

# The Circulatory System

# 5

## Objectives

- Describe the location of the heart in terms of body cavities and relationship to other structures. (p 104)
- Name the chambers of the heart and the vessels that enter or leave each. (p 105)
- State the valves of the heart and their function. (p 105)
- State how heart sounds are created. (p 106)
- Trace the pathway of a blood cell throughout the body. (p 106)
- Describe coronary circulation. (p 106)
- Describe the cardiac conduction pathway and its relationship to a normal electrocardiogram. (p 109)
- Explain stroke volume, cardiac output and Starling's law of the heart. (p 113)
- Explain how the nervous system regulates the function of the heart. (p 109)
- List the structure and function of each of the blood vessels: arteries, veins, and capillaries. (p 114)
- Describe the exchange of gases that occurs at the capillary level. (p 114)
- Name the major systemic arteries and the parts of the body they nourish. (p 116)
- Name the major systemic veins and the parts of the body they drain of blood. (p 120)
- Define blood pressure and state the normal ranges for the systolic and diastolic indices. (p 113)
- Describe the primary functions of blood. (p 124)
- List the formed elements of blood and state the primary functions of each. (p 124)
- Describe what happens to red blood cells at the end of their life span including the fate of hemoglobin. (p 125)
- Explain the ABO and Rh blood types. (p 125)
- Name the five kinds of white blood cells and the functions of each. (p 126)
- State what platelets are and explain how they are involved in hemostasis. (p 126)
- Describe the three stages of blood clotting. (p 127)
- Explain how abnormal clotting is prevented in the vascular system. (p 127)

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- Vocabulary Explorer
- Anatomy Review
- Web Links

- Case Studies
- Pathophysiology Tips
- Medication Tips
- Paramedic Safety Tips
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- Vital Vocabulary
- Prep Kit

The cardiovascular system consists of the heart, the blood vessels, and the blood. All components must interact effectively to maintain life. Cardiovascular disease accounts for a significant number of EMS calls.

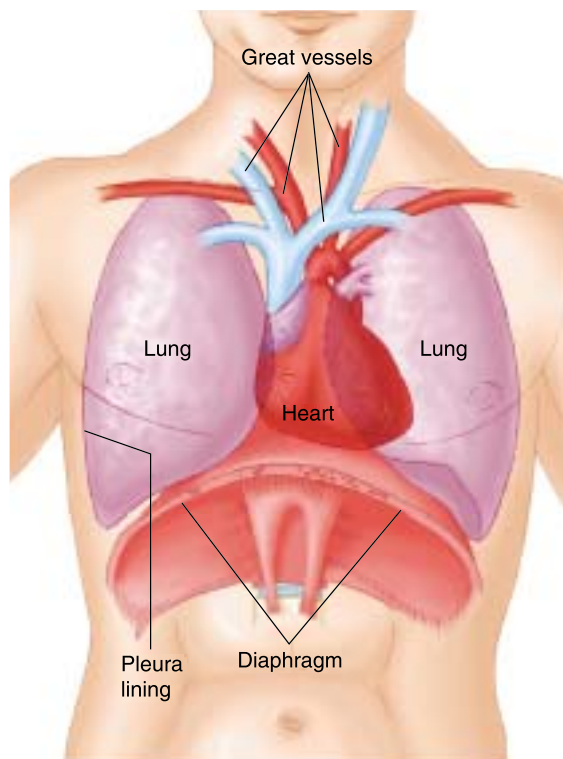
## The Heart

### Location and Major Structures of the Heart

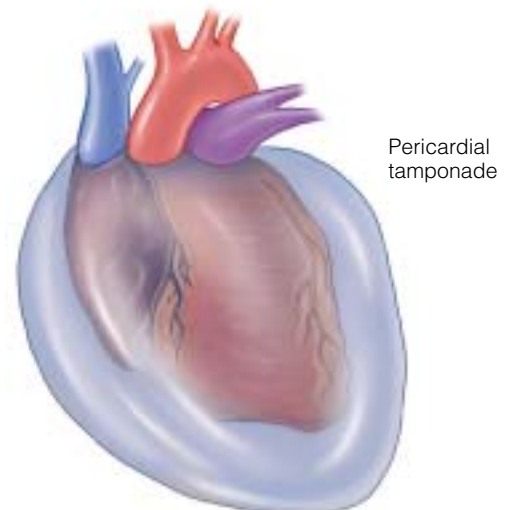
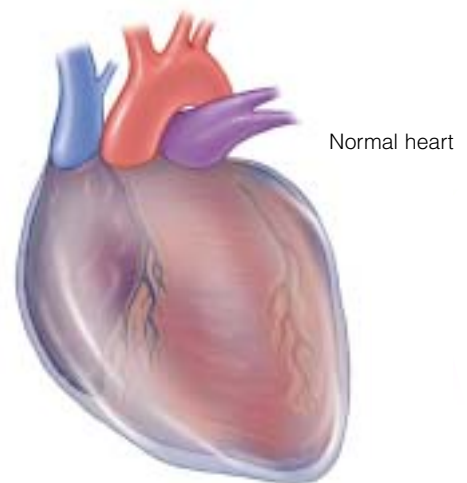
The **heart** is a muscular, cone-shaped organ whose function is to pump blood throughout the body. The heart is located behind the sternum and is about the size of a closed fist, roughly 5" long, 3" wide, and 2½" thick. It weighs 10 to 12 oz in male adults and 8 to 10 oz in female adults (▼ **Figure 5-1**). Roughly two thirds of the heart lies in the left part of the **mediastinum**, the area between the lungs that also contains the great vessels.

The heart muscle is referred to as the **myocardium**. The term “myo” means muscle and “cardium” means heart. The **pericardium**, also called the **pericardial sac**, is a thick fibrous membrane that surrounds the heart (► **Figure 5-2**). The pericardium anchors the heart within the mediastinum and prevents overdistention of the heart. The inner membrane of the pericardium is the **serous pericardium**.

This inner membrane contains two layers: the visceral layer and the parietal layer. The **visceral layer** of the pericardium lies closely against the heart and is also called the **epicardium**. The second layer of the pericardium, the **parietal layer**, is separated from the visceral layer by a small amount of **pericardial fluid** that reduces friction within the pericardial sac.



**Figure 5-1** The anterior aspect of the thorax shows the relative position of the heart beneath the surface.



**Figure 5-2** The pericardial sac surrounds the heart. When the pericardial sac fills with too much fluid (pericardial effusion), a life-threatening state of cardiac tamponade can develop. In this situation, the chambers of the heart are unable to expand and contract properly. Death can rapidly result.

## Pathophysiology



Complete blockage of an artery that supplies oxygen to the heart results in death to a portion of the myocardium, or a **myocardial infarction**.

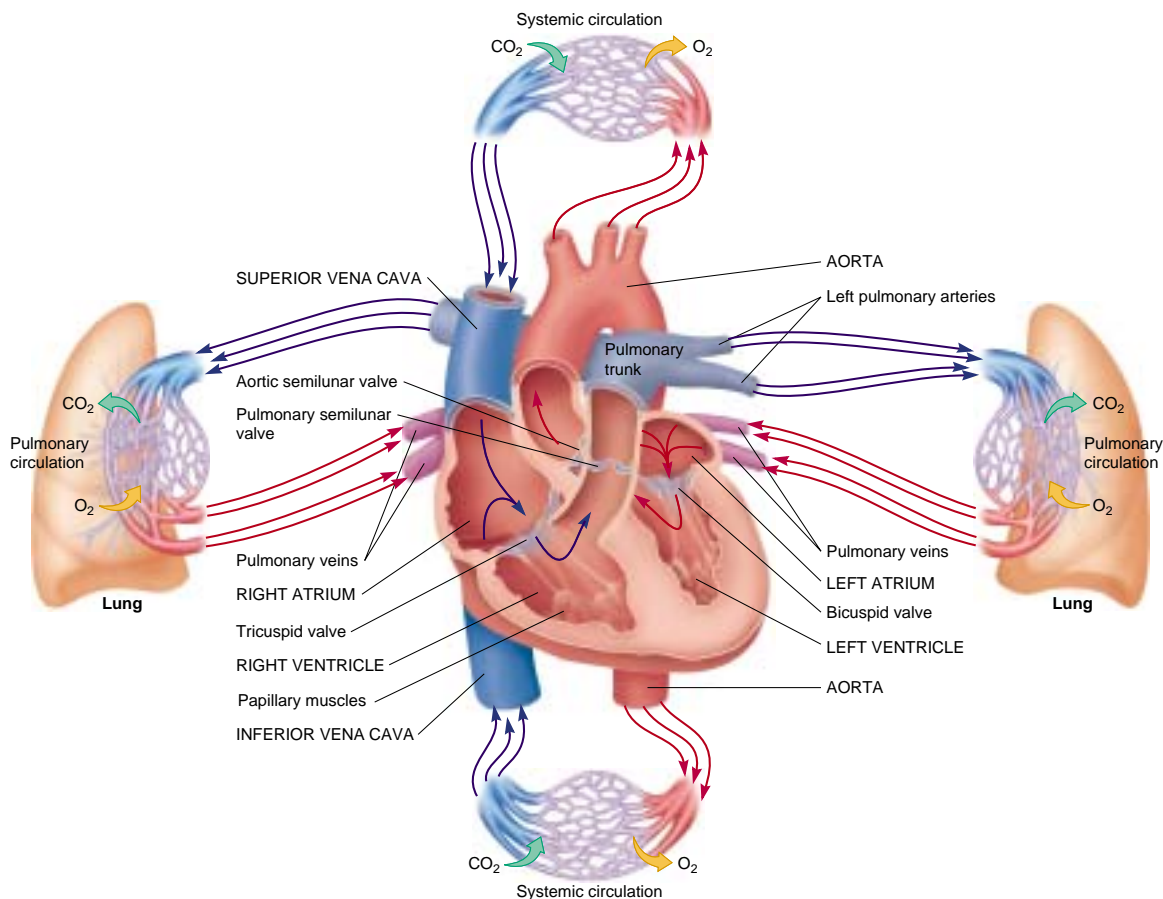
The normal human heart consists of four chambers: two atria and two ventricles. The upper chambers are the atria, and the lower chambers are the ventricles. Each side of the heart contains one atrium and one ventricle. A membrane, the **interatrial septum**, separates the two atria; a thicker wall, the **interventricular septum**, separates the right and left ventricles. Each **atrium** receives **blood** that is returned to the heart from other parts of the body; each **ventricle** pumps blood out of the heart. The upper and lower portions of the heart are separated by the atrioventricular valves, which prevent backward flow of blood. Similar valves, the semilunar

valves, are located between the ventricles and the arteries into which they pump blood (▼ **Figure 5-3**).

Blood enters the right atrium via the superior and inferior venae cavae and the **coronary sinus**, which consists of veins that collect blood that is returning from the walls of the heart. Blood from four pulmonary veins enters the left atrium. Between the right and left atria is a depression, the **fossa ovalis**, that represents the former location of the **foramen ovale**, an opening between the two atria that is present in the fetus.

## Valves of the Heart

Blood passing from the atria to the ventricles flows through one of two **atrioventricular valves**. The **tricuspid valve** separates the right atrium from the right ventricle, and the **mitral valve** separates the left atrium from the left ventricle. The valves consist of flaps called **cusps**. **Papillary muscles** attach to the ventricles and send small muscular strands called **chordae tendineae cordis** to the cusps. When the papillary muscle contracts, these strands tighten,



**Figure 5-3** Blood flow through the heart.

## Pathophysiology



Infection or inflammation of the pericardial membranes causes severe chest pain, a condition known as **pericarditis**.

preventing regurgitation of blood through the valves from the ventricles to the atria.

Two **semilunar valves**, the aortic valve and the pulmonic valve, divide the heart from the aorta and the pulmonary artery. The **pulmonic valve** regulates blood flow from the right ventricle to the pulmonary artery. The **aortic valve** regulates blood flow from the left ventricle to the aorta. The semilunar valves are not attached to papillary muscles. When these valves close, they prevent backflow from the aorta and pulmonary artery into the left and right ventricles, respectively.

## Blood Flow Within the Heart

Two large veins, the **superior vena cava** and the **inferior vena cava**, return deoxygenated blood from the body to the right atrium. Blood from the upper part of the body returns to the heart through the superior vena cava, and blood from the lower part of the body returns through the inferior vena cava. The inferior vena cava is the larger of the two veins. From the right atrium, blood passes through the tricuspid valve into the right ventricle. Blood is then pumped by the right ventricle through the pulmonic valve into the pulmonary artery and to the lungs. In the lungs, various processes take place that return oxygen to the blood, and at the same time, remove carbon dioxide and other waste products. These processes will be discussed in greater detail in Chapter 7: The Respiratory System.

Freshly oxygenated blood is returned to the left atrium through the pulmonary veins. Blood then flows through the mitral valve into the left ventricle, which pumps the oxygenated blood through the aortic valve, into the **aorta**, the body's largest artery, and then to the entire body. The left ventricle is the strongest and largest of the four cardiac chambers because it is responsible for pumping blood through blood vessels throughout the body.

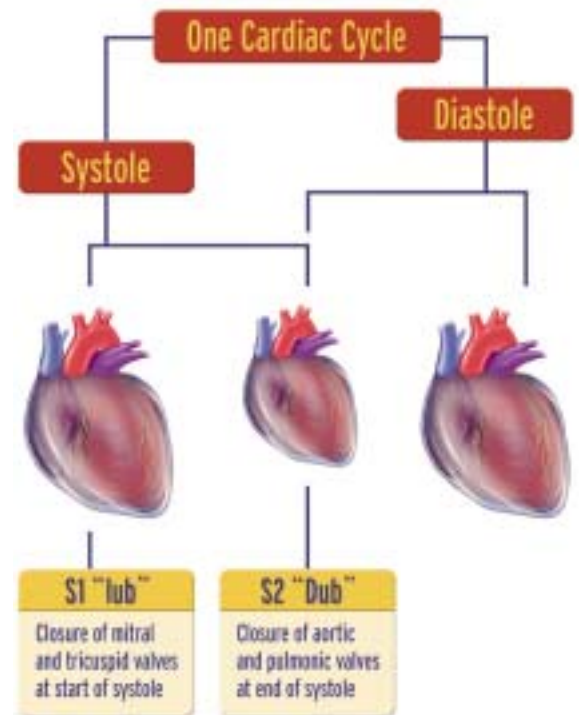
The contraction and relaxation of the heart, combined with the flow of blood, generates characteristic heart sounds during auscultation with a stethoscope. The normal pattern sounds much like

## Pathophysiology



If the pericardial sac fills with too much fluid (**pericardial effusion**), the heart's ability to expand and contract properly is hampered significantly. A common cause of a pericardial effusion is trauma. When sufficient fluid is present in the pericardial sac to restrict filling of the heart, a condition called **cardiac tamponade** exists and life-threatening shock rapidly develops. A needle must be placed immediately into the pericardial sac (**pericardiocentesis**), to remove the fluid (see Figure 5-2).

“lub-DUB, lub-DUB, lub-DUB...” The “lub” is referred to as the first heart sound or S1, and the “DUB” (emphasized because it is often louder) as the second heart sound or S2 (▼ Figure 5-4). Sound caused by the sudden closure of the mitral and tricuspid valves at the start of ventricular contraction results in the S1 sound or the first heart sound. The S2 or second heart sound results from the closure of both the aortic and pulmonic valves at the end of a ventricular contraction.



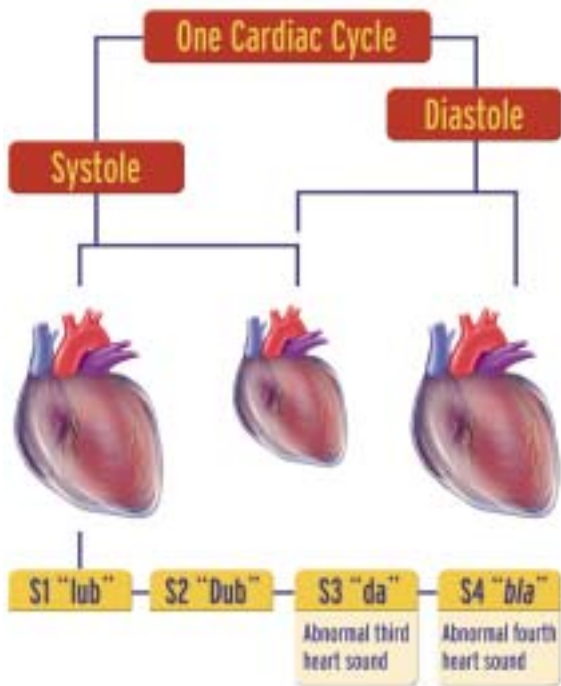
**Figure 5-4** The normal S1 and S2 heart sounds.

**Pathophysiology**



Disease processes may involve any of the heart valves. **Rheumatic fever** is an acute condition that affects children and young adults and can cause permanent damage to the aortic and mitral valves. In rheumatic fever, the valve cusps (leaflets) become rigid, failing to open and close properly. If the valve becomes limited in its ability to open, the amount of forward blood flow is decreased, resulting in valvular stenosis. If the valve fails to close properly, blood leaks between the leaflets during cardiac contraction, resulting in valvular regurgitation. Ischemia to or rupture of a papillary muscle during a myocardial infarction is another common cause of mitral regurgitation. **Ischemia** occurs when arterial blood flow to a localized tissue site is decreased, resulting in a lack of oxygen to that site. An infection of a heart valve is called **endocarditis**.

