The Cardiac Cycle and Circulation

11.4

Phrases such as “the old ticker” and “regular as clockwork” are commonly used when talking about the heart and the heartbeat. They refer to the regular rhythmic beating of the heart that we are, for the most part, unaware of. In Section 11.1, you learned about the four-chambered, two-circuit circulatory system of mammals. In this section, you will examine the structure of the human heart more closely, look at circulation in the two-circuit system, and investigate normal and abnormal heart rhythms.

The Structure of the Heart

The human heart is the remarkable, muscular organ at the centre of the circulatory system (**Figure 1**). Despite the common misconception that the heart is on the left, it is located in the middle of the chest, directly under the breastbone.

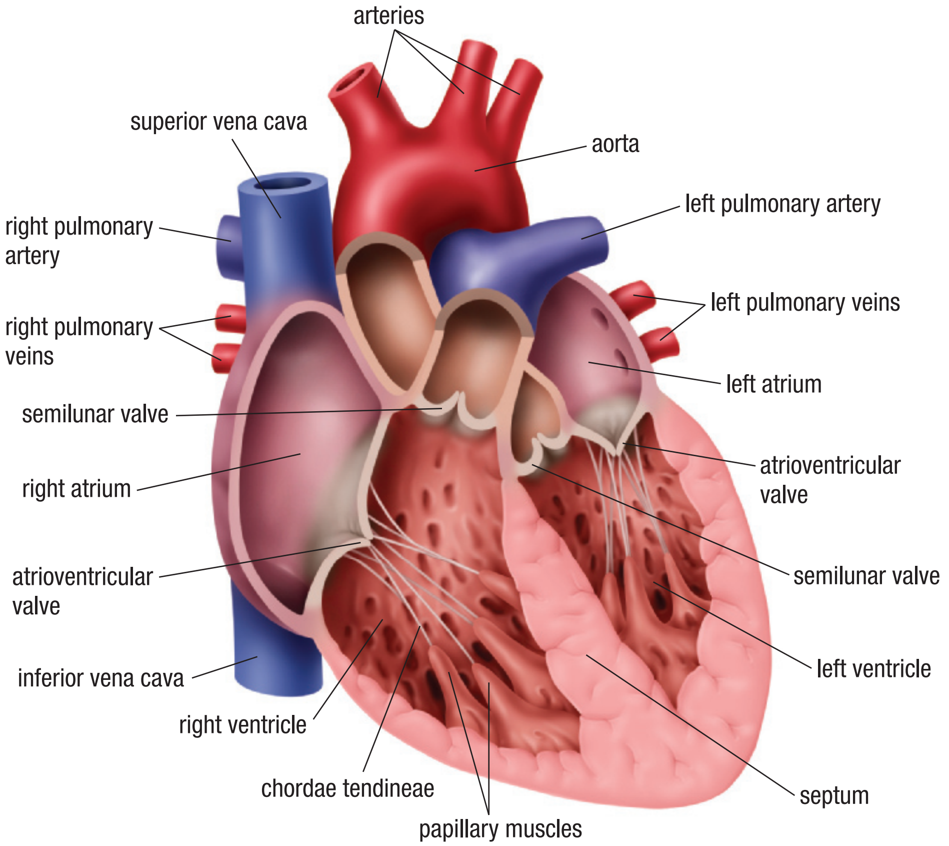

Figure 1 The human heart is a four-chambered double pump. The “left” and “right” in the labels refer to the left and right of the individual whose heart is represented in this diagram.

A wall of muscle called the septum separates the heart into two parallel pumps, each with an atrium and a ventricle. The atria, located at the top of the heart, receive blood and pump it into the ventricles. The ventricles, located at the bottom of the heart, pump blood out into two circuits: the pulmonary circuit and the systemic circuit. The right side of the heart circulates blood to the pulmonary circuit, that is, to the lungs. The left side of the heart receives this blood and pumps it out through the systemic circuit, or the rest of the body.

