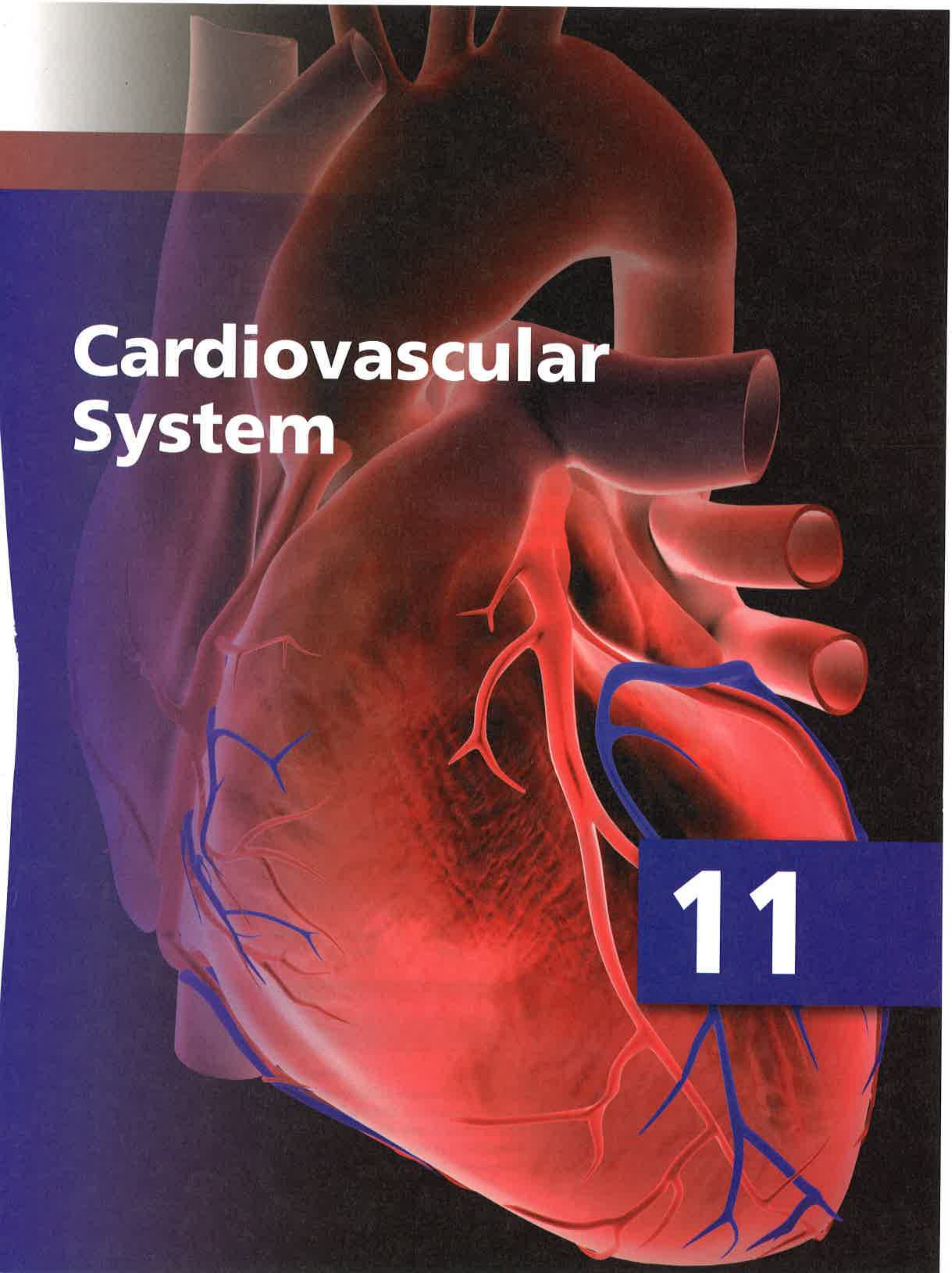
Cardiovascular System

11



INTRODUCTION

Body cells are dependent on a constant supply of nutrients and oxygen. When the supplies are delivered and then chemically combined, they release the energy necessary to do the work of each cell. How does the body ensure that oxygen and food will be delivered to all of its cells? The cardiovascular system, consisting of the heart (a powerful muscular pump) and blood vessels (fuel line and transportation network), performs this important work. This chapter explores terminology related to the heart and blood vessels.

BLOOD VESSELS AND THE CIRCULATION OF BLOOD

BLOOD VESSELS

There are three types of blood vessels in the body: **arteries, veins,** and **capillaries.**

Arteries are large blood vessels that carry blood away from the heart. Their walls are lined with connective tissue, muscle tissue, and elastic fibers, with an innermost layer of epithelial cells called **endothelium.** Endothelial cells, found in all blood vessels, secrete factors that affect the size of blood vessels, reduce blood clotting, and promote the growth of blood vessels. Because arteries carry blood away from the heart, they must be strong enough to withstand the high pressure of the pumping action of the heart. Their elastic walls allow them to expand as the heartbeat forces blood into the arterial system throughout the body.

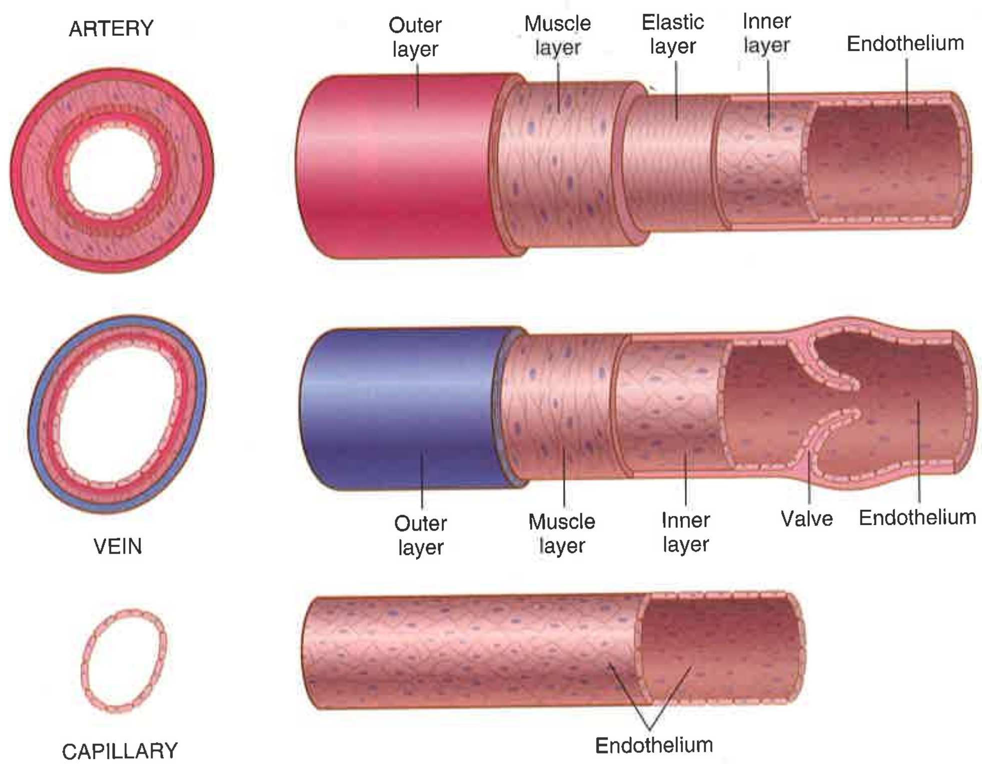


FIGURE 11–1 **Blood vessels.** Observe the differences in thickness of walls among an artery, a vein, and a capillary. All three vessels are lined with endothelium. Endothelial cells actively secrete substances that prevent clotting and regulate the tone of blood vessels. Examples of endothelial secretions are endothelium-derived relaxing factor (EDRF) and endothelin (a vasoconstrictor). (Portions modified from Damjanov I: Pathology for the Health-Related Professions, 3rd ed., Philadelphia, Saunders, 2006, p. 139.)

Smaller branches of arteries are **arterioles.** Arterioles are thinner than arteries and carry the blood to the tiniest of blood vessels, the capillaries.

Capillaries have walls that are only one endothelial cell in thickness. These delicate, microscopic vessels carry nutrient-rich, oxygenated blood from the arteries and arterioles to the body cells. Their thin walls allow passage of oxygen and nutrients out of the bloodstream and into cells. There, the nutrients are burned in the presence of oxygen (catabolism) to release energy. At the same time, waste products such as carbon dioxide and water pass out of cells and into the thin-walled capillaries. Waste-filled blood then flows back to the heart in small **venules,** which combine to form larger vessels called veins.

Veins have thinner walls compared with arteries. They conduct blood (that has given up most of its oxygen) toward the heart from the tissues. Veins have little elastic tissue and less connective tissue than that typical of arteries, and blood pressure in veins is extremely low compared with pressure in arteries. In order to keep blood moving back toward the heart, veins have **valves** that prevent the backflow of blood and keep the blood moving in one direction. Muscular action also helps the movement of blood in veins. Figure 11-1 illustrates the differences in blood vessels. Figure 11-2 reviews their characteristics and relationship to one another.

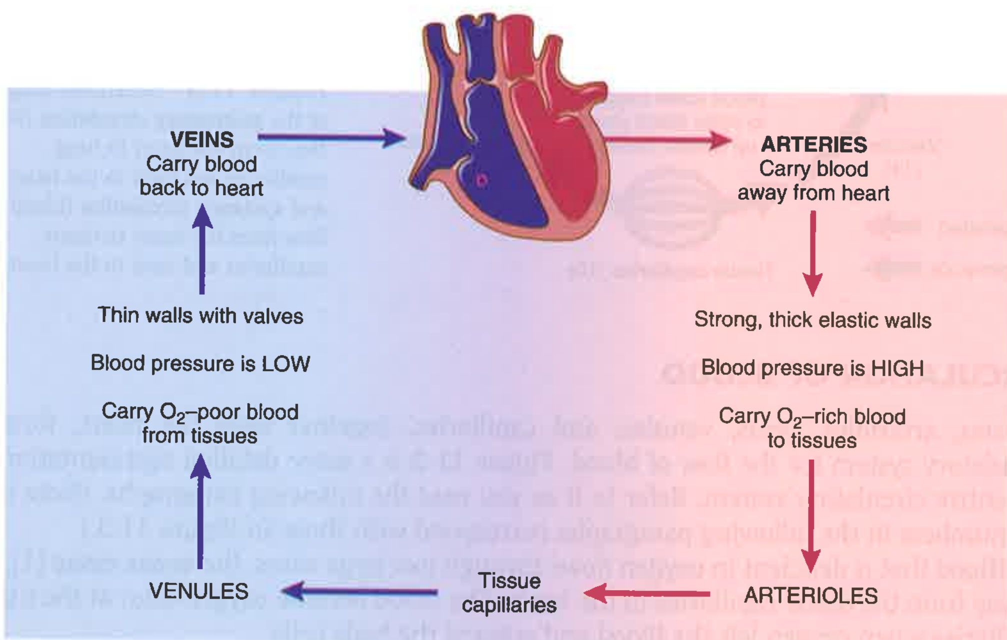


FIGURE 11–2 **Relationship and characteristics of blood vessels.**

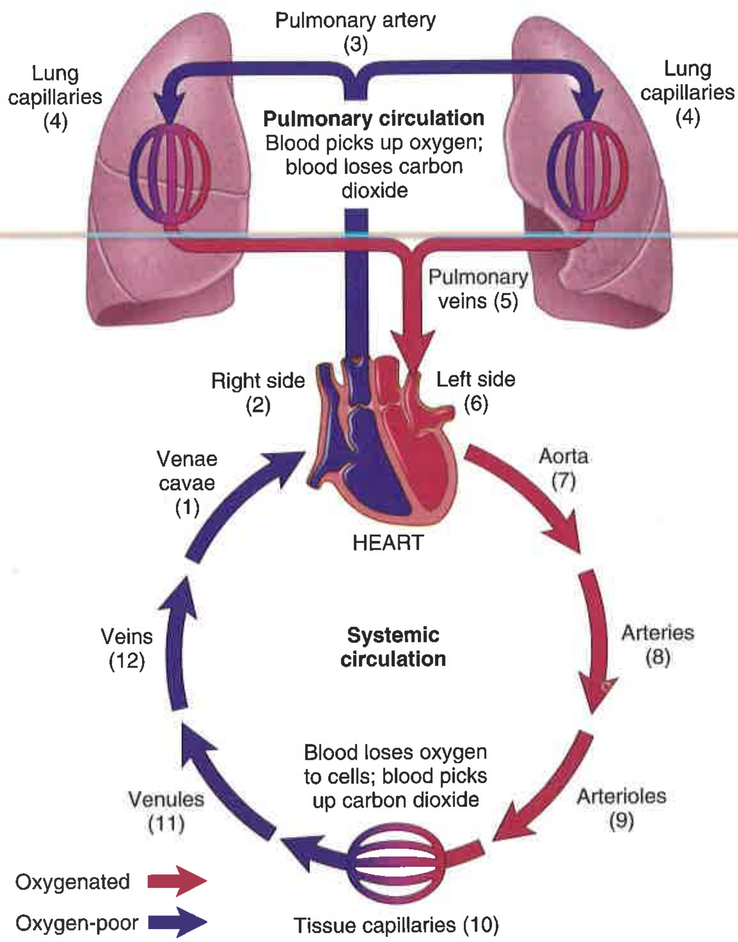


FIGURE 11–3 Schematic diagram of the **pulmonary circulation** (blood flow from the heart to lung capillaries and back to the heart) and **systemic circulation** (blood flow from the heart to tissue capillaries and back to the heart).

CIRCULATION OF BLOOD

Arteries, arterioles, veins, venules, and capillaries, together with the heart, form a circulatory system for the flow of blood. Figure 11-3 is a more detailed representation of the entire circulatory system. Refer to it as you read the following paragraphs. (Note that the numbers in the following paragraphs correspond with those in Figure 11-3.)

Blood that is deficient in oxygen flows through two large veins, the **venae cavae** [1], on its way from the tissue capillaries to the heart. The blood became oxygen-poor at the tissue capillaries when oxygen left the blood and entered the body cells.

Oxygen-poor blood enters the **right side of the heart** [2] and travels through that side and into the **pulmonary artery** [3], a vessel that divides in two: one branch leading to the left lung, the other to the right lung. The arteries continue dividing and subdividing within the lungs, forming smaller and smaller vessels (arterioles) and finally reaching the **lung capillaries** [4]. The pulmonary artery is unusual in that it is the only artery in the body that carries blood deficient in oxygen.

While passing through the lung (pulmonary) capillaries, blood absorbs the oxygen that entered the body during inhalation. The newly oxygenated blood next returns immediately to the heart through **pulmonary veins** [5]. The pulmonary veins are unusual in that they are the only veins in the body that carry oxygen-rich **(oxygenated)** blood. The circulation of blood through the vessels from the heart to the lungs and then back to the heart again is the **pulmonary circulation.**

Oxygen-rich blood enters the **left side of the heart** [6] from the pulmonary veins. The muscles in the left side of the heart pump the blood out of the heart through the largest single artery in the body, the **aorta** [7]. The aorta moves up at first (ascending aorta) but then arches over dorsally and runs downward (descending aorta) just in front of the vertebral column. The aorta divides into numerous branches called **arteries** [8] that carry the oxygenated blood to all parts of the body. The names of some of these arterial branches will be familiar to you: brachial (brachi/o means arm), axillary, splenic, gastric, and renal arteries. The **carotid** arteries supply blood to the head and neck.

The relatively large arterial vessels branch further to form smaller **arterioles** [9]. The arterioles, still containing oxygenated blood, branch into smaller **tissue capillaries** [10], which are near the body cells. Oxygen leaves the blood and passes through the thin capillary walls to enter the body cells. There, food is broken down, in the presence of oxygen, and energy is released.

This chemical process also releases **carbon dioxide (CO_2)** as a waste product. Carbon dioxide passes out from the cell into the tissue capillaries at the same time that oxygen enters. Thus the blood returning to the heart from tissue capillaries through **venules** [11] and **veins** [12] is filled with carbon dioxide but is depleted of oxygen.

As this oxygen-poor blood enters the heart from the venae cavae, the circuit is complete. The pathway of blood from the heart to the tissue capillaries and back to the heart is the **systemic circulation.**

Figure 11-4 shows the aorta, selected arteries, and pulse points. (The pulse is the beat of the heart as felt through the walls of arteries.)