Two other heart sounds, S3 and S4, usually are not heard in individuals with normal heart sounds (▼ **Figure 5-5**). The S3 or third heart sound is a soft, low-pitched heart sound that occurs about one third of the way through diastole (the period during which



**Figure 5-5** The abnormal S3 and S4 heart sounds.

**Case Study**

**Case Study, Part 1**

Your unit is dispatched to a private suburban residence at 3:00 am. A teenage boy meets you in the driveway, yelling, "My dad's real bad... please come quick!" After you establish scene safety, you follow the boy into the house and the patient's bedroom. You find the 46-year-old patient sitting on the edge of his bed. Your general impression is that of an overweight middle-aged man who is clutching his chest in severe distress. The patient is alert, has an open airway, is having difficulty catching his breath, and has a strong irregular rapid radial pulse. A second unit of paramedics arrives to help, and oxygen via a nonbreathing mask is immediately applied to the patient. You find out from the patient that the onset of crushing pain occurred suddenly about 3 hours earlier and worsened during the night, possibly because of the patient's stressful job. The pain is located under the sternum and radiates to the left arm.

**Initial Assessment**

*Recording time*  
0 minutes  
*Appearance*  
Struggling to breathe  
Severely distressed

*Level of consciousness*  
Alert  
*Airway*  
Appears patent

**Vital Signs**

*Pulse rate/quality*  
110 beats/min, irregular, strong  
*Blood pressure*  
156/90 mm Hg  
*Respiratory rate/depth*  
24 breaths/min, labored

**Question 1: What is cardiac output?**

**Question 2: How can a heart attack affect cardiac output?**

**Question 3: Which blood vessels supply oxygen and nutrients to the myocardium and are the location for partial or full occlusion(s) that can result in a heart attack?**

CASE STUDY

**Pathophysiology**



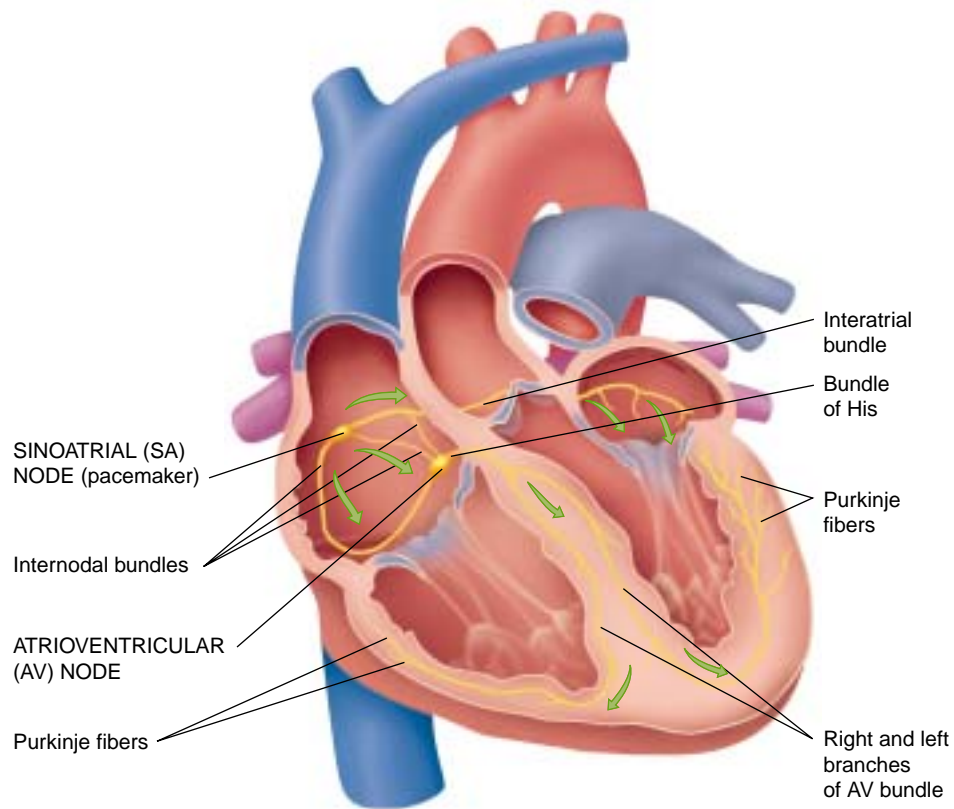
In most people, the foramen ovale closes shortly after birth. In some individuals, it remains open, resulting in a patent foramen ovale. This condition is one of the most common forms of congenital heart disease. It may be asymptomatic or may result in severe symptoms, requiring surgery.

the ventricles are relaxed). When an S3 sound is present, the heart beat cycle is described as sounding like “lub-DUB-da.” This sound may represent a period of rapid ventricular filling associated with sound made by an inrush of blood. Although the S3 sound sometimes is present in healthy young individuals, it most commonly is associated with abnormally increased filling pressures in the atria secondary to moderate to severe heart failure.

The S4 heart sound is a moderately pitched sound that occurs immediately before the normal S1 sound. When an S4 sound is present, the heart contraction cycle sounds like “bla-lub-DUB.” The S4 sound represents either decreased stretching (compliance) of the left ventricle or increased pressure in the atria. An S4 heart sound almost always is abnormal.

Four other sounds, all abnormal, may be heard when auscultating the heart and great vessels. Some

of these sounds are very easy to hear; others may require years of experience to identify. These additional abnormal sounds include murmurs, bruits, clicks, and snaps. A **murmur** is an abnormal “whooshing-like” sound heard over the heart that indicates turbulent blood flow within the heart. Although many murmurs are “functional” (benign) and often go away, several are characteristic of heart disease. A **bruit** is an abnormal “whooshing-like” sound heard over a main blood vessel that indicates turbulent blood flow within the blood vessel. A bruit often indicates localized atherosclerotic disease (hardening of the arteries). Both clicks and snaps indicate abnormal cardiac valve function. They occur at different times in the cardiac cycle, depending on which valve is diseased. Although these sounds are significant, most of these sounds are fleeting and difficult to hear.



**Figure 5-6** The cardiac conduction system. Specialized groups of cardiac muscle cells initiate an electrical impulse throughout the heart. The normal conduction pathway travels through the six parts of the cardiac conduction system. The impulse begins in the SA node and spreads through internodal bundles to the AV node. The AV node slows the impulse and initiates a signal that is conducted through the ventricles by way of the Bundle of His, right and left bundle branches, and the Purkinje fibers.

## Pathophysiology



If a patient is bleeding or severely dehydrated, baroreceptors sense abnormally low blood volume. Although several different body responses occur at once, a major response is the release of epinephrine and norepinephrine from the adrenal glands, causing sympathetic (adrenergic) stimulation, resulting in an increased heart rate, as well as increased contractility.

**Table 5-1**  
Regulation of Heart Function

Chronotropic state = the heart's rate of contraction

Dromotropic state = the heart's rate of conduction

Inotropic state = the heart's strength of contraction

## Electrical Properties of the Heart and Conduction System

The mechanical pumping action of the heart can only occur in response to an electrical stimulus. This impulse causes the heart to beat via a set of complex chemical changes within the myocardial cells. The brain partially controls the heart's rate and strength of contraction via the autonomic nervous system. Contractions of myocardial tissue, however, are initiated within the heart itself, in a group of complex electrical tissues that are part of a **conduction system**. The cardiac conduction system consists of six parts: the sinoatrial (SA) node, the atrioventricular (AV) node, the bundle of His, the right and left bundle branches, and the Purkinje fibers. (◀ **Figure 5-6**)

The **sinoatrial (SA) node** is located high in the right atrium and is the normal site of origin of the electrical impulse. It is the heart's natural pacemaker. Impulses originating in the SA node travel through the right and left atria, resulting in atrial contraction. The impulse then travels to the **atrioventricular (AV) node**, located in the right atrium adjacent to the septum, where it transiently slows. Electrical stimulation of the heart muscle then continues toward the **bundle of His**, which is a continuation of the AV node. From here, it proceeds rapidly to the right and left bundle branches, stimulating the intraventricular septum. The impulse then spreads out, via the Purkinje fibers, to the left, then the right ventricular myocardium, resulting in ventricular contraction or systole.

### Special Electrical Properties of Cardiac Cells

The ability of cells to respond to electrical impulses is referred to as the property of **excitability**. The ability of the cells to conduct electrical impulses is referred to as the property of **conductivity**. Cardiac

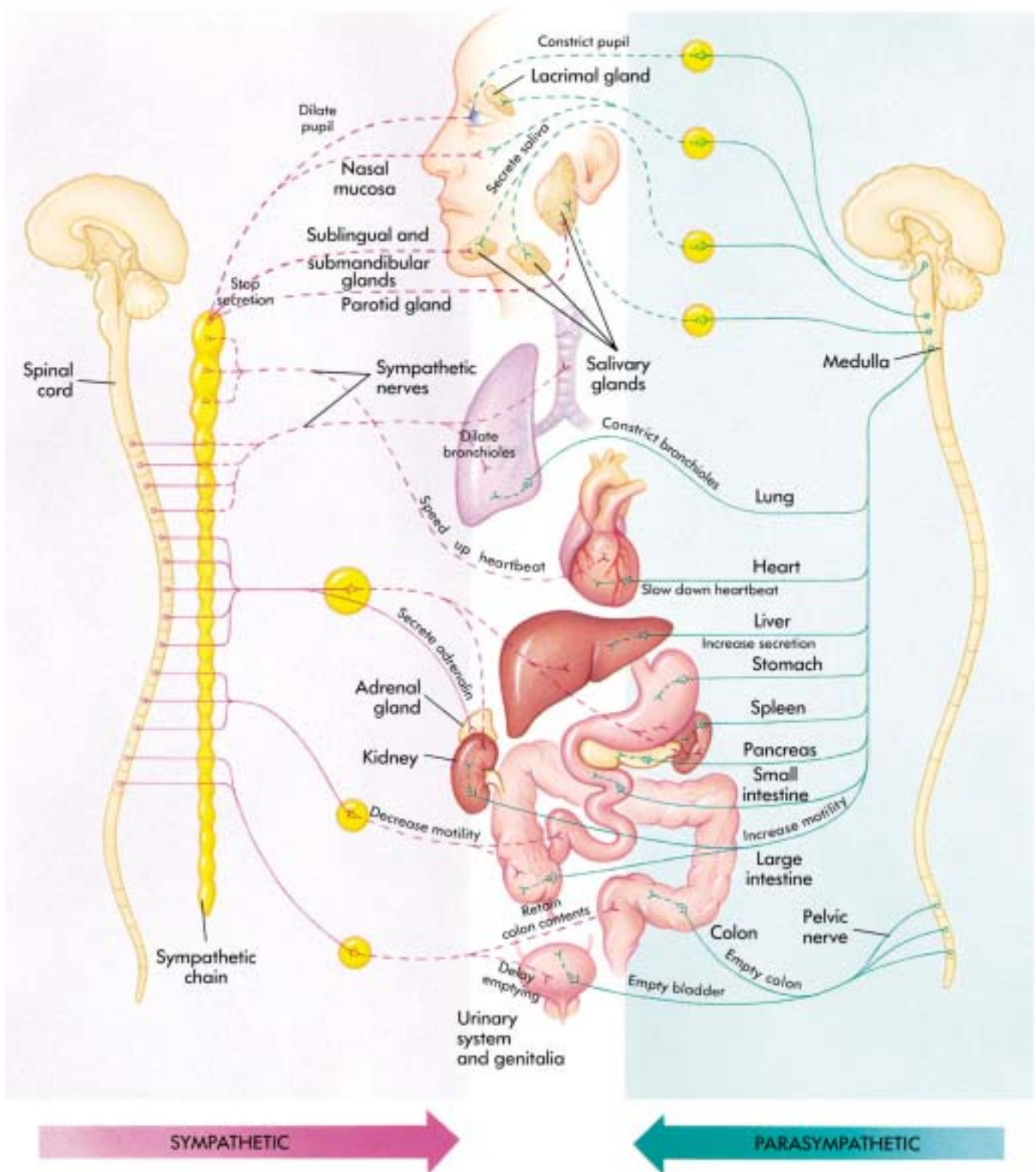
cells possess an ability to generate an impulse to contract even when there is no external nerve stimulus, a process called intrinsic **automaticity**.

### Regulation of Heart Function

The heart's **chronotropic state** (control of the rate of contraction), **dromotropic state** (control of the rate of electrical conduction), and **inotropic state** (control of the strength of contraction) are provided by the brain, via the autonomic nervous system, the hormones of the endocrine system, and the heart tissue (▲ **Table 5-1**). Receptors in the blood vessels, kidneys, brain, and heart constantly monitor body functions to help maintain homeostasis. **Baroreceptors** respond to changes in pressure, usually within the heart or the main arteries. **Chemoreceptors** sense changes in the chemical composition of the blood. If abnormalities are sensed, nerve signals are transmitted to the appropriate target organs, and hormones or neurotransmitters are released to correct the situation. Once conditions normalize, the receptors stop firing and the signals cease.

Often, stimulation of receptors causes activation of either the parasympathetic or sympathetic branches of the autonomic nervous system, affecting both the heart rate and the strength of heart muscle contraction (**contractility**). Parasympathetic stimulation slows the heart rate, primarily by affecting the AV node. Sympathetic stimulation has two potential effects, alpha effects or beta effects, depending on which nerve receptor is stimulated (▶ **Figure 5-7**). **Alpha effects** occur when alpha receptors are stimulated, resulting in vasoconstriction. **Beta effects** occur when beta receptors are stimulated, resulting in increased inotropic, dromotropic, and chronotropic states.

**Epinephrine** and **norepinephrine** are naturally occurring hormones that also may be given as cardiac drugs. Epinephrine has a greater stimulatory effect



**Figure 5-7** The autonomic receptors. Stimulation of the alpha receptors causes vasoconstriction of the organs they affect. Stimulation of beta receptors is split into beta-1, which causes increased heart rate and contractility, and beta-2, which causes bronchodilation.

on beta receptors, and norepinephrine has predominant stimulatory actions on alpha receptors.

### Electrolytes (Ions) and the Heart

Like all other cells in the body, myocardial cells are bathed in solutions of chemicals, or electrolytes (also called ions). Three positively charged ions, sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), and calcium ( $\text{Ca}^{2+}$ ), are responsible for initiating and conducting electrical signals in the heart. In the resting cell, the concentration of potassium is greater inside the cell, whereas the concentration of sodium is greater outside the cell. To maintain this difference, sodium is pumped out of the cell by a special ion-transporting mechanism called the **sodium-potassium pump**, and potassium is moved in. This process requires the expenditure of energy.

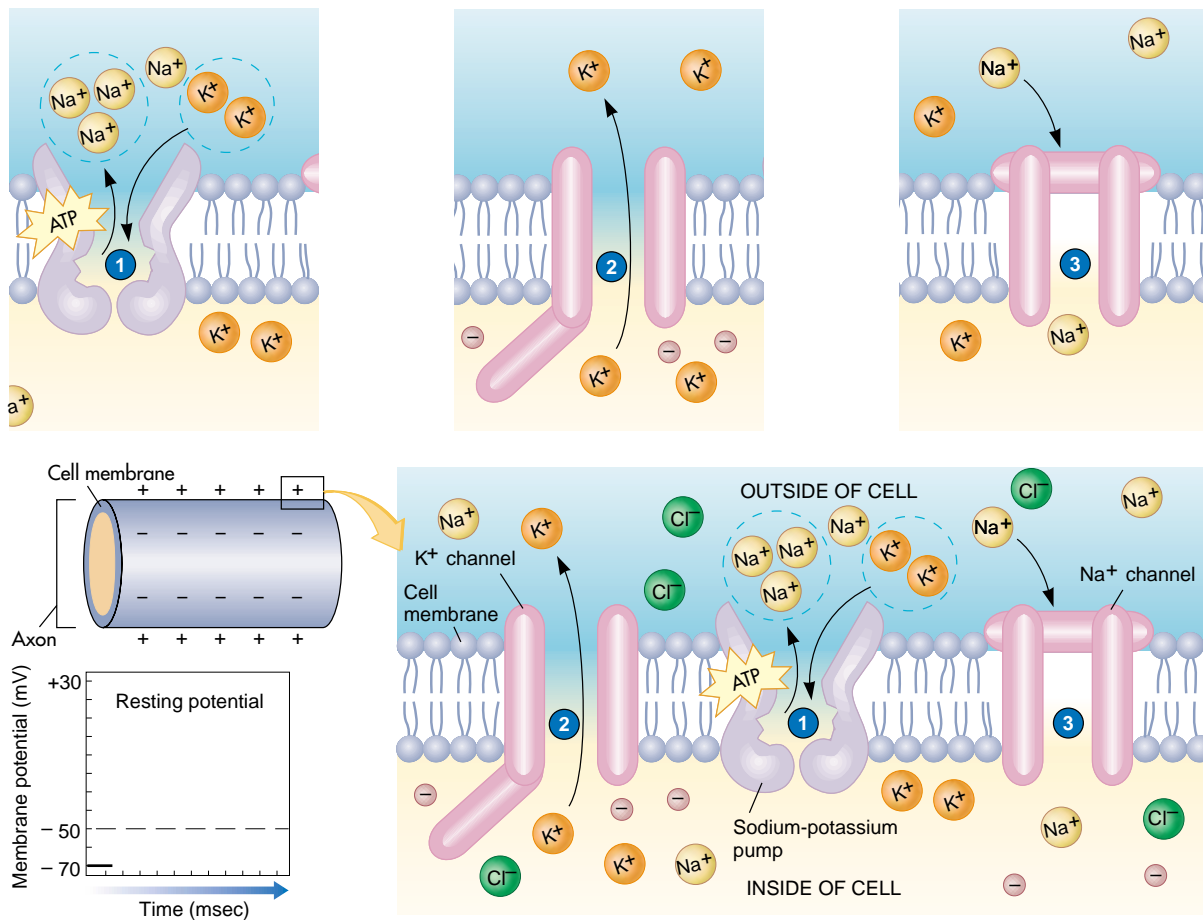
### The Electrical Potential

The difference in sodium and potassium concentration across a cell membrane at any given instant produces

an electrical charge difference referred to as an **electrical potential**. An electrical potential is measured in millivolts. In a resting cell, the area outside the cell is more positively charged than the inside of the cell. Hence, a negative electrical potential exists across the cell membrane. The resting cell normally has a net negative charge with respect to the outside of the cell. This is referred to as the **polarized state** (▼ Figure 5-8).

