

SELECTED KEY TERMS

The following terms and other boldface terms in the chapter are defined in the Glossary



arrhythmia
atherosclerosis
atrium
bradycardia
coronary
coronary thrombosis
diastole
echocardiograph
electrocardiography
endocardium
epicardium
fibrillation
infarct
ischemia
murmur
myocardium
pacemaker
pericardium
plaque
septum
stenosis
systole
tachycardia
valve
ventricle

LEARNING OUTCOMES

After careful study of this chapter, you should be able to:

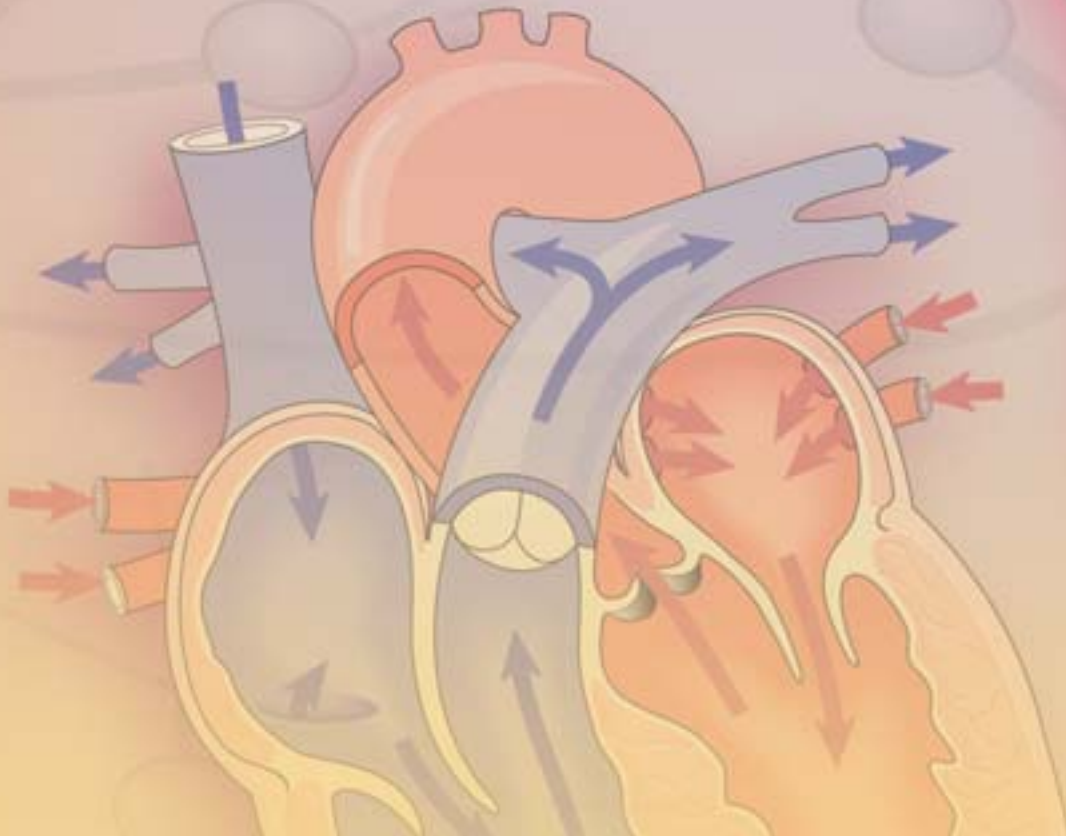
1. Describe the three layers of the heart wall
2. Describe the structure of the pericardium and cite its functions
3. Compare the functions of the right and left sides of the heart
4. Name the four chambers of the heart and compare their functions
5. Name the valves at the entrance and exit of each ventricle and cite the function of the valves
6. Briefly describe blood circulation through the myocardium
7. Briefly describe the cardiac cycle
8. Name and locate the components of the heart's conduction system
9. Explain the effects of the autonomic nervous system on the heart rate
10. List and define several terms that describe variations in heart rates
11. Explain what produces the two main heart sounds
12. Describe several common types of heart disease
13. List five actions that can be taken to minimize the risk of heart disease
14. Briefly describe four methods for studying the heart
15. Describe several approaches to the treatment of heart disease
16. Show how word parts are used to build words related to the heart (see Word Anatomy at the end of the chapter)



chapter

14

The Heart and Heart Disease



► Circulation and the Heart

The next two chapters investigate how the blood delivers oxygen and nutrients to the cells and carries away the waste products of cell metabolism. The continuous one-way circuit of blood through the body in the blood vessels is known as the **circulation**. The prime mover that propels blood throughout the body is the **heart**. This chapter examines the structure and function of the heart to lay the foundation for the detailed discussion of blood vessels that follows.

The importance of the heart has been recognized for centuries. Strokes (the contractions) of this pump average about 72 per minute and are carried on unceasingly for the whole of a lifetime. The beating of the heart is affected by the emotions, which may explain the frequent references to it in song and poetry. However, the vital functions of the heart and its disorders are of more practical concern.

Location of the Heart

The heart is slightly bigger than a person's fist. This organ is located between the lungs in the center and a bit to the left of the midline of the body (Fig. 14-1). It occupies most of the mediastinum, the central region of the thorax. The heart's **apex**, the pointed, inferior portion, is directed toward the left. The broad, superior **base** is the area of attachment for the large vessels carrying blood into and out of the heart.

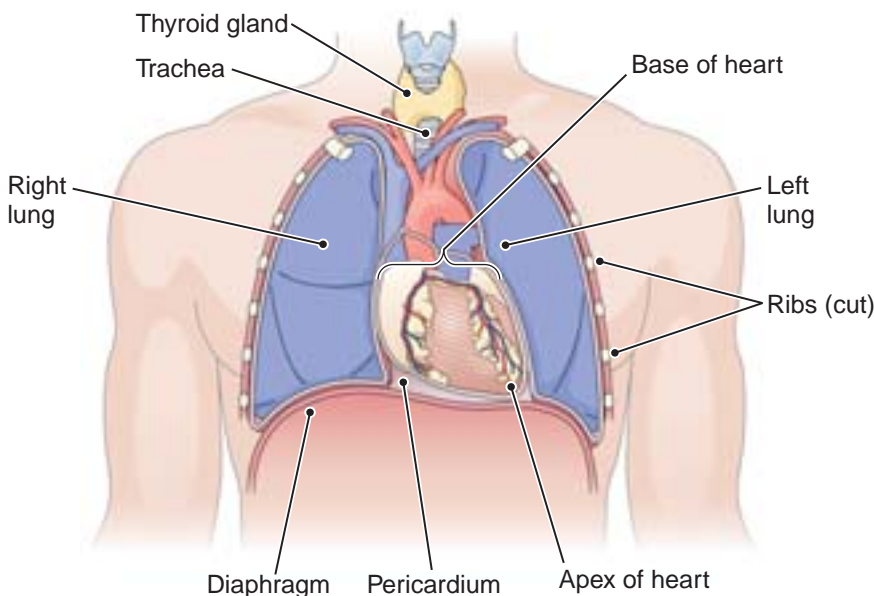


Figure 14-1 The heart in position in the thorax (anterior view). **ZOOMING IN**
♦ Why is the left lung smaller than the right lung?

► Structure of the Heart

The heart is a hollow organ, with walls formed of three different layers. Just as a warm coat might have a smooth lining, a thick and bulky interlining, and an outer layer of a third fabric, so the heart wall has three tissue layers (Fig. 14-2, Table 14-1). Starting with the innermost layer, these are as follows:

- The **endocardium** (en-do-KAR-de-um) is a thin, smooth layer of epithelial cells that lines the heart's interior. The endocardium provides a smooth surface for easy flow as blood travels through the heart. Extensions of this membrane cover the flaps (cusps) of the heart valves.
- The **myocardium** (mi-o-KAR-de-um), the heart muscle, is the thickest layer and pumps blood through the vessels. Cardiac muscle's unique structure is described in more detail next.
- The **epicardium** (ep-ih-KAR-de-um) is a serous membrane that forms the thin, outermost layer of the heart wall.

The Pericardium

The **pericardium** (per-ih-KAR-de-um) is the sac that encloses the heart (Fig. 14-2, Table 14-2). The formation of the pericardial sac was described and illustrated in chapter 4 under a discussion of membranes (see Fig. 4-9). The outermost and heaviest layer of this sac is the fibrous pericardium. Connective tissue anchors this pericardial

layer to the diaphragm, located inferiorly; the sternum, located anteriorly; and to other structures surrounding the heart, thus holding the heart in place. A serous membrane lines this fibrous sac and folds back at the base to cover the heart's surface. Anatomically, the outer layer of this serous membrane is called the parietal layer, and the inner layer is the visceral layer, also known as the epicardium, as previously noted. A thin film of fluid between these two layers reduces friction as the heart moves within the pericardium. Normally the visceral and parietal layers are very close together, but fluid may accumulate in the region between them, the pericardial cavity, under certain disease conditions.

Checkpoint 14-1 What are the names of the innermost, middle, and outermost layers of the heart?

Checkpoint 14-2 What is the name of the sac that encloses the heart?

Table 14•1 Layers of the Heart Wall

LAYER	LOCATION	DESCRIPTION	FUNCTION
Endocardium	Innermost layer of the heart wall	Thin, smooth layer of epithelial cells	Lines the interior of the chambers and covers the heart valves
Myocardium	Middle layer of the heart wall	Thick layer of cardiac muscle	Contracts to pump blood into the arteries
Epicardium	Outermost layer of the heart wall	Thin serous membrane	Covers the heart and forms the visceral layer of the serous pericardium

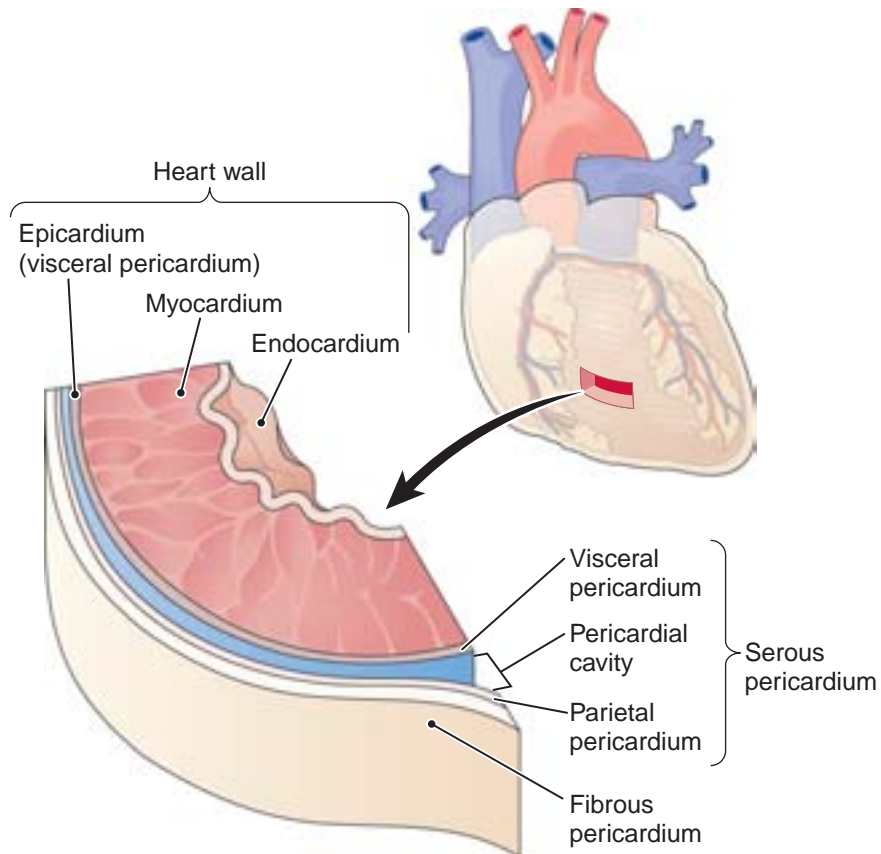


Figure 14-2 Layers of the heart wall and pericardium. The serous pericardium covers the heart and lines the fibrous pericardium. *ZOOMING IN ♦ Which layer of the heart wall is the thickest?*

Table 14•2 Layers of the Pericardium

LAYER	LOCATION	DESCRIPTION	FUNCTION
Fibrous pericardium	Outermost layer	Fibrous sac	Encloses and protects the heart; anchors heart to surrounding structures
Serous pericardium	Between the fibrous pericardium and the myocardium	Doubled membranous sac with fluid between layers	Fluid reduces friction within the pericardium as the heart functions
Parietal layer	Lines the fibrous pericardium	Serous membrane	Forms the outer layer of the serous pericardium
Visceral layer	Surface of the heart	Serous membrane	Forms the inner layer of the serous pericardium; also called the epicardium

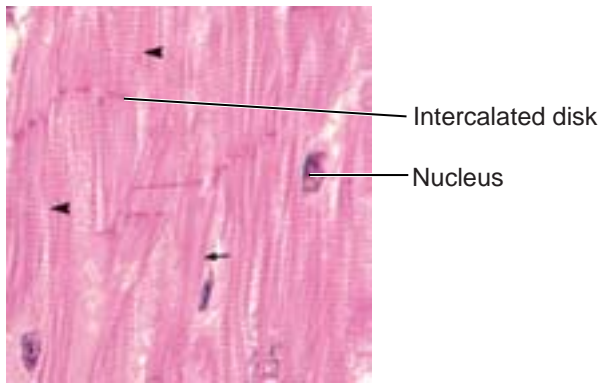


Figure 14-3 Cardiac muscle tissue viewed under the microscope (×540). The sample shows light striations (arrowheads), intercalated disks, and branching fibers (arrow). (Reprinted with permission from Gartner LP, Hiatt JL. *Color Atlas of Histology*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

Special Features of the Myocardium

Cardiac muscle cells are lightly striated (striped) based on alternating actin and myosin filaments, as seen in skeletal muscle cells (see Chapter 8). Unlike skeletal muscle cells, however, cardiac muscle cells have a single nucleus instead of multiple nuclei. Also, cardiac muscle tissue is involuntarily controlled. There are specialized partitions between cardiac muscle cells that show faintly under a microscope (Fig. 14-3). These **intercalated** (in-TER-cah-la-ted) disks are actually modified plasma membranes that firmly attach adjacent cells to each other but allow for rapid transfer of electrical impulses between them. The adjective *intercalated* is from Latin and means “inserted between.”