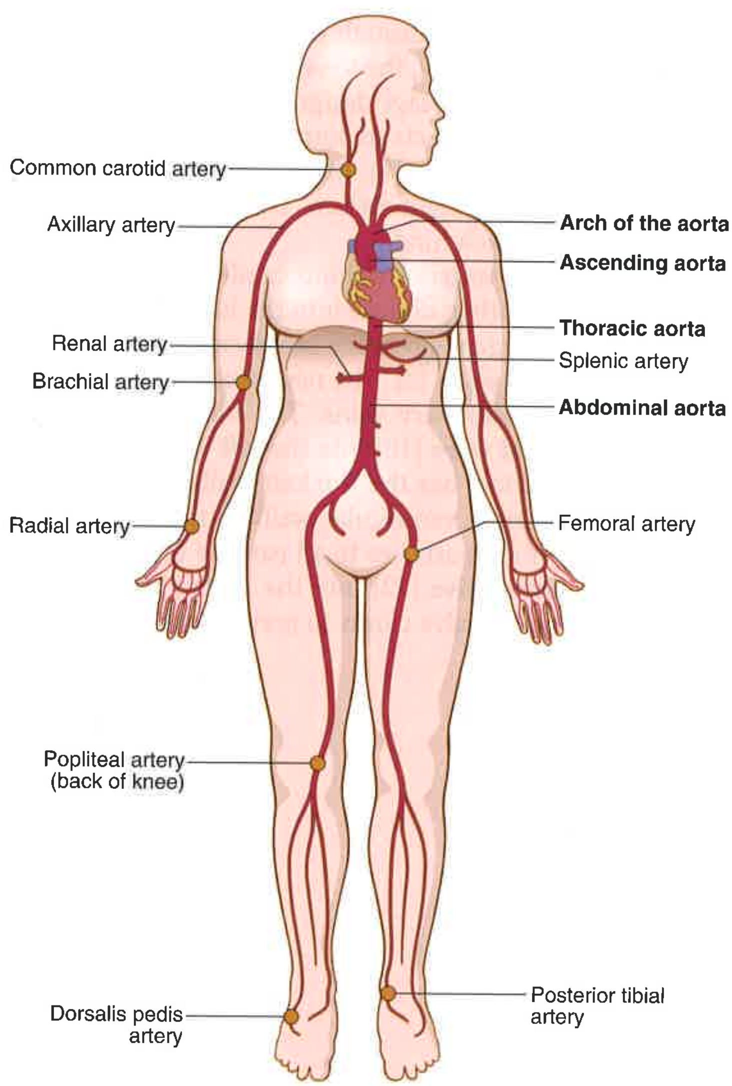


FIGURE 11–4 The aorta and arteries. *Solid gold dots* indicate pulse points in arteries. These are areas in which the pulse (expansion and contraction of a superficial artery) can be felt.

11

ANATOMY OF THE HEART

The human heart weighs less than a pound, is roughly the size of an adult fist, and lies in the thoracic cavity, just behind the breastbone in the mediastinum (between the lungs).

The heart is a pump, consisting of four chambers: two upper chambers called **atria** (*singular:* **atrium**) and two lower chambers called **ventricles.** It is actually a double pump, bound into one organ and synchronized very carefully. Blood passes through each pump in a definite pattern. Pump station number one, on the right side of the heart, sends oxygen-deficient blood to the lungs, where the blood picks up oxygen and releases its carbon dioxide. The newly oxygenated blood returns to the left side of the heart to pump station number two and does not mix with the oxygen-poor blood in pump station number one. Pump station number two then forces the oxygenated blood out to all parts of the body. At the body tissues, the blood loses its oxygen, and on returning to the heart, to pump station number one, blood poor in oxygen (rich in carbon dioxide) is sent out to the lungs to begin the cycle anew.

Label Figure 11-5 as you learn the names of the parts of the heart and the vessels that carry blood to and from it.

Oxygen-poor blood enters the heart through the two largest veins in the body, the **venae cavae.** The **superior vena cava** [1] drains blood from the upper portion of the body, and the **inferior vena cava** [2] carries blood from the lower part of the body.

The venae cavae bring oxygen-poor blood that has passed through all of the body to the **right atrium** [3], the thin-walled upper right chamber of the heart. The right atrium contracts to force blood through the **tricuspid valve** [4] (cusps are the flaps of the valves) into the **right ventricle** [5], the lower right chamber of the heart. The cusps of the tricuspid valve form a one-way passage designed to keep the blood flowing in only one direction. As the right ventricle contracts to pump oxygen-poor blood through the **pulmonary valve** [6] into the **pulmonary artery** [7], the tricuspid valve stays shut, thus preventing blood from pushing back into the right atrium. The pulmonary artery then branches to carry oxygen-deficient blood to each lung.

The blood that enters the lung capillaries from the pulmonary artery soon loses its large quantity of carbon dioxide into the lung tissue, and the carbon dioxide is expelled. At the same time, oxygen enters the capillaries of the lungs and is brought back to the heart via the **pulmonary veins** [8]. The newly oxygenated blood enters the **left atrium** [9] of the heart from the pulmonary veins. The walls of the left atrium contract to force blood through the **mitral valve** [10] into the **left ventricle** [11].

The left ventricle has the thickest walls of all four heart chambers (three times the thickness of the right ventricular wall). It must pump blood with great force so that the blood travels through arteries to all parts of the body. The left ventricle propels the blood through the **aortic valve** [12] into the **aorta** [13], which branches to carry blood all over the body. The aortic valve closes to prevent return of aortic blood to the left ventricle.

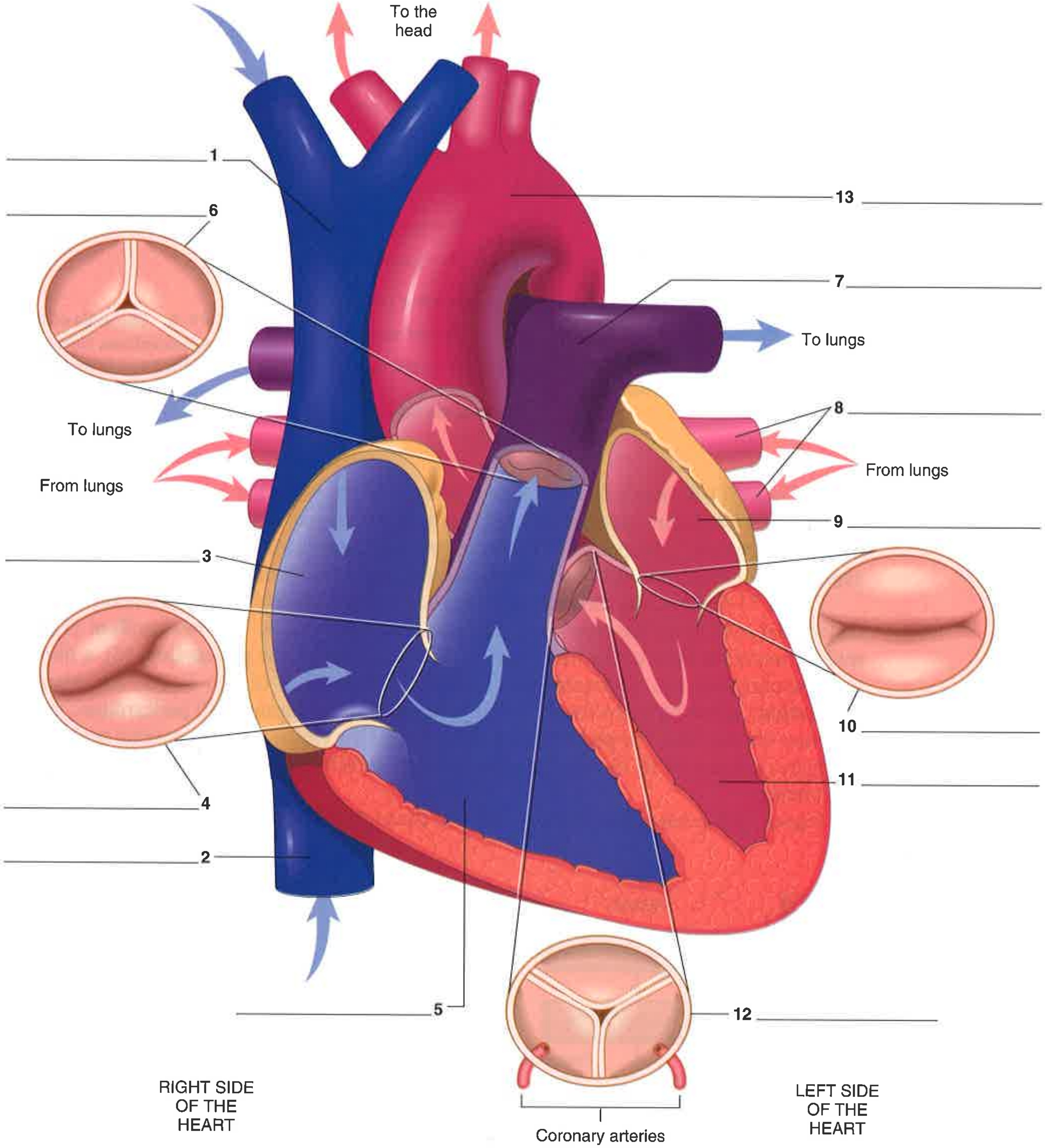


FIGURE 11–5 **Structure of the heart.** *Blue arrows* indicate oxygen-poor blood flow. *Red arrows* show oxygenated blood flow.

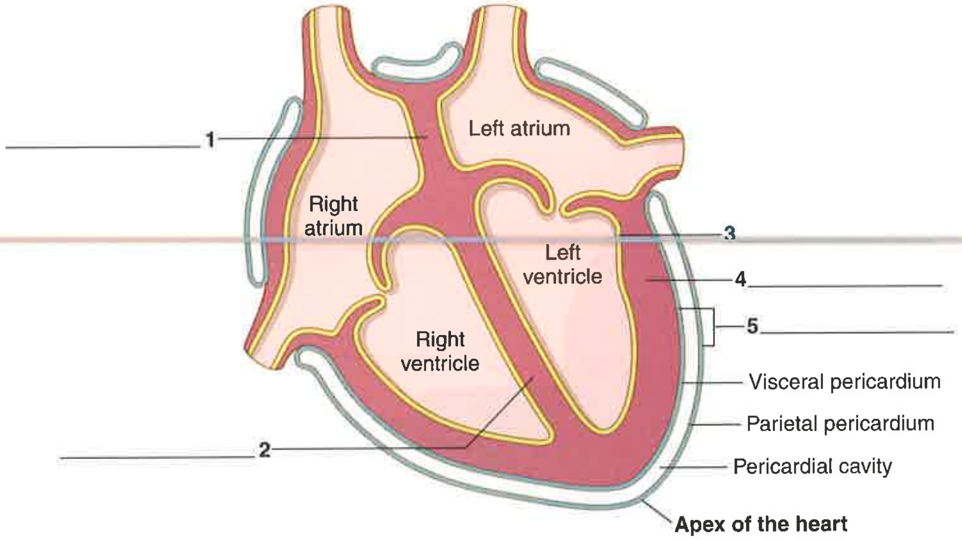


FIGURE 11–6 **The walls of the heart and pericardium.** Note that the apex of the heart is the conical (shaped like a cone) lower tip of the heart.

In Figure 11-6, notice that the four chambers of the heart are separated by partitions called **septa** (*singular:* **septum**). (Label Figure 11-6 as you read these paragraphs.) The **interatrial septum** [1] separates the two upper chambers (atria), and the **interventricular septum** [2], a muscular wall, comes between the two lower chambers (ventricles).

Figure 11-6 shows the three layers of the heart. The **endocardium** [3], a smooth layer of endothelial cells, lines the interior of the heart and heart valves. The **myocardium** [4], the middle, muscular layer of the heart wall, is its thickest layer. The **pericardium** [5], a fibrous and membranous sac, surrounds the heart. It is composed of two layers, the **visceral pericardium,** adhering to the heart, and the **parietal** (parietal means wall) **pericardium,** lining the outer fibrous coat. The **pericardial cavity** (between the visceral and the parietal pericardia) normally contains 10 to 15 mL of pericardial fluid, which lubricates the membranes as the heart beats.

Figure 11-7 reviews the pathway of blood through the heart.

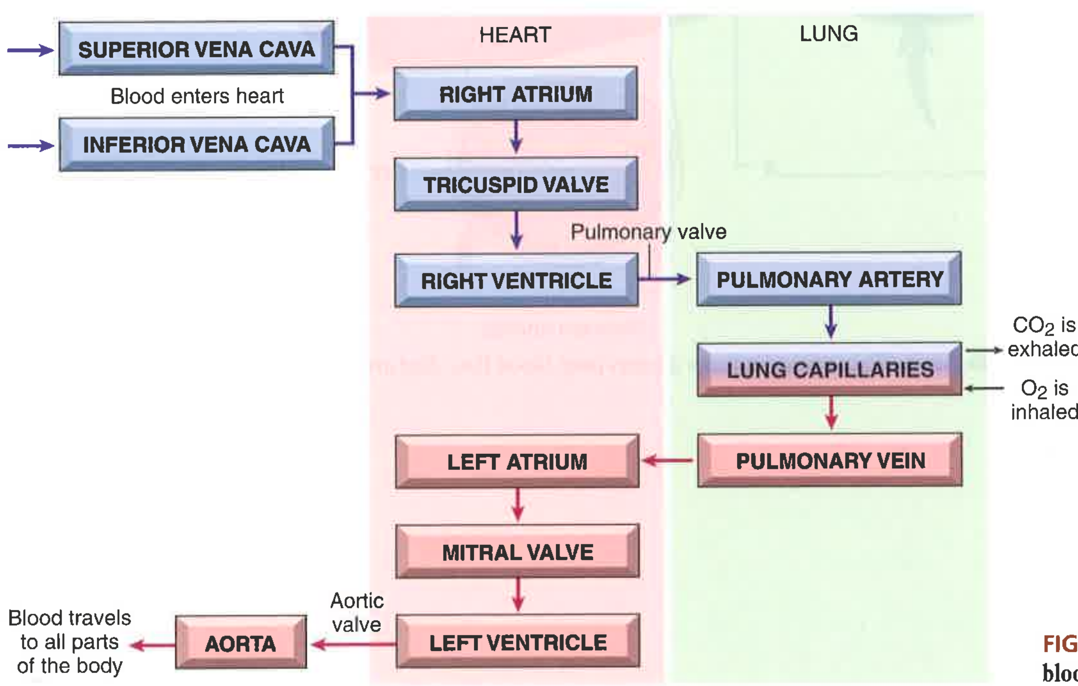


FIGURE 11–7 **Pathway of blood through the heart.**

PHYSIOLOGY OF THE HEART

HEARTBEAT AND HEART SOUNDS

There are two phases of the heartbeat: **diastole** (relaxation) and **systole** (contraction). Diastole occurs when the ventricle walls relax and blood flows into the heart from the venae cavae and the pulmonary veins. The tricuspid and mitral valves open in diastole, as blood passes from the right and left atria into the ventricles. The pulmonary and aortic valves close during diastole (Figure 11-8).

Systole occurs next, as the walls of the right and left ventricles contract to pump blood into the pulmonary artery and the aorta. Both the tricuspid and the mitral valves are closed during systole, thus preventing the flow of blood back into the atria (see Figure 11-8).

This diastole-systole cardiac cycle occurs between 70 and 80 times per minute (100,000 times a day). The heart pumps about 3 ounces of blood with each contraction. This means that about 5 quarts of blood are pumped by the heart in 1 minute (75 gallons an hour and about 2000 gallons a day).

Closure of the heart valves is associated with audible sounds, such as "lubb-dubb," which can be heard on listening to a normal heart with a stethoscope. The "lubb" is associated with closure of the tricuspid and mitral valves at the beginning of systole, and the "dubb" with the closure of the aortic and pulmonary valves at the end of systole. The "lubb" sound is called the first heart sound (S_1) and the "dubb" is the second heart sound (S_2) because the normal cycle of the heartbeat starts with the beginning of systole. Sometimes the flow of blood through the valves can produce an abnormal swishing sound known as a **murmur.**

CONDUCTION SYSTEM OF THE HEART

What keeps the heart at its perfect rhythm? Although the heart has nerves that affect its rate, they are not primarily responsible for its beat. The heart starts beating in the embryo before it is supplied with nerves, and continues to beat in experimental animals even when the nerve supply is cut.