### Depolarization and Cardiac Contraction

When a myocardial cell receives a stimulus from the conduction system, the permeability of the cell wall changes and sodium rushes into the cell. This causes the inside of the cell to become more positive. Calcium also enters the cell, although its passage occurs more slowly. The resulting exchange of ions generates an electrical current. The rapid influx of sodium and the slow influx of calcium continue, causing the inside of the cell to continue to become more positively charged, eventually achieving a slightly positive electrical potential. The process of



**Figure 5-8** The cell's electrical potential. The cell membrane has an electrical charge on either side of it. A polarized state occurs when the inside of the nerve cell along its membrane is more negatively charged than the outside of the cell along the membrane. The difference in charge is the resting potential and is the basis for the transmission of signals by the nerves. ① indicates the sodium-potassium pump. ② indicates an open potassium channel. ③ indicates a closed sodium channel.

electrical discharge and flow of electrical activity is called **depolarization** (▼ Figure 5-9).

The flow of electrical current is passed from cell to cell along the conduction pathway in a wave-like motion throughout the heart. As the myocardial cells are depolarized, calcium is released and comes into close proximity with the actin and myosin filaments, as discussed in Chapter 4: Muscle Tissue. This process causes the filaments to slide together, resulting in muscle contraction. Contraction of heart muscle squeezes blood out of the chambers. The combination of electrical stimulation and the resultant muscle contraction sometimes is referred to as excitation-contraction coupling.

### Repolarization

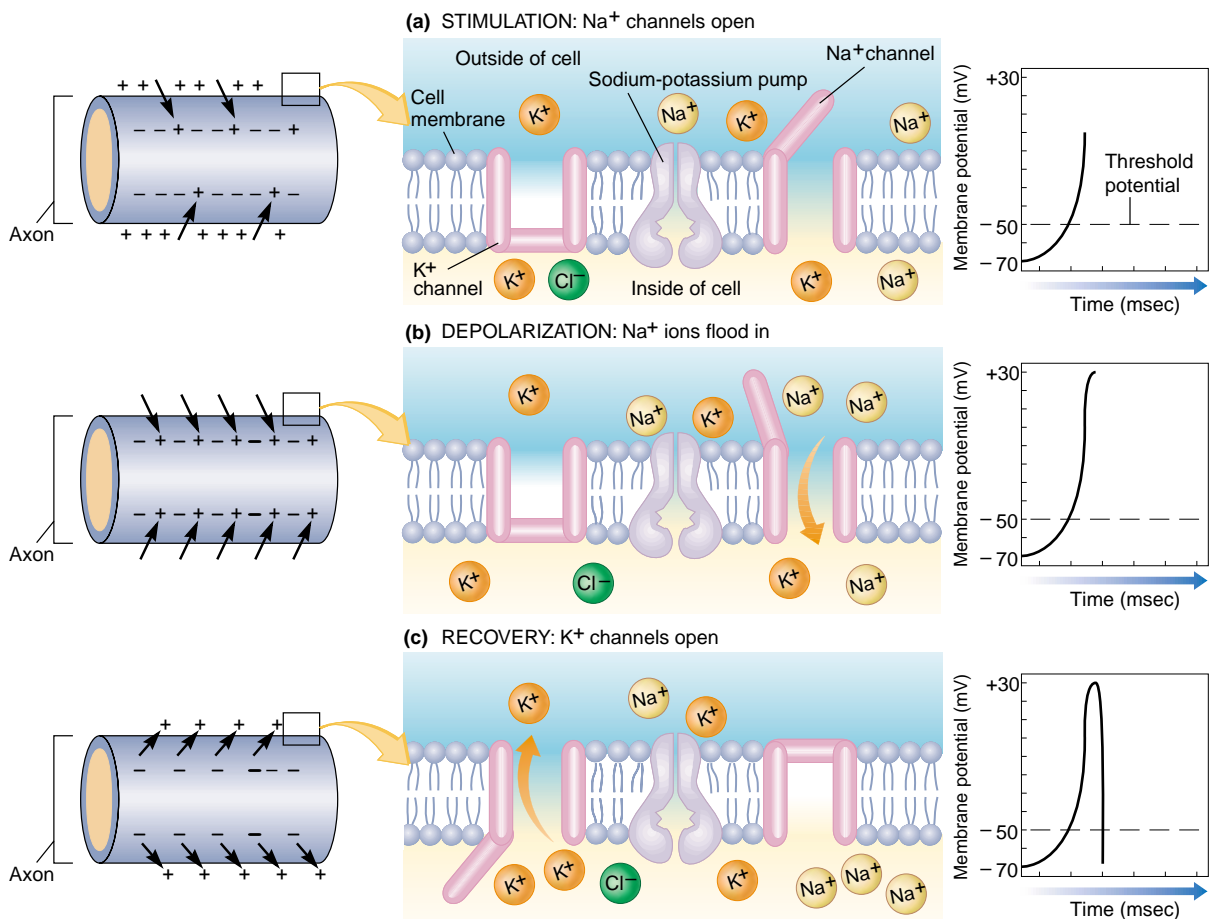
Once the cardiac cells depolarize, they begin to return to their resting or polarized state, a process called **repolarization**. At this time, the inside of the cell returns to its negative charge. Repolarization begins when the entry of sodium into the cells slows down and positively charged potassium ions begin to flow out of the cells. Following the efflux of potassium,

sodium is actively pumped out of the cells, and potassium is pumped back in. Calcium is returned to storage sites in the cells. As a result, the transmembrane potential returns to its baseline negative resting membrane potential and the cells regain both their polarized state and resting length.

In the early phase of repolarization, the cell contains such a large concentration of ions that it cannot be stimulated to depolarize. This period is known as the **absolute refractory period**. In the latter phase of repolarization, the cells are able to respond to a stronger-than-normal stimulus. This period is known as the **relative refractory period**.

### The Electrocardiogram

The electrical currents generated during depolarization and repolarization of the heart can be visualized on an **electrocardiogram (ECG)**, which is a graphic recording of the electrical activity of the heart. The standard ECG consists of 12 leads that record different “views” of the heart’s electrical activity. The shape of the normal ECG reading differs for each lead.



**Figure 5-9** The action potential of the cell has three stages: **A.** stimulation, **B.** depolarization, and **C.** recovery (repolarization, polarized state).

## Pathophysiology



Sodium, potassium, and calcium move between cells through protein-lined passages known as ion channels. Cardiac drugs such as lidocaine, procainamide, and calcium-channel blockers affect the function of these channels. Numerous genetic abnormalities of the ion channel proteins have been described, some of which can predispose a patient to sudden death.

Several deflections, or waves, are noted on the ECG (▼ Figure 5-10). These represent the normal cardiac conduction pattern. The **P wave** occurs first and represents movement of the electrical impulse through the atria that results in atrial contraction. Following this is a flat line, or electrical pause, called the **P-R segment**, representing the time delay that occurs within the AV node.

Next is a larger wave, the **QRS complex**, which represents depolarization of the ventricles. This complex corresponds to ventricular contraction, or systole. Another pause then occurs, known as the **ST segment**. During this period, repolarization of the heart is beginning. The **T wave** follows, representing completion of repolarization.

Thus, a normal ECG cycle, representing a single heart beat in a normal sinus rhythm, consists of P waves that occur at regular intervals at a rate of 60 to 100 times per minute, a P-R interval of normal duration (less than 0.2 seconds) followed by a QRS complex of normal contour and configuration, and a pause known as the ST segment, which is flat, followed by a T wave of normal contour and configuration.

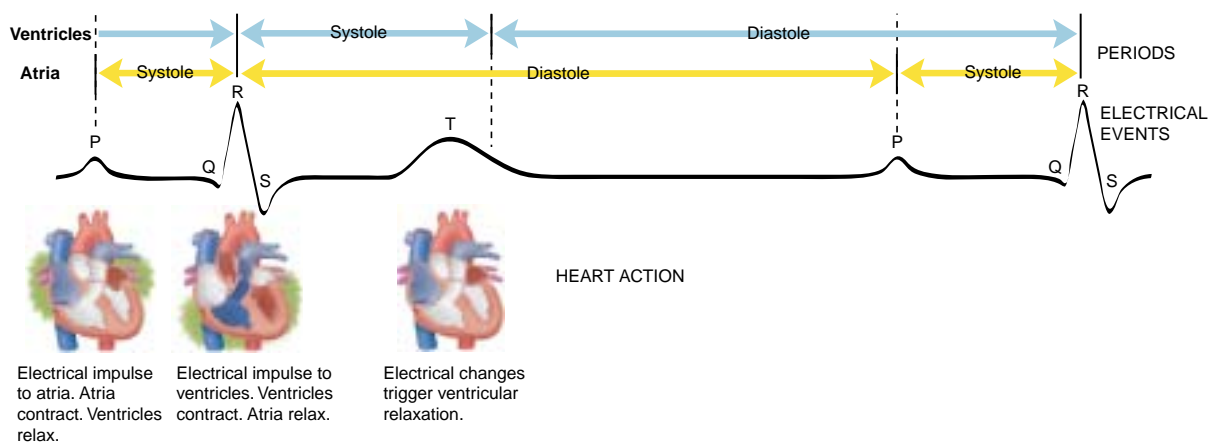
## The Cardiac Cycle

The **cardiac cycle** is the repetitive pumping process that begins with the onset of cardiac muscle contraction and ends with the beginning of the next contraction. Myocardial contraction results in pressure changes within the cardiac chambers, causing the blood to move. Blood moves from areas of high pressure to areas of low pressure.

Contraction of the ventricular mass, with its concomitant pumping of blood into the systemic circulation, is known as **systole**. During systole, a pressure is created within the arteries that can be recorded and is known as the systolic blood pressure. A normal systolic blood pressure in an adult is between 110 and 140 mm Hg. A pressure also exists in the vessels during diastole, the relaxation phase of the heart cycle, and is called the diastolic blood pressure. A normal diastolic blood pressure in an adult is between 70 and 90 mm Hg.

Blood pressure is noted as a fraction, and the systolic reading is placed above the diastolic reading (for example, a systolic reading of 140 and a diastolic reading of 70 would be noted as 140/70 mm Hg). The unit of measure mm Hg refers to millimeters of mercury and describes the height, in millimeters, to which the blood pressure elevates a column of liquid mercury in a glass tube. Although many blood pressure measurement devices now use dials, blood pressure is still described in millimeters of mercury.

The pressure in the aorta against which the left ventricle must pump blood is called the **afterload**. The greater the afterload, the harder it is for the ventricle to eject blood into the aorta, reducing the **stroke volume**, or the amount of blood ejected per contraction. To a large degree, afterload is governed



**Figure 5-10** The normal deflections or waves of the electrocardiogram (ECG). The electrical impulse corresponds with muscle contraction and relaxation within the heart.

by arterial blood pressure. Afterload is greater with vasoconstriction and less with vasodilation.

The amount of blood pumped through the circulatory system in 1 minute is referred to as the **cardiac output**. Cardiac output is expressed in liters per minute (L/min). The cardiac output equals the heart rate multiplied by the stroke volume:

$$\text{Cardiac Output} = \text{Stroke Volume} \times \text{Heart Rate}$$

Factors that influence the heart rate, the stroke volume, or both will affect cardiac output and, thus, oxygen delivery (perfusion) to tissue.

To a point, increased venous return to the heart stretches the ventricles, resulting in increased cardiac contractility. This relationship was first described by the British physiologist Dr. Ernest Henry Starling and has become known as Starling's law of the heart. Starling noted that if a muscle is stretched slightly, prior to stimulating it to contract, it would contract harder. So, if the heart is stretched, the muscle contracts harder. This is a normal defense mechanism. The amount of blood returning to the right atrium may vary somewhat from minute to minute, yet the normal heart continues to pump out the same percentage of blood returned. This is called the **ejection fraction**. If more blood returns to the heart, the stretched heart pumps harder rather than allowing the blood to back up into the veins. The result is that more blood is pumped with each contraction, yet the ejection fraction remains unchanged (the amount of blood that is pumped out increases, but so does the amount of blood returned). This relationship maintains normal cardiac function when an individual changes positions, coughs, breathes, and moves.

## The Blood Vessels

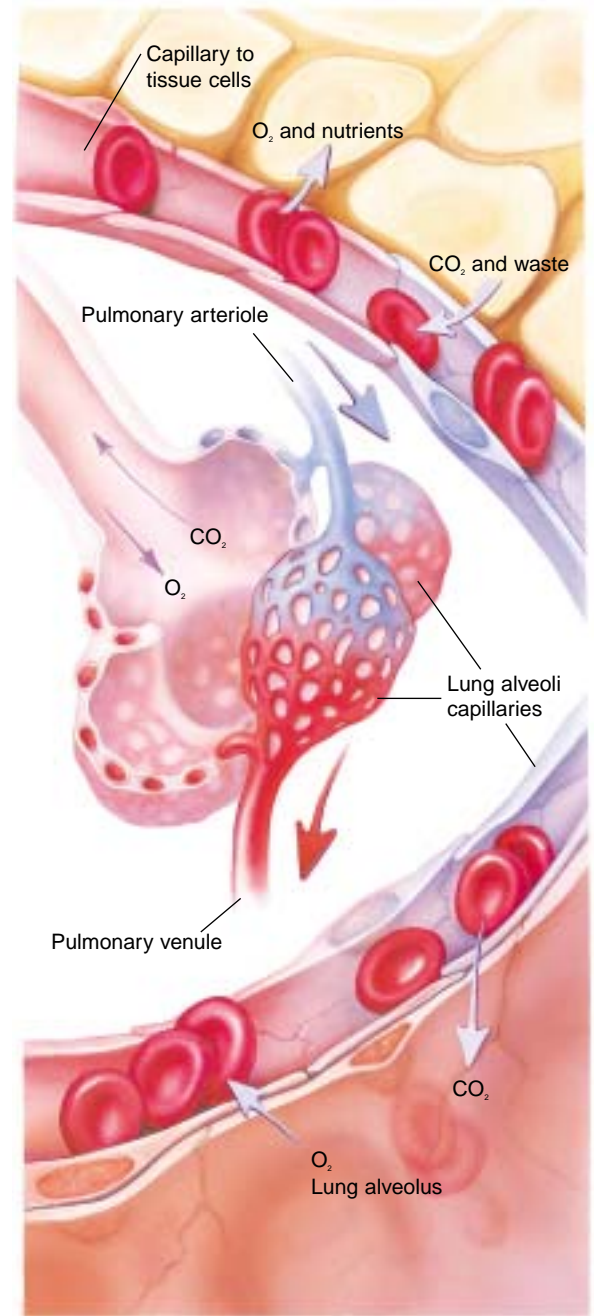
### The General Scheme of Blood Circulation

**Arteries** are blood vessels that carry blood away from the heart. **Veins** are blood vessels that transport blood back to the heart. As arteries get farther from the heart, they get smaller. Eventually, they branch into many small arterioles that divide even further into **capillaries**, microscopic, thin-walled blood vessels. Oxygen and nutrients pass out of the capillaries into the cells, and carbon dioxide and waste products pass from the cells into the capillaries in a process called diffusion (► **Figure 5-11**).

To return deoxygenated blood to the heart, groups of capillaries gradually enlarge to form venules. Venules then merge together, forming larger veins that eventually empty into the heart (► **Figure 5-12**).

