

vessels dilate and increase their permeability. The formation of atherosclerotic plaques begins when excess LDLs from the blood accumulate in the artery wall and undergo oxidation. In response, endothelial and smooth muscle cells of the artery secrete substances that attract monocytes from the blood and convert them into macrophages. The macrophages then ingest and become so filled with the oxidized LDL particles that they have a foamy appearance when viewed microscopically (*foam cells*). Together with T cells (lymphocytes), foam cells form a *fatty streak*, the beginning of an atherosclerotic plaque. Following fatty streak formation, smooth muscle cells of the artery migrate to the top of the atherosclerotic plaque, forming a cap over it and thus walling it off from the blood.

Because most atherosclerotic plaques expand away from the bloodstream rather than into it, blood can flow through an artery with relative ease, often for decades. Most heart attacks occur when the cap over the plaque breaks open in response to chemicals produced by foam cells, causing a clot to form. If the clot in a coronary artery is large enough, it can significantly decrease or stop the flow of blood and result in a heart attack.

Treatment options for CAD include drugs (antihypertensive drugs, nitroglycerin, beta-blockers, and cholesterol-lowering and clot-dissolving agents) and various surgical and nonsurgical procedures designed to increase the blood supply to the heart.

## Myocardial Ischemia and Infarction

Partial obstruction of blood flow in the coronary arteries may cause *myocardial ischemia* (is-KĒ-mē-a; *is-* = to obstruct; *-emia* = in the blood), a condition of reduced blood flow to the myocardium. Usually, ischemia causes *hypoxia* (reduced oxygen supply), which may weaken cells without killing them. *Angina pectoris* (an-JĪ-na or AN-ji-na PEK-tō-ris), which literally means “strangled chest,” is a severe pain that usually accompanies myocardial ischemia. Typically, sufferers describe it as a tightness or squeezing sensation, as though the chest were in a vise. The pain associated with angina pectoris is often referred to the neck, chin, or down the left arm to the elbow. *Silent myocardial ischemia*, ischemic episodes without pain, is particularly dangerous because the person has no forewarning of an impending heart attack.

A complete obstruction to blood flow in a coronary artery may result in a *myocardial infarction* (in-FARK-shun), or *MI*, commonly called a *heart attack*. *Infarction* means the death of an area of tissue because of interrupted blood supply. Because the heart tissue distal to the obstruction dies and is replaced by noncontractile scar tissue, the heart muscle loses some of its strength. Depending on the size and location of the infarcted (dead) area, an infarction may disrupt the conduction system of the heart and cause sudden death by triggering ventricular fibrillation. Treatment for a myocardial infarction may involve injection of a thrombolytic (clot-dissolving) agent such as streptokinase or tPA, plus heparin (an anticoagulant), or performing coronary angioplasty or coronary artery bypass grafting. Fortunately, heart muscle can remain alive in a resting person if it receives as little as 10–15% of its normal blood supply.

## Congenital Defects

A defect that exists at birth (and usually before) is a *congenital defect*. Among the several congenital defects that affect the heart are the following:

- In *patent ductus arteriosus*, the ductus arteriosus (temporary blood vessel) between the aorta and the pulmonary trunk, which normally closes shortly after birth, remains open (see Figure 16.17 on page 413). Closure of the ductus arteriosus leaves a remnant called the ligamentum arteriosum (see Figure 15.3a).
- *Atrial septal defect (ASD)* is caused by incomplete closure of the interatrial septum. The most common type involves the foramen ovale, which normally closes shortly after birth (see Figure 16.17 on page 413).
- *Ventricular septal defect (VSD)* is caused by an incomplete closure of the interventricular septum.
- *Valvular stenosis* is a narrowing of one of the valves associated with blood flow through the heart.
- *Tetralogy of Fallot* (te-TRAL-Ō-jē of fa-LŌ) is a combination of four defects: an interventricular septal defect, an aorta that emerges from both ventricles instead of from the left ventricle only, a narrowed pulmonary semilunar valve, and an enlarged right ventricle.

Some congenital heart defects are being surgically corrected prior to birth in order to prevent complications at the time of birth and following the birth of an infant.