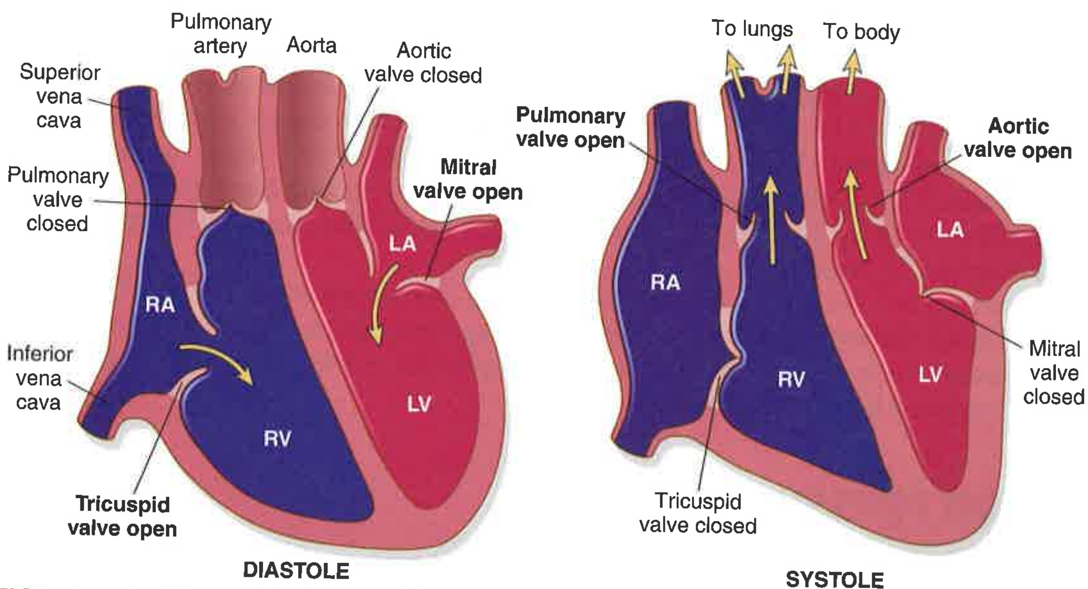


FIGURE 11–8 Phases of the heartbeat: diastole and systole. During diastole, the tricuspid and mitral valves are open as blood enters the ventricles. During systole, the pulmonary and aortic valves are open as blood is pumped to the pulmonary artery and aorta. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

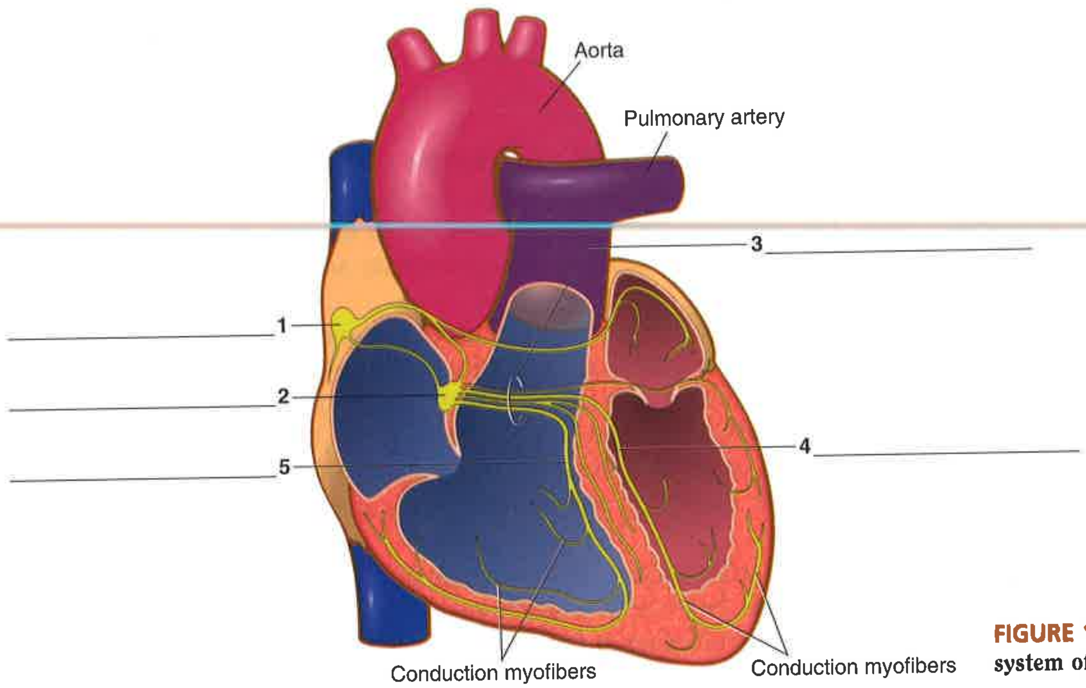


FIGURE 11-9 Conduction system of the heart.

Label Figure 11-9 as you read the following. Primary responsibility for initiating the heartbeat rests with a small region of specialized muscle tissue in the posterior portion of the right atrium, where an electrical impulse originates. This is the **sinoatrial node (SA node)** or **pacemaker** [1] of the heart. The current of electricity generated by the pacemaker causes the walls of the atria to contract and force blood into the ventricles.

Almost like ripples in a pond of water when a stone is thrown, the wave of electricity passes from the pacemaker to another region of the myocardium. This region is within the interatrial septum and is the **atrioventricular node (AV node)** [2]. The AV node immediately sends the excitation wave to a bundle of specialized muscle fibers called the **atrioventricular bundle,** or **bundle of His** [3]. Within the interventricular septum, the bundle of His divides into the **left bundle branch** [4] and **right bundle branch** [5], which form the conduction myofibers that extend through the ventricle walls and contract on stimulation. Thus systole occurs and blood is pumped away from the heart. A short rest period follows, and then the pacemaker begins the wave of excitation across the heart again.

The record used to detect these electrical changes in heart muscle as the heart beats is an **electrocardiogram** (**ECG** or **EKG**). The normal ECG shows five waves, or **deflections,** that represent the electrical changes as a wave of excitation spreads through the heart. The deflections are called **P, QRS,** and **T** waves. Figure 11-10 illustrates P, QRS, and T waves on a normal ECG tracing.

Heart rhythm (originating in the SA node and traveling through the heart) is called **normal sinus rhythm (NSR).** Sympathetic nerves speed up the heart rate during conditions of emotional stress or vigorous exercise. Parasympathetic nerves slow the heart rate when there is no need for extra pumping.

BLOOD PRESSURE

Blood pressure is the force that the blood exerts on the arterial walls. This pressure is measured with a **sphygmomanometer** (Figure 11-11).

The sphygmomanometer consists of a rubber bag inside a cloth cuff that is wrapped around the upper arm, just above the elbow. The rubber bag is inflated with air using a

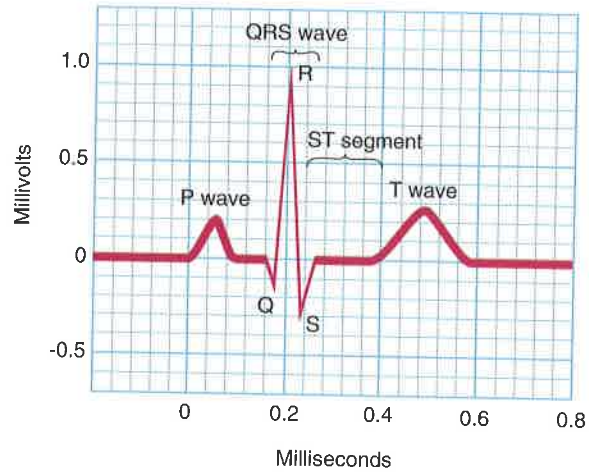


FIGURE 11–10 **Electrocardiogram. P wave** = spread of excitation wave over the atria just before contraction; **QRS wave** = spread of excitation wave over the ventricles as the ventricles contract; **T wave** = electrical recovery and relaxation of ventricles. A heart attack or myocardial infarction (MI) can be recognized by an elevation in the **ST segment** of the electrocardiographic tracing. Thus, one type of MI is an ST elevation MI **(STEMI)**. (From Applegate MS: The Anatomy and Physiology Learning System, 2nd ed., Philadelphia, Saunders, 2000, p. 250.)

hand bulb pump. As the bag is pumped up, the pressure within it increases and is measured on a recording device attached to the cuff.

The brachial artery in the upper arm is compressed by the air pressure in the bag. When there is sufficient air pressure in the bag to stop the flow of blood, the pulse in the lower arm (where the observer is listening with a stethoscope) drops.

Air is then allowed to escape from the bag and the pressure is lowered slowly, allowing the blood to begin to make its way through the gradually opening artery. At the point when the person listening with the stethoscope first hears the sounds of the pulse beats, the reading on the device attached to the cuff shows the higher, systolic, blood pressure (pressure in the artery when the left ventricle is contracting to force the blood into the aorta and other arteries).

As air continues to escape, the sounds become progressively louder. Finally, when a change in sound from loud to soft occurs, the observer makes note of the pressure on the recording device. This is the diastolic blood pressure (pressure in the artery when the ventricles relax and the heart fills, receiving blood from the venae cavae and pulmonary veins).

Blood pressure is expressed as a fraction—for example, 120/80 mm Hg, in which the upper (120) is the systolic pressure and the lower number (80) is the diastolic pressure.

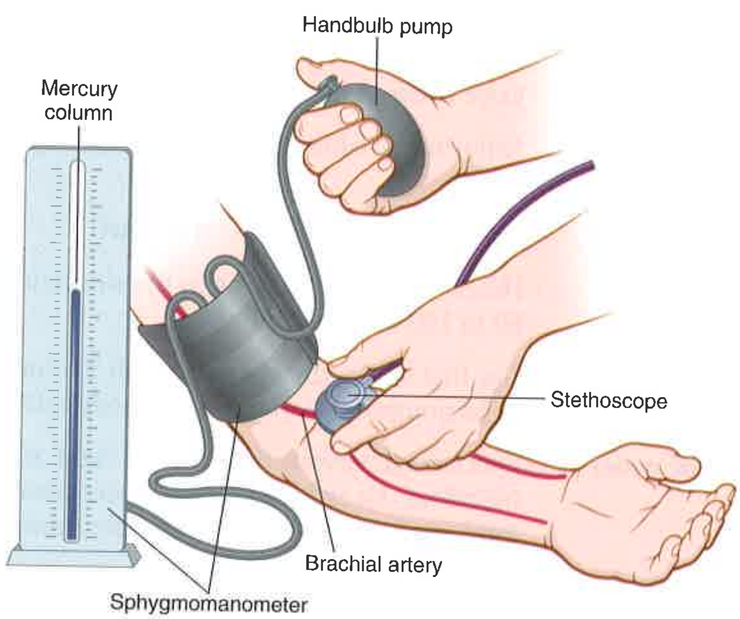


FIGURE 11–11 **Measurement of blood pressure** with a sphygmomanometer and stethoscope.

VOCABULARY

This list reviews new terms introduced in the text. Short definitions reinforce your understanding of the terms. See page 448 of this chapter for pronunciation of terms.

aorta	Largest artery in the body.
arteriole	Small artery.
artery	Largest type of blood vessel; carries blood away from the heart to all parts of the body. Notice that artery and away begin with an "a."
atrioventricular bundle (bundle of His)	Specialized muscle fibers connecting the atria with the ventricles and transmitting electrical impulses between them. His is pronounced "hiss."
atrioventricular node (AV node)	Specialized tissue in the wall between the atria. Electrical impulses pass from the pacemaker (SA node) through the AV node and the atrioventricular bundle or bundle of His toward the ventricles.
atrium (*plural*: **atria**)	One of two upper chambers of the heart.
capillary	Smallest blood vessel. Materials pass to and from the bloodstream through the thin capillary walls.
carbon dioxide (CO_2)	Gas (waste) released by body cells, transported via veins to the heart, and then to the lungs for exhalation.
coronary arteries	Blood vessels that branch from the aorta and carry oxygen-rich blood to the heart muscle.
deoxygenated blood	Blood that is oxygen-poor.
diastole	Relaxation phase of the heartbeat. From the Greek *diastole*, dilation.
electrocardiogram	Record of the electricity flowing through the heart. The electricity is represented by waves or deflections called P, QRS, or T.
endocardium	Inner lining of the heart.
endothelium	Innermost lining of blood vessels.
mitral valve	Valve between the left atrium and the left ventricle; bicuspid valve.
murmur	Abnormal swishing sound caused by improper closure of the heart valves.
myocardium	Muscular, middle layer of the heart.
normal sinus rhythm	Heart rhythm originating in the sinoatrial node with a resting rate of 60 to 100 beats per minute.
oxygen	Gas that enters the blood through the lungs and travels to the heart to be pumped via arteries to all body cells.
pacemaker (sinoatrial node)	Specialized nervous tissue in the right atrium that begins the heartbeat. An artificial cardiac pacemaker is an electronic apparatus implanted in the chest to stimulate heart muscle that is weak and not functioning.

pericardium	Double-layered membrane surrounding the heart.
pulmonary artery	Artery carrying oxygen-poor blood from the heart to the lungs.
pulmonary circulation	Flow of blood from the heart to the lungs and back to the heart.
pulmonary valve	Valve positioned between the right ventricle and the pulmonary artery.
pulmonary vein	One of two pairs of vessels carrying oxygenated blood from the lungs to the left atrium of the heart.
pulse	Beat of the heart as felt through the walls of the arteries.
septum (*plural*: **septa**)	Partition or wall dividing a cavity; such as between the right and left atria (interatrial septum) and right and left ventricles (interventricular septum).
sinoatrial node (SA node)	Pacemaker of the heart.
sphygmomanometer	Instrument to measure blood pressure.
systemic circulation	Flow of blood from body tissue to the heart and then from the heart back to body tissues.
systole	Contraction phase of the heartbeat. From the Greek *systole*, a contracting.
tricuspid valve	Located between the right atrium and the right ventricle; it has three (tri-) leaflets, or cusps.
valve	Structure in veins or in the heart that temporarily closes an opening so that blood flows in only one direction.
vein	Thin-walled vessel that carries blood from body tissues and lungs back to the heart. Veins contain valves to prevent backflow of blood.
vena cava (*plural*: **venae cavae**)	Largest vein in the body. The superior and inferior venae cavae return blood to the right atrium of the heart.
ventricle	One of two lower chambers of the heart.
venule	Small vein.

TERMINOLOGY

Write the meaning of the medical term in the space provided.

