tricuspid and bicuspid valves, respectively); a pulmonary semilunar valve; and an aortic (semilunar) valve.
2. The two principal circulatory divisions are the pulmonary and the systemic; in addition, the coronary system serves the heart.
   (a) The pulmonary circulation includes the vessels that carry blood from the right ventricle through the lungs, and from there to the left atrium.
   (b) The systemic circulation includes all other arteries, capillaries, and veins in the body. These vessels carry blood from the left ventricle through the body and return blood to the right atrium.
   (c) The myocardium of the heart is served by right and left coronary arteries that branch from the ascending portion of the aorta. The coronary sinus collects and empties the blood into the right atrium.
3. Contraction of the atria and ventricles is produced by action potentials that originate in the sinoatrial (SA) node.
   (a) These electrical waves spread over the atria and then enter the atrioventricular (AV) node.
   (b) From here, the impulses are conducted by the atrioventricular bundle and conduction myofibers into the ventricular walls.
4. During contraction of the ventricles, the intraventricular pressure rises and causes the AV valves to close; during relaxation, the pulmonary and aortic valves close because the pressure is greater in the arteries than in the ventricles.
5. Closing of the AV valves causes the first sound (lub); closing of the pulmonary and aortic valves causes the second sound (dub). Heart murmurs are commonly caused by abnormal valves or by septal defects.
6. A recording of the pattern of electrical conduction is called an electrocardiogram (ECG or EKG).

Blood Vessels (pp. 555–559)

1. Arteries and veins have a tunica externa, tunica media, and tunica interna.
   (a) Arteries have thicker muscle layers in proportion to their diameters than do veins because arteries must withstand a higher blood pressure. Arteries transport blood away from the heart.
   (b) Veins have venous valves that direct blood to the heart when the veins are compressed by the skeletal muscle pumps.
2. Capillaries are composed of endothelial cells only. They are the basic functional units of the circulatory system.

Principal Arteries of the Body (pp. 559–571)

1. Three arteries arise from the aortic arch: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. The brachiocephalic trunk divides into the right common carotid artery and the right subclavian artery.
2. The head and neck receive an arterial supply from branches of the internal and external carotid arteries and the vertebral arteries.
   (a) The brain receives blood from the paired internal carotid arteries and the paired vertebral arteries, which form the cerebral arterial circle surrounding the pituitary gland.
   (b) The external carotid artery gives off numerous branches that supply the head and neck.
3. The upper extremity is served by the subclavian artery and its derivatives.
   (a) The subclavian artery becomes first the axillary artery and then the brachial artery as it enters the arm.
   (b) The brachial artery bifurcates to form the radial and ulnar arteries, which supply blood to the forearm and hand.
4. The abdominal portion of the aorta has the following branches: the inferior phrenic, celiac trunk, superior mesenteric, renal, suprarenal, testicular (or ovarian), and inferior mesenteric arteries.
5. The common iliac arteries divide into the internal and external iliac arteries, which supply branches to the pelvis and lower extremities.

Principal Veins of the Body (pp. 571–580)

1. Blood from the head and neck is drained by the external and internal jugular veins; blood from the brain is drained by the internal jugular veins.
2. The upper extremity is drained by both superficial and deep veins.

3. In the thorax, the superior vena cava is formed by the union of the two brachiocephalic veins and also collects blood from the azygos system of veins.
4. The lower extremity is drained by both superficial and deep veins. At the level of the fifth lumbar vertebra, the right and left common iliac veins unite to form the inferior vena cava.
5. Blood from capillaries in the GI tract is drained via the hepatic portal vein to the liver.
   (a) This venous blood then passes through hepatic sinusoids and is drained from the liver in the right and left hepatic veins.
   (b) The pattern of circulation characterized by two capillary beds in a series is called a portal system.

Fetal Circulation (pp. 580–582)

1. Structural adaptations in the fetal cardiovascular system reflect the fact that oxygen and nutrients are obtained from the placenta rather than from the fetal lungs and GI tract.
2. Fully oxygenated blood is carried only in the umbilical vein, which drains the placenta. This blood is carried via the ductus venosus to the inferior vena cava of the fetus.
3. Partially oxygenated blood is shunted from the right to the left atrium via the foramen ovale and from the pulmonary trunk to the aorta via the ductus arteriosus.

Lymphatic System (pp. 582–587)

1. The lymphatic system returns excess interstitial fluid to the venous system and helps protect the body from disease; it also transports fats from the small intestine to the blood.
2. Lymphatic capillaries drain interstitial fluid, which is formed from blood plasma; when this fluid enters lymphatic capillaries, it is called lymph.
3. Lymph is returned to the venous system via two large lymph ducts—the thoracic duct and the right lymphatic duct.
4. Lymph filters through lymph nodes, which contain phagocytic cells and lymphatic nodules that produce lymphocytes.
5. Lymphoid organs include the lymph nodes, tonsils, spleen, and thymus.