Another feature of cardiac muscle tissue is the branching of the muscle fibers (cells). These fibers are interwoven so that the stimulation that causes the contraction of one fiber results in the contraction of a whole group. The intercalated disks and the branching cellular networks allow cardiac muscle cells to contract in a coordinated manner.

Divisions of the Heart

Healthcare professionals often refer to the *right heart* and the *left heart*, because

the human heart is really a double pump (Fig. 14-4). The right side pumps blood low in oxygen to the lungs through the **pulmonary circuit**. The left side pumps oxygenated blood to the remainder of the body through the **systemic circuit**. Each side of the heart is divided into two chambers.

Four Chambers The upper chambers on the right and left sides, the **atria** (A-tre-ah), are mainly blood-receiving chambers (Fig. 14-5, Table 14-3). The lower chambers on the right and left side, the **ventricles** (VEN-trih-klz) are forceful pumps. The chambers, listed in the order in which blood flows through them, are as follows:

1. The **right atrium** (A-tre-um) is a thin-walled chamber that receives the blood returning from the body tissues. This blood, which is low in oxygen, is carried in veins, the blood vessels leading back to the heart from the body tissues. The superior vena cava brings blood

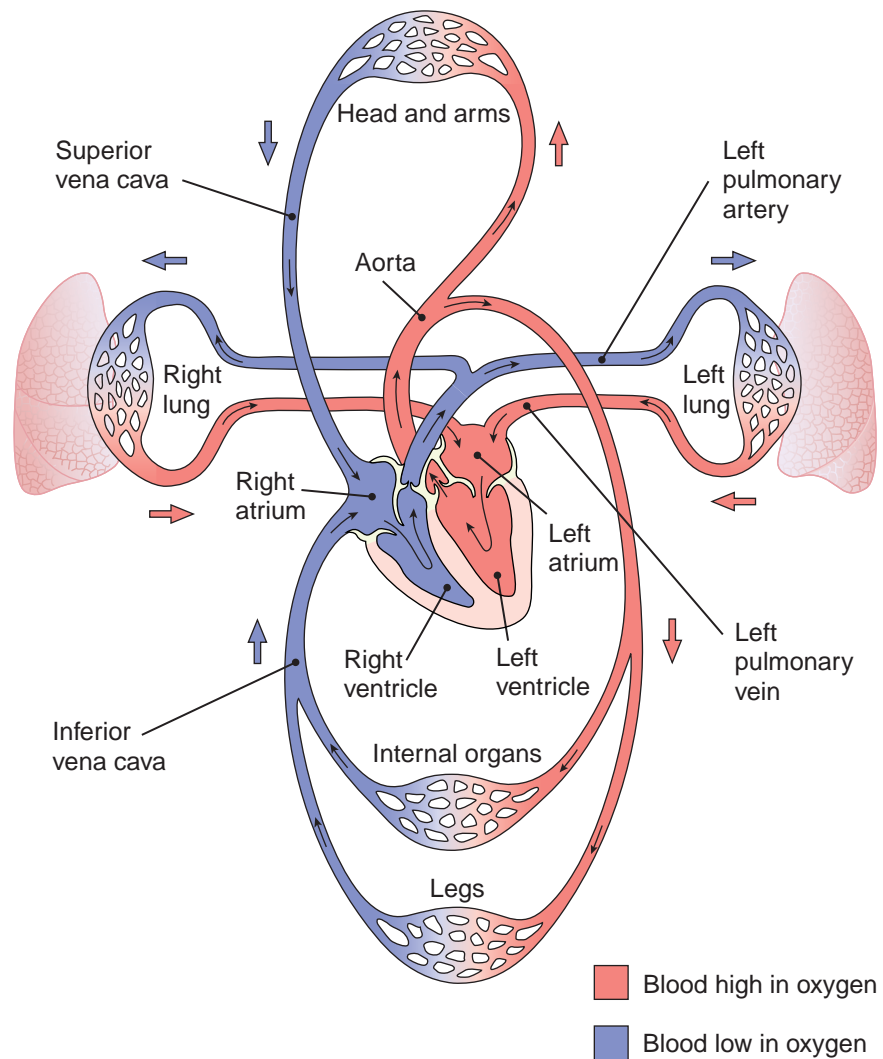


Figure 14-4 The heart as a double pump. The right side of the heart pumps blood through the pulmonary circuit to the lungs to be oxygenated; the left side of the heart pumps blood through the systemic circuit to all other parts of the body. **ZOOMING IN** ♦ What vessel carries blood into the systemic circuit?

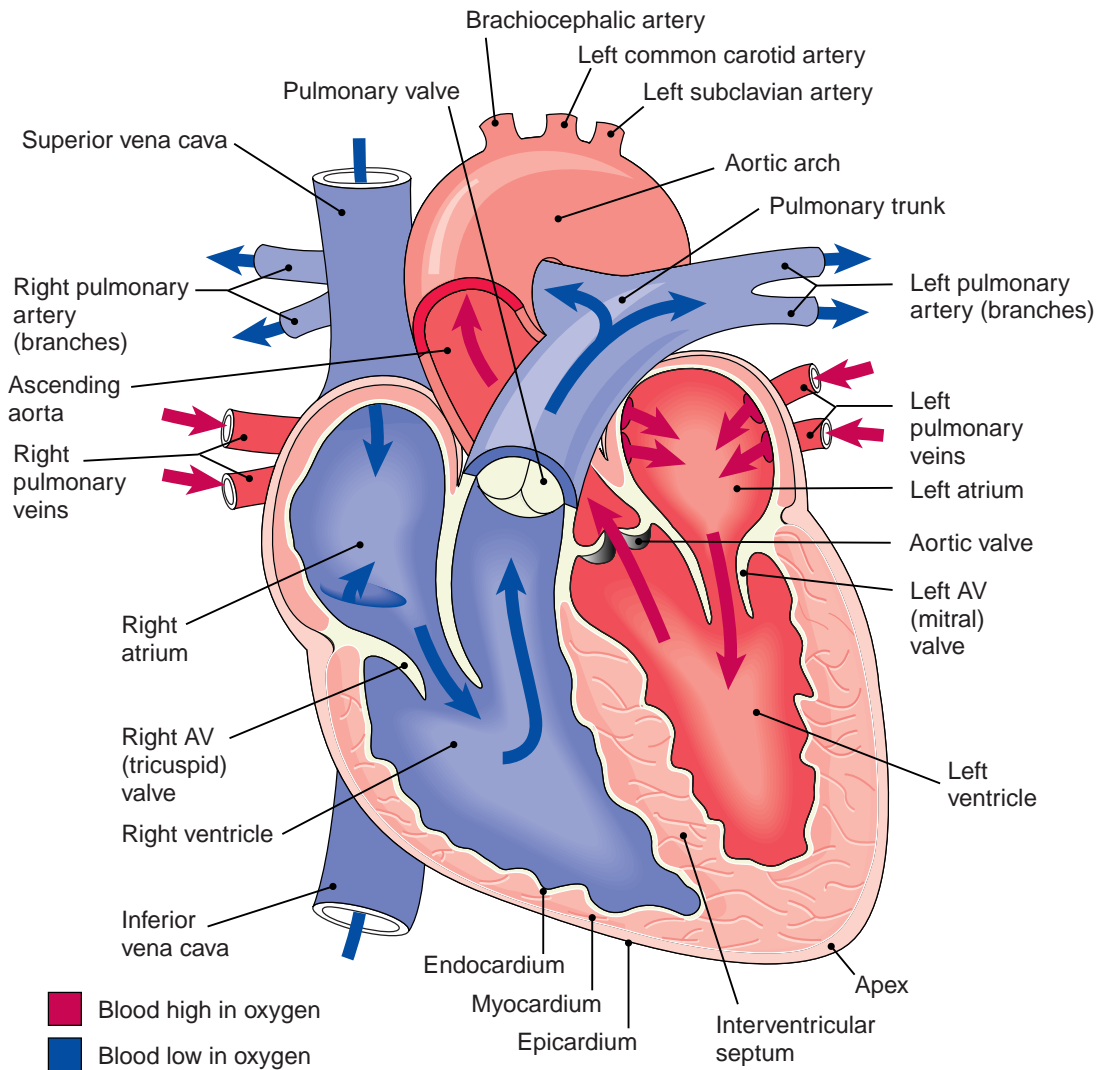


Figure 14-5 The heart and great vessels. ZOOMING IN ♦ Which heart chamber has the thickest wall?

from the head, chest, and arms; the inferior vena cava delivers blood from the trunk and legs. A third vessel that opens into the right atrium brings blood from the heart muscle itself, as described later in this chapter.

2. The **right ventricle** pumps the venous blood received

from the right atrium to the lungs. It pumps into a large pulmonary trunk, which then divides into right and left pulmonary arteries, which branch to the lungs. An artery is a vessel that takes blood from the heart to the tissues. Note that the pulmonary arteries

Table 14•3 Chambers of the Heart

CHAMBER	LOCATION	FUNCTION
Right atrium	Upper right chamber	Receives blood from the vena cavae and the coronary sinus; pumps blood into the right ventricle
Right ventricle	Lower right chamber	Receives blood from the right atrium and pumps blood into the pulmonary artery, which carries blood to the lungs to be oxygenated
Left atrium	Upper left chamber	Receives oxygenated blood coming back to the heart from the lungs in the pulmonary veins; pumps blood into the left ventricle
Left ventricle	Lower left chamber	Receives blood from the left atrium and pumps blood into the aorta to be carried to tissues in the systemic circuit

in Figure 14-5 are colored blue because they are carrying deoxygenated blood, unlike other arteries, which carry oxygenated blood.

3. The **left atrium** receives blood high in oxygen content as it returns from the lungs in pulmonary veins. Note that the pulmonary veins in Figure 14-5 are colored red because they are carrying oxygenated blood, unlike other veins, which carry deoxygenated blood.
4. The **left ventricle**, which is the chamber with the thickest wall, pumps oxygenated blood to all parts of the body. This blood goes first into the aorta (a-OR-tah), the largest artery, and then into the branching systemic arteries that take blood to the tissues. The heart's apex, the lower pointed region, is formed by the wall of the left ventricle (see Fig. 14-2).

The heart's chambers are completely separated from each other by partitions, each of which is called a **septum**. The **interatrial** (in-ter-A-tre-al) septum separates the two atria, and the **interventricular** (in-ter-ven-TRIK-u-lar) septum separates the two ventricles. The septa, like the heart wall, consist largely of myocardium.

Checkpoint 14-3 The heart is divided into four chambers. What is the upper receiving chamber on each side called? What is the lower pumping chamber called?

Four Valves One-way valves that direct blood flow through the heart are located at the entrance and exit of each ventricle (Fig. 14-6, Table 14-4). The entrance valves are the **atrioventricular** (a-tre-o-ven-TRIK-u-lar) (AV) valves, so named because they are between the atria and ventricles. The exit valves are the **semilunar** (sem-e-LU-nar) valves, so named because each flap of these valves resembles a half-moon. Each valve has a specific name, as follows:

- The **right atrioventricular (AV) valve** is also known as the **tricuspid** (tri-KUS-pid) valve because it has three cusps, or flaps, that open and close. When this valve is open, blood flows freely from the right atrium into the right ventricle. When the right ventricle begins to contract, however, the valve is closed by blood squeezed backward against the cusps. With the valve closed, blood cannot return to the right atrium but must flow forward into the pulmonary arterial trunk.
- The **left atrioventricular (AV) valve** is the bicuspid valve, but it is commonly referred to as the **mitral** (MI-tral) valve (named for a miter, the pointed, two-sided hat worn by bishops). It has two heavy cusps that permit blood to flow freely from the left atrium into the left ventricle. The cusps close when the left ventricle begins to