## Arrhythmias

The usual rhythm of heartbeats, established by the SA mode, is called *normal sinus rhythm*. The term *arrhythmia* (a-RITH-mē-a; *a-* = without) or *dysrhythmia* refers to an abnormal rhythm as a result of a defect in the conduction system of the heart. The heart may beat irregularly, too fast, or too slowly. Symptoms include chest pain, shortness of breath, lightheadedness, dizziness, and fainting. Arrhythmias may be caused by factors that stimulate the heart, such as stress, caffeine, alcohol, nicotine, cocaine, and certain drugs that contain caffeine or other stimulants. Arrhythmias may also be caused by a congenital defect, coronary artery disease, myocardial infarction, hypertension, defective heart valves, rheumatic heart disease, hyperthyroidism, and potassium deficiency.

One serious arrhythmia is called a *heart block*. The most common heart block occurs in the atrioventricular node, which conducts impulses from the atria to the ventricles. This disturbance is called *atrioventricular (AV) block*.

In *atrial flutter*, the atrial rhythm averages between 240 and 360 beats per minute. The condition is essentially rapid atrial contractions accompanied by AV block. *Atrial fibrillation* is an uncoordinated contraction of the atrial muscles. When the muscle fibrillates, the muscle fibers of the atrium quiver individually instead of contracting together, canceling out the pumping of the atrium. *Ventricular fibrillation (VF)* is characterized by uncoordinated haphazard ventricular muscle contractions. Ventricular ejection ceases, and circulatory failure and death occur.

## MEDICAL TERMINOLOGY AND CONDITIONS

**Angiocardiology** (an'-jē-ō-kar'-dē-OG-ra-fē; *angio-* = vessel; *cardio-* = heart) X-ray examination of the heart and great blood vessels after injection of a radiopaque dye into the bloodstream.

**Cardiac arrest** (KAR-dē-ak a-REST) A clinical term meaning cessation of an effective heartbeat. The heart may be completely stopped or in ventricular fibrillation.

**Cardiac catheterization** (kath'-e-ter-i-ZĀ-shun) Procedure that is used to visualize the heart's coronary arteries, chambers, valves, and great vessels. It may also be used to measure pressure in the heart and blood vessels; to assess cardiac output; and to measure the flow of blood through the heart and blood vessels, the oxygen content of blood, and the status of the heart valves and conduction system. The basic procedure involves inserting a catheter into a peripheral vein (for right heart catheterization) or artery (for left heart catheterization) and guiding it under fluoroscopy (x-ray observation).

**Cardiac rehabilitation** (rē-ha-bil-i-TĀ-shun) A supervised program of progressive exercise, psychological support, education, and training to enable a patient to resume normal activities following a myocardial infarction.

**Cardiomegaly** (kar'-dē-ō-MEG-a-lē; *mega-* = large) Heart enlargement.

**Cor pulmonale (CP)** (kor pul-mōn-ALE; *cor-* = heart; *pulmon-* =

lung) Right ventricular hypertrophy caused by hypertension (high blood pressure) in the pulmonary circulation.

**Cardiopulmonary resuscitation** (kar'-dē-ō-PUL-mō-ner-ē re-sus'-i-TĀ-shun) (**CPR**) The artificial establishment of normal or near-normal respiration and circulation. The **ABCs** of cardiopulmonary resuscitation are **Airway**, **Breathing**, and **Circulation**, meaning the rescuer must establish an airway, provide artificial ventilation if breathing has stopped, and reestablish circulation if there is inadequate cardiac action.

**Palpitation** (pal'-pi-TĀ-shun) A fluttering of the heart or abnormal rate or rhythm of the heart.

**Paroxysmal tachycardia** (par'-ok-SIZ-mal tak'-e-KAR-dē-a) A period of rapid heartbeats that begins and ends suddenly.

**Rheumatic fever** (roo-MAT-ik) An acute systemic inflammatory disease that usually occurs after a streptococcal infection of the throat. The bacteria trigger an immune response in which antibodies that are produced to destroy the bacteria attack and inflame the connective tissues in joints, heart valves, and other organs. Even though rheumatic fever may weaken the entire heart wall, most often it damages the bicuspid (mitral) and aortic valves.

