

2

The Cardiovascular System

Learning Outcomes

- 2.1 Explain how circulation occurs in relation to the ECG.
- 2.2 Recall the structures of the heart including valves, chambers, and vessels.
- 2.3 Differentiate among pulmonary, systemic, and coronary circulation.
- 2.4 Explain the cardiac cycle including the difference between systole and diastole.
- 2.5 Describe the structure and function of the heart and conduction system and how they relate to the ECG.

Key Terms

aorta	myocardial
aortic semilunar valve	oxygenated blood
atrioventricular (AV) node	papillary muscles
atrium (pl. atria)	parasympathetic
automaticity	pericardium
Bachmann's bundle	pulmonary artery
bundle branches	pulmonary circulation
bundle of His (AV bundle)	pulmonary semilunar valve
cardiac cycle	pulmonary veins
chordae tendineae	Purkinje fibers
conductivity	Purkinje network
contractility	right atrium
coronary circulation	right ventricle
deoxygenated blood	semilunar valve
diastole	sinoatrial (SA) node
excitability	sympathetic
interatrial septum	systemic circulation
interventricular septum	systole
left atrium	tricuspid valve
left ventricle	vena cava (pl. venae cavae)
mitral (bicuspid) valve	

2.1 Circulation and the ECG

The heart is a four-chambered hollow organ that functions as a pump. Deoxygenated blood is received into the right-sided chambers and is pumped to the lungs for re-oxygenation. Oxygenated blood is returned to the left-sided chambers of the heart and it is pumped to the body. These events happen with each beat of the heart and the process is called circulation. Blood circulation depends on the heart's ability to contract or beat.

Blood cells carry oxygen and nutrients to the tissues and carry cellular waste away from the tissues. Blood circulation depends on the heart's ability to contract or beat.

The electrical activity of the heart is recorded on the ECG. Knowledge of the heart, its functions, and what produces each deflection on the ECG tracing will provide you with a clear understanding of the tasks you will be performing as an ECG healthcare professional.

Checkpoint Questions (LO 2.1)

1. What is circulation?

2. What is recorded on the ECG strip?

2.2 Anatomy of the Heart

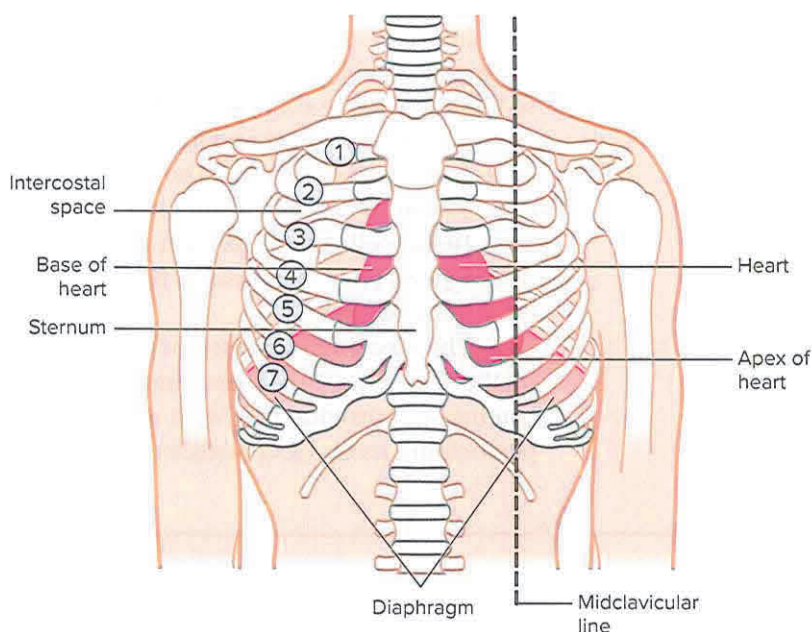
The heart lies near the center of the chest, behind the sternum, in front of the thoracic spine, and between the lungs. Two-thirds of it lies to the left of the sternum. The heart varies in size and weight depending on a person's weight, physical condition, and sex. The average heart is approximately the size of your fist and weighs about 10.6 ounces or 300 grams (Figure 2-1).

The heart is a powerful muscular pump that beats an average of 72 times per minute, 100,000 times per day, and 3 billion times in the average lifetime. Each ventricle pumps about 70 milliliters (mL) of blood per beat, for a total cardiac output of roughly 5 liters (L) per minute. Each day the heart pumps approximately 1800 gallons or 7250 liters of blood. This is enough to fill an average-size bathtub about 36 times.

The heart muscle consists of three layers: the endocardium, myocardium, and epicardium (or visceral pericardium) (Table 2-1 and Figure 2-2). The entire heart is enclosed in a sac of tissue called the **pericardium**. This sac consists of two layers: the tough, outer layer is called the *parietal pericardium layer*, and the inner layer is called the *visceral pericardium layer*. The visceral pericardium adheres closely to the heart. It is also referred to as the *epicardium*, the outermost layer of the heart. The purpose of the pericardium is to protect the heart from infection and trauma. The space between the two layers is called the *pericardial space*. It contains about 10 to 20 mL (about ½ ounce) of fluid, which cushions the heart against blows and decreases friction between the layers created by the pumping heart.

pericardium A two-layered sac of tissue enclosing the heart.

Figure 2-1 The heart is tipped to the right side of the body with about two-thirds of it located on the left side of the chest.



right atrium The right upper chamber of the heart, which receives blood from the body.

left atrium The left upper chamber of the heart, which receives blood from the lungs.

right ventricle The right lower chamber of the heart, which pumps blood to the lungs.

left ventricle The left lower chamber of the heart, which pumps oxygenated blood through the body. It is the biggest and strongest chamber, known as the workhorse of the heart.

interatrial septum A wall of tissue that separates the left and right atria of the heart.

interventricular septum A partition or wall (septum) that divides the right and left ventricles.

atrium (pl. atria) Top two chambers of the heart.

tricuspid valve Valve located between the right atrium and right ventricle; it prevents backflow of blood into the right atrium.

mitral (bicuspid) valve Valve with two cusps or leaflets located between the left atrium and left ventricle; it prevents backflow of blood into the left atrium.

TABLE 2-1 Heart Layers

Layer	Location and Function
Endocardium	Inner layer of the heart that lines the chambers and valves. The Purkinje fibers are located in the myocardium just above this layer.
Myocardium	Middle, thickest muscular layer, responsible for heart contraction.
Epicardium (also called the visceral pericardium)	Outside, thin layer of the heart that contains the coronary arteries; it is also known as the inner layer of the pericardium.
Pericardium (made up of the visceral pericardium and the parietal pericardium)	A double-layer sac that encloses the heart. The inner layer, or visceral pericardium, is also called the epicardium; the outer layer is the parietal pericardium.