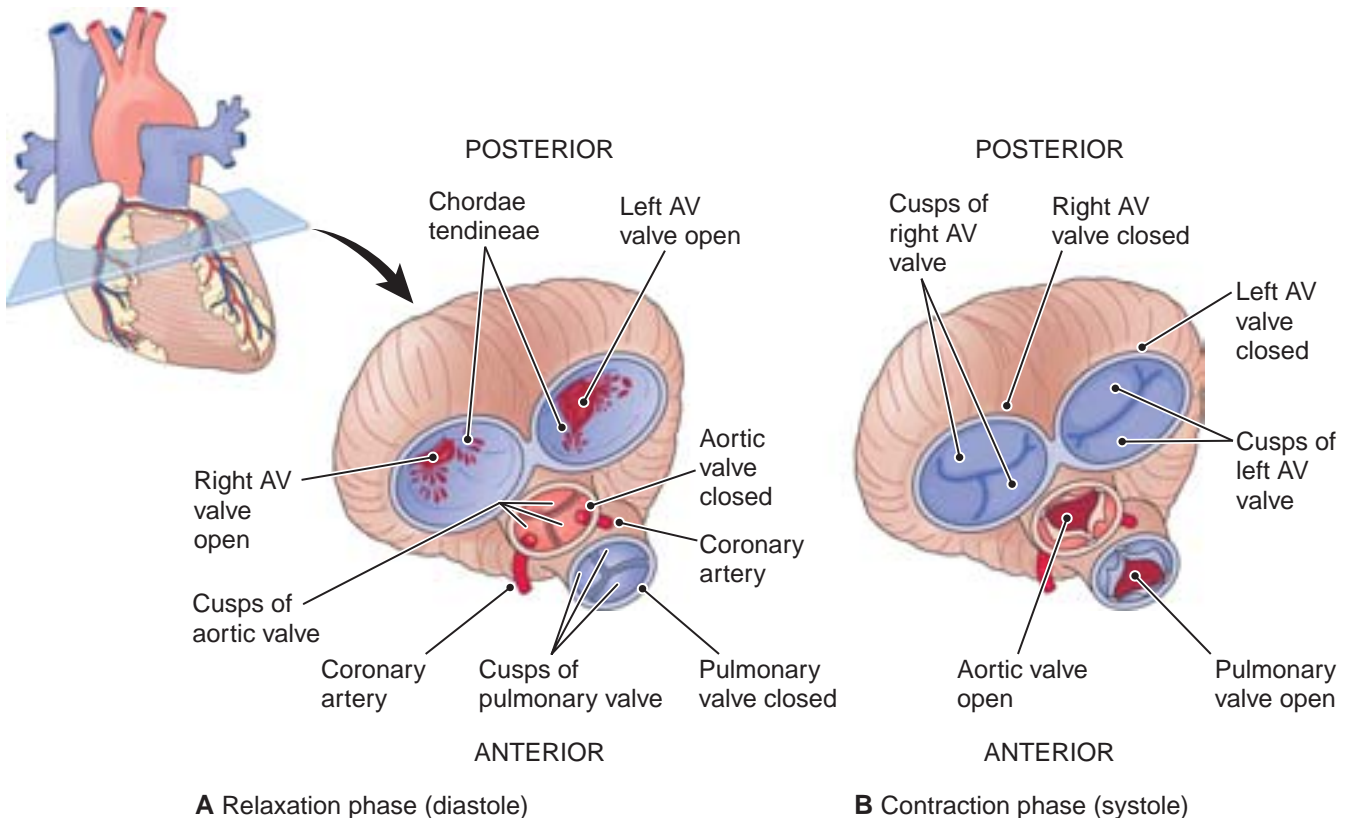


Figure 14-6 Valves of the heart (superior view from anterior, atria removed). (A) When the heart is relaxed (diastole), the AV valves are open and blood flows freely from the atria to the ventricles. The pulmonary and aortic valves are closed. (B) When the ventricles contract, the AV valves close and blood pumped out of the ventricles opens the pulmonary and aortic valves. **ZOOMING IN**

♦ How many cusps does the right AV valve have? The left?

Table 14•4 Valves of the Heart

VALVE	LOCATION	DESCRIPTION	FUNCTION
Right AV valve	Between the right atrium and right ventricle	Valve with three cusps; tricuspid valve	Prevents blood from flowing back up into the right atrium when the right ventricle contracts (systole)
Left AV valve	Between the left atrium and left ventricle	Valve with two cusps; bicuspid or mitral valve	Prevents blood from flowing back up into the left atrium when the left ventricle contracts (systole)
Pulmonary semi-lunar valve	At the entrance to the pulmonary artery	Valve with three half-moon shaped cusps	Prevents blood from flowing back into the right ventricle when the right ventricle relaxes (diastole)
Aortic semilunar valve	At the entrance to the aorta	Valve with three half-moon shaped cusps	Prevents blood from flowing back into the left ventricle when the left ventricle relaxes (diastole)

contract; this closure prevents blood from returning to the left atrium and ensures the forward flow of blood into the aorta. Both the right and left AV valves are attached by means of thin fibrous threads to muscles in the walls of the ventricles. The function of these threads, called the **chordae tendineae** (KOR-de ten-DIN-e-e) (see Fig. 14-6), is to stabilize the valve flaps when the ventricles contract so that the force of the blood will not push them up into the atria. In this manner, they help to prevent a back-flow of blood when the heart beats.

- The **pulmonary** (PUL-mon-ar-e) valve, also called the *pulmonic valve*, is a semilunar valve located between the right ventricle and the pulmonary trunk that leads to the lungs. As soon as the right ventricle begins to relax from a contraction, pressure in that chamber drops. The higher pressure in the pulmonary artery, described as *back pressure*, closes the valve and prevents blood from returning to the ventricle.
- The **aortic** (a-OR-tik) valve is a semilunar valve located between the left ventricle and the aorta. After contraction of the left ventricle, back pressure closes the aortic valve and prevents the back flow of blood from the aorta into the ventricle.

Figure 14-7 traces a drop of blood as it completes a full circuit through the heart's chambers. Note that blood

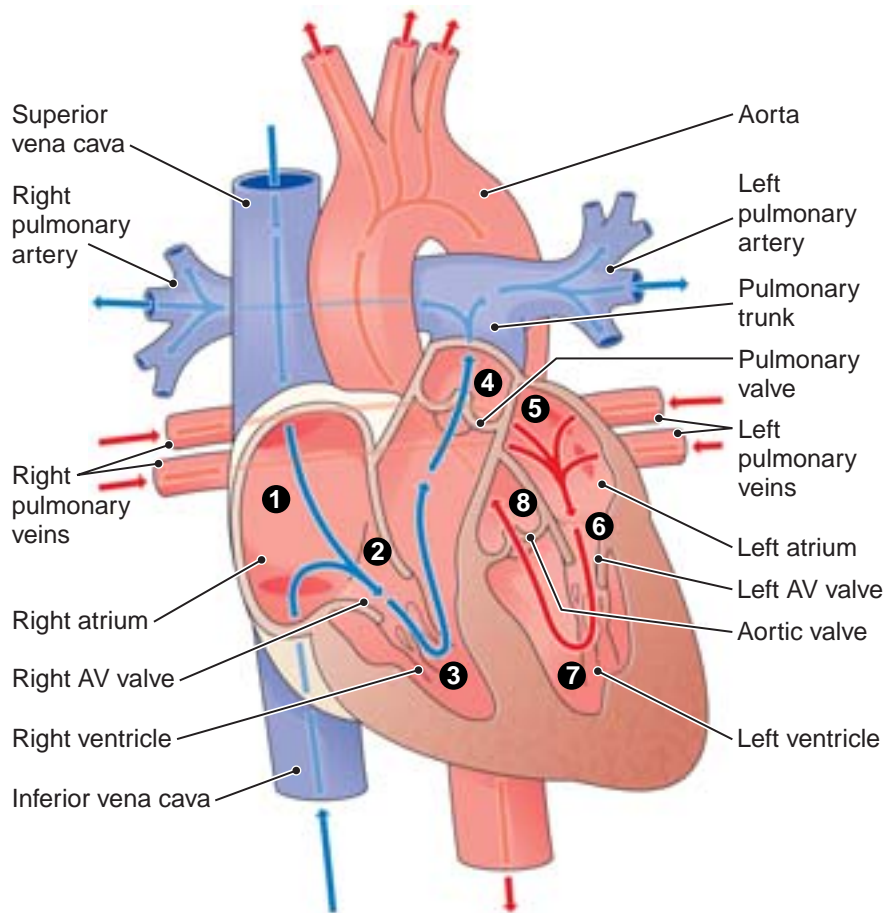


Figure 14-7 Pathway of blood through the heart. Blood from the systemic circuit enters the right atrium (1) through the superior and inferior venae cavae, flows through the right AV (tricuspid) valve (2), and enters the right ventricle (3). The right ventricle pumps the blood through the pulmonary (semilunar) valve (4) into the pulmonary trunk, which divides to carry blood to the lungs in the pulmonary circuit. Blood returns from the lungs in the pulmonary veins, enters the left atrium (5), and flows through the left AV (mitral) valve (6) into the left ventricle (7). The left ventricle pumps the blood through the aortic (semilunar) valve (8) into the aorta, which carries blood into the systemic circuit.

passes through the heart twice in making a trip from the heart's right side through the pulmonary circuit to the lungs and back to the heart's left side to start on its way through the systemic circuit. Although Figure 14-7 follows the path of a single drop of blood in sequence through the heart, the heart's two sides function in unison to pump blood through both circuits at the same time.

Checkpoint 14-4 What is the purpose of valves in the heart?

Blood Supply to the Myocardium

Only the endocardium comes into contact with the blood that flows through the heart chambers. Therefore, the myocardium must have its own blood vessels to provide oxygen and nourishment and to remove waste products. Together, these blood vessels provide the **coronary (KOR-o-na-re) circulation**. The main arteries that supply blood to the muscle of the heart are the right and left coronary arteries (Fig. 14-8), named because they encircle the heart like a crown. These arteries, which are the first to branch off the aorta, arise just above the cusps of the aortic valve and branch to all regions of the heart muscle. They receive blood when the heart relaxes because the aortic valve must be closed to expose the entrance to these vessels (Fig. 14-9). After passing through capillaries in the myocardium, blood drains into a system of cardiac veins that brings blood back toward the right atrium. Blood finally collects in the **coronary sinus**, a dilated vein that opens into the right atrium near the inferior vena cava (see Fig. 14-8).

Checkpoint 14-5 The myocardium must have its own vascular system to supply it with blood. What name is given to this blood supply to the myocardium?

Function of the Heart

Although the heart's right and left sides are separated from each other, they work together. Blood is squeezed through the chambers by a heart muscle contraction that begins in the thin-walled upper chambers, the atria, and is followed by a contraction of the thick muscle of the lower chambers, the ventricles. This active phase is called **systole (SIS-to-le)**, and in each case, it is followed by a resting period known as **diastole (di-AS-to-le)**. One complete sequence of heart contraction and relaxation is called the **cardiac cycle (Fig. 14-10)**. Each cardiac cycle represents a single heart-beat. At rest, one cycle takes an average of 0.8 seconds.

The contraction phase of the cardiac cycle begins with contraction of both atria, which forces blood through the AV valves into the ventricles. The atrial walls are thin, and their contractions are not very powerful. However, they do improve the heart's efficiency by forcing blood into the ventricles before these lower chambers contract. Atrial contraction is completed at the time ventricular contraction begins. Thus, a resting phase (diastole) begins in the atria at the same time that a contraction (systole) begins in the ventricles.

After the ventricles have contracted, all chambers are relaxed for a short period as they fill with blood. Then another cycle begins with an atrial contraction followed by a ventricular contraction. Although both upper and lower chambers

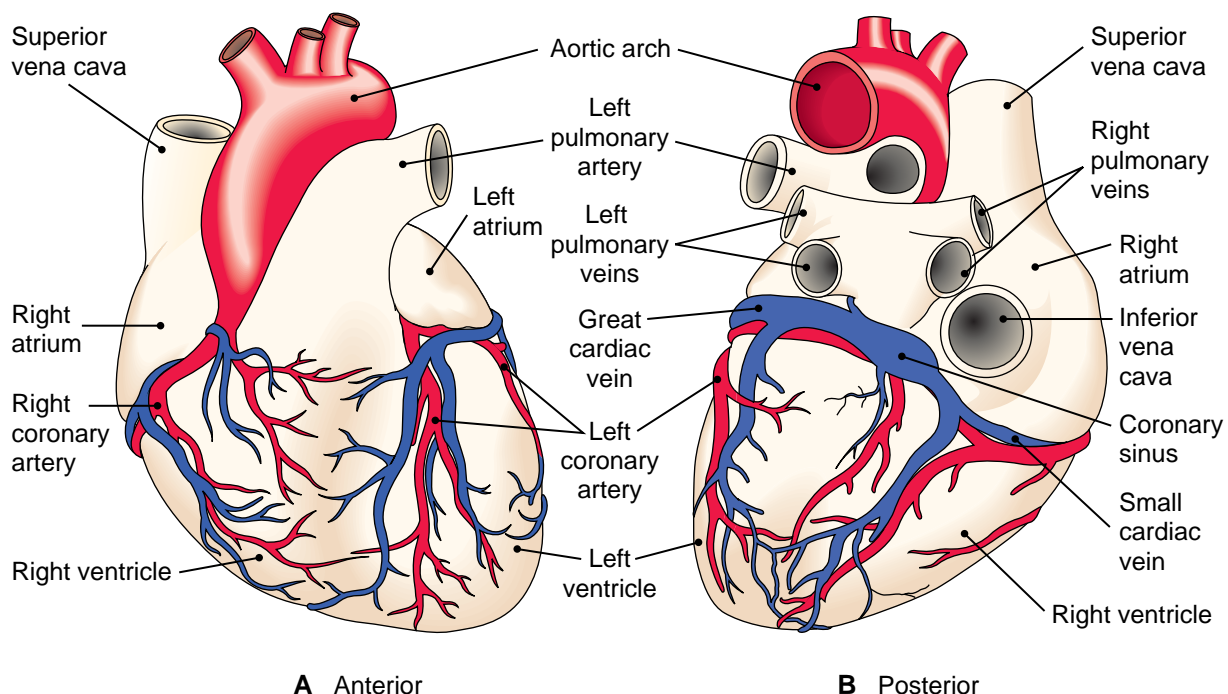


Figure 14-8 Blood vessels that supply the myocardium. Coronary arteries and cardiac veins are shown. (A) Anterior view. (B) Posterior view.