The muscular walls of the ventricles are much thicker than the walls of the atria because the ventricles have to pump the blood over much longer distances and through capillary networks. The layers of muscles in the ventricles are arranged spirally around the heart. Contraction of these muscles produces a slight twisting motion that wrings the blood out of the ventricles.

LEARNING TIP

Root Words

The words “cardiac” and “coronary” both mean “of or related to the heart.” Cardiac comes from *kardia*, the Greek word for “heart.” Coronary comes from *corona*, the Latin word for “crown.”

There are not many materials, natural or synthetic, as durable or resilient as human heart muscles. Each beat requires the contraction and relaxation of the heart muscles. On average, your heart beats over 100 000 times per day, about 37 million times per year, and more than 2.5 billion times in your lifetime. To appreciate this, clench and open your fist as many times as you can at about the same rate as your heart beats. How long can you keep doing it before you have to stop?

pericardium a two-layered fluid-filled membrane that surrounds the heart and prevents friction between the heart and other tissues and organs

The heart is surrounded by the **pericardium**, a two-layered connective tissue membrane that has fluid between the two layers. This fluid-filled membrane protects the heart from friction with other tissues and organs in the thoracic (chest) cavity as the heart beats.

Since the heart is a muscular organ that works continuously, it has a high demand for oxygen and nutrients. It is estimated that the heart requires over 10 % of the total oxygen load of the blood, proportionally much higher than any other muscle of the same size. Even when the body is at rest, the heart requires eight times as much oxygen as a comparable mass of skeletal muscle. The heart has its own supply of blood vessels, known as the **coronary blood vessels**. This network of arteries and veins provides oxygen and nutrients to the muscle cells of the heart and removes the waste products. The coronary arteries branch from the aorta. The coronary veins join to form the coronary sinus, which empties directly into the right atrium.

coronary blood vessel a blood vessel that circulates blood to and from the muscle cells of the heart

Circulation

The heart is a very efficient circulation pump. When the body is resting, the heart can pump about 5 L of blood in one minute—a volume equal to the total volume of blood in the body. At its maximum output, it can pump more than 25 L/min. The following paragraph traces the circulation of blood through the heart, starting with blood that arrives at the heart from the body. Refer to **Figure 2** as you follow the path of the blood.

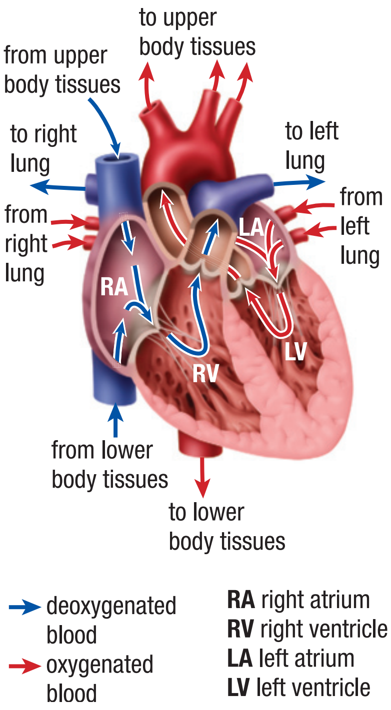

Figure 2 The path of blood through the circulatory system

Deoxygenated blood from the body enters the right atrium of the heart. Contraction of the right atrium, along with the pull of gravity, forces the blood into the right ventricle. The right ventricle contracts to force the blood out through the pulmonary arteries to the lungs. Oxygen diffuses into the blood as it passes through the capillary networks in the lungs. The oxygenated blood from the lungs enters the left atrium through the pulmonary veins. The left atrium contracts and squeezes blood into the left ventricle. The left ventricle contracts and forces blood out through the aorta, the largest blood vessel in the body. The aorta branches into major arteries that carry blood around the body. As blood passes through the capillary networks in the body tissues, oxygen diffuses out of the blood into the cells. After passing through the tissues, the deoxygenated blood enters the venules, which merge to form veins. These veins, in turn, merge to form larger veins. The largest veins, the inferior vena cava and the superior vena cava, enter the right atrium of the heart. The vena cava veins collect blood from the upper and lower parts of the body and return it to the right atrium. The cycle begins again.