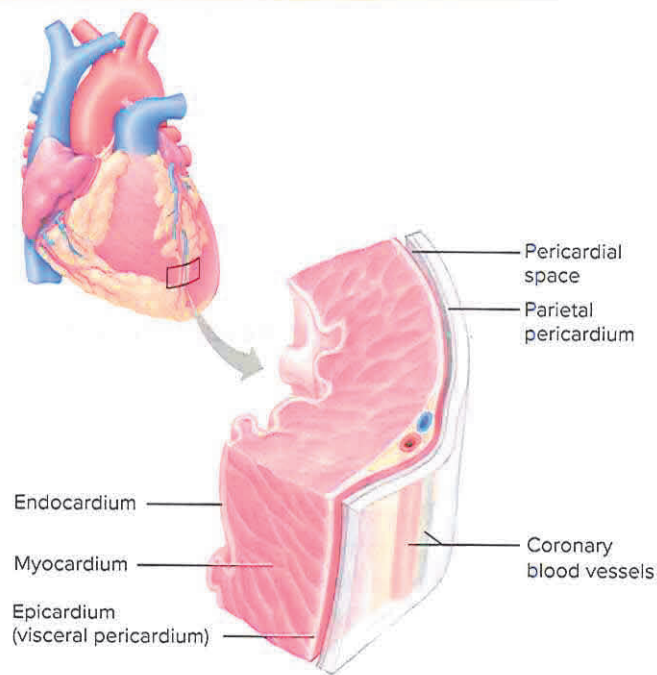
Chambers and Valves

The heart is divided into four chambers. The top chambers are the **right atrium** and **left atrium**. The bottom chambers are the **right ventricle** and **left ventricle**. The left and right atria are separated by a wall of tissue called the **interatrial septum**. Between the right and left ventricles is a partition known as the **interventricular septum**.

The myocardium (muscular layer) is thin in the **atria** (sing. atrium), thick in the right ventricle, and thickest in the left ventricle. The thicker the myocardium of a chamber is, the stronger the muscular contraction of that chamber. The left ventricle is sometimes known as the “workhorse of the heart” because of its thick myocardium and powerful muscular contraction.

Between the right atrium and right ventricle is the **tricuspid valve**. Between the left atrium and left ventricle is the **mitral (bicuspid) valve**. These two valves are known as *atrioventricular (AV) valves* because they

Figure 2-2 Three distinct layers can be identified on the heart. A sac called the *pericardium* protects it.

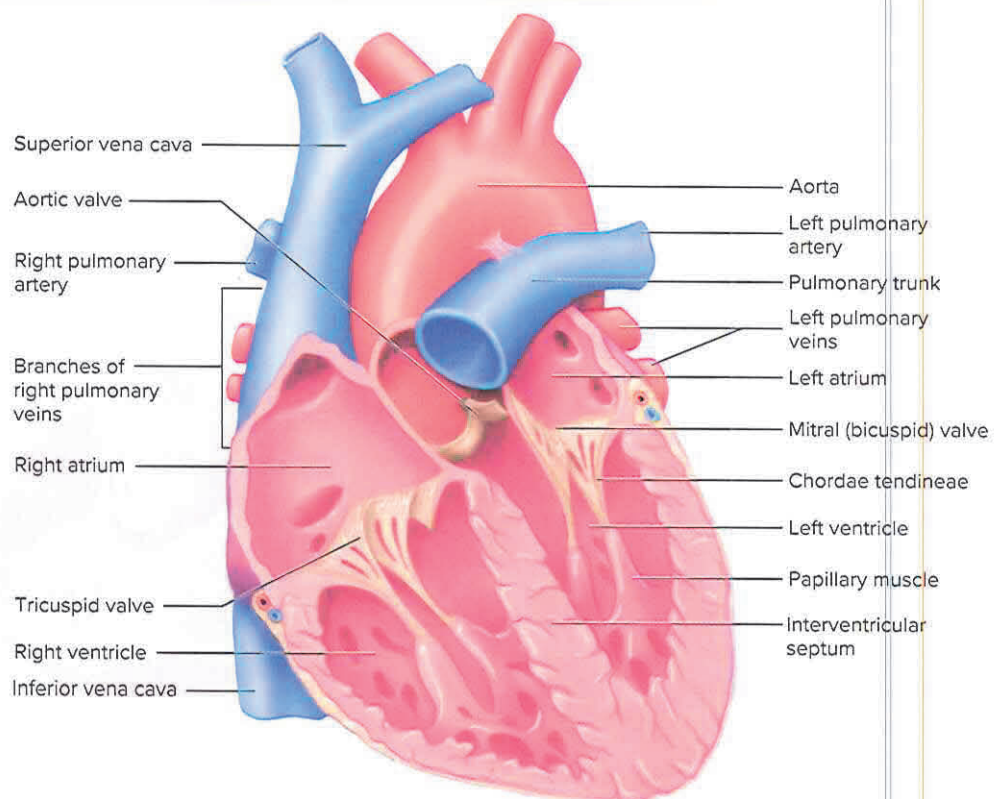


chordae tendineae Structures that connect the atrioventricular (tricuspid and mitral) valves to the papillary muscles and prevent them from opening in the wrong direction.

papillary muscles Muscles in the ventricles that anchor the chordae tendineae and atrioventricular valves.

divide the atria from the ventricles. **Chordae tendineae** (sometimes referred to as “heartstrings”) connect the atrioventricular valves to the papillary muscles. The chordae tendineae prevent the valves from opening in the wrong direction. The **papillary muscles** are structures within the ventricles that are attached to the chordae tendineae and serve as the anchor for both the chordae tendineae and the AV valves (Figure 2-3).

Figure 2-3 Heart chambers, valves, and vessels.



pulmonary artery Large artery that transports deoxygenated blood from the right ventricle to the lungs. This is the only artery in the body that carries deoxygenated blood.

aorta The largest artery of the body; transports blood from the left ventricle of the heart to the entire body.

semilunar valve A valve with half-moon-shaped cusps that open and close, allowing blood to travel only one way; located in the pulmonary artery and the aorta.

aortic semilunar valve Valve located in the aorta that prevents the backflow of blood into the left ventricle.

pulmonary semilunar valve A valve found in the pulmonary artery that prevents backflow of blood into the right ventricle during pulmonary circulation.

The **pulmonary artery** and the **aorta** each has a **semilunar valve**. They are called *semilunar* because the valve flaps look like a half (*semi*) moon (*lunar*). These valves are called the **aortic semilunar valve** and the **pulmonary semilunar valve** (Table 2-2). The semilunar valves separate the ventricles from the arteries leading to the lungs or body. These one-way valves in the heart keep the blood flow headed in the right direction (away from the heart). The flaps or “cusps” open to allow the blood to flow, then close to prevent the backflow of blood (Figure 2-4).

The Major Vessels to and From the Heart

Blood vessels are the veins and arteries that transport blood all over the body. The major blood vessels that transport blood to and from the heart are the venae cavae, pulmonary artery, pulmonary veins, and aorta.

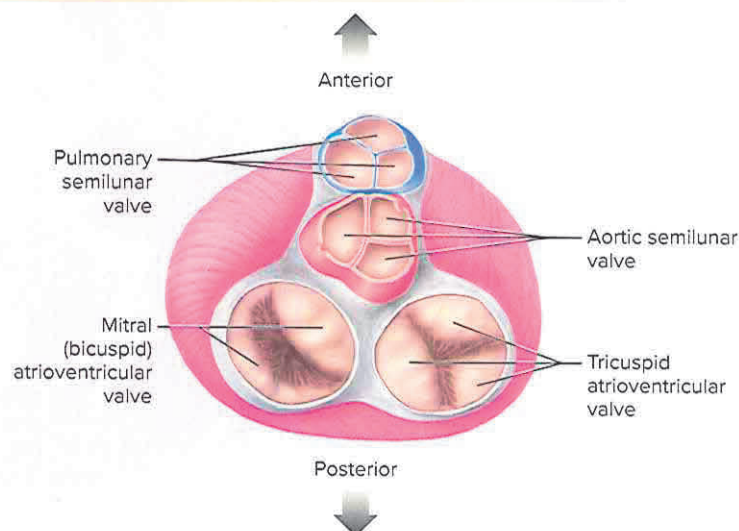
Blood travels from the body tissue through the veins toward the heart. The blood is returned through the largest vein of the body, the **vena cava** (pl. venae cavae), to the right atrium. The superior vena cava transports blood from the head, arms, and upper body. The inferior vena cava transports blood from the lower body and legs (Figure 2-5).