**Sudden cardiac death** The unexpected cessation of circulation and breathing due to an underlying heart disease such as ischemia, myocardial infarction, or a disturbance in cardiac rhythm.



## STUDY OUTLINE

### Structure and Organization of the Heart (p. 365)

1. The heart is situated between the lungs, with about two-thirds of its mass to the left of the midline.
2. The pericardium consists of an outer fibrous layer and an inner serous pericardium.
3. The serous pericardium is composed of a parietal layer and a visceral layer.
4. Between the parietal and visceral layers of the serous pericardium is the pericardial cavity, a space filled with pericardial fluid that reduces friction between the two membranes.
5. The wall of the heart has three layers: epicardium, myocardium, and endocardium.
6. The chambers include two upper atria and two lower ventricles.
7. The blood flows through the heart from the superior and inferior venae cavae and the coronary sinus to the right atrium, through the tricuspid valve to the right ventricle, and through the pulmonary trunk to the lungs.
8. From the lungs, blood flows through the pulmonary veins into the left atrium, through the bicuspid valve to the left ventricle, and out through the aorta.

9. Four valves prevent the backflow of blood in the heart.
10. Atrioventricular (AV) valves, between the atria and their ventricles, are the tricuspid valve on the right side of the heart and the bicuspid (mitral) valve on the left.
11. The atrioventricular valves, chordae tendineae, and their papillary muscles stop blood from flowing back into the atria.
12. Each of the two arteries that leave the heart has a semilunar valve.

### Blood Flow and Blood Supply of the Heart (p. 371)

1. Blood flows through the heart from areas of higher pressure to areas of lower pressure.
2. The pressure is related to the size and volume of a chamber.
3. The movement of blood through the heart is controlled by the opening and closing of the valves and the contraction and relaxation of the myocardium.
4. Coronary circulation delivers oxygenated blood to the myocardium and removes carbon dioxide from it.
5. Deoxygenated blood returns to the right atrium via the coronary sinus.

- Malfunctions of this system can result in angina pectoris or myocardial infarction (MI).

#### Conduction System of the Heart (p. 372)

- The conduction system consists of specialized cardiac muscle tissue that generates and distributes action potentials.
- Components of this system are the sinoatrial (SA) node (pace-maker), atrioventricular (AV) node, atrioventricular (AV) bundle (bundle of His), bundle branches, and Purkinje fibers.

#### Electrocardiogram (p. 374)

- The record of electrical changes during each cardiac cycle is referred to as an electrocardiogram (ECG).
- A normal ECG consists of a P wave (depolarization of atria), QRS complex (onset of ventricular depolarization), and T wave (ventricular repolarization).
- The ECG is used to diagnose abnormal cardiac rhythms and conduction patterns.

#### The Cardiac Cycle (p. 374)

- A cardiac cycle consists of systole (contraction) and diastole (relaxation) of the chambers of the heart.
- The phases of the cardiac cycle are (a) the relaxation period, (b) atrial systole, and (c) ventricular systole.
- A complete cardiac cycle takes 0.8 sec at an average heartbeat of 75 beats per minute.

- The first heart sound (lubb) represents the closing of the atrioventricular valves. The second sound (dupp) represents the closing of semilunar valves.

#### Cardiac Output (p. 375)

- Cardiac output (CO) is the amount of blood ejected by the left ventricle into the aorta each minute:  $CO = \text{stroke volume} \times \text{beats per minute}$ .
- Stroke volume (SV) is the amount of blood ejected by a ventricle during ventricular systole. It is related to stretch on the heart before it contracts, forcefulness of contraction, and the amount of pressure required to eject blood from the ventricles.
- Nervous control of the cardiovascular system originates in the cardiovascular center in the medulla oblongata.
- Sympathetic impulses increase heart rate and force of contraction; parasympathetic impulses decrease heart rate.
- Heart rate is affected by hormones (epinephrine, norepinephrine, thyroid hormones), ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ), age, gender, physical fitness, and body temperature.

#### Exercise and the Heart (p. 378)

- Sustained exercise increases oxygen demand on muscles.
- Among the benefits of aerobic exercise are increased maximal cardiac output, decreased blood pressure, weight control, and increased ability to dissolve clots.