Review Activities

Objective Questions

1. Which of the following is *not* a formed element of blood?
   (a) a leukocyte (c) a fibrinogen
   (b) an eosinophil (d) a platelet
2. An elevated white blood cell count is referred to as
   (a) leukocytosis. (c) leukopoiesis.
   (b) polycythemia. (d) leukemia.
3. Which of the following vessels transport(s) oxygen-poor blood?
   (a) the aorta
   (b) the pulmonary arteries
   (c) the renal arteries
   (d) the coronary arteries
4. Blood from the coronary circulation directly enters
   (a) the inferior vena cava.
   (b) the superior vena cava.
   (c) the right atrium.
   (d) the left atrium.
5. The first heart sound (lub) is produced by the closing of
   (a) the aortic valve.
   (b) the pulmonary valve.
   (c) the right atrioventricular valve.
   (d) the left atrioventricular valve.
   (e) both a and b.
   (f) both c and d.
6. The QRS complex of an ECG is produced by
   (a) depolarization of the atria.
   (b) repolarization of the atria.
   (c) depolarization of the ventricles.
   (d) repolarization of the ventricles.
7. Which of the following does *not* arise from the aortic arch?
   (a) the brachiocephalic trunk
   (b) the left coronary artery
   (c) the left common carotid artery
   (d) the left subclavian artery
8. Which of the following does *not* supply blood to the brain?
   (a) the external carotid artery
   (b) the internal carotid artery
   (c) the vertebral artery
   (d) the basilar artery
9. The maxillary and superficial temporal arteries arise from
   (a) the external carotid artery.
   (b) the internal carotid artery.
   (c) the vertebral artery.
   (d) the facial artery.
10. Which of the following organs is (are) served by a portal vein?
    (a) the liver (c) both a and b
    (b) the pituitary gland (d) neither a nor b
11. The heart derives from mesoderm and is complete in embryonic form by
    (a) the third week.
    (b) the fifth week.
    (c) the tenth week.
    (d) the seventeenth week.
12. Which of the following fetal blood vessels carries fully oxygenated blood?
    (a) the ductus arteriosus
    (b) the ductus venosus
    (c) the umbilical vein
    (d) the aorta

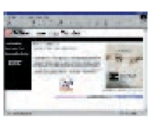
Essay Questions

1. What are the functions of the circulatory system? Identify the body systems that work closely with the circulatory system in maintaining homeostasis.
2. Explain how the development of the aortic arches contributes to the formation of the major vessels associated with the heart.
3. Distinguish between granulocytes and agranulocytes. What are the functions of leukocytes? How do they differ from erythrocytes and platelets?
4. Describe how the heart is compartmentalized within the thoracic cavity. What is the function of the pericardium?
5. Describe the cardiac cycle. Why is the sinoatrial node called the pacemaker of the heart?
6. Diagram and label a normal electrocardiogram. What is the significance of the deflection waves of an ECG?

7. Compare the structure and function of arteries, capillaries, and veins. Why are capillaries considered the functional units of the circulatory system?
8. What is the difference between blood pressure and pulse pressure? What cardiac event determines the systolic blood pressure? What accounts for the diastolic blood pressure?
9. Name the vessels of the thoracic and shoulder regions that are not symmetrical (do not have a counterpart on the opposite side of the body).
10. Trace the path to the brain of a glucose injection into the median cubital vein of the arm. List in sequence all the blood vessels and chambers of the heart through which it passes.
11. What is significant about the hepatic portal system? What do we mean when we say that the liver has two blood supplies?
12. List the functions of the lymphatic system and describe the relationship between the lymphatic system and the circulatory system.
13. Briefly describe the development of the heart.
14. What are five fetal circulatory structures that cease to function in a newborn?
15. Distinguish between congenital and acquired heart diseases and describe several kinds of each.

Critical-Thinking Questions

1. What symptoms would a patient display with a low red blood cell count? A low white blood cell count? A low platelet count?
2. Examine figure 16.8c and predict the structures that might be harmed in the event of damage to the interventricular septum or ventricular wall.
3. The walls of the ventricles are thicker than those of the atria, and the wall of the left ventricle is the thickest of all. How do these structural differences relate to differences in function?
4. An endurance-trained athlete will typically have a lower resting cardiac rate and a greater stroke volume than a person who is out of shape. Explain why these adaptations are beneficial.
5. Some passenger planes are now equipped with defibrillators for use as emergency life-saving devices. Why is it critical that ventricular fibrillation receive attention within minutes? Is atrial fibrillation less urgent? Explain.
6. A hospitalized 45-year-old man developed a thrombus (blood clot) in his lower thigh following severe trauma to his knee. The patient's physician explained that although the clot was near the great saphenous vein, the main concern was the occurrence of a pulmonary embolism. Explain the physician's reasoning and list, in sequence, the vessels the clot would have to pass through to cause a heart problem.
7. Your sister's new baby was diagnosed as having a patent foramen ovale. What does this mean and why is the baby cyanotic?



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CHAPTER 16