TABLE 2-2 Heart Valves and Their Locations

Name	Valve Type	Location
Aortic	Semilunar	Between left ventricle and aorta
Pulmonary	Semilunar	Between right ventricle and pulmonary artery
Tricuspid	Atrioventricular	Separates right atrium and right ventricle
Mitral (bicuspid)	Atrioventricular	Separates left atrium and left ventricle

Figure 2-4 Valves viewed from a cross section of the heart.

vena cava (pl. venae cavae) Largest vein in the body, which provides a pathway for deoxygenated blood to return to the heart; its upper portion, the superior vena cava, transports blood from the head, arms, and upper body; and its lower portion, the inferior vena cava, transports blood from the lower body and legs.



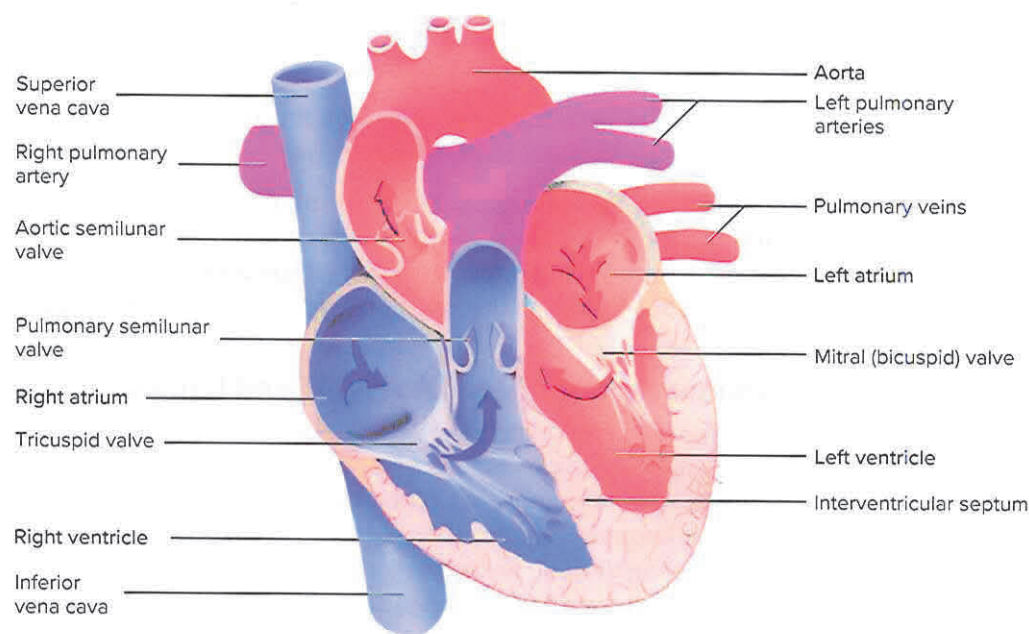
deoxygenated blood Blood that has little or minimal oxygen (oxygen-poor blood).

pulmonary veins Transport oxygenated blood back into the left atrium of the heart. These are the only veins in the body that carry oxygenated blood.

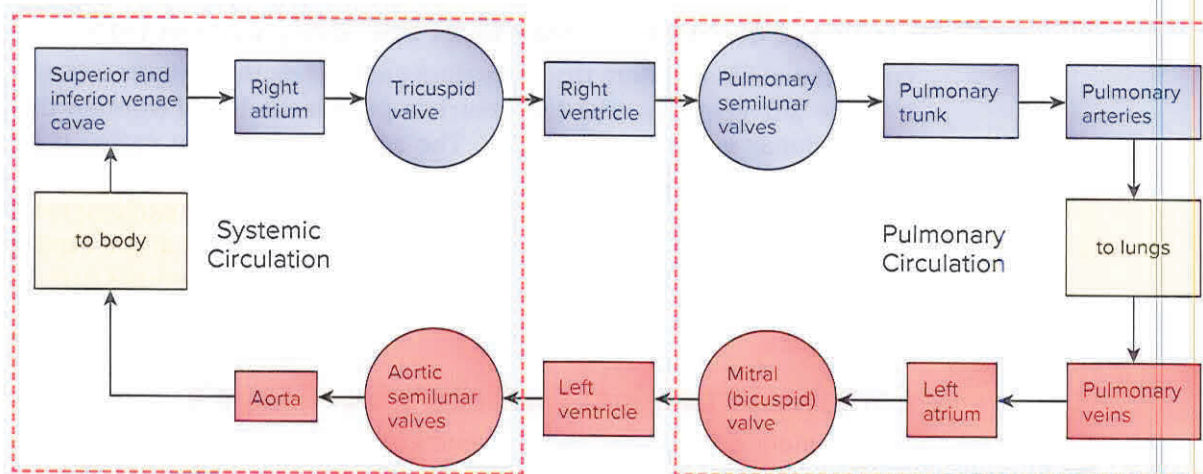
oxygenated blood Blood having oxygen (oxygen-rich blood).

Blood is then pumped into the right ventricle and when the heart contracts. The right ventricle pumps **deoxygenated blood** (blood that has little or minimal oxygen) to the lungs via the pulmonary artery. In the lungs, the exchange of carbon dioxide and oxygen occurs to enrich the blood with oxygen. The **pulmonary veins** transport **oxygenated blood** (blood containing oxygen) back to the heart into the left atrium. Blood is pumped from the left atrium into the left ventricle. When the left ventricle contracts, the blood is pumped through the aortic valve, into the aorta and is transported to the body. The first vessels to branch off the aorta are the coronary arteries. Coronary arteries are part of the coronary circulation, which supplies blood to the muscular heart pump (Figure 2-5).

Figure 2-5 Pathways for blood through the heart.



A. Major blood vessels to and from the heart.



B. Blue = deoxygenated blood; red = oxygenated blood.

Checkpoint Questions (LO 2.2)

1. What is the name of the middle layer of the heart (the muscular layer)?

2. Which valve is located between the left atrium and left ventricle?

2.3 Principles of Circulation

The heart is actually a two-sided pump. The left side of the heart is a high-pressure pump that pumps oxygenated blood to the body tissue. The right side of the heart is a low-pressure pump that pumps deoxygenated blood to the lungs. Think of the heart like this:

left side → high oxygen concentration
right side → low oxygen concentration

pulmonary circulation The transportation of blood to and from the lungs; blood is oxygenated in the lungs during pulmonary circulation.

systemic circulation The pathways for pumping blood throughout the body and back to the heart.

coronary circulation The circulation of blood to and from the heart muscle.

The pathways for pumping blood to and from the lungs are known as **pulmonary circulation**. The pathways for pumping blood throughout the body and back to the heart are known as **systemic circulation**. The circulation of blood to and from the heart muscle is known as **coronary circulation**.

Pulmonary Circulation: The Heart and Lung Connection

Deoxygenated blood enters the right atrium through the superior and inferior venae cavae. Blood travels through the tricuspid valve into the right ventricle. The right ventricle pumps the blood through the pulmonary semilunar valve into the pulmonary artery, then into the lungs. In the lungs, gas exchange occurs. Carbon dioxide is exchanged for oxygen. This oxygen-rich blood then returns to the heart through the pulmonary veins into the left atrium. The left atrium is the last step of pulmonary circulation.