COMBINING FORM	MEANING	TERMINOLOGY	MEANING
angi/o	vessel	angiogram	______________________
		angioplasty	______________________
aort/o	aorta	aortic stenosis	______________________

11

COMBINING FORM	MEANING	TERMINOLOGY	MEANING
arter/o, arteri/o	artery	arteriosclerosis	
		arterial anastomosis *From the Greek* anastomoien, *providing a mouth.*	
		arteriography	
		endarterectomy *See page 430.*	
ather/o	yellowish plaque, fatty substance (Greek *athere* means porridge)	atheroma *The suffix -oma means mass or collection. Atheromas are collections of plaque that protrude into the* ***lumen*** *(opening) of an artery, weakening the muscle lining.*	
		atherosclerosis *The major form of arteriosclerosis in which deposits of yellow plaque (atheromas) containing cholesterol and lipids are found within the lining of the artery (Figure 11-12).*	
		atherectomy	
atri/o	atrium, upper heart chamber	atrial	
		atrioventricular	
brachi/o	arm	brachial artery	
cardi/o	heart	cardiomegaly	
		cardiomyopathy *One type of cardiomyopathy is* ***hypertrophic cardiomyopathy****—abnormal thickening of heart muscle, usually in the left ventricle. The ventricle has to work harder to pump blood. The condition may be inherited or develop over time because of high blood pressure or aging. Often the cause is unknown (idiopathic).*	

FIGURE 11–12 **Atherosclerosis.** *Arrow* points to accumulated plaque in lumen of an artery. (From Kumar V, Cotran RS, Robbins SL: Robbins Basic Pathology, 6th ed., Philadelphia, 1997, Saunders; courtesy Sid Murphree, MD, Department of Pathology, University of Texas Southwestern Medical School.)

ather/o, arteri/o, arthr/o

These three combining forms are easily confused.

ather/o = yellowish plaque
arteri/o = artery
arthr/o = joint

COMBINING FORM	MEANING	TERMINOLOGY	MEANING
		brady<u>cardi</u>a _______________ *Slower than 60 beats per minute. Normal pulse is about 60 to 80 beats per minute.*	
		tachy<u>cardi</u>a _______________ *Faster than 100 beats per minute. Supraventricular tachycardia (SVT) involves rapid beats coming from the atria (above the ventricles) and causing palpitation (abnormal sensations in the chest).*	
		<u>cardi</u>ogenic shock _______________ *Results from failure of the heart in its pumping action.* ***Shock*** *is circulatory failure associated with inadequate delivery of oxygen and nutrients to body tissues.*	
cholesterol/o	cholesterol (a lipid substance)	hyper<u>cholesterol</u>emia _______________ ***Statins*** *are drugs that work by blocking a key enzyme in the production of cholesterol by the liver.*	
coron/o	heart	<u>coron</u>ary arteries _______________ *These arteries come down over the top of the heart like a crown (corona); see Figure 11-22A, page 426.*	
cyan/o	blue	<u>cyan</u>osis _______________ *This bluish discoloration of the skin indicates diminished oxygen content of the blood.*	
myx/o	mucus	<u>myx</u>oma _______________ *A benign tumor derived from connective tissue, with cells embedded in soft mucoid stromal tissue. These rare tumors occur most frequently in the left atrium.*	
ox/o	oxygen	hyp<u>ox</u>ia _______________ *Inadequate oxygen in tissues.* ***Anoxia*** *is an extreme form of hypoxia.*	
pericardi/o	pericardium	<u>pericardi</u>ocentesis _______________	
phleb/o	vein	<u>phleb</u>otomy _______________ *A phlebotomist is trained in opening veins for phlebotomy.*	
		thrombo<u>phleb</u>itis _______________ *Often shortened to phlebitis. If the affected vein is deep within a muscle, the condition is* ***deep vein thrombosis (DVT).***	
rrhythm/o	rhythm	a<u>rrhythm</u>ia _______________ ***Dysrhythmia*** is also used to describe an abnormal heart rhythm. Notice that one "r" is dropped.	
sphygm/o	pulse	<u>sphygm</u>omanometer _______________ *A manometer measures pressure.*	
steth/o	chest	<u>steth</u>oscope _______________ *A misnomer because the examination is by ear, not by eye.* ***Auscultation*** *means listening to sounds within the body, typically using a stethoscope.*	

COMBINING FORM	MEANING	TERMINOLOGY	MEANING
thromb/o	clot	thrombolysis	
valvul/o, valv/o	valve	valvuloplasty *A balloon-tipped catheter dilates a cardiac valve.*	
		mitral valvulitis *Commonly associated with rheumatic fever, an inflammatory disease caused by inadequate treatment of a streptococcal infection. An autoimmune reaction occurs, leading to inflammation and damage to heart valves. (See Figure 11-19, page 420.)*	
		valvotomy	
vas/o	vessel	vasoconstriction *Constriction means to tighten or narrow.*	
		vasodilation	
vascul/o	vessel	vascular	
ven/o, ven/i	vein	venous *A venous cutdown is a small surgical incision to permit access to a collapsed vein. An intravenous infusion is delivery of fluids into a vein.*	
		venipuncture *This procedure is performed for phlebotomy or to start an intravenous infusion.*	
ventricul/o	ventricle, lower heart chamber	interventricular septum	

PATHOLOGY: THE HEART AND BLOOD VESSELS

HEART

arrhythmias

Abnormal heart rhythms (dysrhythmias).

Arrhythmias are problems with the conduction or electrical system of the heart. More than 4 million Americans have recurrent cardiac arrhythmias.

Examples of cardiac arrhythmias are:

1. **bradycardia and heart block (atrioventricular block)**

Failure of proper conduction of impulses from the SA node through the AV node to the atrioventricular bundle (bundle of His).

Damage to the SA node may cause its impulses to be too weak to activate the AV node and impulses fail to reach the ventricles. The heart beats slowly and bradycardia results. If the failure occurs only occasionally, the heart misses a beat in a rhythm at regular intervals (partial heart block). If no impulses reach the AV node from the SA node, the ventricles contract slower than the atria and are not coordinated. This is complete heart block.

Right and left bundle branch block (RBBB and LBBB) are common types of heart block. They involve delay or failure of impulses traveling through the right and left bundle branches to the ventricles.

Implantation of an artificial **cardiac pacemaker** overcomes arrhythmias and keeps the heart beating at the proper rate. The pacemaker power source is a generator that contains a computer and lithium battery. It is implanted under the skin just below the collarbone, with leads (wires) to both chambers, usually on the right side of the heart. A newer type of pacemaker, called a **biventricular pacemaker,** treats delays and abnormalities in ventricular contractions (as in LBBB) and also can improve symptoms of congestive heart failure (Figure 11-13).

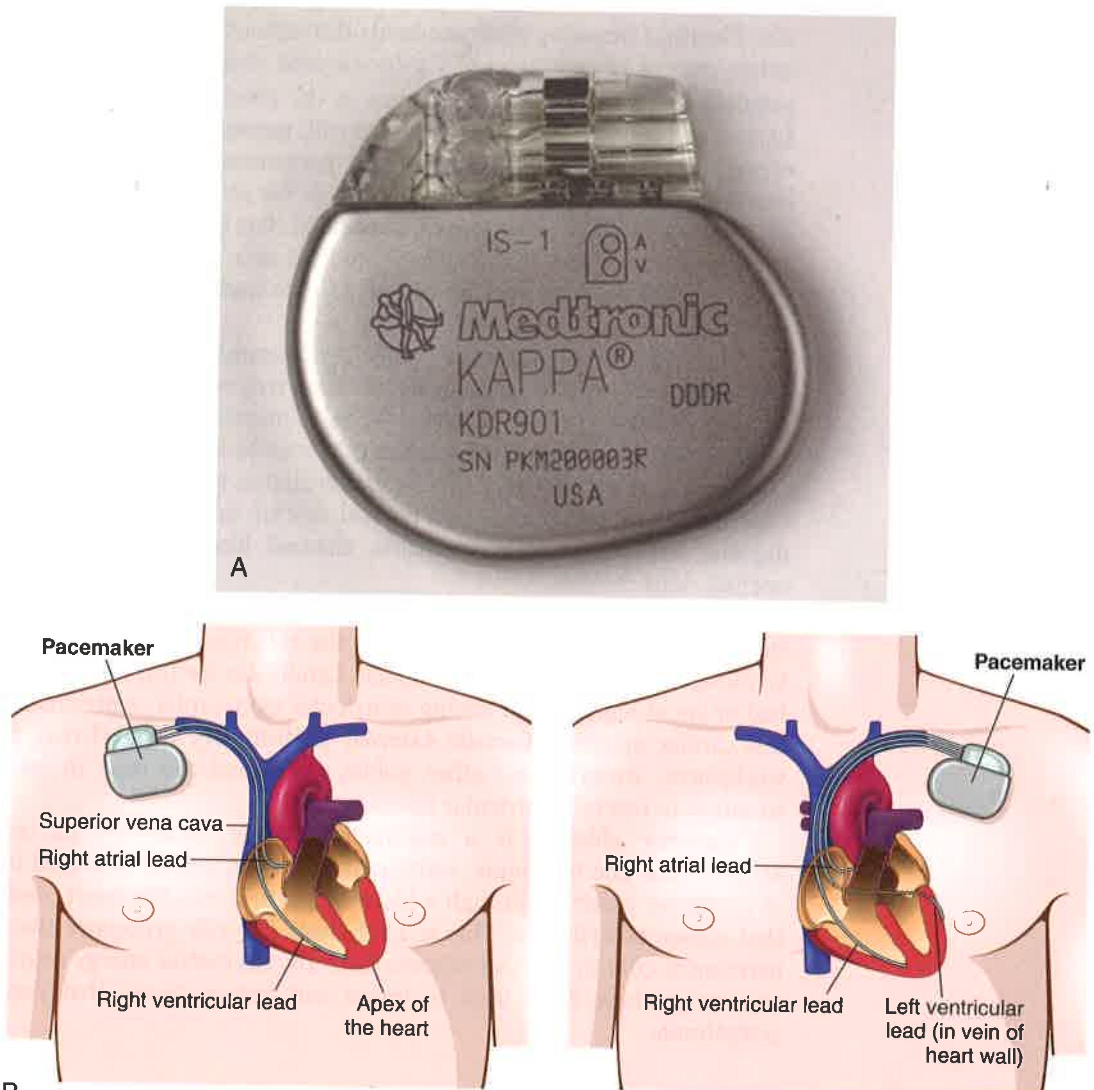


FIGURE 11–13 **(A) A dual-chamber, rate-responsive pacemaker** *(actual size shown)* is designed to detect body movement and automatically increase or decrease paced heart rates based on levels of physical activity. **(B) Cardiac pacemaker** with leads in the right atrium and right ventricle enable it to sense and pace in both heart chambers. **(C) Biventricular pacemaker** with leads in the right atrium and the right and left ventricles to synchronize ventricular contractions. (**A,** From Lewis SM, Heitkemper MM, Dirksen SR: Medical-Surgical Nursing, 6th ed., St. Louis, Mosby, 2004, p. 877.)

How Does a Pacemaker Work?

The pacemaker leads (wires) detect the heart's own electrical activity and transmit that information to the generator (computer). The computer analyzes the heart's signals and decides when and where to pace. If the rate is slow, the generator emits a signal to stimulate contraction and increase the rate. Pacemakers with multiple leads can pace the atrium and ventricle in proper sequence. Rate-responsive pacemakers have sensors that detect body movement and breathing to then determine the best heart rate.

2. flutter

Rapid but regular contractions, usually of the atria.

Heart rhythm may reach up to 300 beats per minute. Atrial flutter is often symptomatic of heart disease and frequently requires treatment such as medication, electrical cardioversion, or catheter ablation (see below under fibrillation).

3. fibrillation

Very rapid, random, inefficient, and irregular contractions of the heart (350 beats or more per minute).

Atrial fibrillation (AF) is the most common type of cardiac arrhythmia, affecting 5% to 10% of 70- to 80-year-old people and greater than 15% of individuals in their 80s. Electrical impulses move randomly throughout the atria, causing the atria to quiver instead of contracting in a coordinated rhythm. Common symptoms are **palpitations** (uncomfortable sensations in the chest from missed heartbeats), fatigue, and shortness of breath. Patients with **paroxysmal AF** (irregular heartbeats occur periodically and episodically) and **permanent** or **persistent AF** (irregular heartbeats continue indefinitely) are at risk for stroke because ineffective atrial contractions can lead to the formation of blood clots in the left atrial appendage (the area where clots form) that may travel to the brain. Also, sometimes AF can make the heart beat very fast for long periods of time leading to weakening of the heart muscle.

In ventricular fibrillation (VF), electrical impulses move randomly throughout the ventricles. This life-threatening situation may result in sudden cardiac death or cardiac arrest (sudden stoppage of heart movement) unless help is provided immediately. If treatment is immediate, VF can be interrupted with defibrillation (application of an electrical shock). Defibrillation stops electrical activity in the heart for a brief moment so that normal rhythm takes over. Medications such as **digoxin, beta-blockers,** and **calcium channel blockers** convert fibrillation to normal sinus rhythm.

An **implantable cardioverter-defibrillator (ICD)** is a small electrical device that is implanted inside the chest (near the collarbone) to sense arrhythmias and terminate them with an electric shock. Candidates for ICDs are people who have had or are at high risk for having ventricular tachycardia, ventricular fibrillation, and cardiac arrest. **Automatic external defibrillators (AEDs)** may be found in workplaces, airports, and other public places and are used in an emergency situation to reverse ventricular fibrillation.

Catheter ablation is a minimally invasive treatment to treat cardiac arrhythmias. The technique, using radiofrequency energy delivered from the tip of a catheter inserted through a blood vessel and into the heart, destroys tissue that causes arrhythmias. This is a relatively low-risk procedure that provides a permanent cure in most situations. Recently, alternative energy sources, such as cryoenergy, have been used to freeze and destroy tissue that may cause an arrhythmia.

Palpitation/Palpation

Don't confuse *palpitation* with *palpation,* which means to touch, feel, or examine with the hands and fingers.

congenital heart disease — **Abnormalities in the heart at birth.**

The following conditions are congenital anomalies resulting from some failure in the development of the fetal heart.

1. **coarctation of the aorta (CoA)** — **Narrowing (coarctation) of the aorta.**

   Figure 11-14A shows coarctation of the aorta. Surgical treatment consists of removal of the constricted region and end-to-end anastomosis of the aortic segments.

2. **patent ductus arteriosus (PDA)** — **Passageway (ductus arteriosus) between the aorta and the pulmonary artery remains open (patent) after birth.**

   The ductus arteriosus normally closes after birth, but in this congenital condition it remains open (see Figure 11-14B), resulting in the flow of oxygenated blood from the aorta into the pulmonary artery. PDA occurs in premature infants, causing cyanosis, fatigue, and rapid breathing. Although the defect often closes on its own within months after birth, treatment may be necessary if patency continues. Treatments include use of a drug (indomethacin) to promote closure; surgery via catheterization (with coil embolization to "plug" the ductus); and ligation (tying off) via a small incision between the ribs.

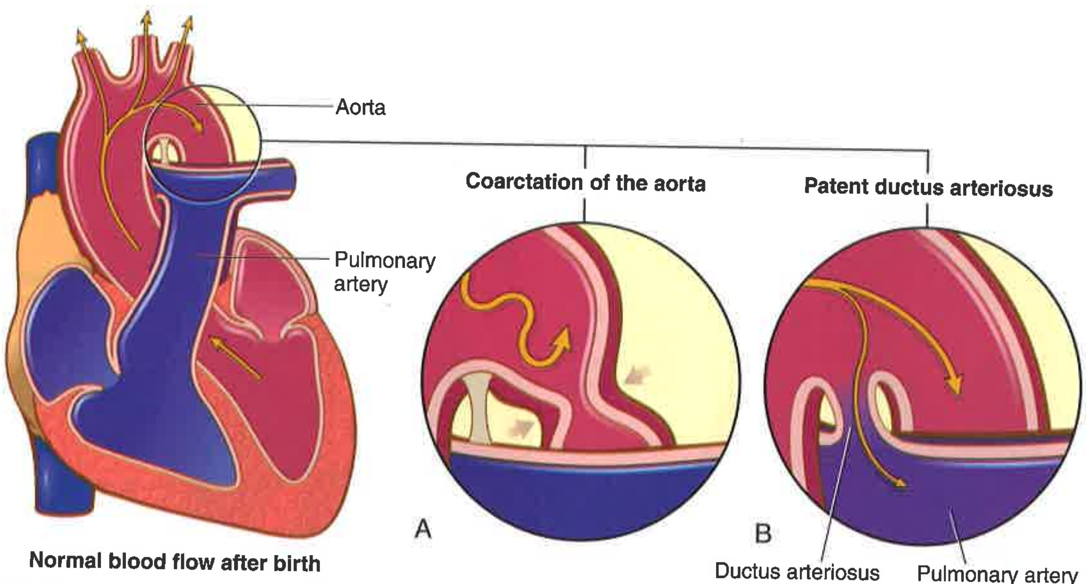


FIGURE 11-14 **(A) Coarctation of the aorta.** Localized narrowing of the aorta reduces the supply of blood to the lower part of the body. **(B) Patent ductus arteriosus.** The ductus arteriosus fails to close after birth, and blood from the aorta flows through it into the pulmonary artery.

3. septal defects

Small holes in the wall between the atria (atrial septal defects) or the ventricles (ventricular septal defects). Figure 11-15A shows a ventricular septal defect.

Although many septal defects close spontaneously, others require open heart surgery to close the hole between heart chambers. Septal defects are closed while maintaining a general circulation by means of a **heart-lung machine.** This machine, connected to the patient's circulatory system, relieves the heart and lungs of pumping and oxygenation functions during heart surgery.

Alternatively, septal defects may be repaired with a less invasive catheter technique using a device (Amplatzer device) in the defect to close it.

4. tetralogy of Fallot (fă-LŌ)

Congenital malformation involving four (tetra-) distinct heart defects.