Four valves in the heart ensure that blood flows in only one direction. Two of the valves are located where the ventricles meet the pulmonary arteries and the aorta. These valves are called the **semilunar valves**, named because they are shaped like half moons (Figure 1, page 495). The semilunar valves prevent blood from flowing back into the ventricles when the ventricles relax.

semilunar valve the valve located between the left ventricle and the aorta and the right ventricle and the pulmonary arteries to prevent the backflow of blood when the ventricles relax

The other two valves, the **atrioventricular valves**, are located between the atria and the ventricles, as the name suggests (Figure 1, page 495). The left atrioventricular valve has two flaps and is sometimes called the bicuspid valve. The right atrioventricular valve has three flaps and is also known as the tricuspid valve. The two atrioventricular valves prevent blood from flowing from the ventricles back into the atria when the ventricles contract. Because atrioventricular valves are subjected to higher pressures than the semilunar valves, they are supported by tough cords known as the **chordae tendineae**. The chordae tendineae are attached to papillary muscles on the inside of the ventricles. Contraction of these muscles and tension in the chordae tendineae prevent the valves from opening backwards into the atria during the high pressure caused by the ventricular contraction.

atrioventricular valve the valve located between each atrium and ventricle to prevent the backflow of blood from the ventricles to the atria

chordae tendineae tendons that support the atrioventricular valves

The Cardiac Cycle

The **cardiac cycle** refers to a complete heartbeat—a contraction and relaxation of each chamber of the heart. Under normal conditions, a cardiac cycle takes about 0.8 s. The above description of the circulation through the heart is sequential for the sake of clarity. The contractions and relaxations of the chambers of the heart occur in a specific sequence, but there is overlap in the various phases, making the cardiac cycle a very complex event.

The cardiac cycle is usually divided into two basic phases: diastole and systole. **Diastole** is the period of relaxation and filling of the heart with blood. **Systole** is the period of contraction and emptying of the heart. **Figure 3** shows a complete cardiac cycle divided into five additional stages. Diastole begins when the relaxed atria begin to fill with blood (stage 1 of Figure 3). As the atria fill, the pressure pushes the atrioventricular valves open, and blood begins to fill the relaxed ventricles (stage 2 of Figure 3). As the atria continue to fill, the muscular walls of the atria contract, and the ventricles completely fill with blood (stage 3 of Figure 3).

Once the ventricles are completely filled with blood, they contract (stage 4 of Figure 3). This contraction of the ventricles marks the beginning of systole. The increasing pressure forces the atrioventricular valves shut, pushing blood through the semilunar valves and into the arteries (stage 5 of Figure 3).

The ventricles then begin to relax, and the volume in the ventricles increases. With increased volume, pressure in the ventricles begins to decrease. Blood is prevented from re-entering the ventricles (which are now an area of lower pressure) by the closing of the semilunar valves (return to stage 1 of Figure 3).

cardiac cycle the contractions and relaxations of the heart muscles during a complete heartbeat

diastole the period of the cardiac cycle when the ventricles are relaxed; blood fills the ventricles

systole the period of the cardiac cycle when the ventricles contract; blood is ejected from the ventricles