The walls of the blood vessels are composed of three layers of tissue (► **Figure 5-13**). The smooth, thin,

inner lining is called the **tunica intima**, or endothelium. The middle layer, the **tunica media**, is composed of elastic tissue and smooth muscle cells that allow the vessels to expand or contract in response to changes in blood pressure and tissue demand. It is the thickest of the three tissue layers. The outer layer of tissue is called the **tunica adventitia** and consists of elastic and fibrous connective tissue.



**Figure 5-11** Diffusion. Oxygen and nutrients pass easily from the capillaries into the cells, and waste and carbon dioxide pass from the cells into the capillaries.

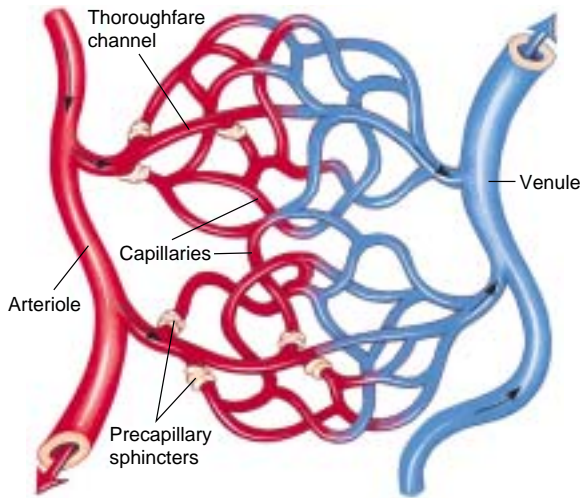


Figure 5-12 The scheme of circulation.

**Circulation to the Heart**

The heart, like any other muscle, requires oxygen and nutrients. These are supplied via the **coronary arteries**, which arise from the aorta shortly after it leaves the left ventricle. The coronary circulation

emanates from the left and right coronary arteries (► Figure 5-14).

The right coronary artery divides into nine important branches: the conus branch, sinus node branch, right ventricular branch, atrial branch, acute marginal branch, atrioventricular node branch, posterior descending branch, left ventricular branch, and left atrial branch. Not all branches are always present in all people. These branches supply blood to the walls of the right atrium and ventricle, a portion of the inferior part of the left ventricle, and portions of the conduction system (the sinus and AV nodes). When vessels to the conduction system fail to arise from the right coronary artery, they originate from the left side instead.

The left main coronary artery is the largest and shortest of the myocardial blood vessels. It rapidly divides into two branches, the left **anterior descending** (LAD) and the **circumflex coronary arteries**. These arteries subdivide further, supplying blood to most of the left ventricle, the intraventricular septum, and, at times, the AV node.

**Arteriosclerosis** is characterized by the deposition of calcium in the arterial walls. These deposits cause a loss of elasticity (thus, the term “hardening of

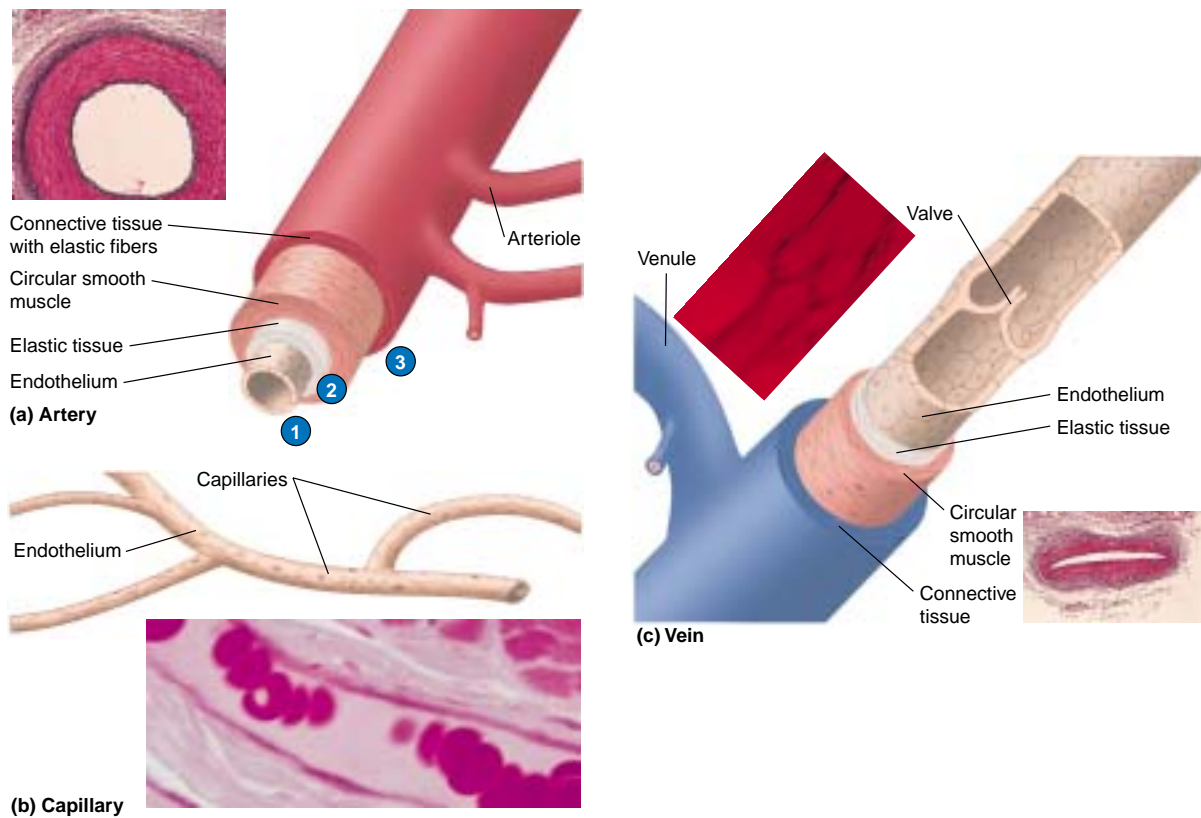
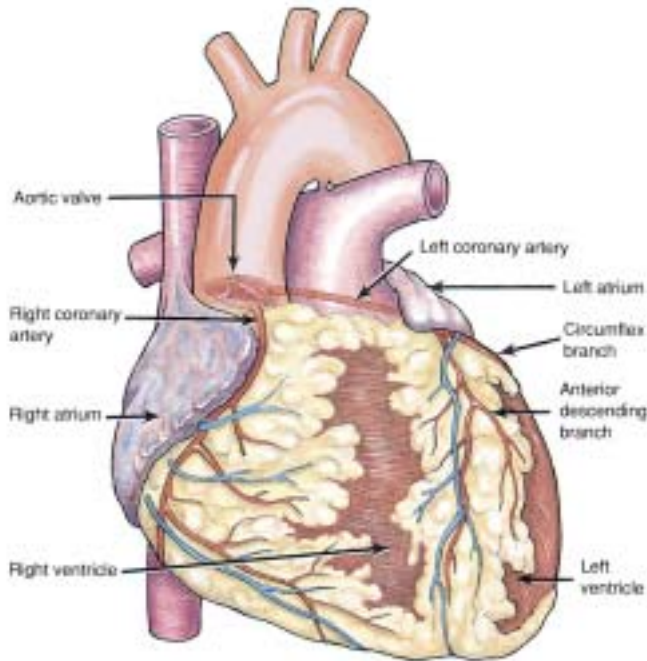


Figure 5-13 The walls of the blood vessels are composed of three layers of tissue: the endothelium, elastic tissue, and the connective tissue. **A.** Artery. **B.** Capillary. **C.** Vein.



**Figure 5-14** The coronary arteries supply oxygen and nutrients to the heart.

the arteries”) with a concomitant reduction in blood flow. Usually, atherosclerosis and arteriosclerosis are present together, and the resulting condition is referred to as **coronary artery disease (CAD)**.

### The Pulmonary Circulation

Within the body, the **pulmonary circulation** carries blood from the right side of the heart to the lungs, and back to the left side of the heart, and the **systemic circulation** is responsible for blood flow in other areas of the body. Deoxygenated blood from the right ventricle is pumped through the pulmonic valve into the pulmonary artery. This artery rapidly divides into the right and left pulmonary arteries. These arteries transport the blood to the right and left lungs. Inside the lungs, the arteries branch, becoming smaller and smaller. At the level of the capillary, waste products are exchanged and the blood is reoxygenated. The reoxygenated blood travels through venules into the pulmonary veins. The four pulmonary veins empty into the left atrium, two from each lung (see **Figure 5-3**).

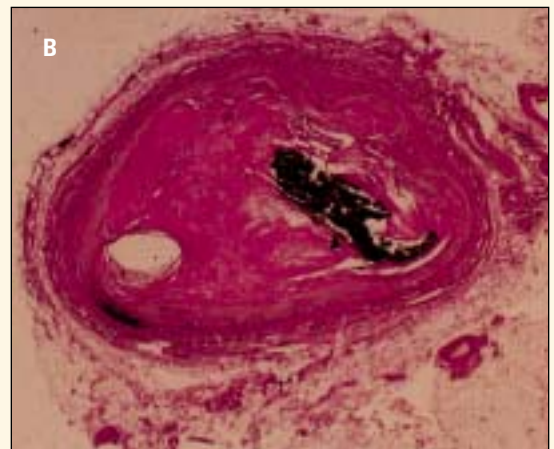
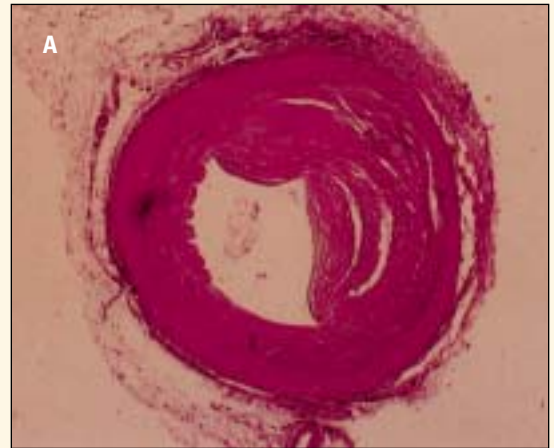
### Systemic Arterial Circulation

Oxygenated blood leaves the heart through the aortic valve and passes into the aorta. From the aorta, blood is distributed to all parts of the body. All arteries of the body are derived from the aorta. The aorta

## Pathophysiology



Various changes in the walls of coronary arteries can result in certain disease states. **Atherosclerosis** is a disorder characterized by the formation of plaques of material, mostly lipids and cholesterol, on the intima of the artery (▼ **Figure 5-15**). This process gradually narrows the **lumen** (opening or hollow part of the artery), resulting in a reduction in arterial blood flow.



**Figure 5-15** The formation of a plaque. **A.** The coronary artery exhibits severe atherosclerosis, and much of the passage of blood is blocked by buildup of cholesterol and other lipids on the intima of the artery, forming masses or plaques. **B.** The coronary artery is almost completely blocked. A blood clot blocks blood flow on the right side of the artery.

is divided into three portions: the ascending aorta, the aortic arch, and the descending aorta.

The **ascending aorta** arises from the left ventricle and consists of only two branches, the right and left main coronary arteries (► **Figure 5-16**). The aorta then arches posteriorly and to the left, forming the **aortic arch**. Three major arteries arise from the aortic arch: the brachiocephalic (innominate) artery, the left common carotid artery, and the left subclavian artery.

The **descending aorta** is the longest portion of the aorta and is subdivided into the thoracic aorta and the abdominal aorta. The descending aorta extends through the thorax and abdomen into the pelvis. In the pelvis, the descending aorta divides into the two common iliac arteries, which further divide into the internal and external iliac arteries. The thoracic aorta and the abdominal aorta will be discussed later in this chapter.

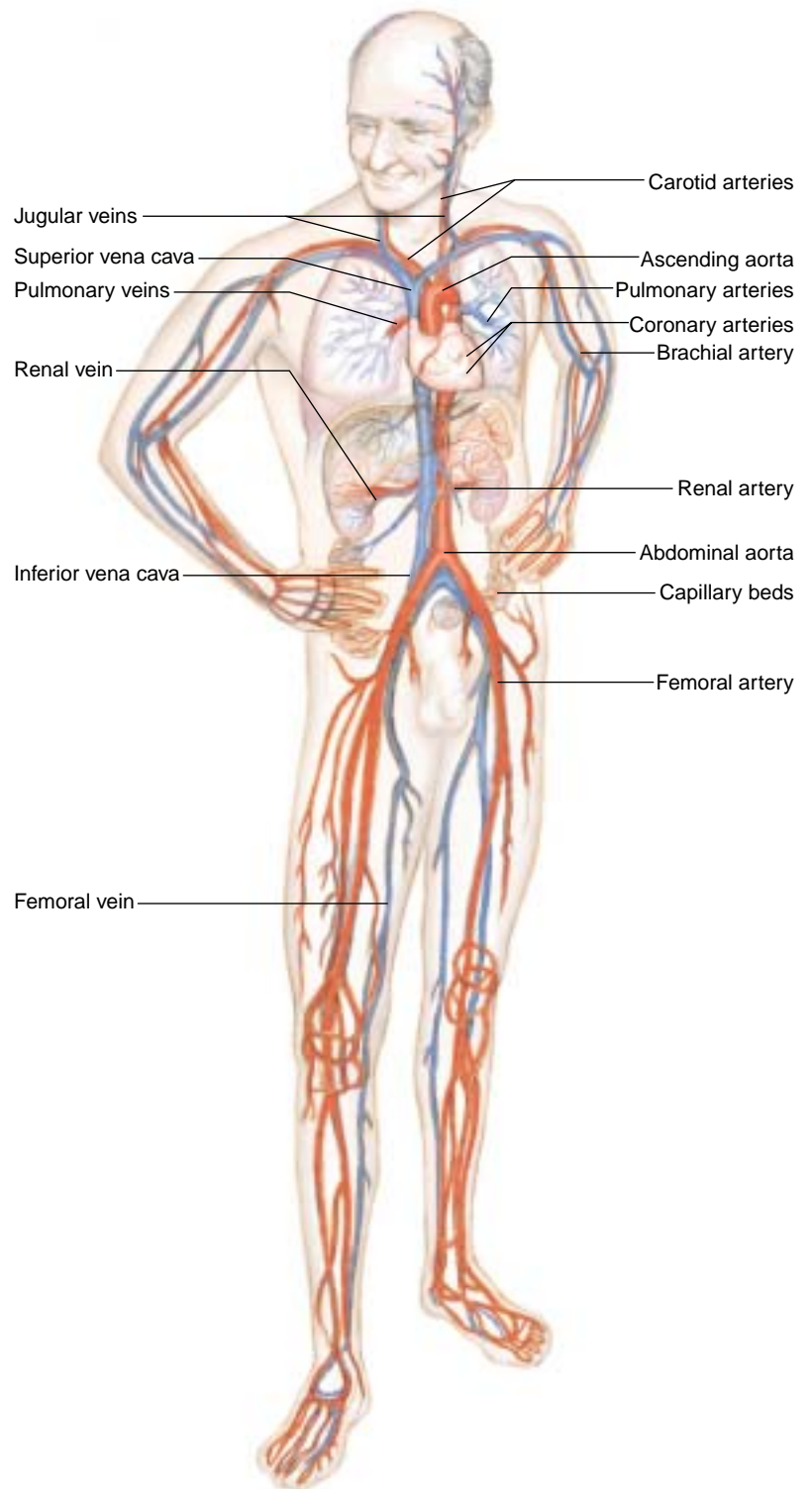
### The Head and Neck

The brachiocephalic artery is the first vessel to branch from the aortic arch. It is relatively short and rapidly divides into the right common carotid artery and the right subclavian artery. The carotid arteries transport blood to the head and neck, whereas the subclavian arteries transport blood to the upper extremities.

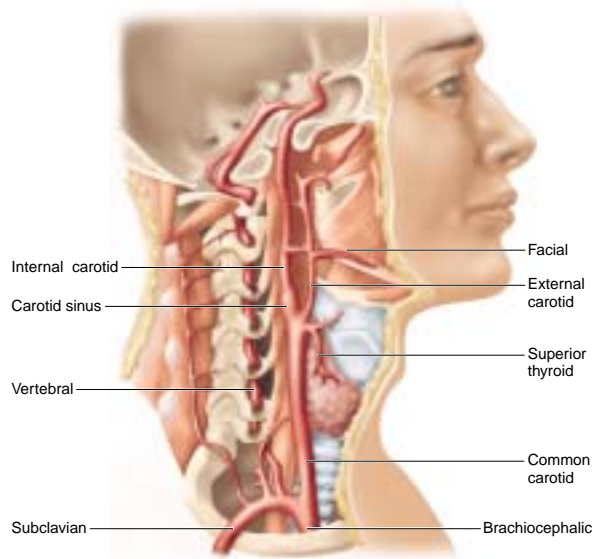
Each common carotid artery branches at the angle of the mandible into the internal and external carotid arteries. This point of division is called the **carotid bifurcation**. Here, a slight dilatation, the **carotid sinus**, contains structures that are important in regulating blood pressure. Branches of the external carotid artery supply blood to the face, nose, and mouth. The internal carotid arteries, together with the vertebral arteries (branches of the subclavian arteries), supply blood to the brain (► **Figure 5-17**).