Systemic Circulation: The Heart and Body Connection

Oxygenated blood enters the left atrium and travels through the mitral valve into the left ventricle. The left ventricle pumps the blood through the aortic semilunar valve into the aorta. The aorta provides the pathway for the blood to circulate through the body. In the body, the oxygen in the blood is exchanged with carbon dioxide at the cellular level. This exchange of oxygen, carbon dioxide, nutrients, and waste products occurs in the capillaries. After traveling through the body, the deoxygenated blood returns to the heart through the superior and inferior venae cavae (Figure 2-6).

Coronary Circulation: The Heart's Blood Supply

Oxygenated blood from the left ventricle travels through the aorta to the coronary arteries. There are two main coronary arteries, the left coronary artery and the right coronary artery. These are the first branches off of the

Figure 2-6 Pulmonary and systemic circulation.

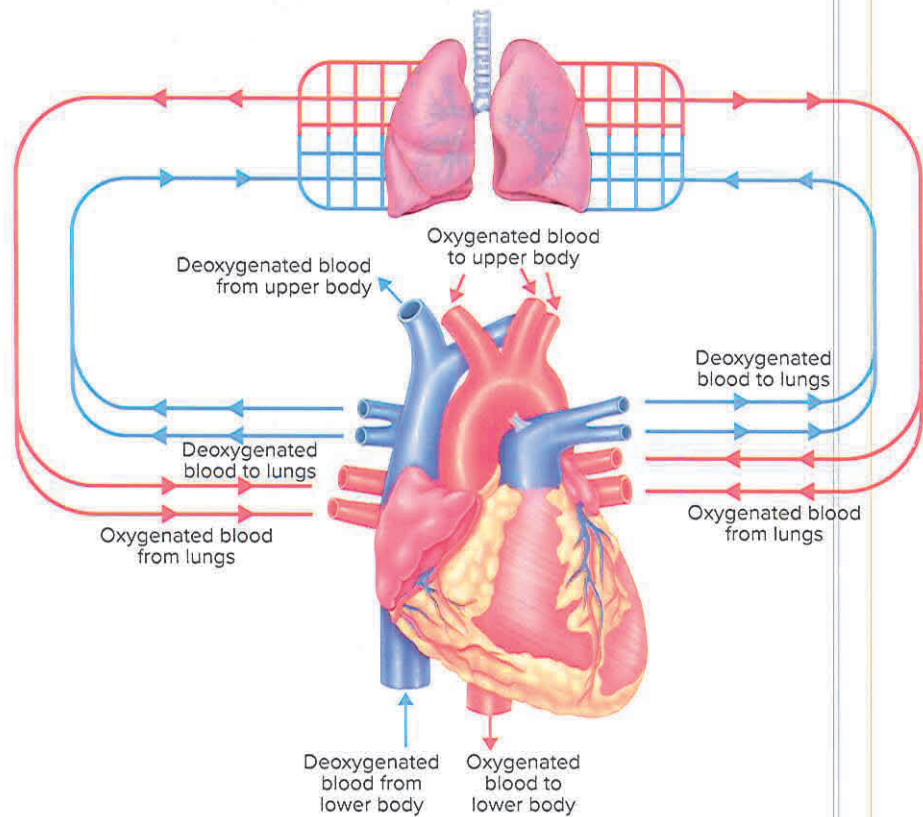
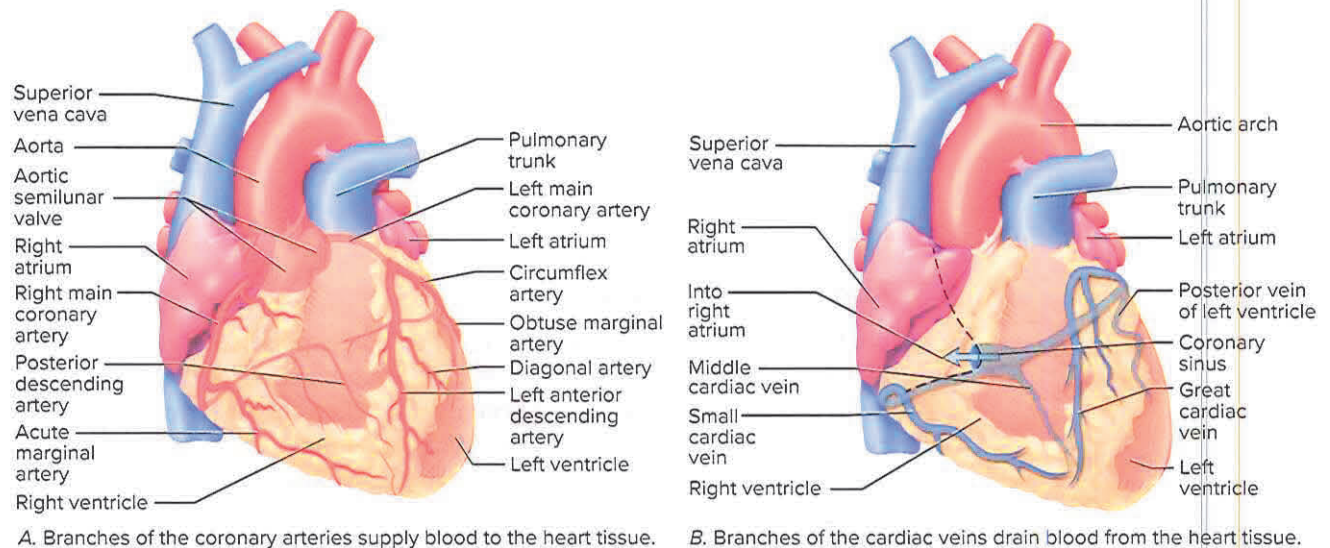


Figure 2-7 Coronary circulation.



aorta. These arteries branch to supply oxygenated blood to the entire heart. The left coronary artery has more branches than the right because the left side of the heart is more muscular and requires more oxygen and blood supply. The deoxygenated blood travels through the coronary veins and is collected in the coronary sinus, which empties the blood directly into the right atrium (Figure 2-7).

The Heart as a Pump

The heart is an amazing pump that distributes blood throughout the body. The average heart beats 72 times every minute. Thus, the heart rate (HR) is the number of times a person's heart beats per minute. Each ventricle pumps about 70 mL of blood during contraction. The volume of blood ejected with each contraction is referred to as *stroke volume (SV)*. This amount can vary depending on things such as a person's sex, size, level of physical fitness, disease state, or genetics. The volume of blood pumped each minute is referred to as *cardiac output (CO)*. The average cardiac output is approximately 5 L per minute. When the volume of blood decreases, the heart rate increases; similarly, if the contractile force of the heart decreases, the stroke volume is decreased. In such cases, patients show signs of decreased or low cardiac output, including pallor, confusion, hypotension (low blood pressure), nausea, and dizziness. A patient's cardiac output is estimated by multiplying heart rate by stroke volume ($HR \times SV = CO$).

Checkpoint Questions (LO 2.3)

1. What are the first vessels to branch off the aorta called?

2. Describe the three types of circulation.

3. What is cardiac output?

cardiac cycle The contraction and relaxation of the heart.

systole The contraction phase of the cardiac cycle, during which the heart is pumping blood out to the pulmonary (lungs) and systemic (body) circulation.

diastole The phase of the cardiac cycle when the heart is expanding and refilling; also known as the relaxation phase.