WEB LINK

To view an animation and learn more about the cardiac cycle,

GO TO NELSON SCIENCE

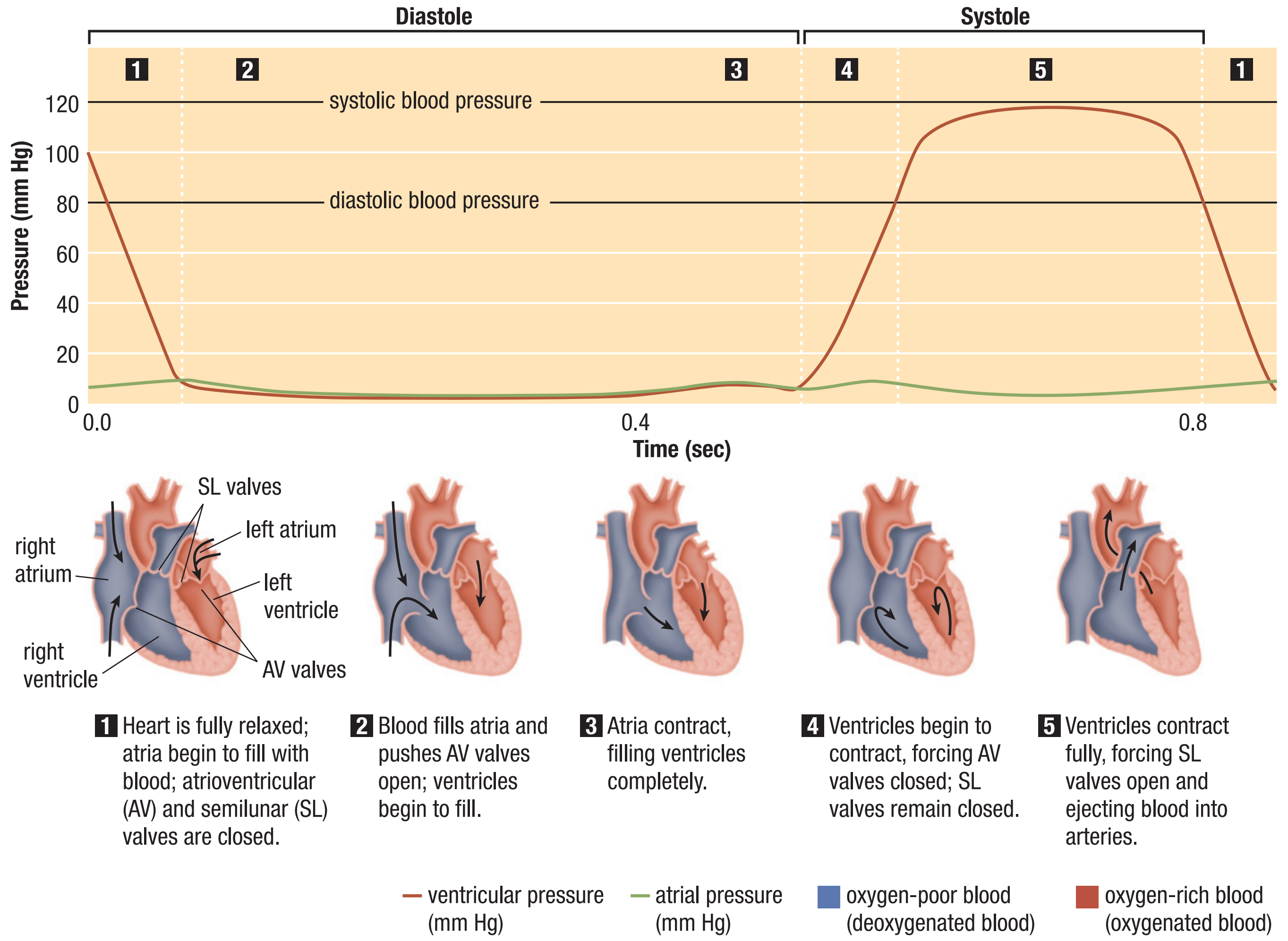

Figure 3 The cardiac cycle

Heart Sounds

The familiar *lubb-DUBB* sound of the heartbeat is caused by the closing of the heart valves. The first sound occurs when the atrioventricular valves close as the ventricles begin to contract. This is a double sound because the left valve closes slightly before the right valve. This is the *lubb* sound. The second sound, the *DUBB* part, occurs as the ventricles relax and the semilunar valves snap shut, preventing blood from flowing back into the ventricles.