The condition, named for Etienne Fallot, the French physician who described it in 1888, is illustrated in Figure 11-15B. The four defects are:

- **Pulmonary artery stenosis.** Pulmonary artery is narrow or obstructed.
- **Ventricular septal defect.** Large hole between two ventricles lets venous blood pass from the right to the left ventricle and out to the aorta without oxygenation.
- **Shift of the aorta to the right.** Aorta overrides the interventricular septum. Oxygen-poor blood passes from the right ventricle to the aorta.
- **Hypertrophy of the right ventricle.** Myocardium works harder to pump blood through a narrowed pulmonary artery.

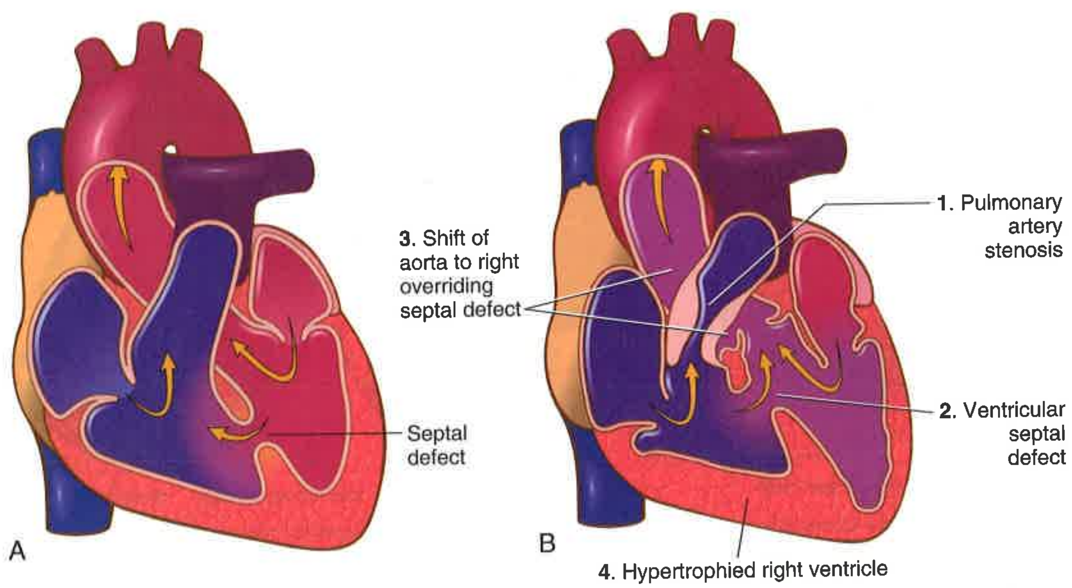


FIGURE 11–15 **(A) Ventricular septal defect.** A hole in the ventricular septum causes blood to flow from the left ventricle to the right and into the lings via the pulmonary artery. **(B) Tetralogy of Fallot** showing the four defects. The flow of blood is indicated by the *arrows*.

An infant with this condition is described as a "blue baby" because of the extreme degree of **cyanosis** present at birth. Surgery for tetralogy of Fallot includes a patch closure of the ventricular septal defect and removing obstruction to the outflow at the pulmonary artery.

Other congenital conditions such as **transposition of the great arteries (TGA)** (pulmonary artery arises from the left ventricle and the aorta from the right ventricle) cause cyanosis and hypoxia as well. Surgical correction of TGA involves an arterial switch procedure (pulmonary artery and aorta are reconnected in their proper positions).

congestive heart failure (CHF)

Heart is unable to pump its required amount of blood.

There are two types of congestive heart failure: systolic and diastolic. In **systolic CHF,** left ventricular dysfunction results in a low ejection fraction (the amount of blood that leaves the left ventricle). Less blood is pumped from the heart. In **diastolic CHF,** the heart can contract normally but is "stiff" or less compliant when relaxed or filling with blood. Fluid backs up in the lungs and other parts of the body. The most common cause of diastolic CHF is hypertension.

Symptoms of CHF include shortness of breath, exercise intolerance, and fluid retention. **Pulmonary edema** (fluid accumulation in the lungs) and swelling or edema in the legs, feet, and ankles are common. Treatment includes lowering dietary intake of sodium and the use of diuretics to promote fluid loss.

Angiotensin-converting enzyme (ACE) inhibitors (type I), beta-blockers, and **spironolactone** (increases excretion of water and sodium by the kidney), and **digoxin** are also used.

If drug therapy and lifestyle changes fail to control congestive heart failure, heart transplantation may be the only treatment option. While waiting for a transplant, patients may need a device to assist the heart's pumping. A **left ventricular assist device (LVAD)** is a booster pump implanted in the abdomen, with a cannula (tube) inserted into the left ventricle. It pumps blood out of the heart to all parts of the body. LVAD may be used either as a "bridge to transplant" or as a "destination" therapy when heart transplantation is not possible. Because of the severe shortage of donor hearts, research efforts are directed at developing total artificial hearts.

coronary artery disease (CAD)

Disease of the arteries surrounding the heart.

The coronary arteries are a pair of blood vessels that arise from the aorta and supply oxygenated blood to the heart. After blood leaves the heart via the aorta, a portion is at once led back over the surface of the heart through the coronary arteries.

CAD usually is the result of **atherosclerosis.** This is the deposition of fatty compounds on the inner lining of the coronary arteries (any other artery can be similarly affected). The ordinarily smooth lining of the artery becomes roughened as the atherosclerotic plaque collects in the artery.

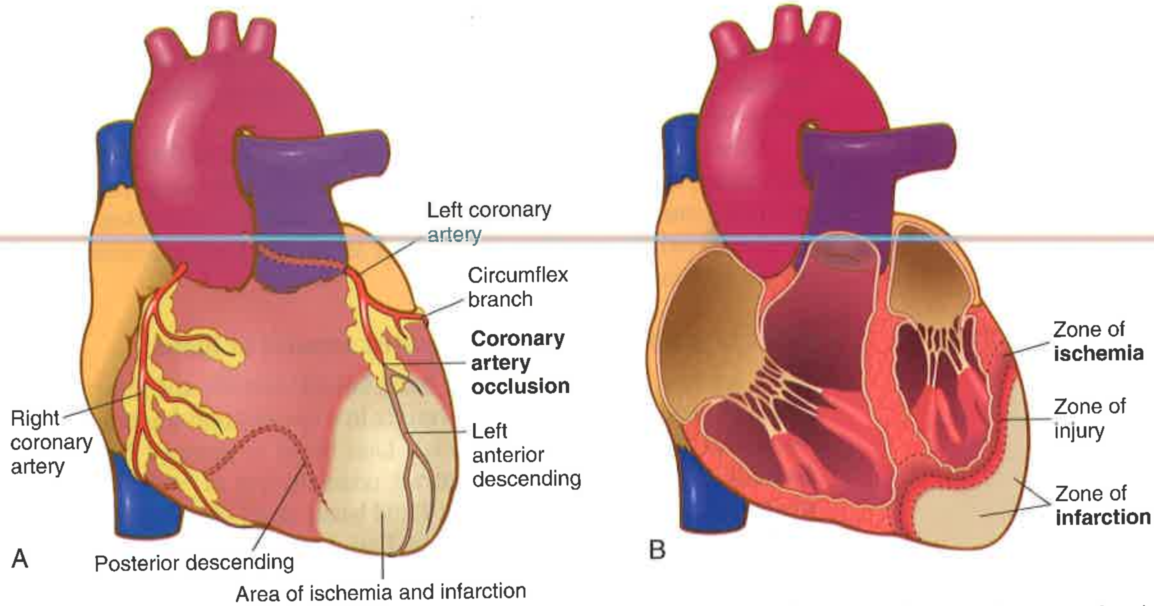


FIGURE 11–16 **(A) Ischemia and infarction** produced by **coronary artery occlusion. (B)** Internal view of the heart showing an area damaged by **myocardial infarction.**

The plaque first causes plugging of the coronary artery. Next, the roughened lining of the artery may rupture or cause abnormal clotting of blood, leading to **thrombotic occlusion** (blocking of the coronary artery by a clot). Blood flow is decreased **(ischemia)** or stopped entirely, leading to death **(necrosis)** of a part of the myocardium. This sequence of events constitutes a **myocardial infarction,** or heart attack, and the area of dead myocardial tissue is known as an infarct. The infarcted area is eventually replaced by scar tissue. Figure 11-16A shows coronary arteries branching from the aorta and illustrates coronary artery occlusion leading to ischemia and infarction of heart muscle. Figure 11-17 is a photograph of myocardium after an acute myocardial infarction.

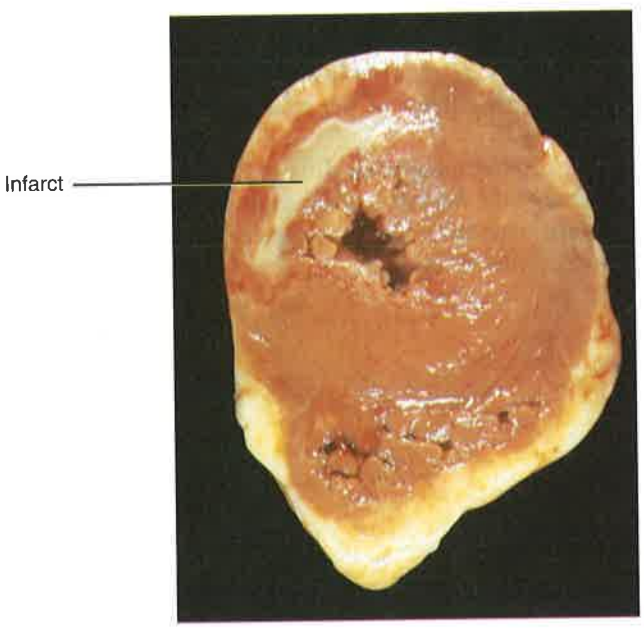


FIGURE 11–17 **Acute myocardial infarction (MI),** 5 to 7 days old. The infarct is visible as a well-demarcated, pale yellow lesion in the posterolateral region of the left ventricle. The border of the infarct is surrounded by a dark red zone of acute inflammation. (From Kumar V, Cotran RS, Robbins SL: Basic Pathology, 7th ed., Philadelphia, Saunders, 2003, p. 369.)

Acute coronary syndromes (ACSs) are conditions caused by myocardial ischemia. These conditions are **unstable angina** (chest pain at rest or chest pain of increasing frequency) and **myocardial infarction** (Figure 11-18).

Patients with ACSs benefit from early angiography (x-ray imaging of coronary arteries) and PCI (percutaneous coronary intervention with a balloon catheter and stents) or CABG (coronary artery bypass grafting) to improve blood flow to the heart muscle (revascularization). Drugs used to treat ACSs are anticoagulants and antiplatelet agents such as aspirin and clopidogrel (Plavix).

For acute attacks of angina, **nitroglycerin** is given sublingually (under the tongue). This drug, one of several called **nitrates,** is a vasodilator that increases coronary blood flow and lowers blood pressure. Nitrates also produce venodilation to reduce venous return and decrease myocardial oxygen consumption, both of which help decrease the work of the heart.

Physicians advise patients to avoid risk factors such as smoking, obesity, and lack of exercise, and they prescribe effective drugs to prevent CAD and ACSs. These drugs include **aspirin** (to prevent clumping of platelets), **beta-blockers** (to reduce the force and speed of the heartbeat and to lower blood pressure), **ACE inhibitors** (to reduce high blood pressure and the risk of future heart attack even if the patient is not hypertensive), **calcium channel blockers** (to relax muscles in blood vessels), and **statins** (to lower cholesterol levels).

Cardiac surgeons perform an open heart operation called **coronary artery bypass grafting (CABG)** to treat CAD by replacing clogged vessels. Interventional cardiologists perform **percutaneous coronary intervention (PCI),** in which catheterization with balloons and stents opens clogged coronary arteries.

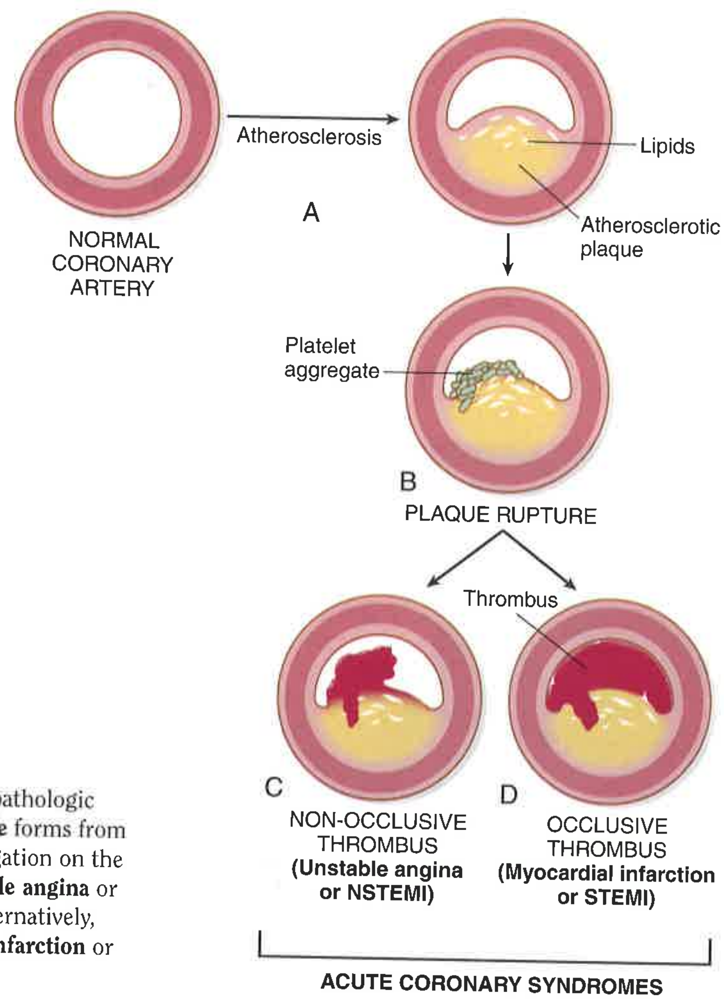


FIGURE 11–18 **Acute coronary syndromes:** sequence of pathologic changes leading to cardiac event. **(A) Atherosclerotic plaque** forms from lipid collection. **(B) Plaque rupture,** causing platelet aggregation on the plaque. **(C) Non-occlusive thrombus** forms, causing **unstable angina** or **NSTEMI** (non–ST elevation myocardial infarction). **(D)** Alternatively, formation of an **occlusive thrombus** leads to a **myocardial infarction** or **STEMI** (ST elevation myocardial infarction).

11

endocarditis

Inflammation of the inner lining of the heart.

Damage to the heart valves from infection **(bacterial endocarditis)** produces lesions called **vegetations** (resembling cauliflower) that break off into the bloodstream as **emboli** (material that travels through the blood). The emboli can lodge in other vessels, leading to a transient ischemic attack (TIA), or stroke, or in small vessels of the skin, where multiple pinpoint hemorrhages known as **petechiae** (from the Italian *petechio*, a flea bite) form. Antibiotics can cure bacterial endocarditis.

hypertensive heart disease

High blood pressure affecting the heart.

This condition results from narrowing of arterioles, which leads to increased pressure in arteries. The heart is affected (left ventricular hypertrophy) because it pumps more vigorously to overcome the increased resistance in the arteries.

mitral valve prolapse (MVP)

Improper closure of the mitral valve.

This condition occurs because the mitral valve enlarges and prolapses into the left atrium during systole. The physician hears a midsystolic click on **auscultation** (listening with a stethoscope). Most people with MVP live normal lives, but prolapsed valves can on rare occasion become infected.

murmur

Extra heart sound, heard between normal beats.

Murmurs are heard with the aid of a stethoscope and usually are caused by a valvular defect or disease that disrupts the smooth flow of blood in the heart. They also are heard in cases of interseptal defects, in which blood flows abnormally between chambers through holes in the septa. Functional murmurs are not caused by valve or septal defects and do not seriously endanger a person's health.

A **bruit** (brū-Ē) is an abnormal sound or murmur heard on auscultation. A **thrill,** which is a vibration felt on palpation of the chest, often accompanies a murmur.

pericarditis

Inflammation of the membrane (pericardium) surrounding the heart.