Circulation to the brain is provided through the vertebral arteries and the internal carotid arteries. The left and right vertebral arteries enter the cranial vault through the foramen magnum. They then unite to form the **basilar artery**. After branching to the **pons** (the mass of nerve fibers at the end of the medulla oblongata) and the **cerebellum** (the part of the brain that is dorsal to the pons and is responsible for coordination and balance), the basilar artery bifurcates into the posterior cerebral arteries. These arteries supply the posterior portion of the brain.

The carotid arteries enter the cranial vault through the **carotid canals** and soon give rise to the middle **cerebral arteries**, which supply blood to large portions of the brain cortex. The middle cerebral arteries give rise to several important branches.

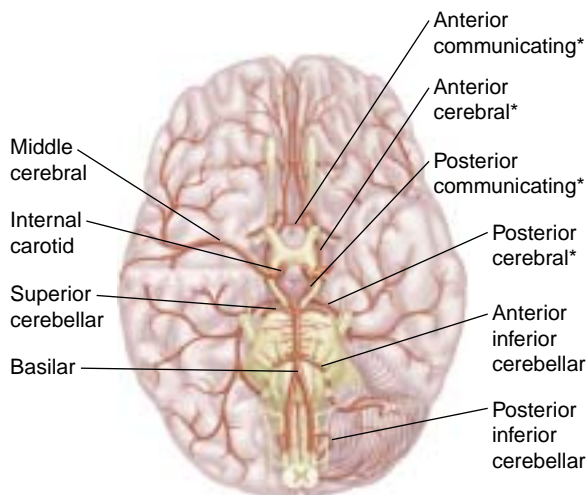


**Figure 5-16** The cardiovascular system. The systemic arterial circulation is noted in red, and the systemic venous system is noted in blue.



**Figure 5-17** The arteries of the head and neck.

The posterior communicating arteries connect with the posterior cerebral arteries. The anterior cerebral arteries interconnect via the anterior communicating artery. This interconnection of arteries forms a collateral network to deliver circulation to the brain, known as the **circle of Willis** (▼ **Figure 5-18**). This helps ensure that circulation to any portion of the brain is not interrupted if a single major artery leading to the brain becomes occluded.



\* Form circle of Willis

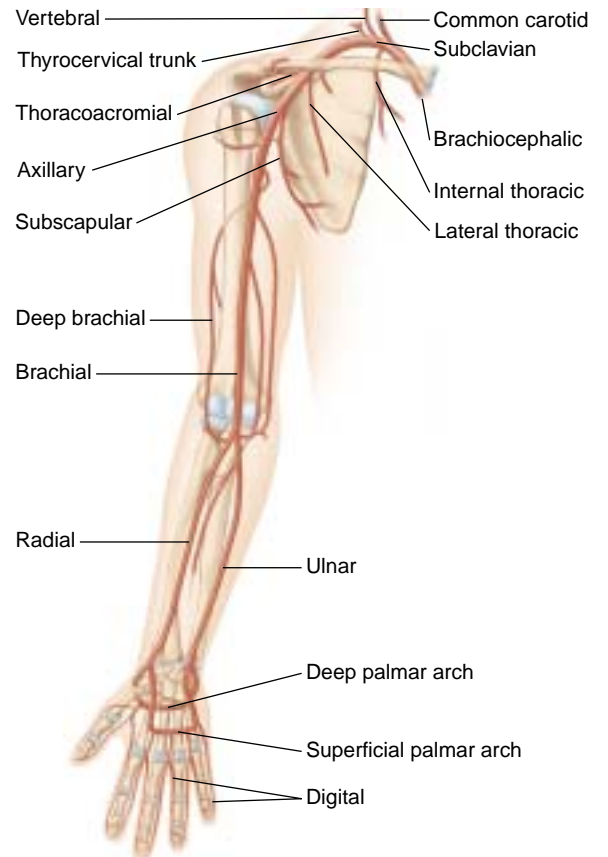
**Figure 5-18** The circulation of the brain.

**The Upper Extremity**

The **subclavian artery** supplies blood to the brain, neck, anterior chest wall, and shoulder. Shortly after its point of origin, the subclavian artery gives rise to the vertebral arteries. The subclavian system then continues from the thorax into the upper extremity. At the shoulder joint, it becomes the axillary artery, then the brachial artery below the head of the humerus. The transitions from subclavian to axillary to brachial are continuous and not due to branching. The brachial artery divides into the ulnar and radial arteries. These arteries form the two **palmar arches** of vessels within the hand: the superficial palmar arch and the deep palmar arch. Digital arteries extend from the superficial palmar arch to each digit (▼ **Figure 5-19**).

**The Thoracic Aorta**

Two types of branches of arteries make up the thoracic aorta: the visceral arteries and the parietal arteries. Visceral arteries supply blood to the thoracic organs, and parietal arteries supply blood to the thoracic wall.



**Figure 5-19** The arteries of the upper extremity.

**Pathophysiology**



Occlusion of one artery in the brain outside of the circle of Willis is a common cause of a stroke, damaging the brain from lack of oxygen.

**Pathophysiology**

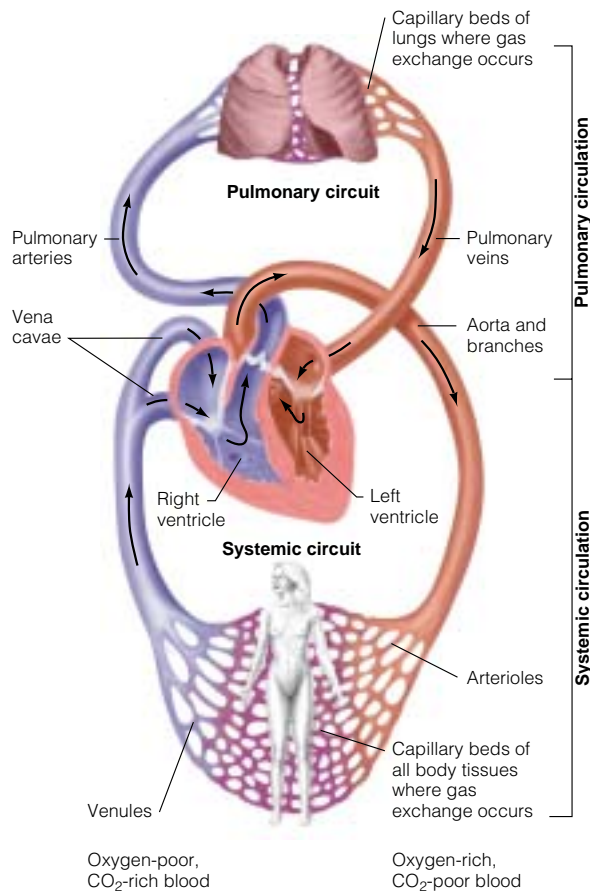
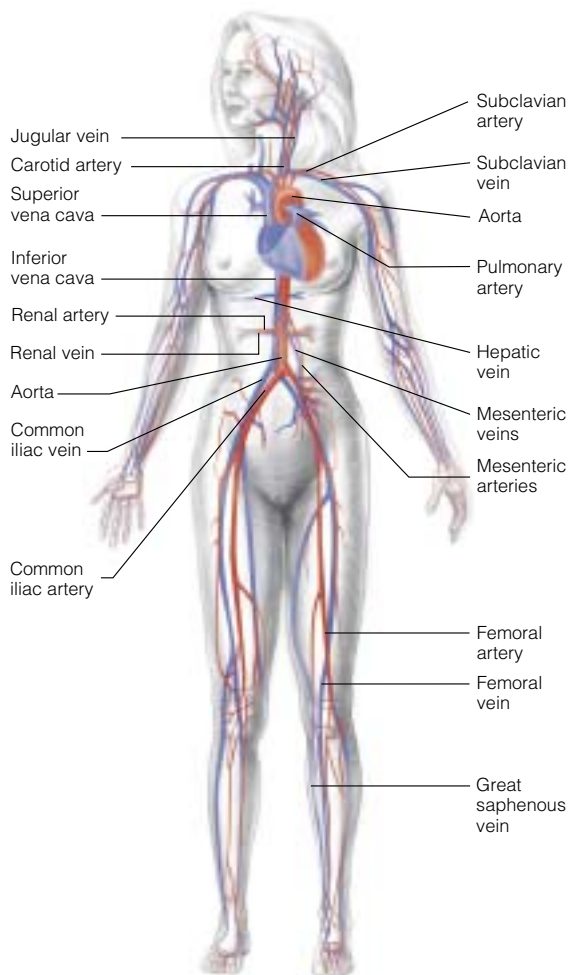


**Raynaud's phenomenon** occurs when spasms in the digital arteries develop, particularly following emotional stress or exposure to cold. The fingertips become white and cool. Usually, the process reverses spontaneously within a few minutes.

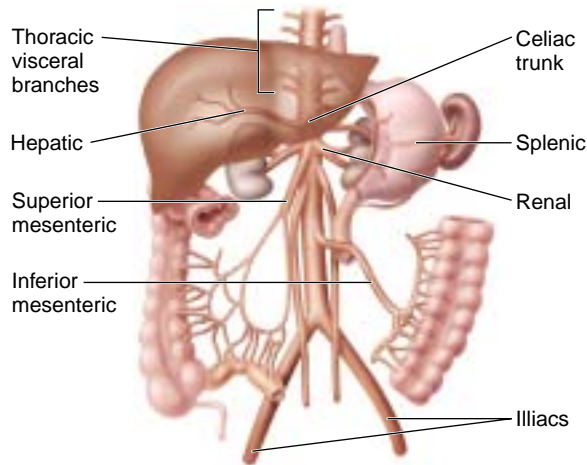
Intercostal arteries run along the ribs and provide circulation to the chest wall. Intercostal arteries branch into anterior and posterior intercostal arteries. The anterior intercostal arteries originate as branches of the subclavian system. The posterior intercostal arteries arise directly from the aorta. Visceral branches of the thoracic aorta supply the bronchial arteries in the lungs and the esophageal arteries (▼ [Figure 5-20](#)).

**The Abdominal Aorta**

Like their thoracic counterpart, branches of the abdominal aorta are divided into visceral and parietal portions. The visceral arteries are subdivided into paired and nonpaired arteries. The three major unpaired branches of the abdominal aorta's visceral arteries include the celiac trunk, the superior mesenteric, and the inferior mesenteric arteries (► [Figure 5-21](#)). The celiac trunk supplies blood to the esophagus,



**Figure 5-20** Systemic circulation rising from the aorta.



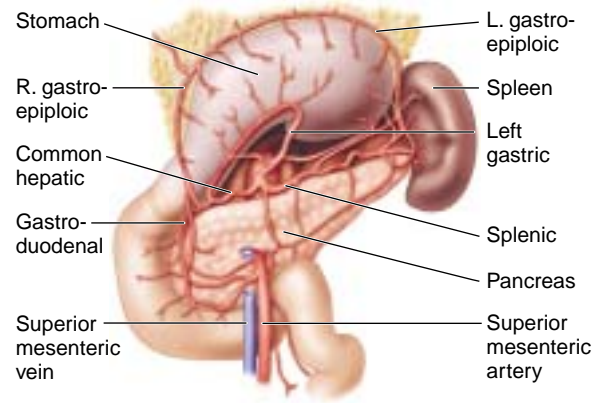
**Figure 5-21** The branches of the abdominal aorta.

stomach, duodenum, spleen, liver, and pancreas (▲ **Figure 5-22**). The superior mesenteric artery and its branches supply blood to the pancreas, small intestine, and colon. The inferior mesenteric artery and its branches supply blood to the descending colon and rectum. Paired branches of the visceral abdominal aorta supply blood to the kidneys, adrenal gland, and gonads. The parietal branches supply blood to the diaphragm and abdominal wall.

#### *The Pelvis and Lower Extremity*

At the level of the fifth lumbar vertebra, the aorta divides into the two common iliac arteries. These arteries further divide into the internal iliac arteries, which supply blood to the pelvis, and the external iliac arteries, which enter the lower extremity (► **Figure 5-23**). The internal iliac artery sends out visceral branches to the rectum, vagina, uterus, and ovary. Parietal branches supply blood to the sacrum, gluteal muscles of the buttocks region, the pubic region, rectum, external genitalia, and proximal thigh.

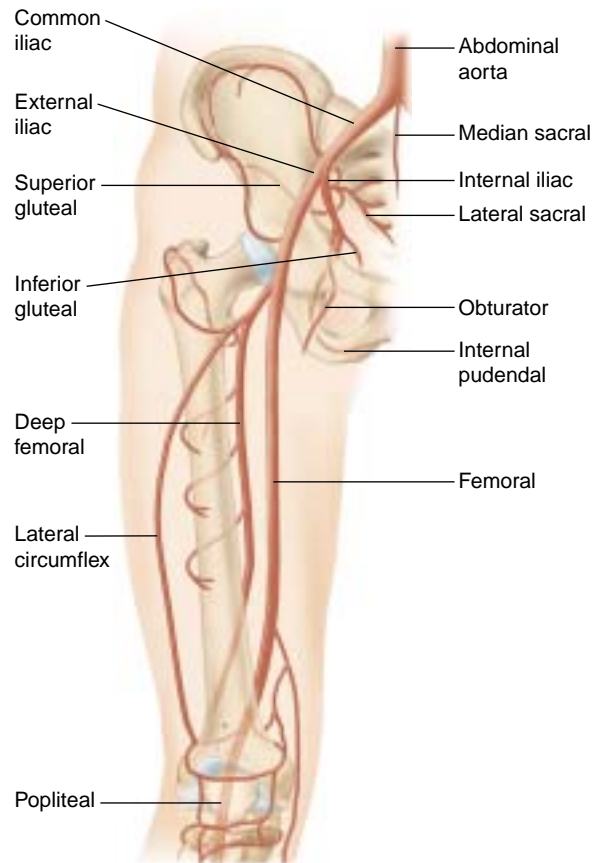
Like the upper extremity, the vessels of the lower extremity form a continuum. The external iliac arteries become the **femoral arteries**. Each femoral artery supplies blood to the thigh, external genitalia, anterior abdominal wall, and knee. The femoral artery becomes the **popliteal artery** in the lower thigh. Each popliteal artery then trifurcates, branching into anterior and posterior tibial and peroneal arteries. At the foot, the anterior tibial artery becomes the **dorsalis pedis artery**. Plantar arteries arise from the posterior tibial artery and subdivide into digital branches that supply blood to the toes (► **Figure 5-24**).



**Figure 5-22** The celiac trunk and superior mesenteric vessels.

### The Systemic Venous Circulation

As a rule, veins accompany the major arteries. Many veins have the same names as the arteries they accompany.



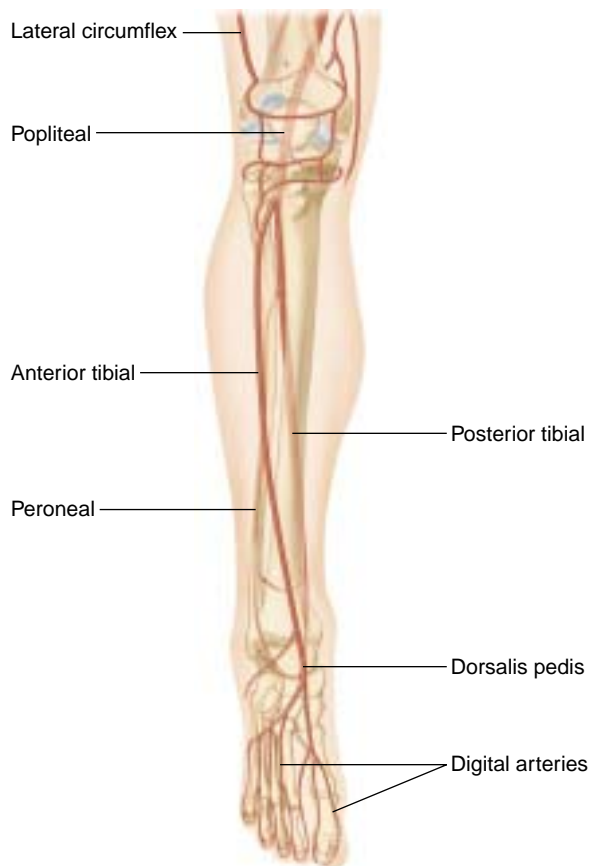
**Figure 5-23** The arteries of the pelvis and thigh.

## Pathophysiology

The digital arteries are end arteries, meaning that they are the final source of blood to the fingers. Each finger has two digital arteries, and if both are damaged, tissue loss may occur. This fact becomes an important consideration during repair of finger lacerations. Inappropriate use of an anesthetic containing epinephrine can result in spasm in the digital arteries and possible necrosis of the fingertip.