Heart sounds can be clearly heard using the most familiar medical instrument, the stethoscope. The stethoscope is a simple but important tool for doctors. It can be used to listen to the normal sounds of the heart, but, more importantly, it can also be used to detect abnormal sounds. For example, if a heart valve fails to close properly or completely, the sound of blood leaking past or through the valve can be heard. This condition is known as a heart murmur, so named because of the sound that is heard. While murmurs are not usually life threatening, they do result in some blood flowing back to the atria or ventricles and a degree of inefficiency in delivering oxygen to the tissues. Individuals with heart murmurs have an increased heart rate that helps compensate for the decreased blood flow through the heart.

Mini **Investigation**

Listening to Heart Sounds

Skills: Observing, Analyzing, Communicating — SKILLS HANDBOOK **A2.1, A3.5**

In this activity you will listen to your own heartbeat and to recordings of normal and abnormal heart sounds.

Equipment and Materials: stethoscope; alcohol towelette; recordings of heart sounds; mp3 or wav player; computer with speakers

1. Use an alcohol towelette to clean the earpieces of the stethoscope.
2. Place the stethoscope on your chest and listen for your heartbeat. You do not have to place the stethoscope directly on the skin to hear your heartbeat. You can listen through a thin shirt. Find and note the location where the sound is the loudest.
3. Perform moderate exercise, such as walking or stepping in place, for 1 min to 2 min. Listen to your heart again. Record your observations.
4. Obtain the recordings of normal and abnormal heart sounds from your teacher or from the website provided by your teacher. Record your observations.

A. Draw a sketch of your chest and indicate on the sketch where the heart sounds are clearest. T/I C

B. Describe how the heart sounds are different after exercise. T/I

C. Identify the abnormal condition(s) and describe how the sounds differ from the normal sounds. T/I

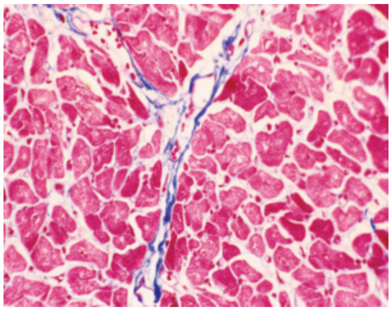

Figure 4 Cardiac muscle cells have a complex branching pattern, which enables the muscle to withstand the forceful contractions of the heart.

myogenic muscle muscle that can contract and relax without input from an external source

Regulation of Heart Rhythm

Experiments have shown that when a heart is removed from a live animal, it continues to beat for a short time. These observations led to the conclusion that the stimulus for the heart muscle contraction must be within the muscle itself. Unlike skeletal muscle, which must be stimulated by signals through nerves, heart muscle has the unusual ability to contract and relax on its own, without stimulation from an external source. This type of muscle is known as **myogenic muscle** (**Figure 4**). These muscles are a safety mechanism that ensures that the heart will continue to beat even if the nervous system is damaged. This explains why the heart continues to beat in a person who has severe brain injury or has been pronounced "brain dead."

The heartbeat is initiated in a cluster of cells in the right atrium called the **sinoatrial (SA) node** (**Figure 5**). This small mass of nerve and muscle cells generates between 50 and 100 electrical signals per minute in a regular pattern. The SA node acts as a pacemaker, and its signals set the normal rhythm of the heartbeat. The electrical signals first pass over the atria in a wave, causing the muscles to contract. The signals then reach a second mass of cells called the **atrioventricular (AV) node**, located in the wall of the heart between the right atrium and right ventricle. From the AV node, special conducting fibres, called **Purkinje fibres**, run down through the septum and throughout the muscle cells of the ventricles.