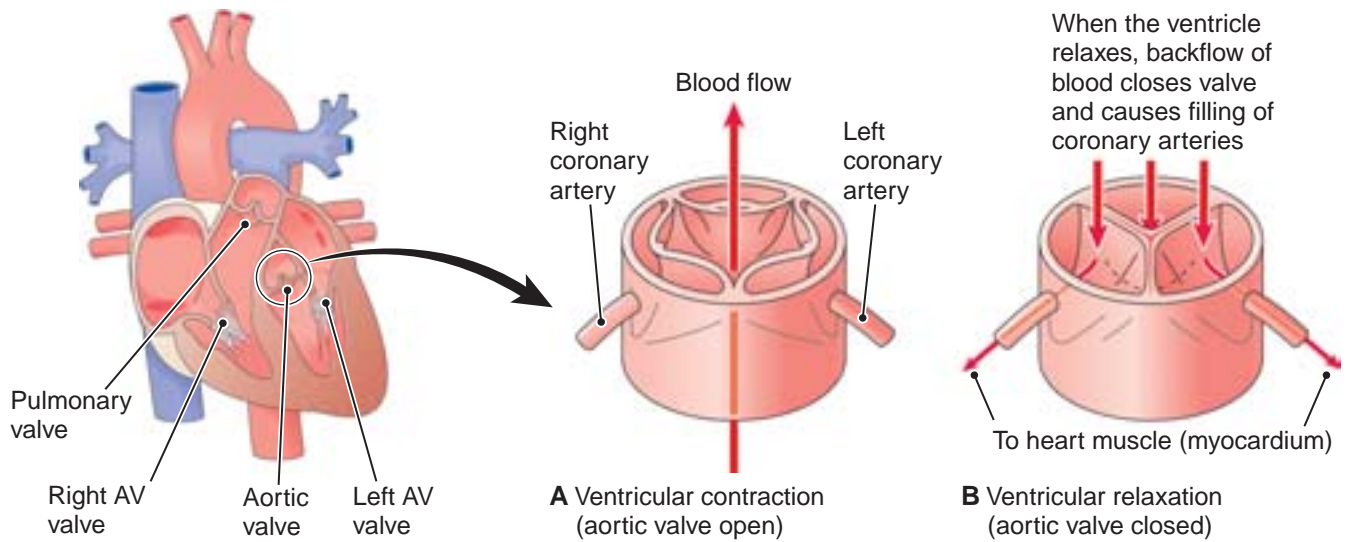


Figure 14-9 Opening of coronary arteries in the aortic valve (anterior view). (A) When the left ventricle contracts, the aortic valve opens. The valve cusps prevent filling of the coronary arteries. (B) When the left ventricle relaxes, backflow of blood closes the aortic valve and the coronary arteries fill. (Modified with permission from Moore KL, Dalley AF. Clinically Oriented Anatomy. 4th ed. Baltimore: Lippincott Williams & Wilkins, 1999.)

have a systolic and diastolic phase in each cardiac cycle, discussions of heart function usually refer to these phases as they occur in the ventricles, because these chambers contract more forcefully and drive blood into the arteries.

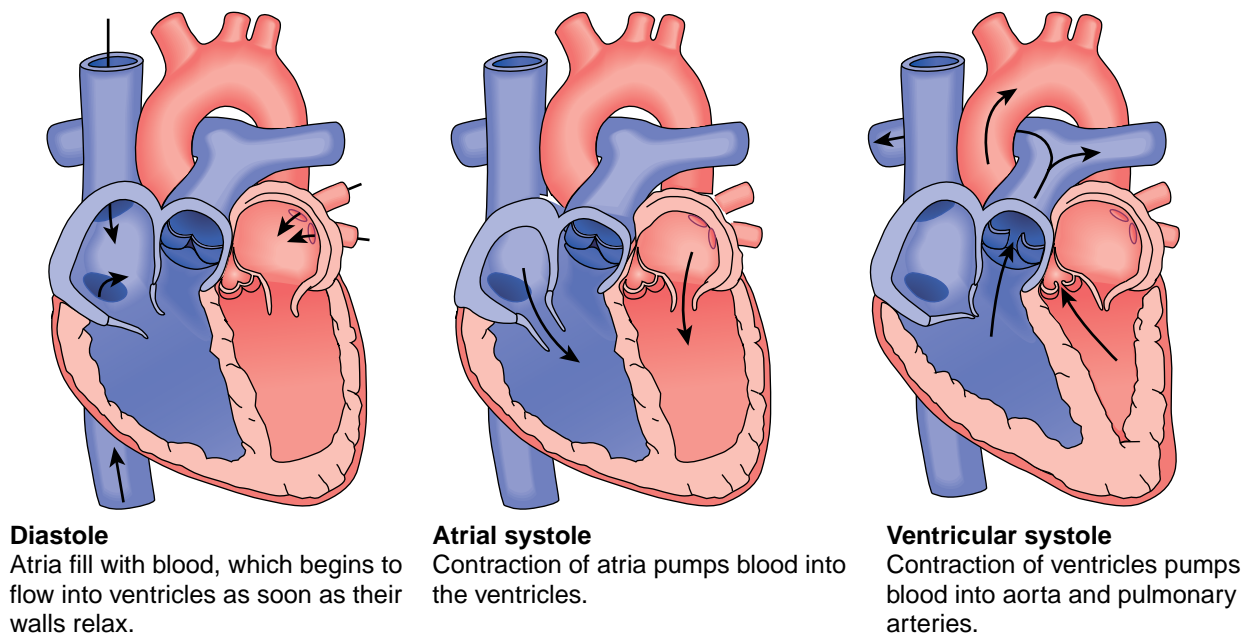
Cardiac Output

A unique property of heart muscle is its ability to adjust the strength of contraction to the amount of blood received. When the heart chamber is filled and the wall stretched (within limits), the contraction is strong. As less blood enters the heart, contractions become less forceful. Thus, as

more blood enters the heart, as occurs during exercise, the muscle contracts with greater strength to push the larger volume of blood out into the blood vessels (see Box 14-1, Cardiac Reserve).

The volume of blood pumped by each ventricle in 1 minute is termed the **cardiac output (CO)**. It is the product of the **stroke volume (SV)**—the volume of blood ejected from the ventricle with each beat—and the **heart rate (HR)**—the number of times the heart beats per minute. To summarize:

$$CO = HR \times SV$$



Diastole
Atria fill with blood, which begins to flow into ventricles as soon as their walls relax.

Atrial systole
Contraction of atria pumps blood into the ventricles.

Ventricular systole
Contraction of ventricles pumps blood into aorta and pulmonary arteries.

Figure 14-10 The cardiac cycle. *ZOOMING IN ♦ When the ventricles contract, what valves close? What valves open?*

Box 14-1 A Closer Look

Cardiac Reserve: Extra Output When Needed

Like many other organs, the heart has great reserves of strength. The cardiac reserve is a measure of how many times more than average the heart can produce when needed. Based on a heart rate of 75 beats/minute and a stroke volume of 70 ml/beat, the average cardiac output for an adult at rest is about 5 L/minute. This means that at rest, the heart pumps the equivalent of the total blood volume each minute.

During mild exercise, this volume might double and even double again during strenuous exercise. For most people the cardiac reserve is 4 to 5 times the resting output. This increase in cardiac output is achieved by an increase in either stroke

volume, heart rate, or both. In athletes exercising vigorously, the ratio may reach 6 to 7 times. In contrast, those with heart disease may have little or no cardiac reserve. They may be fine at rest but quickly become short of breath or fatigued when exercising or even when carrying out the simple tasks of daily living.

Cardiac reserve can be measured using an exercise stress test that measures cardiac output while the patient walks on a treadmill or pedals an exercise bicycle. The exercise becomes more and more strenuous until the patient's peak cardiac output (cardiac reserve) is reached.

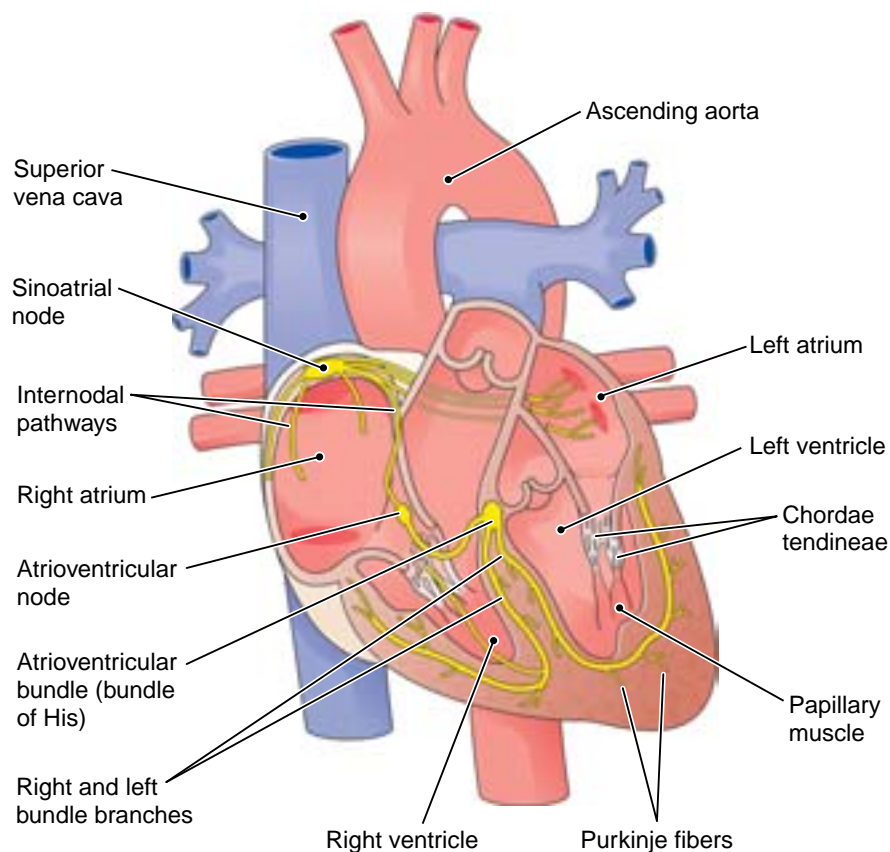


Figure 14-11 Conduction system of the heart. The sinoatrial (SA) node, the atrioventricular (AV) node, and specialized fibers conduct the electrical energy that stimulates the heart muscle to contract. *ZOOMING IN ♦ What parts of the conduction system do the internodal pathways connect?*

Checkpoint 14-6 The cardiac cycle consists of an alternating pattern of contraction and relaxation. What name is given to the contraction phase? To the relaxation phase?

Checkpoint 14-7 Cardiac output is the amount of blood pumped by each ventricle in 1 minute. What two factors determine cardiac output?

The Heart's Conduction System

Like other muscles, the heart muscle is stimulated to contract by a wave of electrical energy that passes along the cells. This action potential is generated by specialized tissue within the heart and spreads over structures that form the heart's conduction system (Fig. 14-11). Two of these structures are tissue masses called **nodes**, and the remainder consists of specialized fibers that branch through the myocardium.

The **sinoatrial (SA) node** is located in the upper wall of the right atrium in a small depression described as a sinus. This node initiates the heartbeats by generating an action potential at regular intervals. Because the SA node sets the rate of heart contractions, it is commonly called the **pacemaker**. The second node, located in the interatrial septum at the bottom of the right atrium, is called the **atrioventricular (AV) node**.

The **atrioventricular bundle**, also known as the **bundle of His**, is located at the top of the interventricular septum. It has branches that extend to all parts of the ventricular walls. Fibers travel first down both sides of the interventricular septum in groups called the right and left bundle branches. Smaller **Purkinje (pur-KIN-je) fibers**, also called *conduction myofibers*, then travel in a branching network throughout the myocardium of the ventricles. Intercalated disks allow the rapid flow of impulses throughout the heart muscle.

The Conduction Pathway The order in which impulses travel through the heart is as follows:

1. The sinoatrial node generates the electrical impulse that begins the heartbeat (see Fig. 14-11).
2. The excitation wave travels throughout the muscle of each atrium, causing the atria to contract. At the same time, impulses also travel directly to the AV node by means of fibers in the wall of the atrium that make up the **internodal pathways**.
3. The atrioventricular node is stimulated. A relatively slower rate of conduction through the AV node allows time for the atria to contract and complete the filling of the ventricles before the ventricles contract.
4. The excitation wave travels rapidly through the bundle of His and then throughout the ventricular walls by means of the bundle branches and Purkinje fibers. The entire ventricular musculature contracts almost at the same time.

A normal heart rhythm originating at the SA node is termed a **sinus rhythm**. As a safety measure, a region of the conduction system other than the sinoatrial node can generate a heartbeat if the sinoatrial node fails, but it does so at a slower rate.

Checkpoint 14-8 The heartbeat is started by a small mass of tissue in the upper right atrium. This structure is commonly called the pacemaker, but what is its scientific name?

Control of the Heart Rate

Although the heart's fundamental beat originates within the heart itself, the heart rate can be influenced by the nervous system, hormones and other factors in the internal environment.

The autonomic nervous system (ANS) plays a major role in modifying the heart rate according to need (Fig. 14-12). Sympathetic nervous system stimulation increases the heart rate. During a fight-or-flight response, the sympathetic nerves can boost the cardiac output two to three times the resting value. Sympathetic fibers increase the contraction rate by stimulating the SA and AV nodes. They also increase the contraction force by acting directly on the fibers of the myocardium. These actions translate into increased cardiac output. Parasympathetic stimulation decreases the heart rate to restore homeostasis. The parasympathetic nerve that supplies the heart is the vagus nerve (cranial nerve X). It slows the heart rate by acting on the SA and AV nodes.

These ANS influences allow the heart to meet changing needs rapidly. The heart rate is also affected by substances circulating in the blood, including hormones, ions, and drugs. Regular exercise strengthens the heart and increases the amount of blood ejected with each beat. Consequently, the circulatory needs of the body at rest can be met with a lower heart rate. Trained athletes usually have a low resting heart rate.

Variations in Heart Rates

- **Bradycardia** (brad-e-KAR-de-ah) is a relatively slow heart rate of less than 60 beats/minute. During rest and sleep, the heart may beat less than 60 beats/minute, but the rate usually does not fall below 50 beats/minute.
- **Tachycardia** (tak-e-KAR-de-ah) refers to a heart rate of more than 100 beats/minute. Tachycardia is normal during exercise or stress but may also occur under abnormal conditions.
- **Sinus arrhythmia** (ah-RITH-me-ah) is a regular variation in heart rate caused by changes in the rate and depth of breathing. It is a normal phenomenon.
- **Premature beat**, also called *extrasystole*, is a beat that comes before the expected normal beat. In healthy people, they may be initiated by caffeine, nicotine, or psychological stresses. They are also common in people with heart disease.