### The Head and Neck

The two major veins that drain the head and neck are called the external and internal **jugular veins**. The external jugular vein is more superficial and often is visible immediately beneath the skin. The external jugular vein primarily drains the posterior head and neck. The internal jugular vein drains the cranial vault as well as the anterior portion of the head, face,



**Figure 5-24** The arteries of the lower extremity.

## Case Study

### Case Study, Part 2

You discover that the patient has been experiencing periods of chest pain over the past month, which he wrote off as heartburn. The focused physical exam reveals a severely distressed overweight patient with mild dyspnea, normal lung and heart sounds, no jugular vein distention, pale and moist skin, no scars on his chest or abdomen, and no peripheral edema. The patient says he feels weak and is nauseated. The SAMPLE history adds nothing pertinent at this time. The ECG shows sinus tachycardia with occasional PVCs, and you apply the rest of the leads for a quick 12-lead ECG.

Nitroglycerin did not relieve the patient's pain. Because his vital signs are the same as the initial set, you administer another nitroglycerin tablet. One of the paramedics from the second unit has started an IV, and the patient is being carefully transferred to a stair chair so he can be taken out of the house and transported to the hospital.

### Focused Physical Assessment

Normal lung sounds with mild dyspnea

Normal heart sounds

Skin CTC is pale and moist. No scarring indicating prior surgeries.

No JVD or peripheral edema.

Overweight

### Diagnostic tools

ECG = sinus tachycardia with occasional PVCs.

12-lead is being obtained.

First nitroglycerin did not reduce pain.

**Question 4: What blood vessels are most likely to be occluded if a 12-lead ECG is showing features of ischemia and infarction to the left ventricle of the heart?**

**Question 5: What vessels supply the conduction system of the heart?**

CASE STUDY

## Pathophysiology

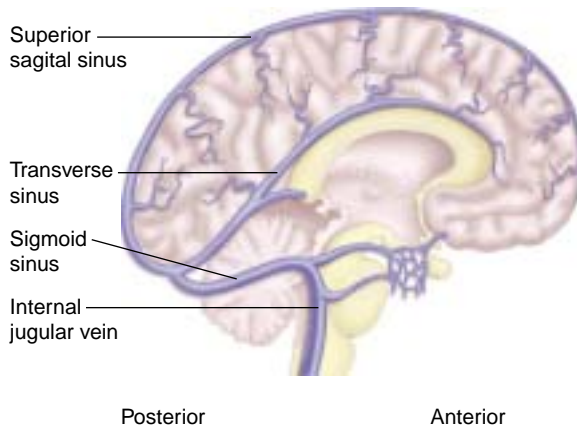
Atherosclerosis can affect the mesenteric arteries. When this occurs, patients experience cramping pain after eating because the narrowed artery is no longer able to supply adequate oxygen to the intestine for digestive processes to occur. The pain is called **mesenteric angina**. Complete blockage of a mesenteric artery can result in necrosis (death) of a portion of the bowel, a serious life-threatening condition known as **mesenteric infarction**.

and neck. Spaces between membranes surrounding the brain form **venous sinuses**. These sinuses are the primary means of venous drainage from the brain and feed into the internal jugular vein (▼ **Figure 5-25**).

The external jugular vein joins the internal jugular vein at the base of the neck (▼ **Figure 5-26**). The internal jugular veins join the **subclavian veins** (the proximal part of the main vein of the arm) to form the brachiocephalic veins, which drain into the superior vena cava.

### The Upper Extremity

The veins of the upper extremity vary somewhat from individual to individual (► **Figure 5-27**). The names of the veins of the hands, wrists, and forearm follow the arteries of the same name. In the upper forearm, these



**Figure 5-25** Venous drainage of the brain.

### Did You Know ?

The right subclavian or internal jugular veins are common sites for placement of percutaneous catheters, referred to as central lines, into the main or central circulation. Using the guide-wire or Seldinger technique, a needle is placed through the skin, into the deep vein. A guide wire that serves as a guide for placement of the catheter is placed through the needle.

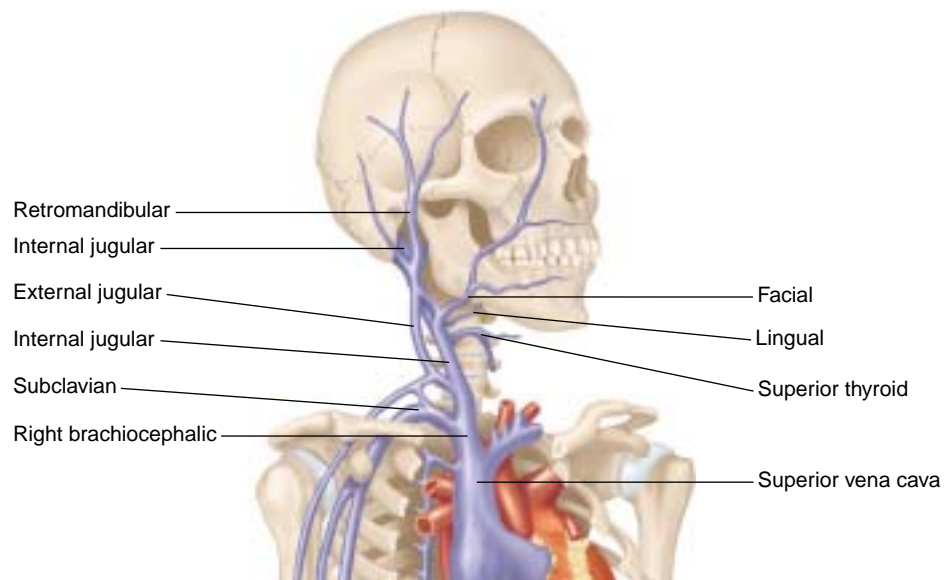
veins combine to form the **basilic vein** and the **cephalic vein**, the major veins of the arm. The basilic and cephalic veins combine to form the **axillary vein**, which drains into the subclavian vein.

### The Thorax

In the thorax, venous drainage begins at the anterior and posterior intercostal veins. The intercostal veins empty into the azygos vein on the right side of the thorax and the hemiazygos vein on the left. These veins, along with the right and left brachiocephalic veins, provide the major source of flow into the superior vena cava.

### The Abdomen and Pelvis

Ultimately, all venous drainage from the lower part of the body passes through the inferior vena cava. The inferior vena cava returns deoxygenated blood from the lower parts of the body to the right atrium for oxygenation. Within the abdominal and pelvic



**Figure 5-26** The veins of the head and neck.

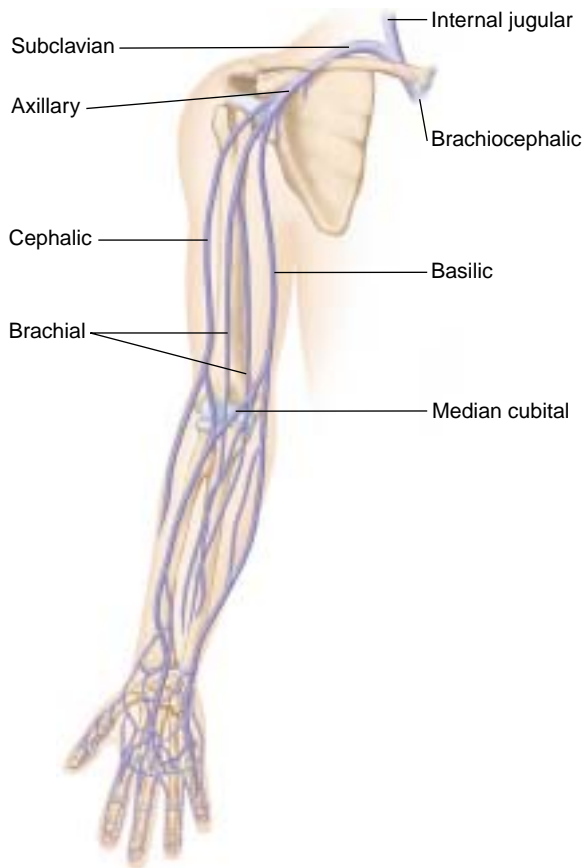


Figure 5-27 The veins of the upper extremity.

cavities, veins of the same name accompany the major arteries, providing venous drainage from structures including the kidney, adrenal glands, gonads, and diaphragm. The internal iliac veins drain the pelvis, and the external iliac veins drain the lower limbs. The internal and external iliac veins combine together in the pelvis, forming the common iliac veins, which combine to form the inferior vena cava.

The **hepatic portal system** is a specialized part of the venous system that drains blood from the liver, stomach, intestines, and spleen (▼ Figure 5-28). Blood from the system flows first through the liver, where blood collects in **sinusoids**. In the sinusoids, the liver extracts nutrients, filters the blood, and metabolizes various drugs. The blood then empties into the **hepatic veins**, which join the inferior vena cava.

**The Lower Extremity**

The longest vein in the body is the great **saphenous vein**. It drains the foot, leg, and thigh. The saphenous vein originates over the dorsal and medial side of the foot, ascends along the medial side of the leg and thigh, and empties into the **femoral vein**, which then drains into the external iliac vein. Laterally, the small saphenous vein helps drain the leg and lateral side of the foot. The veins of the feet also drain into the anterior and posterior **tibial veins**, which accompany their respective arteries, uniting at the knee to form the **popliteal vein**. The popliteal vein

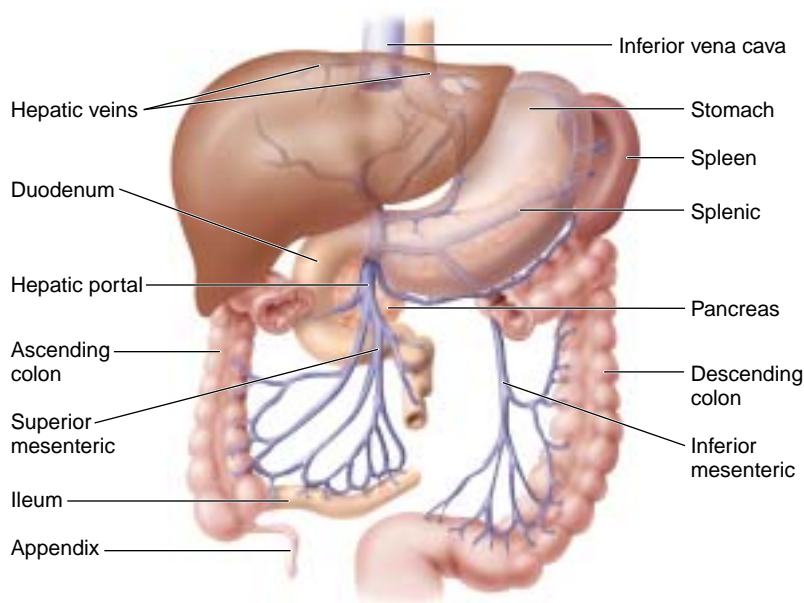


Figure 5-28 The hepatic portal system.

### Pathophysiology



Venous anatomy of the lower extremity varies, particularly of the superficial, smaller veins. Inflammation of these veins, a condition known as **phlebitis**, may develop. Inflammation of deeper veins can result in formation of blood clots, or **thrombi**, which can break off and travel to other parts of the body. A potentially life-threatening condition known as **pulmonary embolism** develops when a piece of a clot, or an **embolus**, travels to the lung, blocking blood flow to a portion of the lung.

ascends through the thigh, becoming the femoral vein (► [Figure 5-29](#)).

## Blood and Its Components

### Plasma and Formed Elements (Cells)

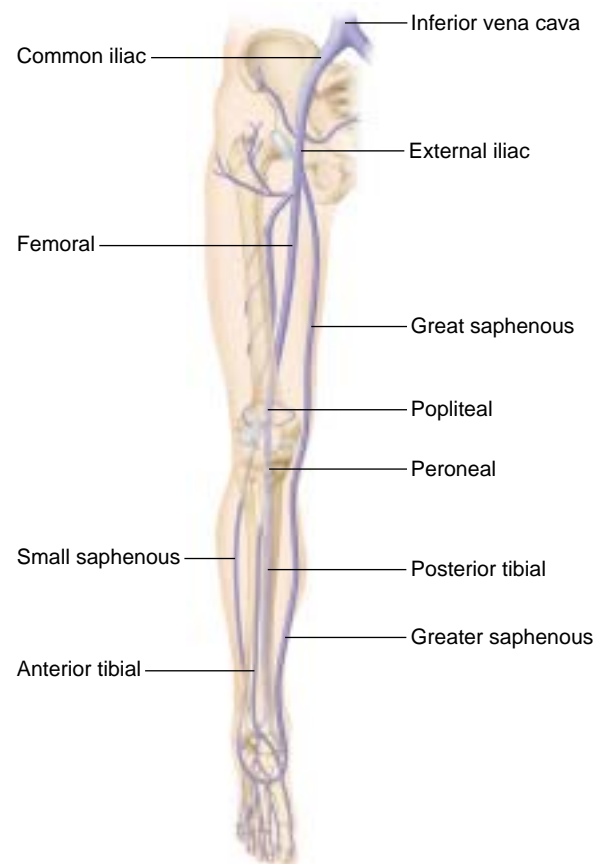
**Blood** is the substance that is pumped by the heart through the arteries, veins, and capillaries (► [Figure 5-30](#)). Blood consists of plasma and formed elements or cells that are suspended in the plasma. These cells include red blood cells, white blood cells, and platelets. The purpose of blood is to carry oxygen and nutrients to the tissues and carry cell waste products away from the tissues. In addition, the formed elements are the mainstay of numerous other body functions such as fighting infection and controlling bleeding. Human adult male bodies contain approximately 70 mL/kg, or about 5 L, of blood, whereas female bodies contain approximately 65 mL/kg.

**Plasma** is a watery, straw-colored fluid that accounts for more than half of the total blood volume. Plasma is made up of 92% water and 8% dissolved substances such as chemicals, minerals, and nutrients. Water enters the plasma from the digestive tract, from fluids between cells, and as a by-product of metabolism.

### Pathophysiology



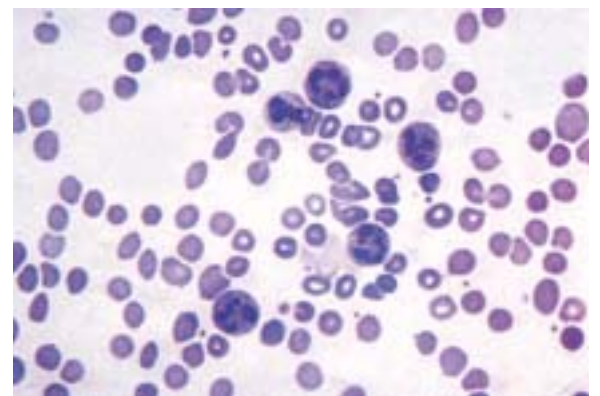
Bilirubin may accumulate in the blood for a number of reasons, ranging from liver disease to bleeding. When blood concentrations of bilirubin are increased, **jaundice** occurs, in which the skin and sclera of the eyes often turn yellow.



**Figure 5-29** The veins of the lower extremity.

### Red Blood Cells

Red blood cells are also known as **erythrocytes** and are disk-shaped cells that carry oxygen to the tissues. These are the most numerous of the formed elements. An average human has between 4.2 and 5.8 million erythrocytes per cubic millimeter of blood. Erythrocytes are unable to move on their own; the



**Figure 5-30** Components of blood include plasma and formed elements or cells, including red blood cells, white blood cells, and platelets.

## Pathophysiology



Any decrease in the number of red blood cells in the body is called **anemia**. Anemia may be caused by inadequate nutrition (such as iron deficiency), inadequate production of erythrocytes by bone marrow, increased destruction of red blood cells by the body (hemolysis), or bleeding.

flowing plasma passively propels them. Red blood cells contain a protein known as **hemoglobin**, which gives them their reddish color. Hemoglobin binds oxygen that is absorbed in the lungs and transports it to the tissues where it is needed.

**Erythropoiesis** is the ongoing process by which red blood cells are made. Approximately 25 trillion erythrocytes are contained in the normal adult circulation; of these, 2.5 million erythrocytes are destroyed every second.

Red blood cells have a finite lifespan of 120 days. Those cells that are destined for destruction decompose in the spleen and other tissues that are rich in cells known as **macrophages**. Macrophages protect the body against infection. The body “recycles” some components of hemoglobin, such as the protein, globin, and iron. The part of hemoglobin that is not recycled is converted to **bilirubin**, which is a waste product that undergoes further metabolism in the liver. Normally, a chemical derivative of bilirubin, urobilinogen, is excreted in the stool and in the urine.

## Pathophysiology



During pregnancy, Rh grouping is very important. During late pregnancy and delivery, the mother often is exposed to a small amount of fetal blood. If the mother’s blood is Rh negative and the fetus’ blood is Rh positive, the mother’s body will produce antibodies to Rh antigens. These antibodies may enter the fetal circulation and destroy the fetus’ red blood cells. This condition, known as **erythroblastosis fetalis**, can be fatal to the child. Erythroblastosis fetalis usually is prevented if the mother is given an injection of a specific type of antibody preparation called Rh<sub>0</sub>(D) immune globulin (RhoGAM) immediately after each delivery or miscarriage. RhoGAM inactivates fetal antigens, and the mother’s body does not produce Rh-positive antibodies.

## Case Study

### Case Study, Part 3

After the patient has been moved to the ambulance and transport has begun, you perform an ongoing assessment of the patient. The patient’s symptoms have not improved, he is still feeling short of breath, the intensity of the chest pain has not lessened, he is sweaty, and the nausea is persisting. Vital signs have not changed from the last set taken 5 minutes ago. Lung and heart sounds are normal, oxygen saturation (SpO<sub>2</sub>) is 100%, and the ECG is continuing to show irritability of the heart. You give the patient another nitroglycerin tablet and call medical control.