Although the heart has a self-contained nervous system responsible for maintaining the heartbeat, the heart rate can be adjusted by the sympathetic and parasympathetic nervous systems. The sympathetic nervous system is the part of the nervous system that controls processes in the body in preparation for stress. It is often referred to as the "fight or flight" system. The parasympathetic nervous system, often referred to as the "rest and digest" system, is the part of the nervous system that conserves energy by relaxing muscles in the heart and digestive system.

In preparation for stress, signals from the brain through the sympathetic nervous system cause the heart rate to increase. The increased heart rate increases the flow of blood and the supply of oxygen to areas of the body where it is needed. When the stress is no longer present, the brain sends signals through the parasympathetic nervous system and the heart rate returns to normal. Heart rate can be affected by many factors, including emotional stress, physical stress such as being overweight, physical activity, drugs such as caffeine and nicotine, and various medical conditions.

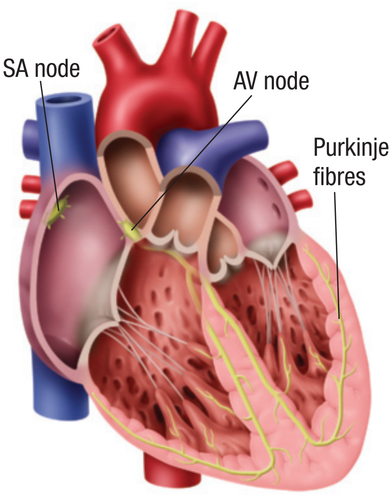

Figure 5 The heart has its own system for conducting electrical stimuli from the SA node to the muscle cells.

sinoatrial (SA) node a mass of muscle and nerve cells in the right atrium; initiates the heartbeat and maintains the regular rhythm

atrioventricular (AV) node a mass of conducting cells that transmits the signals from the SA node to the muscles of the ventricles

Purkinje fibre a conducting fibre that carries the electrical signals from the AV node to the muscle cells of the ventricles

Observing the Heartbeat

As early as 1786, Luigi Galvani was studying the effects of electricity on animal tissues. He learned that stimulation of the nerves in a dissected frog's leg caused the leg muscles to contract. His name is associated with the galvanometer, an instrument used to detect and measure electrical current. In 1791, Galvani progressed to studying the reaction of the frog's heart muscle to electrical stimulation. In 1887, a British physiologist named Augustus Waller discovered that you could detect the electrical current from the heart from various places on the skin. This is the basis of modern electrocardiography.

Since the heartbeat is electrically stimulated, it can be indirectly observed by measuring the strength and duration of its electrical signals with an instrument called an **electrocardiograph**. The electrocardiograph measures the electrical signals and records them as an electrocardiogram. Both an electrocardiograph and an electrocardiogram are referred to as an ECG (also commonly referred to as an EKG); the context indicates whether the reference is to the machine or to the recording.

electrocardiograph a device that detects the electrical activity of the heart through electrodes placed on the body's surface

The electrocardiograph is connected to the body using a number of electrodes, usually 12. These electrodes are sensitive to the small variations in potential difference caused by the electrical signals in the heart. The variations in the voltage cause a marker needle to deflect. The strength of the current determines how much the needle is deflected. The ECG tracing is recorded on paper that moves under the needle as it is deflected (**Figure 6**).

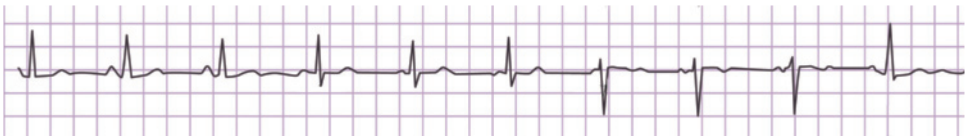

Figure 6 An ECG tracing showing the strength and duration of the electrical signals from the heart. Each repeating pattern represents one heartbeat.