### SELF-QUIZ

- Match the following:
 

___ a. valve between the left atrium and left ventricle	A. aortic valve
___ b. valve between the right atrium and right ventricle	B. right atrium
___ c. chamber that pumps blood to the lungs	C. left atrium
___ d. chamber that pumps blood into aorta	D. bicuspid (mitral) valve
___ e. chamber that receives oxygenated blood from lungs	E. pulmonary valve
___ f. chamber that receives deoxygenated blood from body	F. right ventricle
___ g. valve between the left ventricle and aorta	G. left ventricle
___ h. valve between right ventricle and pulmonary trunk	H. tricuspid valve
- Which of the following statements describes the pericardium?
  - It is a layer of nervous tissue.
  - It lines the inside of the myocardium.
  - It is continuous with the epithelial lining of the large blood vessels.
  - It is responsible for the contraction of the heart.
  - It is a membrane that surrounds and protects the heart.
- Which blood vessel delivers deoxygenated blood from the head and neck to the heart?
  - pulmonary vein
  - thoracic aorta
  - pulmonary artery
  - inferior vena cava
  - superior vena cava
- An embolus originating in the coronary sinus would first enter the
  - right atrium
  - pulmonary veins
  - left atrium
  - right ventricle
  - aorta
- The chordae tendineae and papillary muscles of the heart
  - are responsible for connecting cardiac muscle fibers for the spread of action potentials
  - can develop self-excitability and stimulate contraction
  - help prevent the atrioventricular valves from protruding into the atria when the ventricles contract
  - help anchor and protect the heart
  - form the cusps (flaps) of the heart valves
- Which chamber of the heart has the thickest layer of myocardium?
  - right ventricle
  - right atrium
  - left ventricle
  - left atrium
  - coronary sinus
- The normal "pacemaker" of the heart is the
  - sinoatrial (SA) node
  - atrioventricular (AV) node
  - Purkinje fibers
  - atrioventricular (AV) bundle
  - right bundle branch

8. In normal heart action,
  - a. the right atrium and ventricle contract, followed by the contraction of the left atrium and ventricle
  - b. the order of contraction is right atrium, then right ventricle, then left atrium, then left ventricle
  - c. the two atria contract together, and then the two ventricles contract together
  - d. the right atrium and left ventricle contract, followed by the contraction of the left atrium and right ventricle
  - e. all four chambers of the heart contract and then relax simultaneously
9. Heart sounds are produced by
  - a. contraction of the myocardium
  - b. closure of the heart valves
  - c. the flow of blood in the coronary arteries
  - d. the flow of blood in the ventricles
  - e. the transmission of action potentials through the conduction system
10. Heart rate and strength of contraction are controlled by the cardiovascular center, which is located in the
  - a. cerebrum    b. pons    c. right atrium    d. medulla
  - e. atrioventricular node
11. The portion of the ECG that corresponds to atrial depolarization is the
  - a. R peak    b. space between the T wave and P wave
  - c. T wave    d. P wave    e. QRS complex
12. The opening of the semilunar valves is due to the pressure in the
  - a. ventricles exceeding the pressure in the aorta and pulmonary trunk
  - b. ventricles exceeding the pressure in the atria
  - c. atria exceeding the pressure in the ventricles
  - d. atria exceeding the pressure in the aorta and pulmonary trunk
  - e. aorta and pulmonary trunk exceeding the pressure in the ventricles
13. On the anterior surface of each atrium is a wrinkled pouchlike structure called a(n)
  - a. anterior interventricular sulcus    b. coronary sulcus
  - c. auricle    d. interatrial septum
  - e. posterior interventricular sulcus
14. The Frank-Starling law of the heart
  - a. is important in maintaining equal blood output from both ventricles
  - b. is used in reference to the force of contraction of the atria
  - c. results in a decreased heart rate
  - d. causes blood to accumulate in the lungs
  - e. is related to the stretching of the cardiac muscle cells in the atria
15. Which of the following sequences best represents the pathway of an action potential through the heart's conduction system?
  1. sinoatrial (SA) node    2. Purkinje fibers
  3. atrioventricular (AV) bundle
  4. atrioventricular (AV) node
  5. right and left bundle branches
  - a. 1, 4, 3, 2, 5    b. 4, 1, 3, 5, 2    c. 3, 4, 1, 2, 5
  - d. 1, 4, 3, 5, 2    e. 2, 5, 3, 4, 1
16. Which of the following is NOT true concerning ventricular filling during the cardiac cycle?
  - a. The atrioventricular (AV) valves are open.
  - b. The ventricles fill to 75% of their capacity before the atria contract.
  - c. The remaining 25% of the ventricular blood is forced into the ventricles when the atria contract.
  - d. The semilunar valves are open.
  - e. Ventricular filling begins when the ventricular pressure drops below the atrial pressure, causing the AV valves to open.
17. Cardiac output
  - a. equals stroke volume (SV)  $\times$  blood pressure (BP)
  - b. equals stroke volume (SV)  $\times$  heart rate (HR)
  - c. is calculated using the formula for the Frank-Starling law of the heart
  - d. is about 70 mL in the average adult male
  - e. equals blood pressure (BP)  $\times$  heart rate (HR)
18. Most heart problems are due to
  - a. old age    b. leakages at the valves
  - c. problems in the coronary circulation
  - d. the failure of the conduction system
  - e. infections in the heart coverings
19. Using the situations that follow, indicate if the heart rate would speed up (A) or slow down (B).
  - \_\_\_ a. sympathetic stimulation of the sinoatrial (SA) node
  - \_\_\_ b. decrease in blood pressure
  - \_\_\_ c. fever
  - \_\_\_ d. parasympathetic stimulation of the heart's conduction system
  - \_\_\_ e. release of epinephrine
  - \_\_\_ f. elevated  $K^+$  level
  - \_\_\_ g. release of acetylcholine
  - \_\_\_ h. strenuous exercise
  - \_\_\_ i. stimulation by the vagus (X) nerve
  - \_\_\_ j. fear, anger, stress
  - \_\_\_ k. cooling the body
  - \_\_\_ l. hypoxia
  - \_\_\_ m. excessive thyroid hormones
20. Match the following:
 