2.4 The Cardiac Cycle

Each beat of the heart has two phases that correspond to the contraction and the relaxation periods of the heart. The contraction and relaxation of the heart together make up the **cardiac cycle**. When the heart contracts, the ventricles squeeze blood out to the pulmonary (lungs) and systemic (body) circulation. The contraction phase is known as **systole**. As the heart relaxes, its chambers expand and refill. The relaxation phase of the heart is known as **diastole**.

Diastole: Relaxation of the Heart

During diastolic phase, blood from the vena cava fills the right atrium, pushing open the tricuspid valve. This allows blood to flow into the right ventricle. At the same time, blood is returning from the lungs via the pulmonary veins to the left atrium. This blood fills the left atrium and forces the mitral valve open to allow blood to flow into the left ventricle.

Systole: Contraction of the Heart

During the systolic phase, the heart muscle contracts, creating pressure to open the pulmonary and aortic valves. Blood from the right ventricle is pushed into the lungs to exchange oxygen and carbon dioxide. Blood from the left ventricle is pushed through the aorta to be distributed throughout the body to provide oxygen for tissues and remove carbon dioxide (Figure 2-8).

In adults, the average heart beats approximately 60 to 100 times per minute. In general, females have a faster heart rate than males. Children's heart rates are usually faster than an adult's heart rate and depend on the age and size of the child.

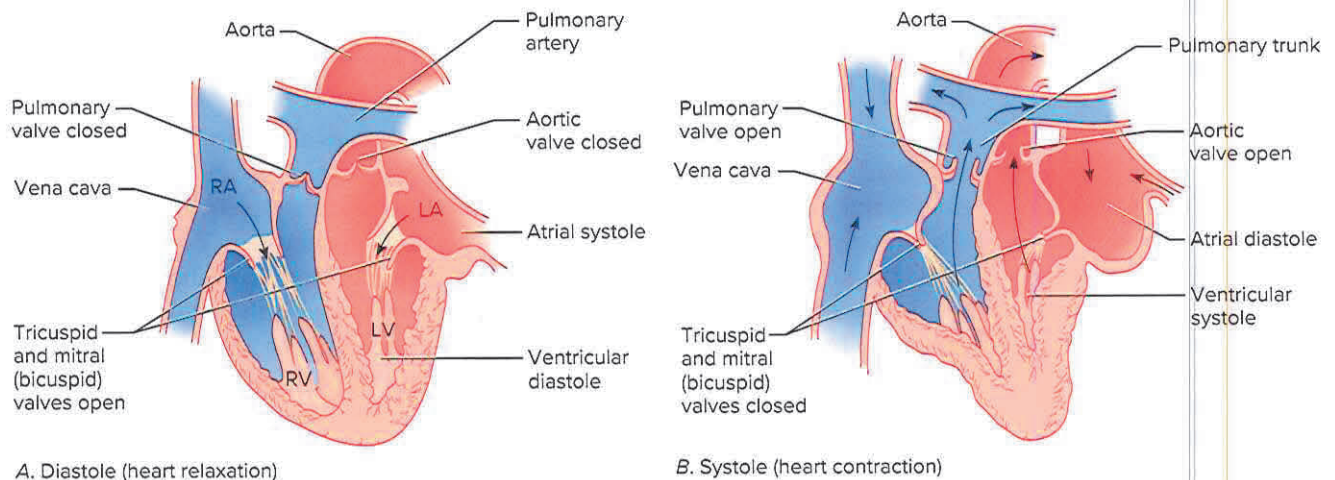
If you listen to the heart with a stethoscope, you will hear two sounds: "lubb" and "dupp." These sounds are made by the closing of the heart valves, which is caused by the contraction and relaxation of the heart. The "lubb" you hear is the sound made during the systolic phase by the contraction of the ventricles and the closing of the mitral and tricuspid valves. The "dupp" sound is made during the diastolic phase. It is shorter and occurs during the beginning of ventricular relaxation. This sound is from the closure of the pulmonary and aortic valves. Each complete "lubb-dupp" you hear is actually one beat of the heart.

Checkpoint Questions (LO 2.4)

1. What is the cardiac cycle?

2. How are diastole and systole different from one another?

Figure 2-8 Diastole and systole.



2.5 Conduction System of the Heart

The pumping cycle is controlled by electrical impulses: Electrical impulses stimulate contraction of the heart muscle, and the absence of electrical impulses allows the heart muscle to relax. These electrical impulses are initiated by specialized pacemaker cells in the heart. The electrical impulses are transferred through the heart by the electrical conduction system. The working cells of the heart respond by shortening, causing cardiac contraction and blood flow. The conduction system is necessary for the heart to pump continuously and rhythmically.

Unique Qualities of the Heart

The conduction system is a network of conducting cells that create the heartbeat and establishes a pattern for the electrical activity of the heart. The conducting cells of the heart have several unique qualities that control the beat of the heart and produce the electrical wave. They include automaticity, conductivity, contractility, and excitability.

Automaticity is the ability of the each heart cell to initiate an electrical impulse without being stimulated by a source outside the heart. Automaticity is a form of the word *automatic*, which is exactly how the heart beats—automatically. The heart cells have the innate ability to initiate an electrical impulse.

The heartbeat relies on the ability of the **myocardial** cells to conduct electrical impulses. **Conductivity** is the ability of the heart cells to receive and transmit an electrical impulse. The electrical impulse is initiated by automaticity and then travels through the rest of the heart due to the conductivity of the heart cells.

When the heart muscle cells are stimulated by an electrical impulse, they contract. This ability of the heart muscle cells to shorten in response to an electrical stimulus is known as **contractility**. The contraction of the heart muscle cells produces the heartbeat or pumping of the heart.

Excitability (also referred to as irritability) is the ability of the heart muscle cells to respond to an impulse or stimulus. Without the quality of excitability, the heart would not react to the electrical impulses that are initiated within the heart.

As you can see, the heart's unique qualities are essential to the rhythmic contraction of the heart muscle and the circulation of blood through the body. Without these qualities, the heart would not beat.

Regulation of the Heart

In addition to automaticity, the heartbeat is controlled by the *autonomic nervous system (ANS)*. The ANS is involuntary. This means you have no conscious control over its functions. The **sympathetic** branch of the ANS increases the heart rate and contractility by secreting norepinephrine. This happens automatically when you are under stress or become frightened. You can think of the automaticity of the heart as the cruise control in your car. In a normal heart, its automaticity sets the rate of the heart to 60 to 100 beats a minute. When the sympathetic branch of the ANS is stimulated,

automaticity The ability of the heart to initiate an electrical impulse without being stimulated by an independent source.

myocardial Pertaining to the heart (*cardia*) muscle (*myo*).

conductivity The ability of the heart cells to receive and transmit an electrical impulse.

contractility The ability of the heart muscle cells to shorten in response to an electrical stimulus.

excitability The ability of the heart muscle cells to respond to an impulse or stimulus; also called *irritability*.

sympathetic The branch of the autonomic nervous system (ANS) that causes an increase in the heart rate.

parasympathetic The branch of the autonomic nervous system (ANS) that helps to slow the heart rate.

it speeds up the heart. When you take your foot off the accelerator (remove the stimulation to the sympathetic branch of the ANS), the heart rate coasts down to the cruise control speed of 60 to 100.

The **parasympathetic** branch of the ANS exerts a depressant effect on the heart by secreting acetylcholine. The vagus nerve is the major nerve of the parasympathetic system and exerts an effect on many of the body organs. It is widespread throughout the body. Stimulation of the vagus nerve slows the heart, acting like a brake to the heart rate. When a patient is experiencing an abnormally fast heart rate, stimulation of the vagus nerve is used to bring the heart back to its normal cruise control rate.