Analyzing the Heartbeat

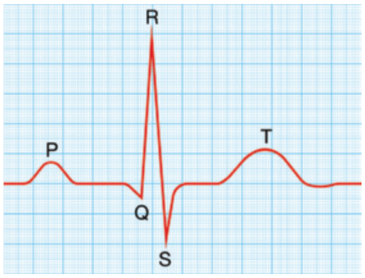

Figure 7 A single heartbeat shown on the ECG includes the P wave, the QRS complex, and the T wave.

Analysis of an electrocardiogram can provide evidence for the presence of abnormal heart conditions. Abnormalities can be identified only by comparing the potential problem with the normal ECG pattern (**Figure 7**). A normal heartbeat starts with an electrical stimulus from the SA node. This stimulus spreads and causes the contraction of the atria, creating the P wave on the ECG. The signal also travels to the AV node, during which there is a very brief delay in transmission of the signal. The QRS complex follows, during which the electrical stimulus moves via the Purkinje fibres to the tip of the ventricles. The contraction of the ventricles starts at the tip of the heart and spreads upward, producing the squeezing action that forces the blood out into the aorta and pulmonary arteries. After the QRS complex, there is another slight delay as the ventricles recover and prepare for the next contraction. The recovery period produces the T wave on the ECG.

11.4 Summary

- The human heart is a four-chambered double pump that pumps blood through two separate circuits: the pulmonary circuit and systemic circuit.
- Two atrioventricular valves and two semilunar valves in the heart ensure that blood flows in only one direction.
- The cardiac cycle has two main phases—diastole and systole. Diastole begins when the ventricles begin to relax and ends when the ventricles are filled with blood. Systole begins when the ventricles begin to contract and ends when the blood is forced out of the ventricles.
- Heart sounds, which can be heard with the use of a stethoscope, are produced by the closing of the heart valves.
- Cardiac muscle is myogenic, which means it can contract and relax without input from external nerve stimuli. The rate of contraction and relaxation, however, can be adjusted by the nervous system.
- The sinoatrial (SA) node initiates the heartbeat by sending electrical signals and maintains the regular rhythm of contraction and relaxation.
- An electrocardiograph can be used to monitor the cardiac cycle. The printout from the electrocardiograph, called an electrocardiogram, can be analyzed to diagnose abnormal heart conditions.

Investigation 11.4.1

Analyzing and Interpreting ECGs (page 514)

Now that you have read about the cardiac cycle, you can complete Investigation 11.4.1.

In this investigation you will analyze normal and abnormal ECGs to determine the heart rate and strength, and to propose possible diagnoses of abnormal heart conditions.

UNIT TASK **BOOKMARK**

Consider what you have learned about the cardiac cycle. How can this information help you as you create a health and fitness profile in the Unit Task?

11.4 Questions

1. Explain why there is a difference in the thickness of the walls of the atria and the walls of the ventricles. K/U A
2. Explain the importance of the coronary blood vessels. K/U
3. Why do the atrioventricular valves have chordae tendineae while the semilunar valves do not? K/U A
4. Describe briefly what happens during diastole and systole. K/U
5. The heartbeat is generally described as a *lubb-DUBB* sound. Explain what is happening in the heart to produce this sound. K/U A
6. Cardiac muscle is myogenic, but the nervous system can influence the heart rate. Explain this apparent contradiction. K/U T/I
7. What is the purpose of the Purkinje fibres in the heart? K/U
8. (a) Why is electrocardiography a useful technology in medicine?
   (b) Using a sketch of a normal ECG wave, describe what is happening in each section. K/U T/I C A
9. Use the Internet and other sources to research digital stethoscopes. K/U T/I C A
   (a) Write a summary of your research. Be sure to explain how a digital stethoscope is different from a regular stethoscope, and describe the capabilities of a digital stethoscope.
   (b) From the perspective of a doctor, how do you think the digital stethoscope benefits both doctor and patient?

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