___ a. may cause a heart murmur	A. pericarditis
___ b. heart compression	B. mitral valve prolapse
___ c. inflammation of heart covering	C. myocardial infarction
___ d. heart chamber contraction	D. angina pectoris
___ e. chest pain from ischemia	E. diastole
___ f. heart attack	F. systole
___ g. heart chamber relaxation	G. cardiac tamponade

## CRITICAL THINKING APPLICATIONS

1. Your uncle had an artificial pacemaker inserted after his last bout with heart trouble. What is the function of a pacemaker? For which heart structure does the pacemaker substitute?
2. Nikos was strolling across a four-lane highway when a car suddenly appeared out of nowhere. As he finished sprinting across the road, he felt his heart racing. Trace the route of the signal from his brain to his heart.
3. Jean-Claude, a member of the college's cross-country ski team, volunteered to have his heart function evaluated by the exercise physiology class. His resting pulse rate was 40 beats per minute. Assuming that he has an average cardiac output (CO), determine Jean-Claude's stroke volume (SV). Next, Jean-Claude rode an exercise bike until his heart rate had risen to 60 beats per minute. Assuming that his SV stayed constant, calculate Jean-Claude's CO during this moderate exercise.
4. Rosa's great Aunt Frieda likes to say that she has complaining feet and a mumbling heart. Aunt Frieda's physician uses the terms "edema" and "murmur." Explain Aunt Frieda's medical condition.



## ANSWERS TO FIGURE QUESTIONS

- 15.1 The base of the heart consists mainly of the left atrium.
- 15.2 The visceral layer of the serous pericardium is also part of the heart wall (epicardium).
- 15.3 Blood flows away from the heart in arteries.
- 15.4 Heart valves prevent the backflow of blood.
- 15.5 The superior vena cava, inferior vena cava, and coronary sinus deliver deoxygenated blood into the right atrium.
- 15.6 The only electrical connection between the atria and the ventricles is the atrioventricular (AV) bundle.
- 15.7 Atrial depolarization causes contraction of the atria.
- 15.8 The contraction phase is called systole; the relaxation phase is called diastole.
- 15.9 Acetylcholine decreases heart rate.
- 15.10 Fatty substances, cholesterol, and smooth muscle fibers make up atherosclerotic plaques.