Other factors can affect the heart. For example, exercise, stress, diet (caffeine), medications (prescribed, over the counter or illegal), or a fever can increase the heart rate. The cardiac control center, located in the brain, sends impulses to decrease the heart rate when the blood pressure rises. When the blood pressure falls, it sends impulses to increase the heart rate.

The levels of the electrolytes potassium (K^+) and calcium (Ca^{++}) play a role in the control of the heart. When there is a low concentration of potassium ions in the blood (hypokalemia), the heart rate decreases. A high concentration of potassium (hyperkalemia) causes an abnormal heart rate. High and low potassium ions in the blood can lead to cardiac dysrhythmias. A low concentration of calcium ions (hypocalcemia) in the blood results in a decrease in the force of the heart's contractions (negative inotropic effect). A high concentration of calcium (hypercalcemia) causes an increase in the force of the heart's contractions (positive inotropic effect).

Electrical Conduction System

The heart's conduction system consists of the sinoatrial (SA) node, atrioventricular (AV) node, bundle of His (AV bundle), bundle branches, and the Purkinje fibers in the ventricles. The SA and AV nodes are individualized groups of specialized cardiac cells at specific locations within the right atrium. Normal conduction in the heart begins with the **sinoatrial (SA) node**, which is located in the upper portion of the right atrium. It is often referred to as the *pacemaker of the heart* because it initiates the electrical activity. In a normal heart, the SA node is inherently the fastest pacemaker and controls the heart rate. The electrical impulse travels through the internodal pathways and stimulates the right atrium and is simultaneously relayed to the left atrium through **Bachmann's bundle**. The automaticity of the cells in the atria causes them to contract. In a normal heart, the SA node fires at about 60 to 100 times per minute and each impulse will result in a heartbeat.

On the floor of the right atrium is another mass of specialized cardiac cells known as the **atrioventricular (AV) node**. Impulses travel to the AV node because of the unique quality of conductivity through a specialized pathway through the atria. The AV node itself causes a delay (slowdown) in the electrical impulse. This process is important for three reasons. First, it provides time for additional blood to travel from the atria to the ventricles before they contract. This additional blood is known as the *atrial kick*. The atrial kick increases the cardiac output. Second, the delay in the electrical impulse reduces the number of electrical impulses that can

sinoatrial (SA) node An area of specialized cells in the upper right atrium that initiates the heartbeat.

Bachmann's bundle The structure that relays the electrical impulse from the SA node to the left atrium in a normal heart.

atrioventricular (AV) node Delays the electrical impulse to allow the atria to complete their contraction.

bundle of His (atrioventricular or AV bundle) Located next to the AV node; provides the transfer of the electrical impulse from the atria to the ventricles.

bundle branches Left and right branches of the bundle of His that conduct impulses down either side of the interventricular septum to the left and right ventricles.

Purkinje fibers The fibers within the heart that distribute electrical impulses from cell to cell throughout the ventricles.

Purkinje network Spreads the electrical impulse throughout the ventricles by means of the Purkinje fibers.

be transmitted to the ventricles in the presence of fast atrial rhythms. The AV node is functioning like a gatekeeper allowing some impulses into the ventricular conduction system while blocking others. This is important when the atria are firing too fast. It prevents an excessive rate of electrical impulses from reaching the ventricles. A third benefit to the delay in contraction of the atria is that it allows the ventricles to contract from the bottom up to avoid conflicting contractions between atria and ventricles. The delay aids in coordinated contraction of the heart. *The AV node can also act as the pacemaker if the SA node is not working.* It will fire at a rate of 40 to 60 times per minute. This is known as the *inherent rate* of the AV node.

The **bundle of His (AV bundle)**, located below the AV node, provides the transfer of electrical impulse from the atria to the ventricles via the septum. When the impulse reaches the ventricles, it divides into the **bundle branches**, located along the left and right sides of the interventricular septum. The left and right bundle branches are like a fork in the road, and the electrical impulse splits and travels down both sides to stimulate the left and right ventricles to contract. Impulses traveling down the left bundle branch also stimulate the interventricular septum to contract in a left-to-right pattern.

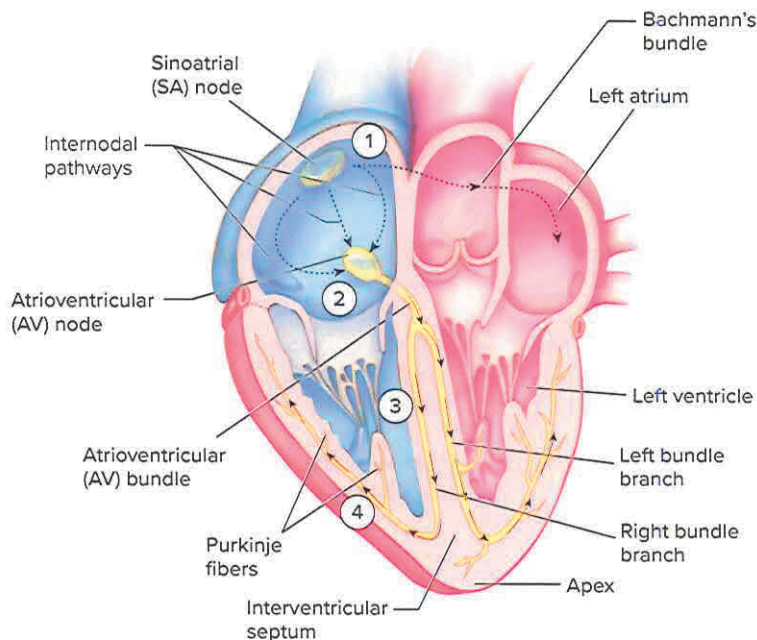
Purkinje fibers form a network, the **Purkinje network**, that spreads the electrical impulse throughout the ventricles. These fibers provide an electrical pathway for each of the cardiac cells. The electrical impulses accelerate and activate the right and left ventricles at the same time to cause the ventricles to contract. The electrical impulse produces an electrical wave, resulting in contraction of the ventricles (Table 2-3 and Figure 2-9). If both the SA and AV nodes (higher pacemakers) fail, *the Purkinje fibers can function as a final pacemaker site.* The inherent rate is 20–40 impulses per minute.

TABLE 2-3 Parts of the Conduction System

Part	Function
Sinoatrial (SA) node (pacemaker)	Pacemaker of the heart. Electrical impulses occur at a rate of 60–100 beats per minute.
Atrioventricular (AV) node	Delays the electrical impulse to allow for the atria to complete their contraction and ventricles to fill before the next contraction; also serves as a secondary pacemaker if the SA node fails with an inherent rate is 40–60 impulses per minute.
Bundle of His (AV bundle)	Conducts electrical impulses from the atria to the ventricles.
Bundle branches	Conduct impulses down both sides of the interventricular septum.
Purkinje fibers (network)	Distributes the electrical impulses through the right and left ventricles. Inherent rate is 20–40 impulses per minute.

Figure 2-9 Conduction pathways.

1. The heartbeat originates in the sinoatrial (SA) node; it travels across the wall of the atrium through the internodal pathways to the atrioventricular (AV) node and Bachmann's bundle to the left atrium.
2. The impulse passes through the AV node into the AV bundle (bundle of His) to the interventricular septum.
3. The impulse is divided between the right and left bundle branches and travels to the apex of the heart through the interventricular septum via the bundle branches.
4. The Purkinje fibers carry the impulse through the right and left ventricles, causing them to contract.