Heart Sounds

The normal heart sounds are usually described by the syllables "lubb" and "dupp." The first, "lubb," is a longer,

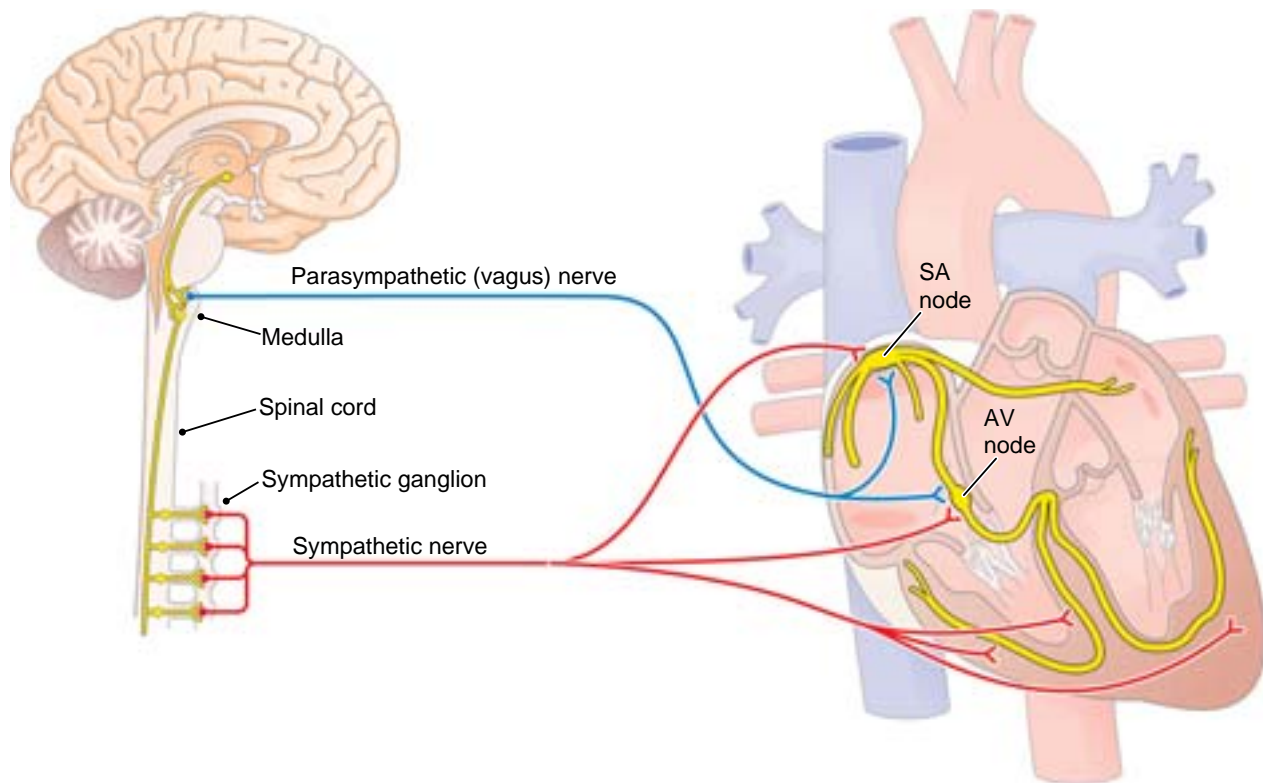


Figure 14-12 Autonomic nervous system regulation of the heart. The ANS affects the rate and force of heart contractions. **ZOOMING IN** ♦ What parts of the conduction system does the autonomic nervous system affect?

lower-pitched sound that occurs at the start of ventricular systole. It is probably caused by a combination of events, mainly closure of the atrioventricular valves. This action causes vibrations in the blood passing through the valves and in the tissue surrounding the valves. The second, or “dupp,” sound is shorter and sharper. It occurs at the beginning of ventricular relaxation and is caused largely by sudden closure of the semilunar valves.

Murmurs An abnormal sound is called a **murmur** and is usually due to faulty action of a valve. For example, if a valve fails to close tightly and blood leaks back, a murmur is heard. Another condition giving rise to an abnormal sound is the narrowing (stenosis) of a valve opening.

The many conditions that can cause abnormal heart sounds include congenital (birth) defects, disease, and physiologic variations. An abnormal sound caused by any structural change in the heart or the vessels connected with the heart is called an **organic murmur**. Certain normal sounds heard while the heart is working may also be described as murmurs, such as the sound heard during rapid filling of the ventricles. To differentiate these from abnormal sounds, they are more properly called **functional murmurs**.

Checkpoint 14-9 What system exerts the main influence on the rate and strength of heart contractions?

Checkpoint 14-10 What is a heart murmur?

Heart Disease

Diseases of the heart and circulatory system are the most common causes of death in industrialized countries. Few people escape having some damage to the heart and blood vessels in a lifetime.

Classifications of Heart Disease

There are many ways of classifying heart disease. The heart’s anatomy forms the basis for one grouping of heart pathology:

- ♦ **Endocarditis** (en-do-kar-DI-tis) means “inflammation of the lining of the heart.” Endocarditis may involve the lining of the chambers, but the term most commonly refers to inflammation of the endocardium on the valves and valvular disease.
- ♦ **Myocarditis** (mi-o-kar-DI-tis) is inflammation of heart muscle.
- ♦ **Pericarditis** (per-ih-kar-DI-tis) refers to inflammation of the serous membrane on the heart surface as well as that lining the pericardial sac.

These inflammatory diseases are often caused by infection, but may also be secondary to other types of respiratory or systemic diseases.

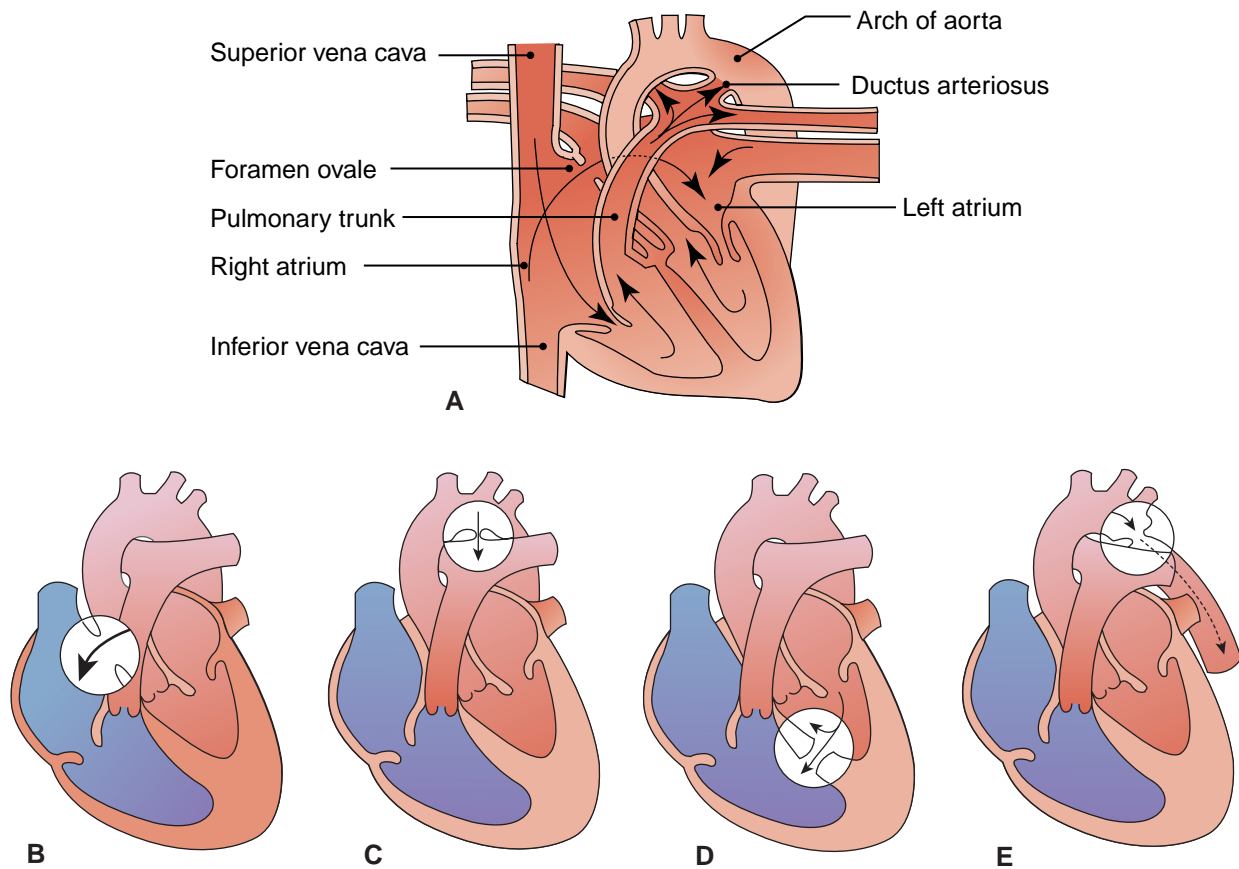


Figure 14-13 Congenital heart defects. (A) Normal fetal heart showing the foramen ovale and ductus arteriosus. (B) Persistence of the foramen ovale results in an atrial septal defect. (C) Persistence of the ductus arteriosus (patent ductus arteriosus) forces blood back into the pulmonary artery. (D) A ventricular septal defect. (E) Coarctation of the aorta restricts outward blood flow in the aorta. (Reprinted with permission from Porth CM. *Pathophysiology*. 7th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

Another classification of heart disease is based on causative factors:

- ▶ **Congenital heart disease** is a condition present at birth.
- ▶ **Rheumatic (ru-MAT-ik) heart disease** originates with an attack of rheumatic fever in childhood or in youth.
- ▶ **Coronary artery disease** involves the walls of the blood vessels that supply the heart muscle.
- ▶ **Heart failure** is caused by deterioration of the heart tissues and is frequently the result of long-standing disorders, such as high blood pressure.

Congenital Heart Disease

Congenital heart diseases often are the result of defects in fetal development. Two of these disorders represent the abnormal persistence of structures that are part of the normal fetal circulation (Fig. 14-13 A). Because the lungs are not used until a child is born, the fetus has some adaptations that allow blood to bypass the lungs. The fetal heart has a small hole, the foramen ovale (for-A-men o-VAL-e), in the septum between the right and left atria. This opening allows some blood to flow directly from the right atrium into the left atrium, thus bypassing the

lungs. Failure of the foramen ovale to close is one cause of an abnormal opening known as an **atrial septal defect** (see Fig. 14-13 B).

The ductus arteriosus (ar-te-re-O-sus) in the fetus is a small blood vessel that connects the pulmonary artery and the aorta so that some blood headed toward the lungs will enter the aorta instead. The ductus arteriosus normally closes on its own once the lungs are in use. Persistence of the vessel after birth is described as **patent (open) ductus arteriosus** (see Fig. 14-13 C).

The most common single congenital heart defect is a hole in the septum between the two ventricles, a disorder known as **ventricular septal defect** (see Fig. 14-13 D).

In each of the above defects, part of the heart's left side output goes back to the lungs instead of out to the body. A small defect remaining from the foramen ovale or a small patent ductus may cause no difficulty and is often not diagnosed until an adult is examined for other cardiac problems. More serious defects greatly increase the left ventricle's work and may lead to heart failure. In addition, ventricular septal defect creates high blood pressure in the lungs, which damages lung tissue.

Other congenital defects that tax the heart involve restriction of outward blood flow. **Coarctation** (ko-ark-TA-shun) of the **aorta** is a localized narrowing of the aortic arch (see Fig. 14-13 E). Another example is obstruction or narrowing of the pulmonary trunk that prevents blood from passing in sufficient quantity from the right ventricle to the lungs.

In many cases, several congenital heart defects occur together. The most common combination is that of four specific defects known as the **tetralogy of Fallot**. So-called “blue babies” commonly have this disorder. The blueness, or **cyanosis** (si-ah-NO-sis), of the skin and mucous membranes is caused by a relative lack of oxygen. (See Chap. 18 for other causes of cyanosis.)

In recent years, it has become possible to remedy many congenital defects by heart surgery, one of the more spectacular advances in modern medicine. A patent ductus arteriosus may also respond to drug treatment. During fetal life, prostaglandins (hormones) keep the ductus arteriosus open. Drugs that inhibit prostaglandins can promote closing of the duct after birth.

Checkpoint 14-11 What is congenital heart disease?

Rheumatic Heart Disease

A certain type of streptococcal infection, the type that causes “strep throat,” is indirectly responsible for rheumatic fever and rheumatic heart disease. The toxin produced by these streptococci causes a normal immune response. However, in some cases, the initial infection may be followed some 2 to 4 weeks later by rheumatic fever, a generalized inflammatory disorder with marked swelling of the joints. The antibodies formed to combat the toxin are believed to cause this disease. These antibodies may also attack the heart valves, producing a condition known

as *rheumatic endocarditis*. The heart valves, particularly the mitral valve, become inflamed, and the normally flexible valve cusps thicken and harden. The mitral valve may not open sufficiently (mitral stenosis) to allow enough blood into the ventricle or may not close effectively, allowing blood to return to the left atrium (mitral regurgitation). Either condition interferes with blood flow from the left atrium into the left ventricle, causing pulmonary congestion, an important characteristic of mitral heart disease. The incidence of rheumatic heart disease has declined with antibiotic treatment of streptococcal infections. However, children who do not receive adequate diagnosis and treatment are subject to developing the disease.