In most instances, pericarditis results from disease elsewhere in the body (such as pulmonary infection). Bacteria and viruses cause the condition, or the etiology may be idiopathic. Malaise, fever, and chest pain occur, and auscultation with a stethoscope often reveals a pericardial friction rub (heard as a scraping or grating sound). Compression of the heart caused by collection of fluid in the pericardial

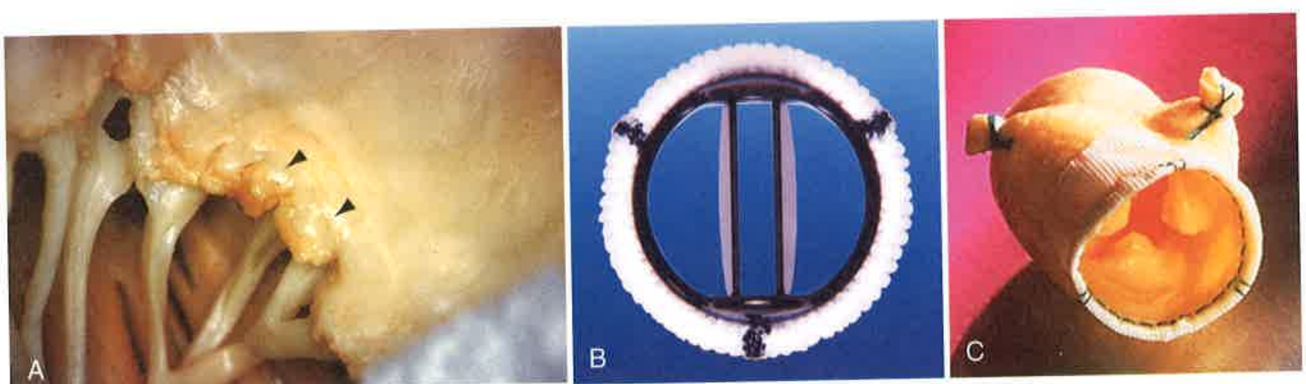


FIGURE 11–19 **(A)** Acute rheumatic **mitral valvulitis** with chronic rheumatic heart disease. Small vegetations are visible along the line of closure of the mitral valve leaflet *(arrows)*. Previous episodes of rheumatic valvulitis have caused fibrous thickening and fusion of the chordae tendineae of the valves. **(B) Artificial heart valve. (C) Porcine xenograft** valve. A xenograft valve (Greek *xen/o* means stranger) is tissue that is transferred from an animal of one species (pig) to one of another species (human). (**A,** From Kumar V, Cotran RS, Robbins SL: Basic Pathology, 7th ed., Philadelphia, Saunders, 2003, p. 377; **B** and **C,** from Lewis SM, Heitkemper MM, Dirksen SR: Medical-Surgical Nursing: Assessment and Management of Clinical Problems, 6th ed., St. Louis, Mosby, 2004, p. 906.)

cavity is **cardiac tamponade** (tăm-pō-NŎD). Treatment includes anti-inflammatory drugs and other agents to manage pain. If the pericarditis is infective, antibiotics or antifungals are prescribed, depending on the microorganisms detected in specimens obtained by pericardiocentesis.

rheumatic heart disease

Heart disease caused by rheumatic fever.

Rheumatic fever is a childhood disease that follows a streptococcal infection. The heart valves can be damaged by inflammation and scarred (with **vegetations**), so that they do not open and close normally (Figure 11-19A). **Mitral stenosis**, atrial fibrillation, and congestive heart failure, caused by weakening of the myocardium, also can result from rheumatic heart disease. Treatment consists of reduced activity, drugs to control arrhythmia, surgery to repair a damaged valve, and anticoagulant therapy to prevent emboli from forming. Artificial and porcine (pig) valve implants can replace deteriorated heart valves (Figure 11-19, B and C).

BLOOD VESSELS

aneurysm

Local widening (dilation) of an arterial wall.

An aneurysm (Greek, *aneurysma*, widening) usually is caused by atherosclerosis and hypertension or a congenital weakness in the vessel wall. Aneurysms are common in the aorta but may occur in peripheral vessels as well. The danger of an aneurysm is rupture and hemorrhage. Treatment depends on the vessel involved, the site, and the health of the patient. In aneurysms of small vessels in the brain **(berry aneurysms),** treatment is occlusion of the vessel with small clips. For larger arteries, such as the aorta, the aneurysm is resected and a synthetic graft is sewn within the affected vessel. Figure 11-20A shows an abdominal aortic aneurysm, and Figure 11-20B illustrates a synthetic graft in place. Stent grafts also may be placed less invasively as an alternative to surgery in some patients.

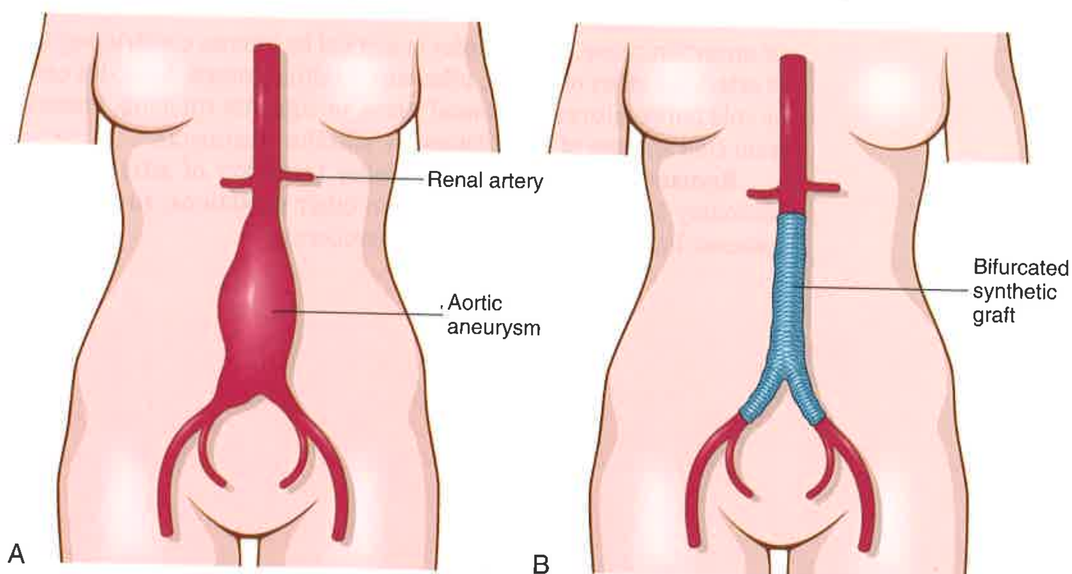


FIGURE 11–20 **(A)** Abdominal aortic aneurysm. A dissecting aortic aneurysm is splitting or dissection of the wall of the aorta by blood entering a tear or hemorrhage within the walls of the vessel. **(B)** Bifurcated synthetic graft in place.

Aortic Aneurysms and Marfan Syndrome

Aortic aneurysms are often associated with Marfan syndrome, a genetic disorder marked by long, thin fingers, great arm span, ocular lens dislocation, and loose joints. Abraham Lincoln is thought to have had Marfan syndrome, and the syndrome has also been diagnosed in basketball and volleyball players who have died suddenly as a result of ruptured aortic aneurysms.

deep vein thrombosis (DVT)

Blood clot (thrombus) forms in a large vein, usually in a lower limb.

This condition may result in a **pulmonary embolism** (clot travels to the lung) if not treated effectively. Anticoagulants (blood-thinning drugs) such as heparin are used to prevent pulmonary emboli.

hypertension (HTN)

High blood pressure.

Most high blood pressure is **essential hypertension,** with no identifiable cause. In adults, a blood pressure of 140/90 mm Hg or greater is considered high. Diuretics, ACE inhibitors, calcium channel blockers, and beta-blockers, are used to treat essential hypertension. Losing weight, limiting sodium (salt) intake, stopping smoking, and reducing fat in the diet also can reduce blood pressure.

In **secondary hypertension,** the increase in pressure is caused by another associated lesion, such as glomerulonephritis, pyelonephritis, or disease of the adrenal glands.

peripheral arterial disease (PAD)

Blockage of arteries carrying blood to the legs, arms, kidneys and other organs.

Any artery can be affected, such as the **carotid** (neck), **femoral** (thigh), or **popliteal** (back of the knee). A sign of PAD in the lower extremities is **intermittent claudication** (absence of pain or discomfort in a leg at rest, but pain, tension, and weakness after walking has begun). Treatment is exercise, avoidance of nicotine (which causes vessel constriction), and control of risk factors such as hypertension, hyperlipidemia, and diabetes. Surgical treatment includes endarterectomy and bypass grafting (from the normal proximal vessel around the diseased area to a normal vessel distally).

Percutaneous treatments include balloon angioplasty, atherectomy, and stenting. **Embolic protection devices** are parachute-like filters used to capture embolic debris during stenting.

Raynaud (rā-NŌ) disease

Recurrent episodes of pallor and cyanosis primarily in fingers and toes.

Of uncertain cause, this disorder is marked by intense constriction and vasospasm of arterioles often of young, otherwise healthy women. Episodes can be triggered by cold temperatures, emotional stress, or cigarette smoking. Protecting the body from cold and use of vasodilators are effective treatments.

Raynaud phenomenon is a similar condition of arterial insufficiency but secondary to arterial narrowing from other conditions, such as atherosclerosis, systemic lupus erythematosus, or scleroderma.

varicose veins

Abnormally swollen and twisted veins, usually occurring in the legs.
This condition is caused by damaged valves that fail to prevent the backflow of blood (Figure 11-21A to C). The blood then collects in the veins, which distend to many times their normal size. Because of the slow flow of blood in the varicose veins and frequent injury to the vein, thrombosis may occur as well. **Hemorrhoids** (piles) are varicose veins near the anus.

Physicians now treat varicose veins with sclerotherapy (injections with sclerosing solution) or laser and pulsed-light treatments to seal off veins. Surgical interventions such as vein stripping and ligation are used less frequently.

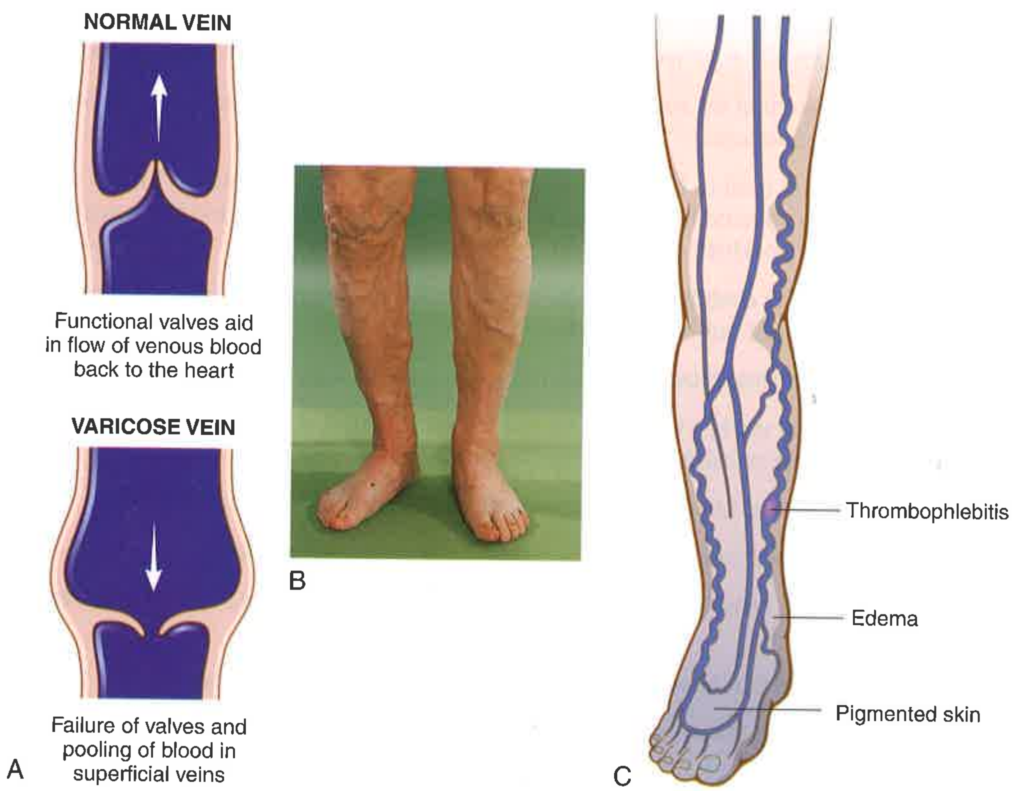


FIGURE 11–21 **(A)** Valve function in normal vein and varicose vein. **(B)** **Varicose veins.** **(C)** The slow flow in veins increases susceptibility to **thrombophlebitis** (clot formation), **edema,** and **pigmented skin** (blood pools in the lower parts of the leg and fluid leaks from distended small capillaries). If a thrombus becomes loosened from its place in the vein, it can travel to the lungs (pulmonary embolism) and block a blood vessel there. (**B,** From Forbes CD, Jackson WF: Color Atlas and Text of Clinical Medicine, 3rd ed., London, Mosby, 2003.)

11

STUDY SECTION

Practice spelling each term and know its meaning.

acute coronary syndromes (ACSs)	Unstable angina and myocardial infarction (heart attack), which are consequences of plaque rupture in coronary arteries.
angina (pectoris)	Chest pain resulting from myocardial ischemia. Stable angina occurs predictably with exertion; unstable angina is chest pain that occurs more often and with less exertion.
angiotensin-converting enzyme (ACE) inhibitor	Antihypertensive drug that blocks the conversion of angiotensin I to angiotensin II, causing blood vessels to dilate. It prevents heart attacks, CHF, stroke, and death. See Table 21-6 on page 886 for names of ACE inhibitors and other cardiovascular drugs.
auscultation	Listening for sounds in blood vessels or other body structures, typically using a stethoscope.
beta-blocker	Drug used to treat angina, hypertension, and arrhythmias. It blocks the action of epinephrine (adrenaline) at receptor sites on cells, slowing the heartbeat and reducing the workload on the heart.
biventricular pacemaker	Device enabling ventricles to beat together (in synchrony) so that more blood is pumped out of the heart.
bruit	Abnormal blowing or swishing sound heard during auscultation of an artery or organ.
calcium channel blocker	Drug used to treat angina and hypertension. It dilates blood vessels by blocking the influx of calcium into muscle cells lining vessels.
cardiac arrest	Sudden, unexpected stoppage of heart action; sudden cardiac death.
cardiac tamponade	Pressure on the heart caused by fluid in the pericardial space.
claudication	Pain, tension, and weakness in a leg after walking has begun, but absence of pain at rest.
digoxin	Drug that treats arrhythmias and strengthens the heartbeat.
embolus (*plural*: emboli)	Clot or other substance that travels to a distant location and suddenly blocks a blood vessel.
infarction	Area of dead tissue.
nitrates	Drugs used in the treatment of angina. They dilate blood vessels, increasing blood flow and oxygen to myocardial tissue.
nitroglycerin	Nitrate drug used in the treatment of angina.
occlusion	Closure of a blood vessel due to blockage.
palpitations	Uncomfortable sensations in the chest related to cardiac arrhythmias, such as premature ventricular contractions (PVCs).
patent	Open.
pericardial friction rub	Scraping or grating noise heard on auscultation of the heart; suggestive of pericarditis.
petechiae	Small, pinpoint hemorrhages.
statins	Drugs used to lower cholesterol in the bloodstream.
thrill	Vibration felt over an area of turmoil in blood flow (as a blocked artery).
vegetations	Clumps of platelets, clotting proteins, microorganisms, and red blood cells on diseased heart valves.

LABORATORY TESTS AND CLINICAL PROCEDURES

LABORATORY TESTS

BNP test

Measurement of BNP (brain natriuretic peptide) in blood.

BNP is elevated in patients with heart failure, and it is useful in the diagnosis of CHF in patients with dyspnea who come to the emergency department. Its presence also identifies patients at risk for complications when presenting with acute coronary syndromes (e.g., myocardial infarction and unstable angina). It is secreted when the heart becomes overloaded, and it acts as a diuretic to help heart function return to normal.

The reference to brain in this substance originates from its initial identification from the brain of a pig.

cardiac biomarkers

Chemicals are measured in the blood as evidence of a heart attack.