### Ongoing Assessment

Symptoms the same; short of breath with chest pain and nausea  
Diaphoretic (sweaty)

Normal lung sounds  
Normal heart sounds  
SpO<sub>2</sub> is 100%  
ECG shows persistent irritability

### Vital signs

Same as the set taken 5 minutes before.

**Question 6: Could this patient be a candidate for fibrinolytic “clot-buster” therapy?**

**Question 7: Besides nitroglycerin (a vasodilator) and morphine (an analgesic), what type of medication could benefit this patient now?**

CASE STUDY

Erythrocytes contain **antigens** on their surface, which are proteins recognized by the immune system. Within the plasma are **antibodies**, which are proteins that react with antigens. Individuals are classified as having one of four blood types based on the presence or absence of these specific antigens. This process of classification is referred to as blood typing, or determining the ABO blood group.

Type A blood contains erythrocytes with type A surface antigens and plasma containing type B antibodies; type B blood contains type B surface antigens and plasma containing type A antibodies. Type AB blood contains both types of antigens but the plasma contains no ABO antibodies. Type O contains neither A nor B antigens but contains both A and B plasma antibodies. A person’s blood type determines which type of blood he or she may receive in a blood transfusion.

Rh blood groups involve a complex of antigens first discovered in rhesus monkeys. The presence of any of the 18 separate Rh antigens makes an individual’s blood Rh positive. If an individual with Rh negative blood were to be exposed to Rh positive blood, antibodies to the antigens could be produced.

## Pathophysiology



During a laboratory test called a complete blood count (CBC), the laboratory technician notes (among other things) the percentage of each type of leukocyte present. This portion of the test is called the white blood cell differential.

## Pathophysiology



All blood cells are produced in the bone marrow. This process is called **hematopoiesis** or hemopoiesis. **Leukemia** is a cancerous condition in which certain cell lines begin to grow abnormally fast. These cells function abnormally and invade other tissues, ultimately resulting in death if treatment fails.

### White Blood Cells

White blood cells are also known as **leukocytes**. There are several different types of white blood cells and each has a different function. The primary function of all white blood cells is to fight infection. Antibodies to fight infection may be produced, or leukocytes may directly attack and kill bacterial invaders. Leukocytes are larger than erythrocytes. Most leukocytes are motile and leave the blood vessels by a process known as **diapedesis** to move toward the tissue where they are needed most.

Leukocytes are named according to their appearance in a stained preparation of blood. In general, **granulocytes** have large cytoplasmic granules that are easily seen with a simple light microscope; **agranulocytes** are leukocytes that lack these granules. There are three types of granulocytes (neutrophils, eosinophils, and basophils) and two types of agranulocytes (monocytes and lymphocytes).

**Neutrophils** are normally the most common type of granulocyte in the blood. Their nuclei are commonly multi-lobed, resembling a string of baseballs held together by a thin strand of thread. For this reason, these cells often are called polymorphonuclear cells or “polys.” Neutrophils destroy bacteria, antigen-antibody complexes, and foreign matter (► **Figure 5-31**). **Eosinophils** are granulocytes that contain granules that stain bright red with the acidic stain, eosin. Eosinophils function in the body’s allergic response and are, thus, increased in individuals with allergies. Certain parasitic infections, such as trichinosis, also result in an increase in the number of eosinophils present. **Basophils** are the least common of all granulocytes and play a role in both allergic and inflammatory reactions. Basophils contain large amounts of **histamine**, a substance that increases tissue inflammation, and **heparin**, a substance that inhibits blood clotting.

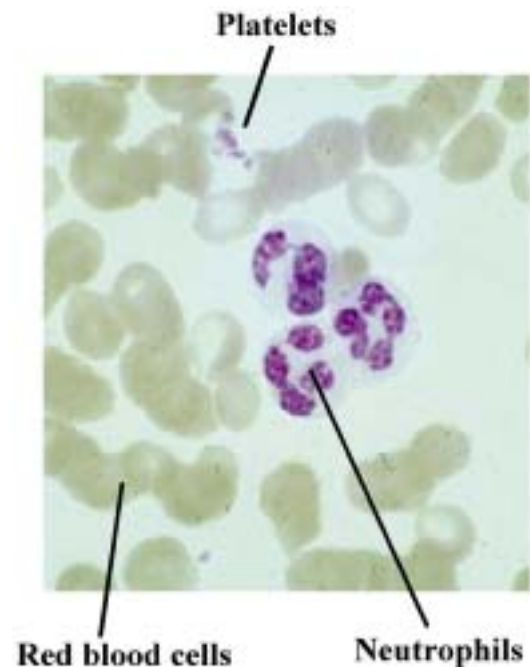
**Lymphocytes** are the smallest of the agranulocytes. Lymphocytes originate in the bone marrow but migrate through the blood to the lymphatic tissues. Most lymphocytes are located in the lymph nodes, spleen, tonsils, lymph nodules, and thymus. Different

types of lymphocytes will be described in Chapter 6: The Lymphatic and Immune System.

**Monocytes** and macrophages are one of the first lines of defense in the inflammatory process. Monocytes migrate out of the blood and into the tissues in response to an infection. They engulf microbes and digest them in a process called phagocytosis. Unlike their counterparts the neutrophils, which are short lived, once in the tissues monocytes mature into long-lived macrophages.

### Platelets and Blood Clotting

**Platelets** are small cells in the blood that are essential for clot formation. Clots are formed as a result of a series of chemical reactions. The blood clotting or coagulation process is a complex set of events involving platelets, clotting proteins in the plasma (clotting factors), other proteins, and calcium. During this process, platelets aggregate together in a clump and



**Figure 5-31** The blood cells

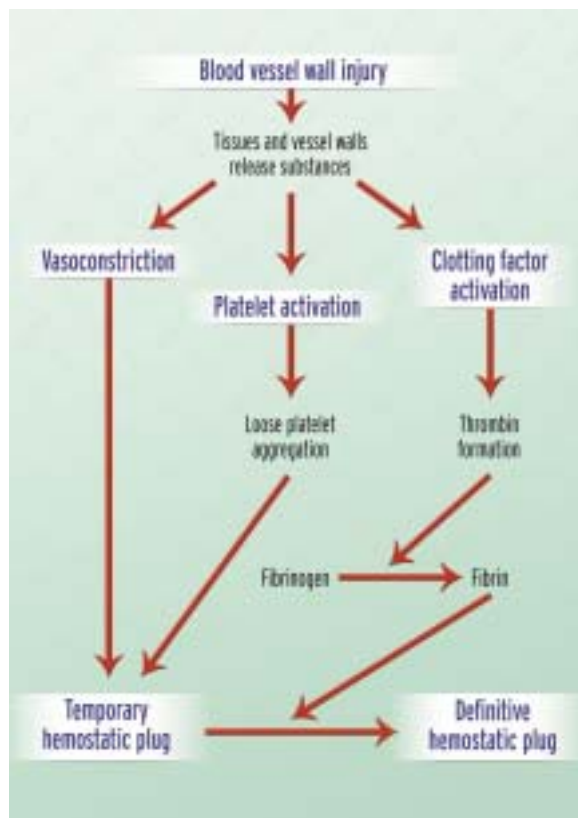
## Pathophysiology



Genetically engineered t-PA is given therapeutically to cause lysis of blood clots. The best known use for this treatment is for myocardial infarction, although its use is becoming increasingly more popular as a treatment of thrombotic stroke and pulmonary embolism.

form much of the foundation of a blood clot. Clotting proteins produced by the liver solidify the remainder of the clot, which eventually includes red and white blood cells.

Following injury to a blood vessel wall, a predictable series of events takes place, resulting in **hemostasis** (cessation of bleeding) and formation of the final blood clot. Chemicals released from the vessel wall cause local vasoconstriction, as well as activation of the platelets. The combination of vessel contraction and loose platelet aggregation forms a temporary “plug.” Other factors released by the tissues, known as tissue thromboplastin, activate a cascade of clotting proteins. Eventually, **thrombin** is formed. This causes the conversion of fibrinogen to



**Figure 5-32** Algorithm showing the reactions in hemostasis.

## Case Study

### Case Study, Part 4

#### Completion of Case Study

While you are en route to the hospital, medical control advises that you give the patient morphine to help alleviate the pain as well as further dilate the coronary vessels. In this patient, morphine may be helpful because the 12-lead ECG shows indications of an acute myocardial infarction. You obtain serial vital signs every 5 minutes, and the patient seems to be breathing easier. You run through the fibrinolytic checklist with the patient in the event he is a good candidate for “clot-buster” therapy upon arrival at the emergency department. As you engage in casual conversation with the patient, trying to keep him calm, he tells you that his father died suddenly while in his 40s.

Fibrinolytic checklist (lists may vary with more or less specificity):

(All of the **Yes** boxes and **No** boxes must be checked before fibrinolytic therapy can be given.)

#### Yes

- Age  $\geq$  18 years
- Pain duration  $>$  15 minutes,  $<$  than 12 hours
- Systolic blood pressure between 90 and 200 mm Hg
- ED physician confirms acute MI

#### No

- Active internal bleeding
- Recent surgery or trauma ( $<$  2 months)
- Taking a blood thinner (Warfarin)
- Pregnant or lactating
- CPR for more than 10 minutes
- Terminal patient
- History of stroke, aneurysm, or brain tumor

**fibrin**, which binds to the platelet plug, forming the final mature clot (▼ **Figure 5-32**)

The body also has two systems to counterbalance the clotting system. One, the fibrinolytic system, lyses or disrupts clots that already have formed. The main steps in the fibrinolytic system are the activation of **tissue plasminogen activator (t-PA)**, which then converts plasminogen to **plasmin**.

The other counterbalance to the clotting system consists of three naturally occurring blood thinners (anticoagulants), protein S, protein C, and antithrombin III, that are activated if a blood clot begins to form in an abnormal location, such as the coronary artery.

Together, the fibrinolytic system and the body’s own anticoagulants attempt to provide a balance between clotting and bleeding; however, neither system is absolutely effective (for example, in patients with thrombotic conditions, such as myocardial infarction or stroke, as well as in patients with spontaneous bleeding, such as subarachnoid hemorrhage).



## Chapter Summary

The heart (myocardium) is surrounded by a thick pericardial membrane, which contains visceral and parietal layers, separated by pericardial fluid. The upper chambers, or the atria, receive blood returning to the heart from other parts of the body and the lower chambers; the ventricles pump blood out of the heart.

The heart valves include the tricuspid, mitral, pulmonic, and aortic valves.

Blood flow within the heart begins with the delivery of deoxygenated blood to the right atrium by the superior and inferior venae cavae.

The electrical activity of the heart is influenced by the brain and autonomic nervous system and the intrinsic conduction system of the heart including the sinoatrial node, atrioventricular node, bundle of His, bundle branches, and the Purkinje fibers.

Special electrical properties of cardiac cells include excitability, conductivity, and automaticity.

The regulation of heart function involves the control of the heart rate (chronotropic state), conductivity (dromotropic state), and strength of the contraction (inotropic state). Receptors, such as baroreceptors and chemoreceptors, constantly monitor body functions.

Three positively charged ions, sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), and calcium ( $\text{Ca}^{2+}$ ) are responsible for initiating and conducting electrical charges in the heart.

The difference in concentration between sodium and potassium across the cell membrane is the electrical potential measured in millivolts.

The process of electrical discharge and flow of electrical activity is called depolarization.

Repolarization of cardiac cells occurs as they begin to return to their resting state. The two phases of repolarization are the early or absolute refractory period, in which depolarization cannot occur, and the latter or relative refractory period, in which cells can respond to a stronger-than-normal stimulus.

The electrocardiogram (ECG) is a visualization of the electrical currents generated during depolarization and repolarization of the heart. The normal sinus rhythm ECG consists of P waves occurring at regular intervals, a P-R segment of normal duration (less than 0.2 seconds), followed by a QRS complex (ventricular depolarization), an ST segment that is flat, and by a T wave (ventricular repolarization).

The cardiac cycle is the repetitive pumping process that begins with the onset of cardiac muscle contraction and ends immediately prior to the start of the next contraction. Contraction of the ventricles is known as systole. A pressure also may be determined in the vessels during diastole, the relaxation phase of the heart cycle.

The amount of blood pumped through the circulatory system in 1 minute is referred to as the cardiac output.  
[Cardiac Output = Stroke Volume  $\times$  Heart Rate]

The arteries are blood vessels that carry blood away from the heart. Veins are blood vessels that transport blood back to the heart. Arterioles are the smallest arteries and venules are the smallest veins. Capillaries are microscopic, thin-walled vessels through which oxygen and other nutrients and carbon dioxide and waste products are exchanged.

The coronary arteries supply the heart with blood and arise from the aorta shortly after it leaves the left ventricle. The right coronary artery divides into several important branches and the left main coronary artery divides into two branches, the anterior descending and the circumflex coronary arteries.

The pulmonary circulation carries blood from the right side of the heart to the lungs and back to the left side of the heart.

The systemic arterial circulation carries oxygenated blood from the heart through the aortic valve, into the aorta, and out to the body.

Circulation to the head and neck involves the brachiocephalic artery, the right common carotid artery, and the right subclavian artery.

Circulation in the upper extremity involves the subclavian artery, vertebral artery, axillary artery, brachial artery, and ulnar and radial arteries.

The thoracic aorta branches into the visceral arteries, supplying the thoracic organs, and the parietal arteries, supplying the thoracic wall.

Intercostal arteries run along the ribs and provide circulation to the chest wall.

The abdominal aorta divides into visceral arteries and parietal arteries. The major arteries are the celiac trunk, superior mesenteric, and inferior mesenteric arteries. Paired branches of the visceral abdominal aorta supply the kidneys, adrenal gland, and gonads. The parietal branches supply the diaphragm and abdominal wall.

The circulation to the pelvis and lower extremities involves the aorta, the two common iliac arteries, the internal and external iliac arteries, the femoral arteries, popliteal arteries, tibial arteries, and dorsalis pedis arteries.

The major veins of the head and neck include the external and internal jugular veins. The internal jugular veins join the subclavian veins to form the brachiocephalic veins, which drain into the superior vena cava.

The venous circulation from the upper extremity involves the veins of the hands, wrists, and forearm and the basilic, cephalic, and axillary veins.

The venous drainage from the thorax includes the anterior and posterior intercostal veins, the azygos vein, the hemiazygos vein, the brachiocephalic veins, and the superior vena cava.

The venous drainage from the abdomen and pelvis empties into the inferior vena cava. Within the abdominal and pelvic cavities, veins of the same name accompany the major arteries, as well as the internal and external iliac veins.

The hepatic portal system is a specialized part of the venous system that drains blood from the liver, stomach, intestines, and spleen.

The venous circulation from the lower extremity involves the greater and lesser saphenous, femoral, anterior and posterior tibial, and popliteal veins.

Blood is a combination of plasma and formed elements (cells) and serves to carry oxygen and nutrients to the tissues

and waste products away. Adult men have approximately 70 mL/kg of blood, or 5 L, and adult women have approximately 65 mL/kg.

The red blood cells (erythrocytes) carry oxygen to the tissues. Hemoglobin gives red blood cells their color and binds to oxygen that is absorbed in the lungs. Red blood cells have a lifespan of 120 days, then they decompose in the spleen and at other sites. The body "recycles" some components of hemoglobin and converts the remainder to bilirubin.

Erythrocytes contain antigens on their surface; within the plasma are antibodies that react with these antigens. Blood typing is based on the presence or absence of these substances.

The white blood cells (leukocytes) primarily fight infection by the production of antibodies or by directly attacking and killing bacterial invaders.

The platelets and blood clotting process can be very helpful or harmful to the circulation. The blood clotting or coagulation process is a complex set of events involving platelets, clotting proteins in the plasma, other proteins, and calcium. Other factors known as tissue thromboplastin activate a cascade of clotting proteins.



## Vital Vocabulary

**absolute refractory period** the early phase of repolarization in which the cell contains such a large concentration of ions that it cannot be stimulated to depolarize.

**afterload** the pressure in the aorta against which the left ventricle must pump blood.

**agranulocytes** leukocytes that lack granules.

**alpha effect** stimulation of alpha receptors that results in vasoconstriction.

**anemia** a decrease in the number of red blood cells, for any reason.

**anterior descending coronary artery** one of the two branches of the left main coronary artery.

**antibodies** proteins within plasma that react with antigens.

**antigens** substances on the surface of erythrocytes that are recognized by the immune system.

**aorta** the largest artery in the body, which carries oxygenated blood from the left ventricle to the entire body.

**aortic arch** one of the three described portions of the aorta; the section of the aorta between the ascending and descending portions that gives rise to the right brachiocephalic (innominate), left common carotid, and left subclavian arteries.

**aortic valve** the semilunar valve that regulates blood flow from the left ventricle to the aorta.

**arteries** the blood vessels that carry blood away from the heart.

**arteriosclerosis** the deposition of calcium in the arterial walls that results in a loss of elasticity and concomitant reduction in blood flow.