Checkpoint 14-12 What types of organisms cause rheumatic fever?

Coronary Artery Disease

Like vessels elsewhere in the body, the coronary arteries that supply the heart muscle, can undergo degenerative changes with time. The lumen (space) inside the vessel may gradually narrow because of a progressive deposit of fatty material known as **plaque** (PLAK) in the lining of the vessels, usually the arteries. This process, called **atherosclerosis** (ath-er-o-skleh-RO-sis), causes thickening and hardening of the vessels with a loss of elasticity (Fig. 14-14). The *athero* part of the name means “gruel,” because of the porridge-like material that adheres to the vessel walls. The vessels’ narrowing leads to **ischemia** (is-KE-me-ah), a lack of blood supply to the areas fed by those arteries. Degenerative changes in the arterial wall also may cause the inside vascular surface to become roughened, promoting blood clot (thrombus) formation. (see Fig. 14-14 C).

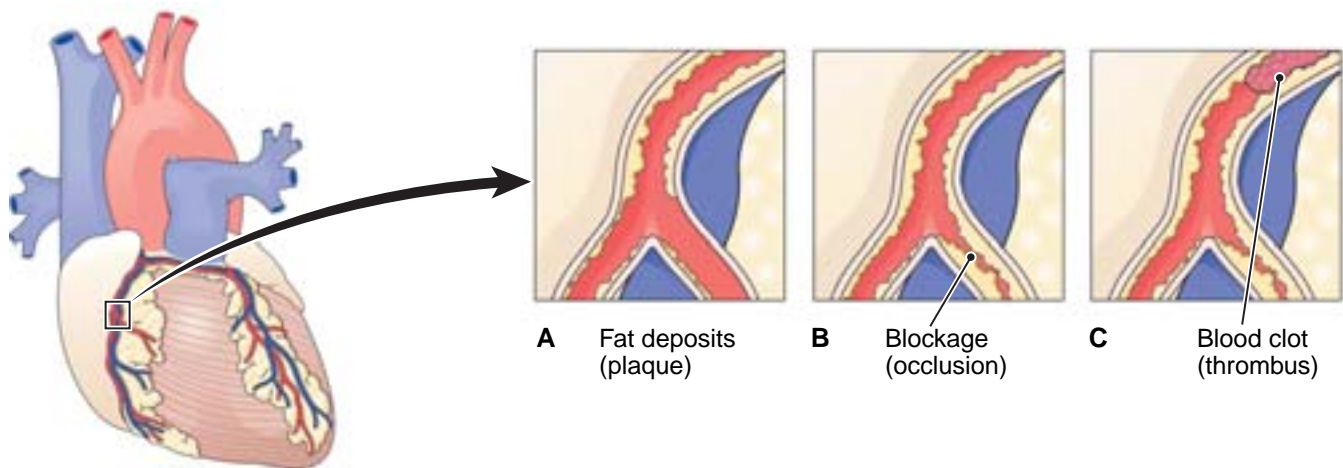


Figure 14-14 **Coronary atherosclerosis.** (A) Fat deposits (plaque) narrow an artery, leading to ischemia (lack of blood supply). (B) Plaque causes blockage (occlusion) of a vessel. (C) Formation of a blood clot (thrombus) in a vessel leads to myocardial infarction (MI).

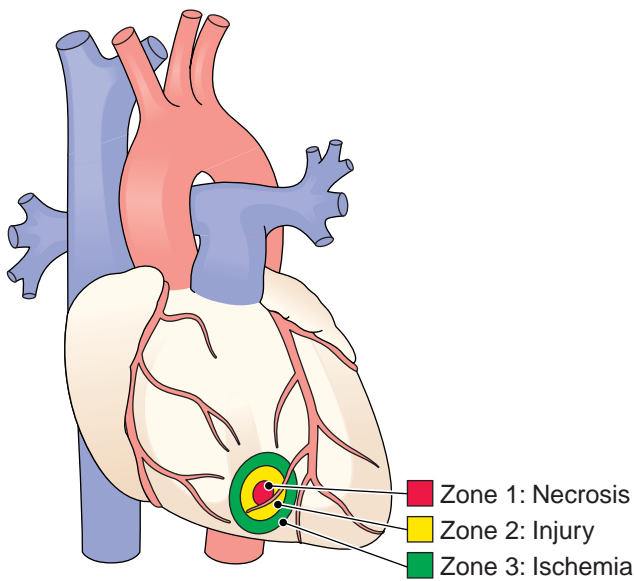


Figure 14-15 Myocardial infarction (MI). (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

Myocardial Infarction In the heart, thrombus formation results in a life-threatening condition known as **coronary thrombosis**. Sudden **occlusion** (ok-LU-zhun), or closure, of a coronary vessel with complete obstruction of blood flow is commonly known as a *heart attack*. Because the area of tissue damaged in a heart attack is described as an **infarct** (IN-farkt), the medical term for a heart attack is **myocardial infarction (MI)** (Fig. 14-15). The oxygen-deprived tissue will eventually undergo necrosis (death). The symptoms of MI commonly include the abrupt onset of severe, constricting chest pain that may radiate to the left arm, back, neck or jaw. Patients may experience shortness of breath, sweating, nausea, vomiting, or pain in the epigastric region, which can be mistaken for indigestion. They may feel weak, restless, or anxious and the skin may be pale, cool and moist.

The outcome of a myocardial infarction depends largely on the extent and location of the damage. Many people die within the first hour after onset of symptoms, but prompt, aggressive treatment can improve outcomes. Medical personnel make immediate efforts to relieve chest pain, stabilize the heart rhythm, and reopen the blocked vessel. Complete and prolonged lack of blood to any part of the myocardium results in tissue necrosis and weakening of the heart wall.

Angina Pectoris Inadequate blood flow to the heart muscle causes a characteristic discomfort, called **angina pectoris** (an-JI-nah PEK-to-ris), felt in the region of the heart and in the left arm and shoulder. Angina pectoris may be accompanied by a feeling of suffocation and a general sensation of forthcoming doom. Coronary artery disease is a common cause of angina pectoris, although the condition has other causes as well.

Abnormalities of Heart Rhythm Coronary artery disease or myocardial infarction often results in an abnormal rhythm of the heartbeat, or **arrhythmia** (ah-RITH-meh-ah). Extremely rapid but coordinated contractions, numbering up to 300 per minute, are described as **flutter**. An episode of rapid, wild, and uncoordinated heart muscle contractions is called **fibrillation** (fih-brih-LA-shun), which may involve the atria only or both the atria and the ventricles. Ventricular fibrillation is a serious disorder because there is no effective heartbeat. It must be corrected by a **defibrillator**, a device that generates a strong electrical current to discharge all the cardiac muscle cells at once, allowing a normal rhythm to resume.

An interruption of electric impulses in the heart's conduction system is called **heart block**. The seriousness of this condition depends on how completely the impulses are blocked. It may result in independent beating of the chambers if the ventricles respond to a second pacemaker.

Treatment of Heart Attacks The death rate for heart attacks is high when treatment is delayed. Initial treatment involves cardiopulmonary resuscitation (CPR) and defibrillation at the scene when needed. The American Heart Association is adding training in the use of the **automated external defibrillator (AED)** to the basic course in CPR. The AED detects fatal arrhythmia and automatically delivers the correct preprogrammed shock. Work is underway to place machines in shopping centers, sports venues, and other public settings.

Prompt transport by paramedics who are able to monitor the heart and give emergency drugs helps people to survive and reach a hospital. The next step is to restore blood flow to the ischemic areas by administering **thrombolytic** (throm-bo-LIT-ik) **drugs**, which act to dissolve the clots blocking the coronary arteries. Therapy must be given promptly to prevent permanent heart muscle damage. In many cases, a pulmonary artery catheter (tube) is put in place to monitor cardiac function and response to medication.

Supportive care includes treatment of chest pain with intravenous (IV) morphine. Healthcare workers monitor heart rhythm and give medications to maintain a functional rhythm. Oxygen is given to improve heart muscle function. Some patients require surgery, such as angioplasty to reopen vessels or a vascular graft to bypass damaged vessels; others may need an artificial pacemaker to maintain a normal heart rhythm.

Recovery from a heart attack and resumption of a normal lifestyle is often possible if the patient follows his or her prescribed drug therapy plan and takes steps to reduce cardiac risk factors.

Checkpoint 14-13 Narrowing or blockage of the vessels that supply the heart muscle causes coronary artery disease. What degenerative process commonly causes narrowing of these vessels?

Heart Failure

Heart failure is a condition in which the heart is unable to pump sufficient blood to supply the tissues with oxygen and nutrients. The heart's chambers enlarge to contain more blood than the stretched fibers are able to pump. Blood backs up into the lungs, increasing blood pressure in the lungs. The ventricular muscles do not get enough blood, decreasing their ability to contract. Additional mechanisms cause the retention of fluid, leading to the name *congestive heart failure* (CHF). In an attempt to increase blood flow, the nervous system increases contraction of smooth muscle in the blood vessels, increasing blood pressure. Soon there is an accumulation of fluids in the lungs, liver, abdomen, and legs. People can live with compensated heart failure by attention to diet, drug therapy, and a balance of activity and rest.

► The Heart in the Elderly

There is much individual variation in the way the heart ages, depending on heredity, environmental factors, diseases, and personal habits. However, some of the changes that may occur with age are as follows. The heart becomes smaller, and there is a decrease in the strength of heart muscle contraction. The valves become less flexible, and incomplete closure may produce an audible murmur. By 70 years of age, the cardiac output may decrease by as much as 35%. Damage within the conduction system can produce abnormal rhythms, including extra beats, rapid atrial beats, and slowing of ventricular rate. Temporary failure of the conduction system (heart block) can cause periodic loss of consciousness. Because of the decrease in the reserve strength of the heart, elderly people are often limited in their ability to respond to physical or emotional stress.

► Prevention of Heart Disease

Prevention of heart ailments is based on identification of cardiovascular risk factors and modification of those factors that can be changed. Risk factors that cannot be modified include the following:

- Age. The risk of heart disease increases with age.
- Gender. Until middle age, men have greater risk than women. Women older than 50 years or past menopause have risk equal to that of males.
- Heredity. Those with immediate family members with heart disease are at greater risk.
- Body type, particularly the hereditary tendency to deposit fat in the abdomen or on the chest surface, increases risk.

Risk factors that can be changed include the following:

- Smoking, which leads to spasm and hardening of the arteries. These arterial changes result in decreased blood flow and poor supply of oxygen and nutrients to heart muscle.
- Physical inactivity. Lack of exercise weakens the heart muscle and decreases the efficiency of the heart. It also decreases the efficiency of the skeletal muscles, which further taxes the heart.
- Weight over the ideal increases risk.
- Saturated fat in the diet. Elevated fat levels in the blood lead to blockage of the coronary arteries by plaque (see Box 14-2, Lipoproteins).
- High blood pressure (hypertension) damages heart muscle.
- Diabetes and gout. Both diseases cause damage to small blood vessels.

Efforts to prevent heart disease should include having regular physical examinations and minimizing the controllable risk factors.

Box 14-2 Clinical Perspectives

Lipoproteins: What's the Big DL?

Although cholesterol has received a lot of bad press in recent years, it is a necessary substance in the body. It is found in bile salts needed for digestion of fats, in hormones, and in the plasma membrane of the cell. However, high levels of cholesterol in the blood have been associated with atherosclerosis and heart disease.

It now appears that the total amount of blood cholesterol is not as important as the form in which it occurs. Cholesterol is transported in the blood in combination with other lipids and with protein, forming compounds called lipoproteins. These compounds are distinguished by their relative density. High-density lipoprotein (HDL) is about one-half protein, whereas low-density lipoprotein (LDL) has a higher proportion of cholesterol and less protein. VLDLs, or very-low-density lipoproteins, are substances that are converted to LDLs.

LDLs carry cholesterol from the liver to the tissues, making it available for membrane or hormone synthesis. HDLs remove cholesterol from the tissues, such as the walls of the arteries, and carry it back to the liver for reuse or disposal. Thus, high levels of HDLs indicate efficient removal of arterial plaques, whereas high levels of LDLs suggest that arteries will become clogged.

Diet is an important factor in regulating lipoprotein levels. Saturated fatty acids (found primarily in animal fats) raise LDL levels, while unsaturated fatty acids (found in most vegetable oils) lower LDL levels and stimulate cholesterol excretion. Thus, a diet lower in saturated fat and higher in unsaturated fat may reduce the risk of atherosclerosis and heart disease. Other factors that affect lipoprotein levels include cigarette smoking, coffee drinking, and stress, which raise LDL levels, and exercise, which lowers LDL levels.

Heart Studies

Experienced listeners can gain much information about the heart using a **stethoscope** (STETH-o-sko-pe). This relatively simple instrument is used to convey sounds from within the patient's body to an examiner's ear.

The **electrocardiograph** (ECG or EKG) is used to record electrical changes produced as the heart muscle contracts. (The abbreviation EKG comes from the German spelling of the word.) The ECG may reveal certain myocardial injuries. Electrodes (leads) placed on the skin surface pick up electrical activity, and the ECG tracing, or electrocardiogram, represents this activity as waves. The P wave represents the activity of the atria; the QRS and T waves represent the activity of the ventricles (Fig. 14-16). Changes in the waves and the intervals between them are used to diagnose heart damage and arrhythmias.

Many people with heart disease undergo **catheterization** (kath-eh-ter-i-ZA-shun). In right heart catheterization, an extremely thin tube (catheter) is passed through the veins of the right arm or right groin and then into the right side of heart. A **fluoroscope** (flu-OR-o-scope), an instrument for examining deep structures with x-rays, is used to show the route taken by the catheter. The tube is passed all the way through the pulmonary valve into the large lung arteries. Blood samples are obtained along the way for testing, and pressure readings are taken.