Damaged heart muscle releases chemicals into the bloodstream. The substances tested for are **troponin-I (cTnI)** and **troponin-T (cTnT).** Troponin is a heart muscle protein released into circulation after myocardial injury.

lipid tests (lipid profile)

Measurement of cholesterol and triglycerides (fats) in a blood sample.

High levels of lipids are associated with atherosclerosis. The National Guideline for total cholesterol in the blood is less than 200 mg/dL. **Saturated fats** (animal origin, such as milk, butter, and meats) increase cholesterol in the blood, whereas **polyunsaturated fats** (of vegetable origin, such as corn and safflower oil) decrease blood cholesterol.

Treatment of hyperlipidemia includes proper diet (low-fat, high-fiber intake) and exercise. Niacin (a vitamin) also helps reduce lipids. Drug therapy includes **statins,** which reduce the risk of heart attack, stroke, and cardiovascular death. Statins lower cholesterol by reducing its production in the liver. Examples are simvastatin (Zocor), atorvastatin (Lipitor), and pravastatin (Pravachol).

lipoprotein electrophoresis

Lipoproteins (combinations of fat and protein) are physically separated and measured in a blood sample.

Examples of lipoproteins are **low-density lipoprotein (LDL)** and **high-density lipoprotein (HDL).** High levels of LDL are associated with atherosclerosis. The National Guideline for LDL is less than 130 mg/dL in normal persons and less than 70 mg/dL in patients with CAD, PAD, and diabetes mellitus. High levels of HDL protect adults from atherosclerosis. Factors that increase HDL are estrogen, exercise, and alcohol in moderation.

CLINICAL PROCEDURES: DIAGNOSTIC

X-Ray and Electron Beam Tests

angiography

X-ray imaging of blood vessels after injection of contrast material.

Arteriography is x-ray imaging of arteries after injection of contrast via a catheter into the aorta or an artery.

computed tomography angiography (CTA)

Three-dimensional x-ray images of the heart and coronary arteries using computed tomography (CT) (64-slice CT scanner).

This newer technique takes hundreds of images of the heart per second. Cross-sectional images are assembled by computer into a three-dimensional picture. It is less invasive than angiography (contrast material is injected into a small peripheral vein with a small needle) and provides excellent views of the coronary arteries for diagnosis of coronary artery disease (Figure 11-22A).

digital subtraction angiography (DSA)

Video equipment and a computer produce x-ray images of blood vessels.

After taking an initial x-ray picture and storing it in a computer, physicians inject contrast material and take a second image of that area. The computer compares the two images and subtracts digital data for the first from the second, leaving an image of vessels with contrast.

electron beam computed tomography (EBCT *or* EBT)

Electron beams and CT identify calcium deposits in and around coronary arteries to diagnose early CAD.

A **coronary artery calcium score** is derived to indicate future risk of heart attack and stroke. This new test is faster (called ultrafast CT) than a standard CT scan and takes a clear picture of coronary arteries while the heart is beating (Figure 11-22B).

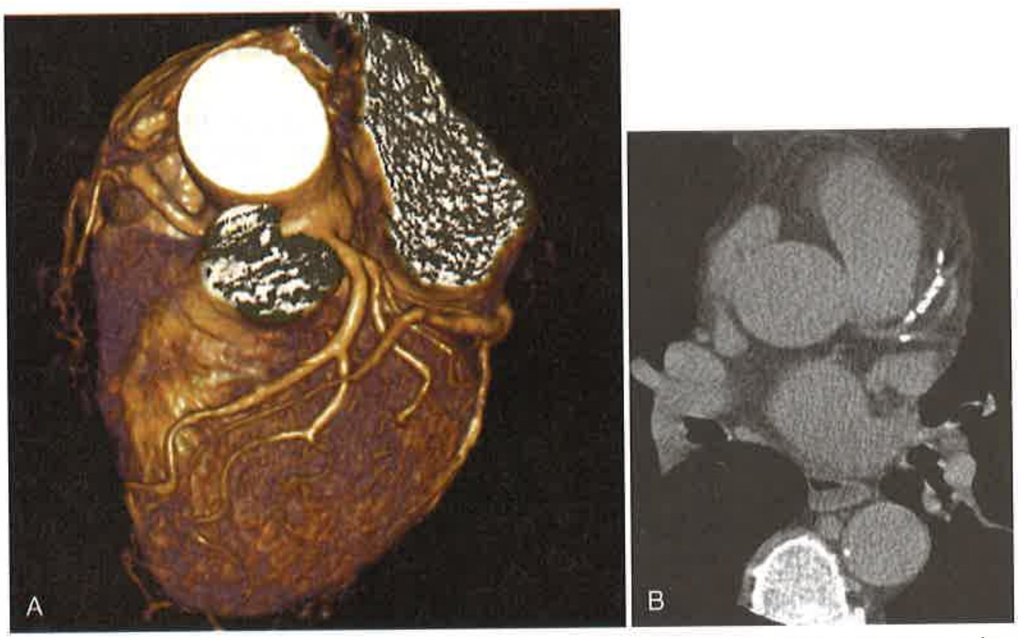


FIGURE 11–22 **(A) Computed tomography angiography (CTA)** showing **coronary arteries.** High radiation is a drawback to the use of CTA. **(B) Electron beam computed tomography** showing significant calcification *(white areas)* in the coronary arteries, indicating advanced coronary artery disease. (**A,** Courtesy Massachusetts General Hospital, Boston; **B,** from Crawford MH, DiMarco JP, Paulus WJ: Cardiology, 2nd ed., St. Louis, Mosby, 2004, p. 224.)

Coronary Artery Calcium Score

0-99	low risk
100-399	intermediate risk
>400	high risk

A calcium score >400 is associated with a nearly 25% chance of a heart attack or stroke occurring within 10 years.

11

Ultrasound Examination

Doppler ultrasound studies

Sound waves measure blood flow within blood vessels.

An instrument focuses sound waves on blood vessels, and echoes bounce off red blood cells. The examiner can hear various alterations in blood flow caused by vessel obstruction. **Duplex ultrasound** combines Doppler and conventional ultrasound to allow physicians to image the structure of blood vessels and measure the speed of blood flow. Carotid artery occlusion, aneurysms, varicose veins, and other vessel disorders can be diagnosed with Duplex ultrasound.

echocardiography (ECHO)

Echoes generated by high-frequency sound waves produce images of the heart (Figure 11-23A).

ECHOs show the structure and movement of the heart. In **transesophageal echocardiography (TEE),** a transducer placed in the esophagus provides ultrasound and Doppler information (Figure 11-23B). This technique detects cardiac masses, prosthetic valve function, aneurysms, and pericardial fluid.

Nuclear Cardiology

positron emission tomography (PET) scan

Images show blood flow and myocardial function following uptake of radioactive glucose.

PET scanning can detect CAD, myocardial function, and differences between ischemic heart disease and cardiomyopathy.

technetium Tc 99m sestamibi scan

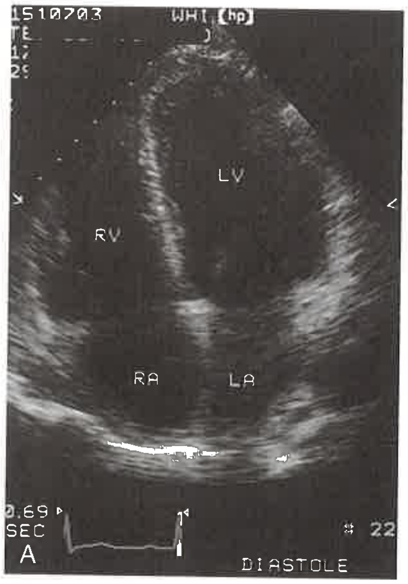
Technetium Tc 99m sestamibi injected intravenously is taken up in cardiac tissue, where it is detected by scanning.

This scan is used in persons who have had an MI, to assess the amount of damaged heart muscle. It also is used with an exercise tolerance test **(ETT-MIBI).** Sestamibi is a radioactive tracer compound used to define areas of poor blood flow in heart muscle.

thallium 201 scan

Concentration of radioactive thallium is measured to give information about blood supply to the heart muscle.

Thallium studies show the viability of heart muscle. Infarcted or scarred myocardium shows up as "cold spots."



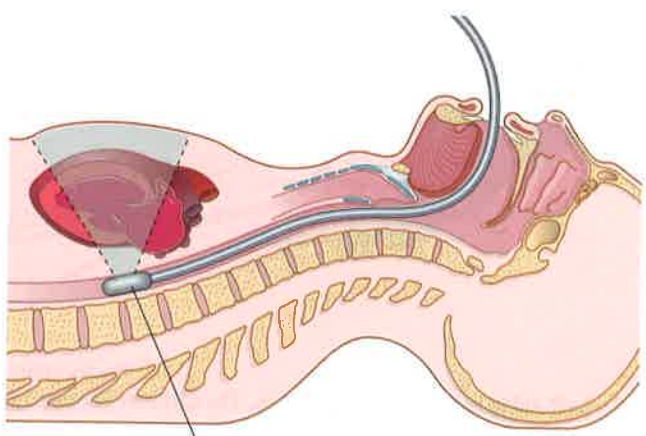


FIGURE 11–23 **(A) Echocardiogram.** Notice that in this view, the ventricles are above the atria. **(B) Transesophageal echocardiography.** (A, From Goldman L et al: Cecil Textbook of Medicine, 23rd ed., Philadelphia, Saunders, 2008.)

Magnetic Resonance Imaging (MRI)

cardiac MRI

Images of the heart are produced using radiowave energy in a magnetic field.

These images in multiple planes give information about aneurysms, cardiac output, and patency of peripheral and coronary arteries. The magnetic waves emitted during MRI could interfere with implanted pacemakers because of their metal content, so it is currently contraindicated for a patient with a pacemaker to undergo cardiac MRI. **Magnetic resonance angiography (MRA)** is a type of MRI that gives highly detailed images of blood vessels. Physicians use MRA to view arteries and blockage inside arteries.

Other Diagnostic Procedures

cardiac catheterization

Thin, flexible tube is guided into the heart via a vein or an artery.

This procedure detects pressures and patterns of blood flow in the heart. Contrast may be injected and x-ray images taken of the heart and blood vessels (Figure 11-24). This procedure may be used in diagnosis and treatment of heart conditions (see under percutaneous coronary intervention [PCI] on page 431).

electrocardiography (ECG)

Recording of electricity flowing through the heart.

Continuous monitoring of a patient's heart rhythm in hospitals is performed via **telemetry** (electronic transmission of data—tele/o means distant). Normal sinus rhythm begins in the SA node and is between 60 to 100 beats per minute. Figure 11-25 shows ECG strips for normal sinus rhythm and several types of dysrhythmias (abnormal rhythms).

Holter monitoring

An ECG device is worn during a 24-hour period to detect cardiac arrhythmias.

Rhythm changes are correlated with symptoms recorded in a diary.

stress test

Exercise tolerance test (ETT) determines the heart's response to physical exertion (stress).

A common protocol uses 3-minute stages at set speeds and elevations of a treadmill. Continual monitoring of vital signs and ECG rhythms is important in the diagnosis of CAD and left ventricular function.

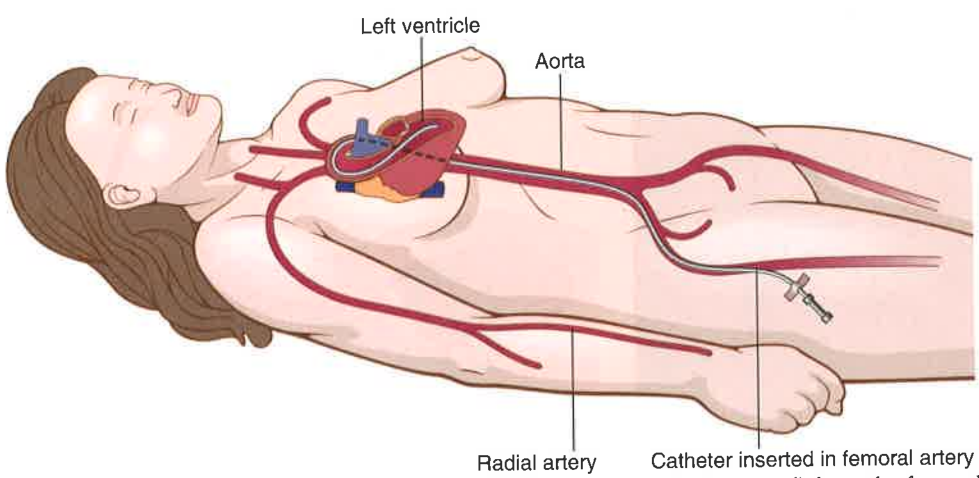
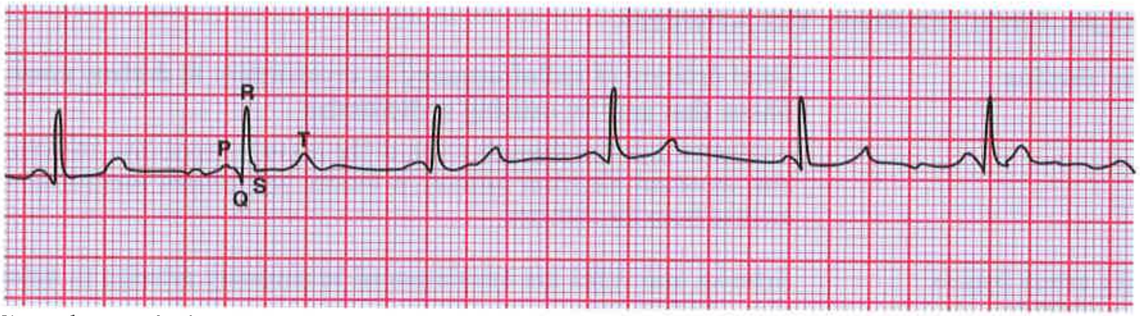
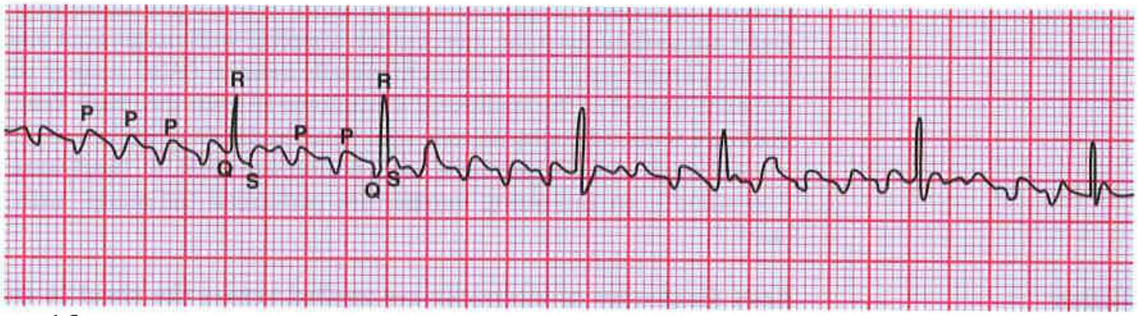


FIGURE 11–24 **Left-sided cardiac catheterization.** The catheter is passed retrograde (backward) from the femoral artery into the aorta and then into the left ventricle. Catheterization also is performed using the radial artery by an increasing number of interventional cardiologists. For right-sided cardiac catheterization, the cardiologist inserts a catheter through the femoral vein and advances it to the right atrium and right ventricle and into the pulmonary artery.



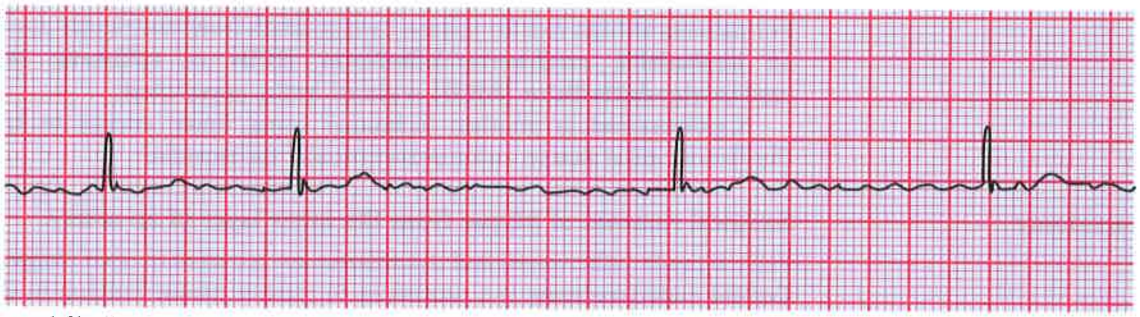
A

Normal sinus rhythm. Notice the regularity of the P, QRS, and T waves.