**ascending aorta** the first of three portions of the aorta; originates from the left ventricle and gives rise to two branches, the right and left main coronary arteries.

**atherosclerosis** a disorder characterized by the formation of plaques of material, mostly lipids and cholesterol, on the inner arterial walls.

**atrioventricular (AV) node** the site located in the right atrium adjacent to the septum that is responsible for transiently slowing electrical conduction.

**atrioventricular valves** the two valves through which blood flows from the atria to the ventricles.

**atrium** one of the two chambers in the heart that receives blood back from the body.

**automaticity** the ability of cardiac cells to generate an impulse to contract even when there is no external nervous stimulus.

**axillary vein** the vein that is formed from the combination of the basilic and cephalic veins; it drains into the subclavian vein.

**baroreceptors** receptors in the blood vessels, kidneys, brain, and heart that respond to changes in pressure in the heart or main arteries to help maintain homeostasis.

**basilar artery** the artery that is formed when the left and right vertebral arteries unite after entering the brain through the foramen magnum.

**basilic vein** one of the two major veins of the arm, it combines with the cephalic vein to form the axillary vein.

**basophils** the least common of all granulocytes; they are important in both allergic and inflammatory reactions.

**beta effect** stimulation of beta receptors that results in increased inotropic, dromotropic, and chronotropic states.

**bilirubin** a waste product of red blood cell destruction that undergoes further metabolism in the liver.

**blood** the fluid tissue that is pumped by the heart through the arteries, veins, and capillaries and consists of plasma and formed elements or cells, such as red blood cells, white blood cells, and platelets.

**bruit** an abnormal “whooshing-like” sound indicating turbulent blood flow within a blood vessel.

**bundle of His** part of the conduction system of the heart; a continuation of the atrioventricular node.

**capillaries** microscopic, thin-walled blood vessels through which oxygen and nutrients and carbon dioxide and waste products are exchanged.

**cardiac cycle** the repetitive pumping process that begins with the onset of cardiac muscle contraction and ends just prior to the beginning of the next contraction.

**cardiac output** the amount of blood pumped through the circulatory system in 1 minute.

**cardiac tamponade** a life-threatening state of shock that develops as a result of a large pericardial effusion.

**carotid bifurcation** the point of division at which the common carotid artery branches at the angle of the mandible into the internal and external carotid arteries.

**carotid canals** an opening in the cranial vault through which the carotid arteries enter.

**carotid sinus** a slight dilatation in the carotid bifurcation that contains structures that are important in the regulation of blood pressure.

**cephalic vein** one of the two major veins of the arm that combine to form the axillary vein.

**cerebellum** the part of the brain that is located dorsal to the pons and is responsible for coordination and balance.

**cerebral arteries** the arteries that supply blood to large portions of the cerebral cortex of the brain.

**chemoreceptors** receptors in the blood vessels, kidneys, brain, and heart that respond to changes in chemical composition of the blood to help maintain homeostasis.

**chordae tendineae cordis** small muscular strands that attach the ventricles and the valves, preventing regurgitation of blood through the valves from the ventricles to the atria.

**chronotropic state** related to the control of the heart's rate of contraction.

**circle of Willis** an interconnection of the anterior cerebral arteries and the anterior communicating artery, which forms an important source of collateral circulation to the brain.

**circumflex coronary artery** one of the two branches of the left main coronary artery.

**conduction system** a group of complex electrical tissues within the heart that initiate and transmit stimuli that result in contractions of myocardial tissue.

**conductivity** the ability of cardiac cells to conduct electrical impulses.

**contractility** the strength of heart muscle contraction.

**coronary arteries** arteries that arise from the aorta shortly after it leaves the left ventricle and supply the heart with oxygen and nutrients.

**coronary artery disease (CAD)** the condition that results when either atherosclerosis or arteriosclerosis is present in the arterial walls.

**coronary sinus** veins that collect blood that is returning from the walls of the heart.

**cusps** the flaps that comprise the heart valves.

**depolarization** the process of electrical discharge and flow of electrical activity from a cell.

**descending aorta** one of the three portions of the aorta, it is the longest portion and extends through the thorax and abdomen into the pelvis.

**diapedesis** a process whereby leukocytes leave blood vessels to move toward tissue where they are needed most.

**dorsalis pedis artery** a continuation of the anterior tibial artery at the foot.

**dromotropic state** related to the control of the heart's conduction rate.

**ejection fraction** the portion of the blood ejected from the ventricle during systole.

**electrical potential** an electrical charge difference that is created by the difference in sodium and potassium concentration across the cell membrane at any given instant.

**electrocardiogram (ECG)** a graphic recording of the electrical activity of the heart.

**embolus** a piece of clot that travels from one part of the body to another, potentially becoming an obstruction to blood flow.

**endocarditis** infection of a heart valve.

**eosinophils** granulocytes that contain granules that stain bright red with the acidic stain, eosin, and function in the body's allergic response.

**epicardium** the layer of the serous pericardium that lies closely against the heart; also called the visceral pericardium.

**epinephrine** a naturally occurring hormone with a greater stimulatory effect on beta receptors that also may be given as a cardiac drug.

**erythroblastosis fetalis** a serious condition that results when a pregnant woman's blood type is incompatible with the fetus' blood type and antibodies from the mother enter the fetal circulation and destroy the fetus' red blood cells.

**erythrocytes** disk-shaped cells that carry oxygen to the tissues; also known as red blood cells.

**erythropoiesis** the process by which red blood cells are made.

**excitability** a property of cardiac cells that provides the cells with the ability to respond to electrical impulses.

**femoral artery** a continuation of the external iliac artery, it supplies circulation to the thigh, external genitalia, anterior abdominal wall, and knee.

**femoral vein** a continuation of the saphenous vein that drains into the external iliac vein.

**fibrin** a white insoluble protein formed in the clotting process.

**foramen ovale** an opening between the two atria that is present in the fetus but closes shortly after birth.



**fossa ovalis** a depression between the right and left atria that indicates where the foramen ovale had been located in the fetus.

**granulocytes** a type of leukocyte that has large cytoplasmic granules that are easily seen with a simple light microscope.

**heart** a muscular, cone-shaped organ whose function is to pump blood throughout the body.

**hematopoiesis** the process of blood cell production in the bone marrow; also called hemopoiesis.

**hemoglobin** the protein in red blood cells that gives them their reddish color, it binds oxygen absorbed in the lungs and transports it to the tissues where it is needed.

**hemostasis** control of bleeding by formation of a blood clot.

**heparin** a substance found in large amounts in basophils that inhibits blood clotting.

**hepatic portal system** a specialized part of the venous system that drains blood from the liver, stomach, intestines, and spleen.

**hepatic veins** the veins to which blood empties after liver cells in the sinusoids of the liver extract nutrients, filter the blood, and metabolize various drugs.

**histamine** a substance found in large amounts in basophils that increases tissue inflammation.

**inferior vena cava** one of two major large veins that return deoxygenated blood to the heart via the right atrium. Blood from the lower body is returned to the heart by the inferior vena cava.

**inotropic state** related to the strength of the heart's contraction.

**interatrial septum** a membrane that separates the right and left atria.

**interventricular septum** a thick wall that separates the right and left ventricles.

**ischemia** insufficient oxygen at a particular tissue site often associated with obstruction of arterial blood flow to the site.

**jaundice** a yellowing of the skin and sclera of the eyes because of excessive concentrations of bilirubin in the blood.

**jugular veins** the two main veins that drain the head and neck.

**leukemia** a cancerous condition in which certain cell lines begin to grow abnormally fast and invade other tissues.

**leukocytes** white blood cells that are responsible for fighting infection.

**lumen** the opening or hollow part of a blood vessel.

**lymphocytes** the smallest of the agranulocytes, they originate in the bone marrow but migrate through the blood to the lymphatic tissues.

**macrophages** cells that are responsible for protecting the body against infection.

**mediastinum** the area in the chest that lies between the lungs and contains the heart and great vessels.

**mesenteric angina** pain caused by partial occlusion of the mesenteric artery from atherosclerosis.

**mesenteric infarction** blockage of a mesenteric artery resulting in necrosis of a portion of the bowel.

**mitral valve** the valve in the heart that separates the left atrium from the left ventricle.

**monocytes** agranulocytes that migrate out of the blood and into the tissues in response to an infection.

**murmur** an abnormal heart sound, heard as a "whooshing-like" sound indicating turbulent blood flow within the heart.

**myocardial infarction (MI)** blockage of the arteries that supply oxygen to the heart, resulting in death to a portion of the myocardium.

**myocardium** the heart muscle.

**neutrophils** one of the three types of granulocytes; they have multi-lobed nuclei that resemble a string of baseballs held together by a thin strand of thread; they destroy bacteria, antigen-antibody complexes, and foreign matter.

**norepinephrine** a naturally occurring hormone with a greater stimulatory effect on alpha receptors that also may be given as a cardiac drug.

**P wave** the first positive wave in the normal cardiac conduction pattern, it represents movement of the electrical impulse through the atria, resulting in atrial contraction.

**palmar arches** the two arches formed from the radial and ulnar vessels within the hand, creating the superficial and deep palmar arches.

**papillary muscles** specialized muscles that attach the ventricles to the cusps of the valves by muscular strands called chordae tendineae cordis.

**parietal layer** one of two layers of the serous pericardium. It is separated from the visceral pericardium by a small amount of pericardial fluid.

**pericardial effusion** a condition, often caused by trauma, in which the pericardial sac fills with too much fluid, hampering the heart's ability to expand and contract properly.

**pericardial fluid** a serous fluid that fills the space between the visceral pericardium and the parietal pericardium and helps to reduce friction.

**pericardial sac** a thick fibrous membrane that surrounds the heart; also called the pericardium.

**pericardiocentesis** a life-saving procedure to correct cardiac tamponade, in which a needle is inserted into the pericardial sac to remove excess fluid that is restricting the heart from expanding and contracting properly.

**pericarditis** infection or inflammation of the pericardial membranes, resulting in severe chest pain.

**pericardium** a thick fibrous membrane that surrounds the heart; also called the pericardial sac.

**phlebitis** inflammatory condition involving veins; often associated with thrombus formation within the vein.

**plasma** a watery, straw-colored fluid that accounts for more than half of the total blood volume.

**plasmin** an enzyme that dissolves the fibrin in blood clots.

**platelets** small cells in the blood that are essential for clot formation.

**polarized state** the state of the resting cell, which normally has a net negative charge with respect to the outside of the cell.

**pons** the mass of nerve fibers at the end of the medulla oblongata.

**popliteal artery** a continuation of the femoral artery at the lower thigh.

**popliteal vein** the vein that forms when the anterior and posterior tibial veins unite at the knee.

**P-R segment** a flat line or electrical pause that follows the P wave in the normal electrical conduction pattern and represents the time delay that occurs within the atrioventricular node.

**pulmonary circulation** the circulatory system in the body that carries blood from the right side of the heart to the lungs, and back to the left side of the heart.

**pulmonary embolism** a potentially life-threatening condition that occurs when an embolus travels from one part of the body (typically the legs) to the lungs, blocking blood flow to a portion of the lung.

**pulmonic valve** the semilunar valve that regulates blood flow between the right ventricle and the pulmonary artery.

**QRS complex** the second positive waveform that follows the P-R segment in the normal electrical conduction pattern and represents the depolarization of the ventricles. This complex corresponds to ventricular contraction, or systole.

**Raynaud's phenomenon** spasms that develop in the digital arteries, particularly following emotional stress or cold exposure, resulting in white and cool fingertips.

**relative refractory period** the latter phase of repolarization in which the cells are able to respond to a stronger-than-normal stimulus.

**repolarization** the process of returning to the cardiac cells' resting or polarized state that occurs once the cardiac cells depolarize.

**rheumatic fever** an acute condition that affects children and young adults and may result in permanent damage to the aortic and mitral valves.

**saphenous vein** the longest vein in the body, it drains the leg, thigh, and dorsum of the foot.

**semilunar valves** the two valves, the aortic and pulmonic valves, that divide the heart from the aorta and pulmonary artery.

**serous pericardium** the inner membrane of the pericardium, which contains two layers called the visceral pericardium and the parietal pericardium.

**sinoatrial (SA) node** the normal site of the origin of electrical impulses; located high in the right atrium, it is the heart's natural pacemaker.

**sinusoids** a part of the hepatic portal system in which blood collects within the liver and the liver cells extract nutrients from the blood, filter the blood, and metabolize various drugs.

**sodium-potassium pump** a molecular (ion-transporting) mechanism whereby sodium is actively moved out of a cell and potassium moved in.

**ST segment** the second pause that occurs in the normal electrical conduction pattern and represents the beginning of repolarization of the heart.

**stroke volume** the amount of blood that the left ventricle ejects into the aorta per contraction.

**subclavian artery** the proximal part of the main artery of the arm, which supplies the brain, neck, anterior chest wall, and shoulder.

**subclavian vein** the proximal part of the main vein of the arm, which unites with the internal jugular vein.

**superior vena cava** one of two major large veins that return deoxygenated blood to the heart via the right atrium. Blood from the upper body is returned to the heart by the superior vena cava.



**systemic circulation** the circulatory system in the body that is responsible for blood flow in all areas of the body, except for areas covered by the pulmonary circulation.

**systole** contraction of the ventricular mass with its concomitant pumping of blood into the system circulation.

**T wave** the third positive waveform in the normal electrical conduction pattern; it represents the completion of repolarization.

**thrombi** blood clots.

**thrombin** an enzyme that causes the conversion of fibrinogen to fibrin, which binds to the platelet plug, forming the final mature clot.

**tibial veins** a continuation of the veins of the feet that unite at the knee to form the popliteal vein, which then drains into the femoral vein.

**tissue plasminogen activator (t-PA)** a major component in the fibrinolytic system, in which clots that have already formed are lysed or disrupted, converting plasminogen to plasmin.

**tricuspid valve** the heart valve that separates the right atrium from the right ventricle.

**tunica adventitia** the outer layer of tissue of a blood vessel wall, composed of elastic and fibrous connective tissue.

**tunica intima** the smooth, thin, inner lining of a blood vessel.

**tunica media** the middle and thickest layer of tissue of a blood vessel wall, composed of elastic tissue and smooth muscle cells that allow the vessel to expand or contract in response to changes in blood pressure and tissue demand.

**veins** the blood vessels that transport blood back to the heart.

**venous sinuses** spaces between the membranes surrounding the brain that are the primary means of venous drainage from the brain.

**ventricle** one of the two lower chambers of the heart that pumps blood out of the heart.

**visceral layer** The layer of the serous pericardium that lies closely against the heart; also called the epicardium.

## Case Study Answers

### Question 1: What is cardiac output?

**Answer:** Cardiac output is the amount of blood pumped through the circulatory system in 1 minute. It is expressed in liters per minute (L/min). The cardiac output equals the heart rate multiplied by the stroke volume or amount of blood (volume) pumped with each heartbeat: Cardiac Output = Stroke Volume  $\times$  Heart Rate.

### Question 2: How can a heart attack affect cardiac output?

**Answer:** Factors that influence the heart rate, the stroke volume, or both will affect cardiac output as well as ischemia or infarction to the electrical conduction system, the myocardium, or both.

### Question 3: Which blood vessels supply oxygen and nutrients to the myocardium and are the location for partial or full occlusion(s) that can result in a heart attack?

**Answer:** The right and left coronary arteries arise from the aorta shortly after it leaves the left ventricle and divide into several important branches that supply the heart with oxygen and nutrients.

### Question 4: What blood vessels are most likely to be occluded if a 12-lead ECG is showing features of ischemia and infarction to the left ventricle of the heart?

**Answer:** Most blood vessels supplying the left ventricle rise from the left main coronary artery. This vessel is the largest and shortest of the myocardial blood vessels. It divides into two branches, the anterior descending and the circumflex coronary arteries. These arteries subdivide further, supplying most of the left ventricle, the intraventricular septum, and, at times, the atrioventricular node. The occlusion may be partial or full and could be in the left main coronary artery or any of its branches.

### Question 5: What vessels supply the conduction system of the heart?

**Answer:** The right coronary artery and its branches supply portions of the conduction system (ie, the primary pacemakers of the heart); however, when vessels to the conduction system do not arise from the right coronary artery, they originate from the left side instead.

### Question 6: Could this patient be a candidate for fibrinolytic “clot-buster” therapy?

**Answer:** At this point, the patient should be evaluated as a candidate for fibrinolytic therapy. A specialized checklist with questions to either include or exclude the patient should be completed. However, this patient most likely will be sent directly to the coronary catheterization lab (if the receiving hospital has one) for visualization of the extent of the occlusion.

### Question 7: Besides nitroglycerin (a vasodilator) and morphine (an analgesic), what type of medication could benefit this patient now?

**Answer:** A beta blocker may be of value for a patient with these signs and symptoms. Recall that in the regulation of heart function, beta effects result in increased heart rate, cardiac conduction, and contractility, all of which are stressing the patient's myocardium and increasing oxygen demand. A beta blocker helps to block the stimulation of beta-receptors and reduce the stress and oxygen demand on the heart.