In left heart catheterization, a catheter is passed through an artery in the left groin or arm to the heart. Dye can then be injected into the coronary arteries to map damage to the vessels. The tube may also be passed through the aortic valve into the left ventricle for studies of pressure and volume in that chamber.

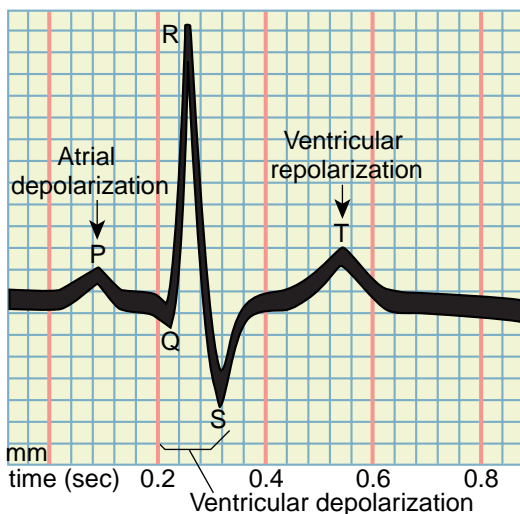


Figure 14-16 Normal ECG tracing. The tracing shows a single cardiac cycle. What is the length of the cardiac cycle shown in this diagram? **ZOOMING IN** ♦ What is the length of the cardiac cycle shown in this diagram

Ultrasound consists of sound waves generated at a frequency above the range of sensitivity of the human ear. In **echocardiography** (ek-o-kar-de-OG-rah-fe), also known as *ultrasound cardiology*, high-frequency sound waves are sent to the heart from a small instrument on the surface of the chest. The ultrasound waves bounce off the heart and are recorded as they return, showing the heart in action. Movement of the echoes is traced on an electronic instrument called an *oscilloscope* and recorded on film. (The same principle is employed by submarines to detect ships.) The method is safe and painless, and it does not use x-rays. It provides information on the size and shape of heart structures, on cardiac function, and on possible heart defects.

Checkpoint 14-14 What do ECG and EKG stand for?

Treatment of Heart Disease

Heart specialists employ medical and surgical approaches to the treatment of heart disease, often in combination.

Medications

One of the oldest drugs for heart treatment, and still the most important drug for many patients, is **digitalis** (dij-ih-TAL-is). This agent, which slows and strengthens heart muscle contractions, is obtained from the leaf of the foxglove, a plant originally found growing wild in many parts of Europe. Foxglove is now cultivated to ensure a steady supply of digitalis for medical purposes.

Several forms of **nitroglycerin** are used to relieve angina pectoris. This drug dilates (widens) the vessels in the coronary circulation and improves the blood supply to the heart.

Beta-adrenergic blocking agents (“beta-blockers”) control sympathetic stimulation of the heart. They reduce the rate and strength of heart contractions, thus reducing the heart's oxygen demand. Propranolol is one example.

Antiarrhythmic agents (e.g., quinidine) are used to regulate the rate and rhythm of the heartbeat.

Slow calcium-channel blockers aid in the treatment of coronary heart disease and hypertension by several mechanisms. They may dilate vessels, control the force of heart contractions, or regulate conduction through the atrioventricular node. Their actions are based on the fact that calcium ions must enter muscle cells before contraction can occur.

Anticoagulants (an-ti-ko-AG-u-lants) are valuable drugs for some heart patients. They may be used to prevent clot formation in patients with damage to heart valves or blood vessels or in patients who have had a myocardial infarction. **Aspirin** (AS-pir-in), chemically known as acetylsalicylic (a-SE-til-sal-ih-sil-ik) acid (ASA), is an inexpensive and time-tested drug for pain and inflammation that reduces blood clotting by interfering with platelet activity. A small daily dose of aspirin is recommended for patients with angina pectoris, those who have suffered a myocardial

infarction, and those who have undergone surgery to open or bypass narrowed coronary arteries. It is contraindicated for people with bleeding disorders or gastric ulcers, because aspirin irritates the lining of the stomach.

Correction of Arrhythmias

If the SA node fails to generate a normal heartbeat or there is some failure in the cardiac conduction system, an electric, battery-operated **artificial pacemaker** can be employed (Fig. 14-17). This device, implanted under the skin, supplies regular impulses to stimulate the heartbeat. The site of implantation is usually in the left chest area. A pacing wire (lead) from the pacemaker is then passed into the heart through a vessel and lodged in the heart. The lead may be fixed in an atrium or a ventricle (usually on the right side). A dual chamber pacemaker has a lead in each chamber to coordinate beats between the atrium and ventricle. Some pacemakers operate at a set rate; others can be set to stimulate a beat only when the heart fails to do so on its own. Another type of pacemaker adjusts its pacing rate in response to changing activity, as during exercise. This rather simple device has saved many people whose hearts cannot beat effectively alone. In an emergency, a similar stimulus can be supplied to the heart muscle through electrodes placed externally on the chest wall.

In cases of chronic ventricular fibrillation, a battery-powered device can be implanted in the chest to restore

a normal rhythm. The device detects a rapid abnormal rhythm and delivers a direct shock to the heart. The restoration of a normal heartbeat either by electric shock or drugs, is called *cardioversion*, and this device is known as an implantable cardioverter-defibrillator (ICD). A lead wire from the defibrillator is placed in the right ventricle through the pulmonary artery. In cases of severe tachycardia, tissue that is causing the disturbance can be destroyed by surgery or catheterization.

Heart Surgery

The heart-lung machine makes many operations on the heart and other thoracic organs possible. There are several types of machines in use, all of which serve as temporary substitutes for the patient's heart and lungs. The machine siphons off the blood from the large vessels entering the heart on the right side, so that no blood passes through the heart and lungs. While in the machine, the blood is oxygenated, and carbon dioxide is removed chemically. The blood is also "defoamed," or rid of air bubbles, which could fatally obstruct blood vessels. The machine then pumps the processed blood back into the general circulation through a large artery. Modern advances have enabled cardiac surgeons to perform certain procedures without bypassing the circulation, immobilizing part of the heart while it continues to beat.

Coronary artery bypass graft (CABG) to relieve obstruction in the coronary arteries is a common and often successful treatment (Fig. 14-18). While the damaged coronary arteries remain in place, healthy segments of blood vessels from other parts of the patient's body are grafted onto the vessels to bypass any obstructions. Usually, parts of the saphenous vein (a superficial vein in the leg) or the mammary artery in the chest are used.

Sometimes, as many as six or seven segments are required to establish an adequate blood supply. The mortality associated with this operation is low, and most patients are able to return to a nearly normal lifestyle after recovery from the surgery. The effectiveness of this procedure diminishes over a period of years, however, owing to blockage of the replacement vessels.

Less invasive surgical procedures include the technique of **angioplasty** (AN-je-o-plas-te), which is used to open restricted arteries in the heart and other areas of the body. In coronary angioplasty, a fluoroscope guides a catheter with a balloon to the affected area (Fig. 14-19). There, the

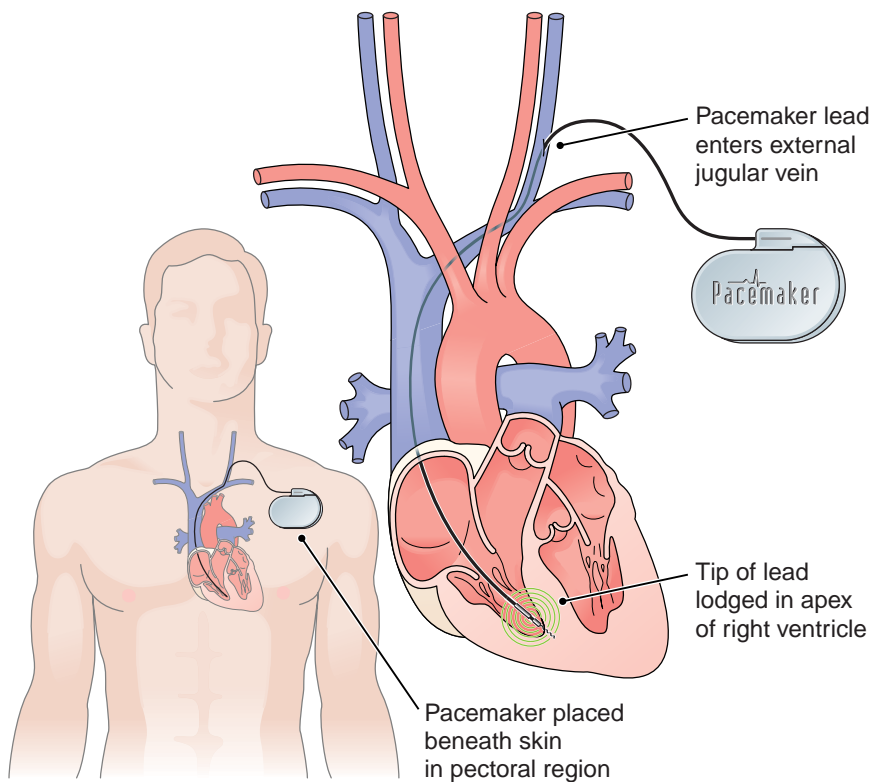


Figure 14-17 Placement of an artificial pacemaker. The lead is placed in an atrium or ventricle (usually on the right side). A dual chamber pacemaker has a lead in both chambers. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

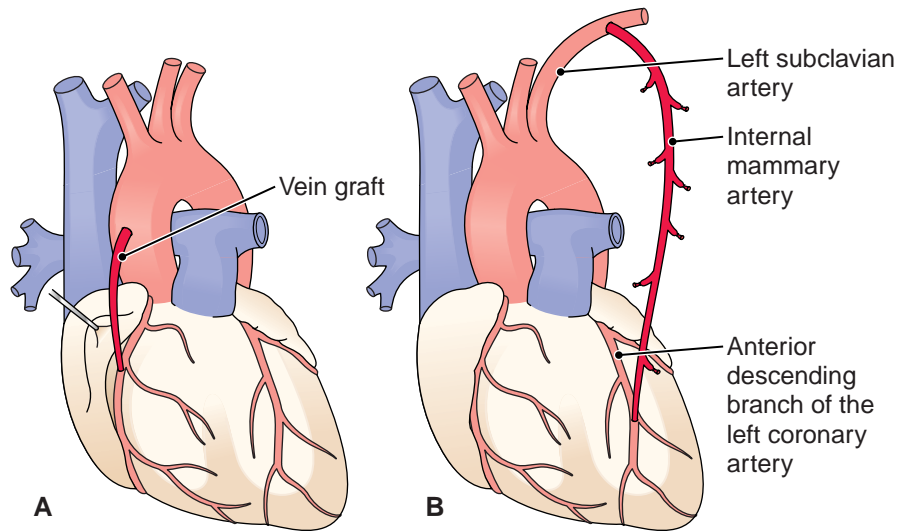


Figure 14-18 Coronary artery bypass graft (CABG) (A) This graft uses a segment of the saphenous vein to carry blood from the aorta to a part of the right coronary artery that is distal to the occlusion. (B) The mammary artery is grafted to bypass an obstruction in the left anterior descending (LAD) artery. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

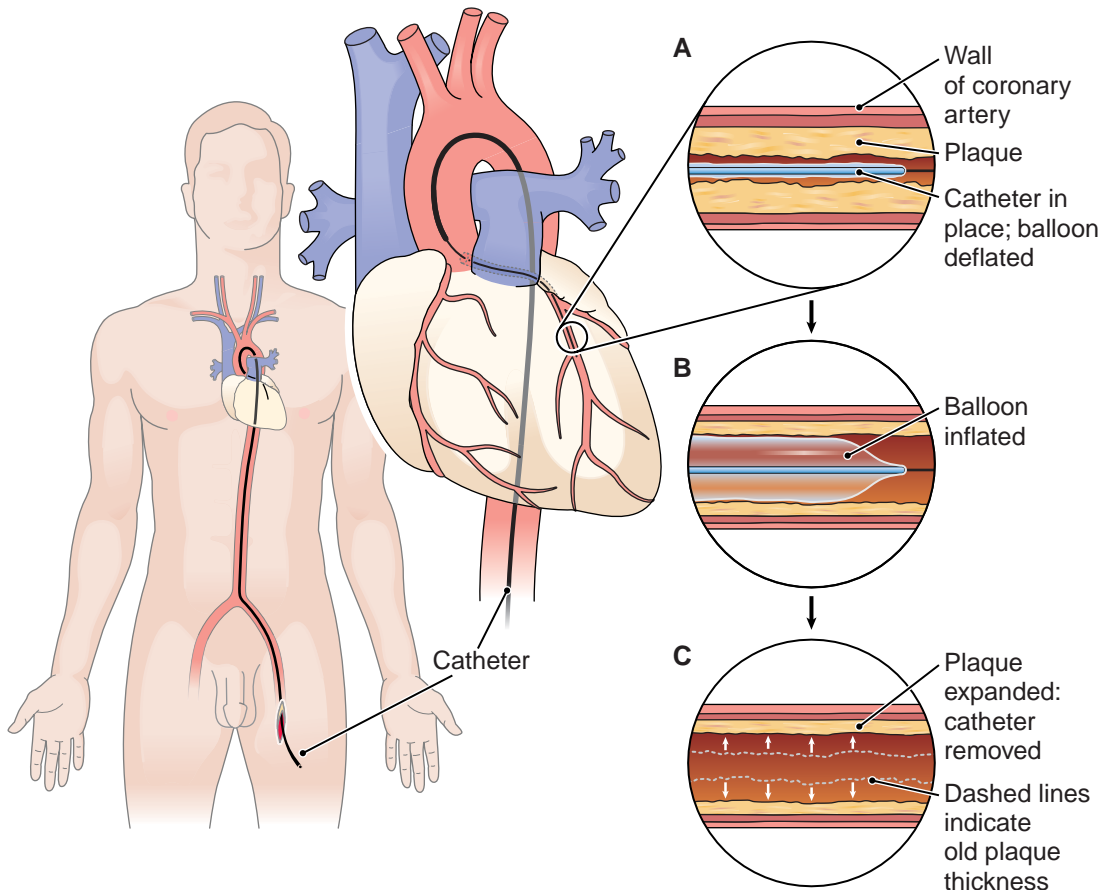


Figure 14-19 Coronary angioplasty (PTCA). (A) A guide catheter is threaded into the coronary artery. (B) A balloon catheter is inserted through the occlusion and inflated. (C) The balloon is inflated and deflated until plaque is flattened and the vessel is opened. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

Box 14-3 Hot Topics

Artificial Hearts: Saving Lives With Technology

More than 2000 Americans receive a heart transplant each year. Because, unfortunately, the number of individuals waiting to receive a transplant far exceeds the number of donor hearts available, researchers are inventing alternate technologies.