B

Atrial flutter. Notice the rapid atrial rate (P wave) compared with the slower ventricular rate (QRS).

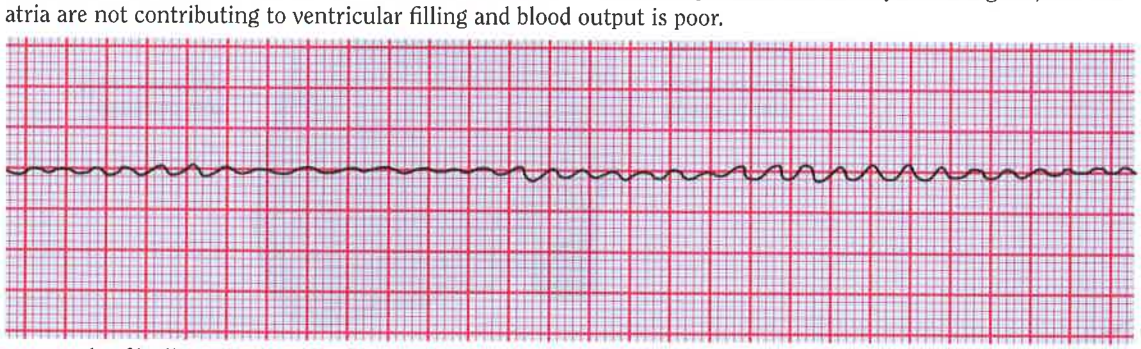


C

Atrial fibrillation. P waves are replaced by irregular and rapid fluctuations. There are no effective atrial contractions.

D

Ventricular tachycardia. Ventricular rate may be as high as 250 beats per minute. The rhythm is regular, but the atria are not contributing to ventricular filling and blood output is poor.



E

Ventricular fibrillation. Notice the abnormal, irregular waves. Ventricles in fibrillation cannot pump blood effectively. Circulation stops and sudden cardiac death follows if fibrillation is not reversed.

FIGURE 11–25 ECG rhythm strips showing normal sinus rhythm and dysrhythmias (arrhythmias). (From Hicks GH: Cardiopulmonary Anatomy and Physiology, Philadelphia, Saunders, 2000.)

CLINICAL PROCEDURES: TREATMENT

catheter ablation

Brief delivery of radiofrequency or cryosurgery to destroy areas of heart tissue that may be causing arrhythmias

A catheter is guided through a vein in the leg to the vena cava and into the heart. The abnormal electrical pathway is located and ablated (destroyed) via energy emitted from the catheter.

coronary artery bypass grafting (CABG)

Arteries and veins are anastomosed to coronary arteries to detour around blockages.

Internal mammary (breast) and radial (arm) arteries and saphenous (leg) vein grafts are used to keep the myocardium supplied with oxygenated blood (Figure 11-26). Cardiac surgeons perform minimally invasive CABG surgery with smaller incisions instead of the traditional sternotomy to open the chest. Vein and artery grafts are removed endoscopically with small incisions as well.

Although most operations are performed with a heart-lung machine ("on-pump"), an increasing number are performed "off-pump" with a beating heart.

defibrillation

Brief discharges of electricity are applied across the chest to stop dysrhythmias (ventricular fibrillation).

For patients at high risk for sudden cardiac death from ventricular dysrhythmias, an **implantable cardioverter-defibrillator (ICD)** or **automatic implantable cardioverter-defibrillator (AICD)** is placed in the upper chest.

Cardioversion is another technique using lower energy to treat atrial fibrillation, atrial flutter, and supraventricular tachycardia.

endarterectomy

Surgical removal of plaque from the inner layer of an artery.

Fatty deposits (atheromas) and thromboses are removed to open clogged arteries. **Carotid endarterectomy** is a procedure to remove plaque buildup in the carotid artery to reduce risk of stroke.

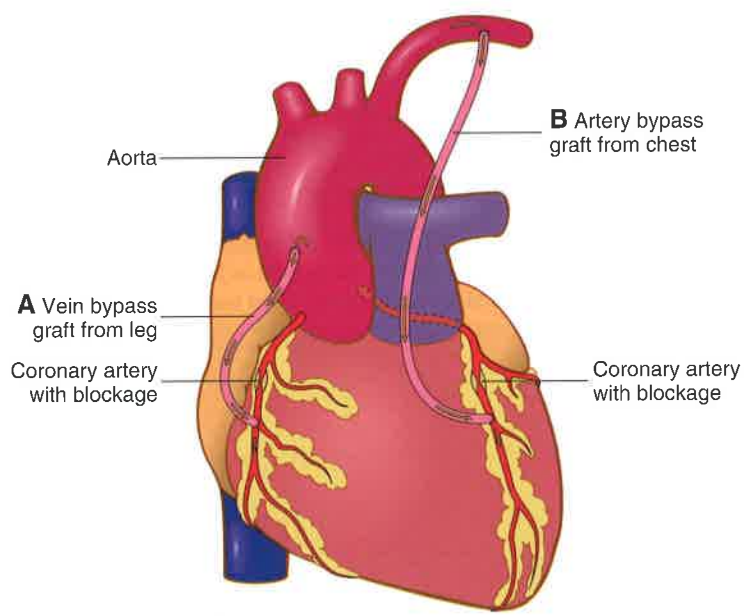


FIGURE 11–26 **Coronary artery bypass graft (CABG)** surgery with anastomosis of vein and arterial grafts. **(A)** A section of a vein is removed from the leg and anastomosed (upside down because of its directional valves) to a coronary artery, to bypass an area of arteriosclerotic blockage. **(B)** An internal mammary artery is grafted to a coronary artery to bypass a blockage.

extracorporeal circulation

Heart-lung machine diverts blood from the heart and lungs while the heart is repaired.

Blood leaves the body, enters the heart-lung machine, where it is oxygenated, and then returns to a blood vessel (artery) to circulate through the bloodstream. The machine uses the technique of **extracorporeal membrane oxygenation (ECMO).**

heart transplantation

A donor heart is transferred to a recipient.

While waiting for a transplant, a patient may need a **left ventricular assist device (LVAD),** which is a booster pump implanted in the abdomen with a cannula (flexible tube) to the left ventricle.

percutaneous coronary intervention (PCI)

Balloon-tipped catheter is inserted into a coronary artery to open the artery; stents are put in place.

An interventional cardiologist places the catheter in the femoral or radial artery and then threads it up the aorta into the coronary artery. **Stents** (expandable slotted tubes that serve as permanent scaffolding devices) create wide lumens and make restenosis less likely. Newer **drug-eluting stents (DESs)** are coated with polymers that elute (release) antiproliferative drugs to prevent scar tissue formation leading to restenosis (Figure 11-27). Stents are also placed in carotid, renal, and other peripheral arteries.

PCI techniques include percutaneous transluminal coronary angioplasty (PTCA), stent placement, laser angioplasty (a small laser on the tip of a catheter vaporizes plaque), and atherectomy.

thrombolytic therapy

Drugs to dissolve clots are injected into the bloodstream of patients with coronary thrombosis.

Tissue plasminogen activator **(tPA)** and **streptokinase** restore blood flow to the heart and limit irreversible damage to heart muscle. The drugs are given within 12 hours after the onset of a heart attack. Thrombolytic agents reduce the mortality rate in patients with myocardial infarction by 25%.

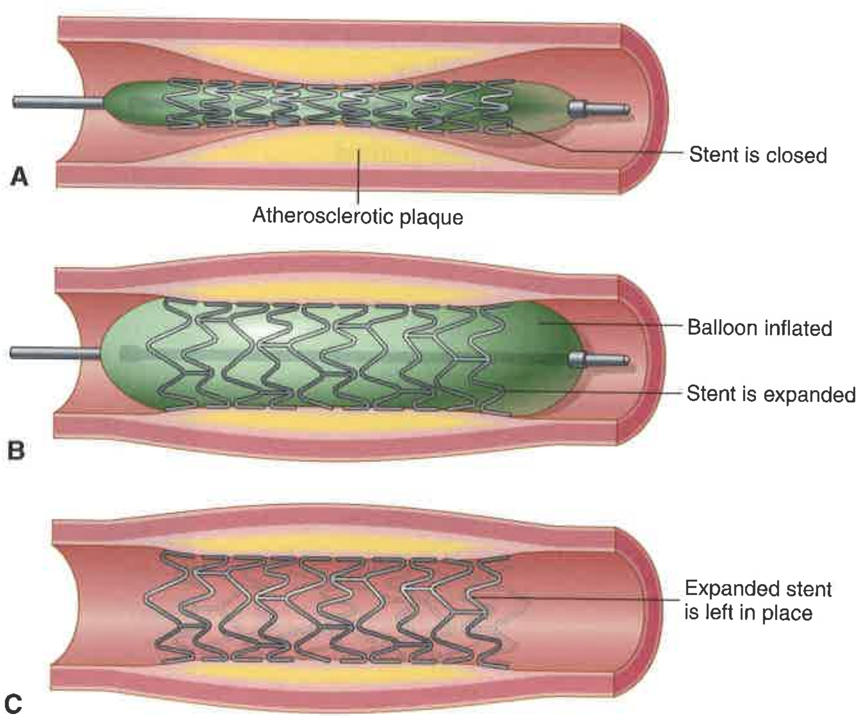


FIGURE 11–27 **Placement of an intracoronary artery drug-eluting stent.** **(A)** The stent is positioned at the site of the lesion. **(B)** The balloon is inflated, expanding the stent and compressing the plaque. **(C)** When the balloon is withdrawn, the stent supports the artery and releases a drug to reduce the risk of restenosis. Stents are stainless-steel scaffolding devices that help hold open arteries, such as the coronary, renal, and carotid arteries.

11

ABBREVIATIONS

AAA abdominal aortic aneurysm
ACE inhibitor angiotensin-converting enzyme inhibitor
ACLS advanced cardiac life support; CPR plus drugs and defibrillation
ACS acute coronary syndrome
ADP adenosine diphosphate; ADP blockers are used to prevent cardiovascular-related death, heart attack, and strokes and after all stent procedures
AED automatic external defibrillator
AF, a-fib atrial fibrillation
AICD automatic implantable cardioverter-defibrillator
AMI acute myocardial infarction
ARVD arrhythmogenic right ventricular dysplasia
AS aortic stenosis
ASD atrial septal defect
AV, A-V atrioventricular
AVR aortic valve replacement
BBB bundle branch block
BNP brain natriuretic peptide; elevated in congestive heart failure
BP blood pressure
CABG coronary artery bypass grafting
CAD coronary artery disease
CCU coronary care unit
Cath catheterization
CHF congestive heart failure
CK creatine kinase; released into the bloodstream after injury to heart or skeletal muscles
CoA coarctation of the aorta
CPR cardiopulmonary resuscitation
CRT cardiac resynchronization therapy; biventricular pacing
CTNI *or* **cTnI; CTNT** *or* **cTnT** cardiac troponin-I and cardiac troponin-T; troponin is a protein released into the bloodstream after myocardial injury
CV cardiovascular
DES drug-eluting stent
DSA digital subtraction angiography
DVT deep vein thrombosis
ECMO extracorporeal membrane oxygenation
ECG; *also seen as* **EKG** electrocardiography
ECHO echocardiography
EF ejection fraction; measure of the amount of blood that pumps out of the heart with each beat
EPS electrophysiology study; electrode catheters are inserted into veins and threaded into the heart and electrical conduction is measured (tachycardias are provoked and analyzed)
ETT exercise tolerance test
ETT-MIBI exercise tolerance test combined with a radioactive tracer (sestamibi) scan
HDL high-density lipoprotein; high blood levels are associated with lower incidence of coronary artery disease
HTN hypertension (high blood pressure)
IABP intra-aortic balloon pump; used to support patients in cardiogenic shock
ICD implantable cardioverter-defibrillator
LAD left anterior descending (coronary artery)
LDL low-density lipoprotein
LMWH low-molecular-weight heparin
LV left ventricle
LVAD left ventricular assist device
LVH left ventricular hypertrophy
MI myocardial infarction

MR	mitral regurgitation
MUGA	multiple-gated acquisition scan; a radioactive test of heart function
MVP	mitral valve prolapse
NSR	normal sinus rhythm
NSTEMI	non–ST elevation myocardial infarction
PAC	premature atrial contraction
PAD	peripheral arterial disease
PCI	percutaneous coronary intervention
PDA	patent ductus arteriosus; posterior descending artery
PVC	premature ventricular contraction
SA, S-A node	sinoatrial node
SCD	sudden cardiac death
SOB	shortness of breath
SPECT	single photon emission computed tomography; used for myocardial imaging with sestamibi scans
SSCP	substernal chest pain
STEMI	ST elevation myocardial infarction
SVT	supraventricular tachycardia; rapid heartbeats arising from the atria and causing palpitations, SOB, and dizziness
Tc	technetium
TEE	transesophageal echocardiography
TGA	transposition of the great arteries
tPA	tissue-type plasminogen activator; a drug used to prevent thrombosis
UA	unstable angina; chest pain at rest or of increasing frequency
VF	ventricular fibrillation
VSD	ventricular septal defect
VT	ventricular tachycardia
WPW	Wolff-Parkinson-White syndrome; an abnormal ECG pattern often associated with paroxysmal tachycardia

PRACTICAL APPLICATIONS

OPERATING ROOM SCHEDULE: General Hospital

Match the operative treatment in Column I with the appropriate surgical indication (diagnosis) in Column II. Answers are found on page 447.

COLUMN I

1. coronary artery bypass graft ____
2. left carotid endarterectomy ____
3. sclerosing injections and laser treatment ____
4. LV aneurysmectomy ____
5. atrial septal defect repair ____
6. left ventricular assist device ____
7. pericardiocentesis ____
8. aortic valve replacement ____
9. pacemaker implantation ____
10. femoral-popliteal bypass graft ____

COLUMN II

A. Congestive heart failure
B. Cardiac tamponade (fluid in the space surrounding the heart)
C. Atherosclerotic occlusion of a main artery leading to the head
D. Congenital hole in the wall of the upper chamber of the heart
E. Disabling angina and extensive coronary atherosclerosis despite medical therapy
F. Peripheral vascular disease
G. Heart block
H. Varicose veins
I. Protrusion of the wall of a lower heart chamber
J. Aortic stenosis

11

CLINICAL CASES: What's Your Diagnosis?

Case 1: A 24-year-old woman with a history of palpitations [heartbeat is unusually strong, rapid, or irregular, so that patient is aware of it] and vague chest pains enters the hospital. With the patient supine, you hear a midsystolic click that is followed by a grade 3/6 [moderately loud—6/6 is loud and 1/6 is quiet] honking murmur.

1. Your diagnosis is
   a. Tetralogy of Fallot
   b. Mitral valve prolapse
   c. Raynaud disease
   d. Congestive heart failure

Case 2: Mr. Smith was admitted to the telemetry unit for cardiac monitoring after an episode of chest pain. His cardiac enzymes (CK, troponin-T, and troponin-I) were slightly elevated and the ECG showed elevation in the ST segment. An angiogram reveals plaque blocking the LAD. PCI with DES is recommended.

1. What did the ECG reveal?
   a. NSTEMI and unstable angina
   b. Aortic aneurysm
   c. CHF
   d. STEMI
2. Your diagnosis for this patient is
   a. Heart attack
   b. Rheumatic heart disease
   c. Unstable angina
   d. Patent ductus arteriosus
3. What treatment is recommended?
   a. Coronary artery bypass grafting
   b. Catheterization with drug-eluting stent placement
   c. Defibrillation and cardioversion
   d. Thrombolytic drugs

Case 3: A 42-year-old female runner recovering from an upper respiratory infection comes to the ED complaining of chest pain that is sharp and constant, worse when she is lying down and decreased with sitting up and leaning forward. Serum CK and troponin I levels rule out an acute MI. The ED physician auscultates a pericardial friction rub.

1. What's your diagnosis for this patient?
   a. Myocardial ischemia
   b. Unstable angina and NSTEMI
   c. Endocarditis
   d. Pericarditis
2. The danger of this condition is the risk for progression to
   a. Cardiac tamponade
   b. Aneurysm
   c. Pulmonary embolism
   d. Claudication