**Checkpoint
Questions
(LO 2.5)**

1. List the parts of the conduction system in the order the electrical impulse travels.

2. What term refers to the ability of the heart muscle cells to respond to a stimulus?

3. Where does the electrical impulse get delayed to allow all the blood to leave the atria before the ventricles contract?

Chapter Summary

Learning Outcomes	Summary	Pages
2.1 Explain how circulation occurs in relation to the ECG.	The heart action creates circulation; circulation provides nutrients and oxygen to the tissues and removes waste and carbon dioxide; the ECG waveform is a measurement of the heart's electrical activity.	37
2.2 Recall the structures of the heart including valves, chambers, and vessels.	The heart consists of four chambers (two atria and two ventricles) and four major valves [mitral (bicuspid), tricuspid, and two semilunar valves]. The major vessels to and from the heart include the venae cavae, pulmonary artery and veins, and aorta.	37–42
2.3 Differentiate among pulmonary, systemic, and coronary circulation.	Pulmonary circulation is the circulation from the right ventricle through the blood vessels of the lungs to the left atrium. Systemic circulation is the circulation from the left ventricle through the blood vessels of the body to the right atrium. Coronary circulation supplies blood within the heart through the coronary arteries and coronary sinus.	42–44
2.4 Explain the cardiac cycle, including the difference between systole and diastole.	The contraction and relaxation period of the heart together make up the cardiac cycle. Diastole is the relaxation phase of the cardiac cycle when blood fills the heart. Systole is the contraction phase of the cardiac cycle when blood leaves the heart.	44–45
2.5 Describe the structure and function of the heart and conduction system and how they relate to the ECG.	The conduction system of the heart includes the SA node, Bachmann's bundle, internodal pathways, AV node, AV bundle, bundle branches, and Purkinje fibers, which together create and maintain the electrical activity of the heart. The conducting tissue of the conduction system has qualities that control the beat of the heart, including automaticity, conductivity, contractility, and excitability. The conduction system of the heart creates the electrical activity and thus creates the ECG waveform.	46–49

Chapter Review

Matching I

Match the valves, vessels, and chambers of the heart on the left with their definitions on the right. (LO 2.2)

- | | |
|-----------------------------------|--|
| _____ 1. left ventricle | a. artery that transports blood to the entire body |
| _____ 2. tricuspid valve | b. type of valve located in the aorta and the pulmonary artery |
| _____ 3. left atrium | c. atrioventricular valve between the left atrium and left ventricle |
| _____ 4. aorta | d. heart chamber that pumps blood to the body, known as the workhorse of the heart |
| _____ 5. pulmonary trunk | e. heart chamber that receives oxygenated blood from the pulmonary veins |
| _____ 6. right atrium | f. chamber of the heart that receives blood from the body |
| _____ 7. right ventricle | g. chamber of the heart that pumps blood to the lungs |
| _____ 8. semilunar valve | h. blood vessel that transports blood from the lungs to the heart |
| _____ 9. pulmonary vein | i. valve located between the right atrium and right ventricle |
| _____ 10. mitral (bicuspid) valve | j. blood vessel that transports deoxygenated blood to the lungs |

Matching II

Match the conduction system parts and unique qualities of the heart on the left with their definitions on the right. (LO 2.5)

- | | |
|---------------------------|--|
| _____ 11. excitability | a. delays the electrical conduction from the atria to the ventricles |
| _____ 12. automaticity | b. ability of the heart to initiate an electrical impulse |
| _____ 13. bundle branches | c. branches off the bundle of His that conduct impulses to the left and right ventricles |
| _____ 14. SA node | d. ability of the heart cells to receive and transmit an electrical impulse |
| _____ 15. contractility | e. ability of the heart muscle cells to shorten in response to an electrical stimulus |
| _____ 16. AV node | f. ability of the heart muscle cells to respond to an impulse or stimulus |
| _____ 17. Purkinje fibers | g. initiates the heartbeat in a normal heart |
| _____ 18. conductivity | h. distribute electrical impulses from cell to cell throughout the ventricles |

Multiple Choice

Circle the correct answer.

19. The heart's ability to create its own electrical impulse is known as (LO 2.5)
 - a. conductivity.
 - b. contractility.
 - c. automaticity.
 - d. excitability.
20. When stimulated, the sympathetic nervous system of the body causes the heart rate to (LO 2.5)
 - a. increase.
 - b. decrease.
 - c. remain the same.
 - d. increase, then decrease.
21. Which vessel of the body contains the highest concentration of oxygen? (LO 2.2)
 - a. Aorta
 - b. Pulmonary artery
 - c. Superior vena cava
 - d. Inferior vena cava
22. The heart is contained inside a structure also known as the (LO 2.2)
 - a. endocardium.
 - b. pericardial sac.
 - c. myocardium sac.
 - d. fluid sac.
23. Which of the following would most likely increase the heart rate? (LO 2.5)
 - a. Stress, exercise, and fever
 - b. High concentration of potassium in the blood
 - c. Decreased respirations
 - d. Increased blood pressure

Matching III

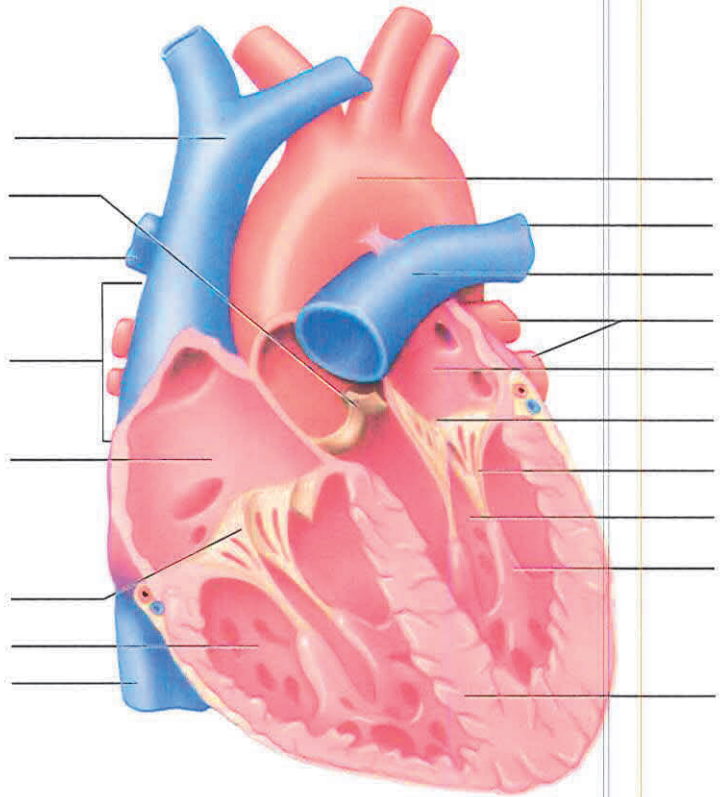
Match the circulation and cardiac cycle terms on the left to their definitions on the right.