The ventricular assist device (VAD) is a mechanical pump that helps a patient's damaged heart to pump blood. The device is surgically implanted into a patient's chest or abdomen and connected to either the left or right ventricle. Powered by an external battery connected to it by a thin wire, the VAD pulls blood from the ventricle and pumps it to the aorta (in the case of a left VAD) or the pulmonary artery (in the case of a right VAD). These devices were first designed to help a patient survive until a suitable donor heart could be found, but a permanent model has recently been approved for use in the United States.

More than thirty years ago, researchers began experimenting with total artificial hearts, which are designed to completely replace a patient's damaged heart. The best known of these pumps is the Jarvik-7, an air-driven pump that required tubes and wires to remain connected through the skin to a large external unit. Unfortunately, all of the patients who received this device died of complications shortly after surgery and testing was discontinued. Today, researchers are experimenting with a new completely self-contained artificial heart that uses a wireless rechargeable external battery. A computer implanted in the abdomen closely monitors and controls the heart's pumping speed. If the experiments are successful, total artificial hearts may become a real alternative for patients who would otherwise die waiting for a heart transplant.

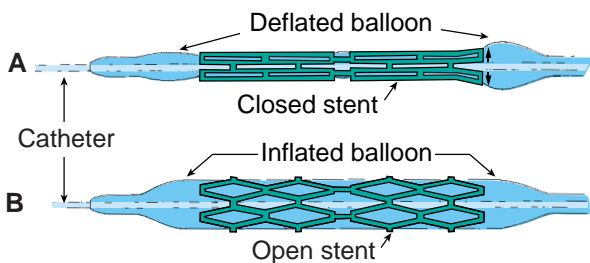


Figure 14-20 Intracoronary artery stent. (A) Stent closed, before the balloon is inflated. (B) The balloon is inflated to open the stent. The stent will remain expanded after the balloon is deflated and removed. (Reprinted with permission from Smeltzer SC, Bare BG. *Brunner and Suddarth's Textbook of Medical-Surgical Nursing*, 9th ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

balloon is inflated to break up the blockage in the coronary artery, thus restoring effective circulation to the heart muscle. To prevent repeated blockage, a small tube called a **stent** may be inserted in the vessel to keep it open (Fig. 14-20).

Diseased valves may become so deformed and scarred

from endocarditis that they are ineffective and often obstructive. In most cases, there is so much damage that **valve replacement** is the best treatment. Substitute valves made of a variety of natural and artificial materials have been used successfully.

The news media have given considerable attention to the **surgical transplantation** of human hearts and sometimes of lungs and hearts together. This surgery is done in specialized centers and is available to some patients with degenerative heart disease who are otherwise in good health. Tissues of the recently deceased donor and of the recipient must be as closely matched as possible to avoid rejection.

Efforts to replace a damaged heart with a completely artificial heart have not met with long term success so far. There are devices available, however, to assist a damaged heart in pumping during recovery from heart attack or while a patient is awaiting a donor heart (see Box 14-3, Artificial Hearts).

Checkpoint 14-15 What technique is used to open a restricted coronary artery with a balloon catheter?

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART

MEANING

EXAMPLE

Structure of the Heart

cardi/o

heart

The *myocardium* is the heart muscle.

pulmon/o

lung

The *pulmonary* circuit carries blood to the lungs.

WORD PART	MEANING	EXAMPLE
Function of the Heart		
sin/o	sinus	The <i>sinoatrial</i> node is in a space (sinus) in the wall of the right atrium.
brady-	slow	<i>Bradycardia</i> is a slow heart rate.
tachy-	rapid	<i>Tachycardia</i> is a rapid heart rate.
Heart Disease		
cyan/o	blue	<i>Cyanosis</i> is a bluish discoloration of the skin due to lack of oxygen.
sten/o	narrowing, closure	<i>Stenosis</i> is a narrowing of a structure, such as a valve.
scler/o	hard	In <i>atherosclerosis</i> , vessels harden with fatty, gruel-like (ather/o) material that deposits on vessel walls.
isch-	suppression	Narrowing of blood vessels leads to <i>ischemia</i> , a lack of blood (-emia) supply to tissues.
Heart Studies		
steth/o	chest	A <i>stethoscope</i> is used to listen to body sounds, such as those heard through the wall of the chest.
Treatment of Heart Disease		
angi/o	vessel	<i>Angioplasty</i> is used to reshape vessels that are narrowed by disease.
-plasty	molding, surgical formation	See preceding example.

Summary

I. Circulation and the heart—heart contractions drive blood through the blood vessels

- A. Location of the heart
- In mediastinum
 - Slightly left of the midline; apex pointed toward left

II. Structure of the heart

- A. Endocardium—thin inner layer of epithelium
- B. Myocardium—thick muscle layer
- C. Epicardium—thin outer layer of serous membrane
- Also called visceral pericardium
 - Pericardium—sac that encloses the heart
 - Outer layer fibrous
 - Inner layers—parietal and visceral serous membranes
 - Special features of myocardium
 - Lightly striated
 - Intercalated disks
 - Branching of fibers
 - Divisions of the heart
 - Two sides divided by septa
 - Four chambers
 - Atria—left and right receiving chambers
 - Ventricles—left and right pumping chambers
 - Four valves—prevent backflow of blood
 - Right atrioventricular (AV) valve—tricuspid
 - Left atrioventricular valve—mitral or bicuspid
 - Pulmonic (semilunar) valve—at entrance to pulmonary artery
 - Aortic (semilunar) valve—at entrance to aorta

- Blood supply to the myocardium
 - Coronary arteries—first branches of aorta; fill when heart relaxes
 - Coronary sinus—collects venous blood from heart and empties into right atrium

III. Function of the heart

- A. Cardiac cycle
- Diastole—relaxation phase
 - Systole—contraction phase
 - Cardiac output—volume pumped by each ventricle per minute
 - Stroke volume—amount pumped with each beat
 - Heart rate—number of beats per minute
 - Heart's conduction system
 - Sinoatrial node (pacemaker)—at top of right atrium
 - Atrioventricular node—between atria and ventricles
 - Atrioventricular bundle (bundle of His)—at top of interventricular septum
 - Bundle branches—right and left, on either side of septum
 - Purkinje fibers—branch through myocardium of ventricles
 - Control of the heart rate
 - Autonomic nervous system
 - Sympathetic system—speeds heart rate
 - Parasympathetic system—slows heart rate through vagus nerve
 - Others—hormones, ions, drugs
 - Variations in heart rates
 - Bradycardia—slower rate than normal; less than 60 beats/minute

- (ii) Tachycardia—faster rate than normal; more than 100 beats/minute
 - (iii) Sinus arrhythmia—related to breathing changes
 - (iv) Premature beat—extrasystole
- d. Heart sounds
- (1) Normal
 - (i) “Lubb”—occurs at closing of atrioventricular valves
 - (ii) “Dupp”—occurs at closing of semilunar valves
 - (2) Abnormal—murmur

IV. Heart disease

- A. Classification of heart disease
1. Anatomic classification—endocarditis, myocarditis, pericarditis
 2. Causal classification
- B. Congenital heart diseases—present at birth
1. Failure of fetal lung bypasses to close
 - a. Atrial septal defect
 - b. Patent ductus arteriosus
 2. Ventricular septal defect
 3. Narrowing of aorta or pulmonary artery
 4. Tetralogy of Fallot
- C. Rheumatic heart disease—results from a type of streptococcal infection
1. Mitral stenosis—valve cusps do not open
 2. Mitral regurgitation—valve cusps do not close
- D. Coronary artery disease
1. Characteristics
 - a. Atherosclerosis—thickening and hardening of arteries with plaque
 - b. Ischemia—lack of blood to area fed by blocked arteries
 - c. Coronary occlusion—closure of coronary arteries, as by a thrombus (clot)
 - d. Infarct—area of damaged tissue
 - e. Angina pectoris—pain caused by lack of blood to heart muscle
 - f. Abnormal rhythm—arrhythmia
 - (1) Flutter—rapid, coordinated beats
 - (2) Fibrillation—rapid, uncoordinated contractions of heart muscle
 - (3) Heart block—interruption of electric conduction
 2. Treatment of heart attacks—CPR, defibrillation, thrombolytic drugs, monitoring, good health habits

- E. Heart failure—due to hypertension, disease, malnutrition, anemia, age

V. The heart in the elderly

- A. Individual variations in how heart ages
- B. Common variations include:
1. Decrease in heart size, strength of muscle contraction, flexibility of valves, cardiac output
 2. Abnormal rhythms, temporary failure of conduction system

VI. Prevention of heart ailments

1. Risk factors
2. Preventive measures—physical examination, proper diet, quitting smoking, regular exercise, control of chronic illness

VII. Heart studies

- A. Stethoscope—used to listen to heart sounds
- B. Electrocardiograph (ECG, EKG)—records electrical activity as waves
- C. Catheterization—thin tube inserted into heart for blood samples, pressure readings, and other tests
- D. Fluoroscope—examines deep tissue with x-rays; used to guide catheter
- E. Echocardiography—uses ultrasound to record pictures of heart in action

VIII. Treatment of heart disease

- A. Medications—examples are digitalis, nitroglycerin, beta-adrenergic blocking agents, antiarrhythmic agents, slow channel calcium-channel blockers, anticoagulants
- B. Correction of arrhythmia
1. Artificial pacemakers—electronic devices implanted under skin to regulate heartbeat
 2. Implantable cardioverter-defibrillator (ICD)
 3. Destruction of abnormal tissue
- C. Heart surgery
1. Bypass—vessels grafted to detour blood around blockage
 2. Angioplasty—balloon catheter used to open blocked arteries
 - a. Stents used to keep vessels open
 3. Valve replacement
 4. Heart transplantation
 5. Artificial hearts

Questions for Study and Review

Building Understanding

Fill in the blanks

1. The central thoracic region that contains the heart is the _____.
2. The layer of the heart responsible for pumping blood is called the _____.
3. The heart beat is initiated by electrical impulses from the _____.
4. Lack of blood to a tissue fed by blocked arteries is called _____.
5. Pain caused by lack of blood to heart muscle is called _____.

Matching

Match each numbered item with the most closely related lettered item.

- | | |
|--|--------------------|
| ___ 6. receives deoxygenated blood from the body | a. right atrium |
| ___ 7. receives oxygenated blood from the lungs | b. left atrium |
| ___ 8. sends deoxygenated blood to the lungs | c. right ventricle |
| ___ 9. sends oxygenated blood to the body | d. left ventricle |

Multiple choice

- ___ 10. Rapid transfer of electrical signals between cardiac muscle cells is promoted by
- the striated nature of the cells
 - branching of the cells
 - the abundance of mitochondria within the cells
 - intercalated disks between the cells
- ___ 11. The upper chambers of the heart are separated by the
- intercalated disk
 - interatrial septum
 - interventricular septum
 - ductus arteriosus
- ___ 12. One complete sequence of heart contraction and relaxation is called the
- systole
 - diastole
 - cardiac cycle
 - cardiac output
- ___ 13. A medication that reduces the rate and strength of heart contractions by lowering sympathetic tone is called a(n)
- anticoagulant
 - antiarrhythmic agent
 - slow calcium-channel blocker
 - beta-adrenergic blocking agent
- ___ 14. The ductus arteriosus shunts blood away from the
- lungs and towards the aorta
 - lungs and towards the superior vena cava
 - aorta and towards the lungs
 - away from the superior vena cava and towards the lungs
- ___ 15. A regular variation in heart rate due to changes in the rate and depth of breathing is called a
- murmur
 - cyanosis
 - sinus arrhythmia
 - stent

Understanding Concepts

16. Differentiate between the terms in each of the following pairs:
- pulmonary and systemic circuit
 - coronary artery and coronary sinus
 - serous pericardium and fibrous pericardium
 - systole and diastole
17. Explain the purpose of the four heart valves and describe their structure and location. What prevents the valves from opening backwards?
18. Trace a drop of blood from the superior vena cava to the lungs and then from the lungs to the aorta.
19. Describe the order in which electrical impulses travel through the heart. What is an interruption of these impulses in the conduction system of the heart called?
20. Compare the effects of the sympathetic and parasympathetic nervous systems on the working of the heart.
21. Compare and contrast the following disease conditions:
- endocarditis and pericarditis
 - tachycardia and bradycardia
 - functional murmur and organic murmur
 - flutter and fibrillation
 - atrial and ventricular septal defect
22. What part does infection play in rheumatic heart disease?
23. List some age-related changes to the heart.

Conceptual Thinking

24. Jim's father has recently passed away following a massive myocardial infarction. At 45 years old, Jim is frightened that he may suffer the same fate. What can Jim do to lower his risk of heart disease? What risk factors can he not change?
25. Three month-old Hannah R. is brought to the doctor by her parents. They have noticed that when she cries she becomes breathless and turns blue. The doctor examines Hannah and notices that she is lethargic, small for her age, and has a loud mitral valve murmur. With this information, explain the cause of Hannah's symptoms.