- | | |
|--|---|
| _____ 24. deoxygenated blood (LO 2.2) | a. period from the beginning of one beat of the heart to the beginning of the next |
| _____ 25. cardiac cycle (LO 2.4) | b. circulation of blood to and from the heart muscle |
| _____ 26. systole (LO 2.4) | c. blood that has little or no oxygen |
| _____ 27. coronary circulation (LO 2.3) | d. phase of the cardiac cycle when the heart is expanding and refilling; also known as the relaxation phase |
| _____ 28. systemic circulation (LO 2.3) | e. blood having oxygen |
| _____ 29. oxygenated blood (LO 2.2) | f. circulation between the heart and the entire body, excluding the lungs |
| _____ 30. diastole (LO 2.4) | g. transportation of blood between the heart and lungs |
| _____ 31. pulmonary circulation (LO 2.3) | h. contraction phase of the cardiac cycle, when the heart is pumping blood out to the body |

Label the Parts

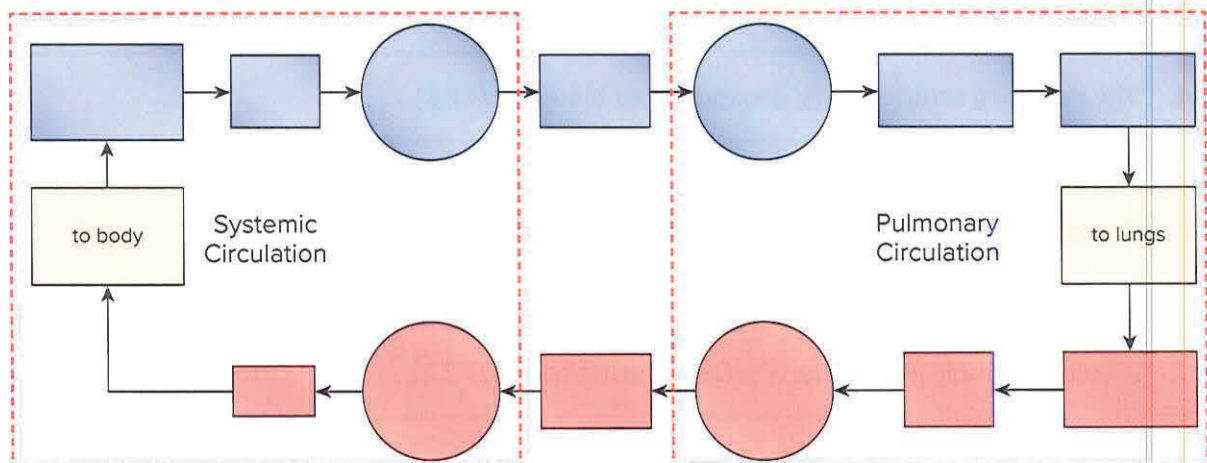
32. a.–r. Label the vessels, valves, chambers, and muscles of the heart by writing the letters on the lines provided. (LO 2.2)

- a. Right atrium
- b. Aorta
- c. Right ventricle
- d. Right pulmonary veins
- e. Left atrium
- f. Left ventricle
- g. Superior vena cava
- h. Pulmonary trunk
- i. Aortic valve
- j. Tricuspid valve
- k. Right pulmonary artery
- l. Mitral (bicuspid) valve
- m. Inferior vena cava
- n. Left pulmonary veins
- o. Left pulmonary artery
- p. Interventricular septum
- q. Chordae tendineae
- r. Papillary muscle



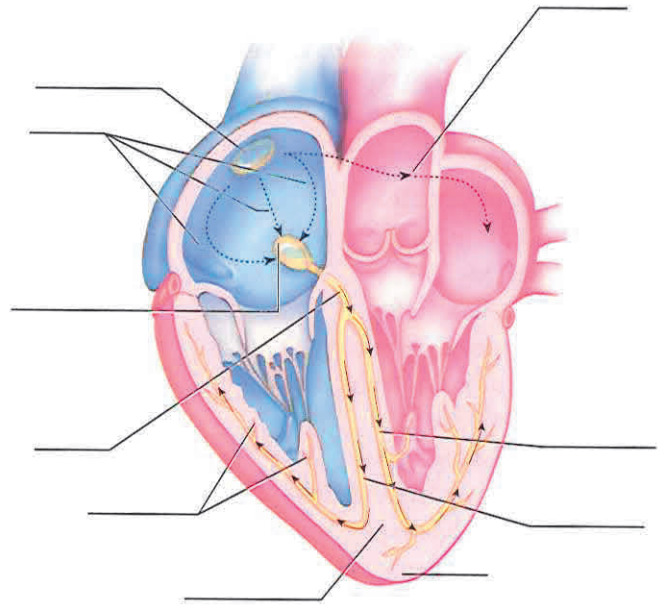
33. a.–m. Label the following diagram representing the flow of blood through the heart by writing the letters in the appropriate circles or boxes. (LO 2.3)

- a. Superior and inferior venae cavae
- b. Right atrium
- c. Aorta
- d. Right ventricle
- e. Pulmonary semilunar valves
- f. Left atrium
- g. Mitral (bicuspid) valve
- h. Pulmonary trunk
- i. Pulmonary veins
- j. Tricuspid valve
- k. Left ventricle
- l. Aortic semilunar valve
- m. Pulmonary arteries



34. a–j. Label the parts of the conduction system by writing the letters on the lines provided. (LO 2.5)

- a. Interventricular septum
- b. Left bundle branch
- c. Purkinje fibers
- d. AV node
- e. SA node
- f. AV bundle
- g. Right bundle branch
- h. Apex
- i. Bachmann's bundle
- j. Internodal pathways



Right or Wrong?

35. You and a friend have just finished studying this chapter. Your friend makes the following statements. Are these statements correct or incorrect? If the statement is incorrect, write down what you would say to correct your friend.

- a. "The valves between the atria and the ventricles are semilunar." (LO 2.2)

- b. "The atria pump the blood to the lungs and body." (LO 2.2)

- c. "The heart is a two-sided pump that produces pulmonary circulation and systemic circulation." (LO 2.4)

- d. "The coronary arteries carry deoxygenated blood." (LO 2.2)

- e. "The pulmonary arteries carry oxygenated blood." (LO 2.2)

- f. "If you are a male you will have a faster heartbeat." (LO 2.5)

- g. "The top chambers of the heart are the ventricles, and the bottom chambers of the heart are the atria." (LO 2.2)

- h. "The right ventricle is sometimes known as the workhorse of the heart." (LO 2.2)

Voyage Through the Heart

36. Imagine that you are a drop of blood traveling through the heart. (LO 2.3)

- a. Returning from the brain, you are about ready to enter the heart. What vessel are you in?

- b. After you enter the right atrium, you must go through a door to enter the right ventricle. What is the name of this door?

- c. You have made it to the lungs successfully and are traveling back to the heart. What vessels are you in?

- d. When you get to the heart from the lungs, where will you be?

- e. You have finally made it to the last chamber of the heart. The left ventricle pumps you into the entire body. After entering the aorta, what are the very first vessels you will travel into?

Critical Thinking Application *What Should You Do?*

Read the following situations, and use your critical thinking skills to determine how you would handle each. Write your answer in detail in the space provided.

37. Sometimes when atrial cells other than the SA node trigger atrial contractions, atrial flutter or atrial fibrillation may occur. When these heart rhythms occur, the ventricles do not beat at the same rate as the atria. What part of the conduction system prevents the ventricles from beating as fast as the atria, and how does it occur? (LO 2.5)

38. You are working in the emergency department recording an ECG when the electricity goes out. There is a short period of darkness followed by a very loud noise. When you regain power, both your heart and the patient's are beating extremely fast. What part of the cardiovascular system is responsible for this increased heart rate? Should you continue recording the ECG now or later, and why? (LO 2.5)
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