The Heart

The heart is located between the lungs in the central region called the mediastinum. The heart is positioned obliquely and is positioned so that about two-thirds of the heart is located to the left of the mid-sternal line. The heart is attached by its fibrous pericardium to the diaphragm. The apex of the heart is located to the left at the fifth intercostal space.

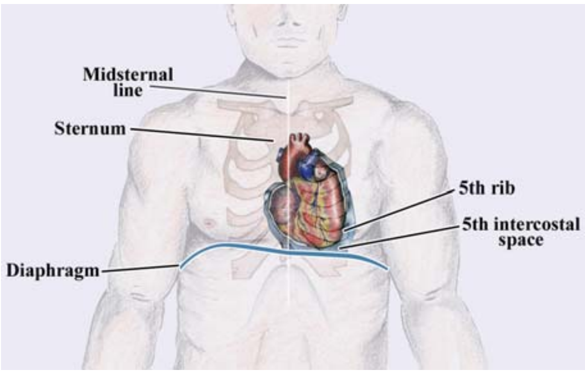

Figure 23.1

The heart is located between the lungs in the central region called the mediastinum.

Coverings of the Heart

The heart is surrounded by the **pericardial sac**, or **pericardium**. The pericardium consists of two layers, **(1) an outer layer and (2) an inner layer.** The outer layer of the pericardium is formed from **dense connective tissue** and is called the fibrous pericardium. The fibrous pericardium functions to protect the heart and to anchor the heart inferiorly to the pericardium and superiorly to the heart's vessels. The inner layer of the pericardium is a **serous membrane** called the parietal layer of the pericardium. At the junction of the pericardium with the heart's vessels, the parietal layer of the pericardium continues inward and to cover and form the serous layer on the surface of the heart called the visceral layer, or epicardium. The two portions of the serous membrane, the visceral and parietal layers form and are separated by the pericardial cavity. The pericardial cavity contains a **lubricating serous fluid** that is produced and maintained by the serous membrane.

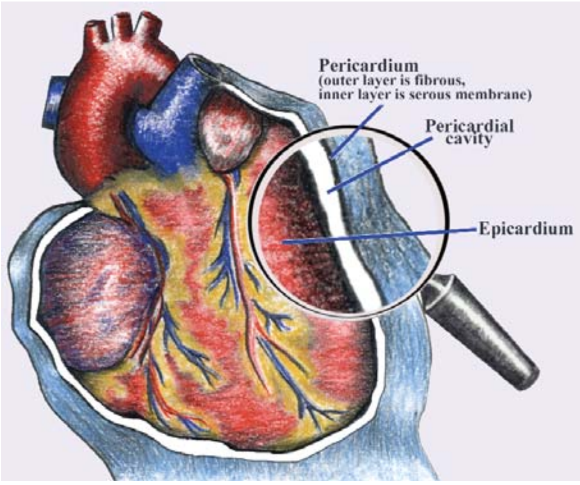

Figure 23.2

The pericardium surrounds the heart.

LAB ACTIVITY 1

Observe a **preserved sheep heart** and/or the following **photograph** that show the pericardium. Sheep hearts typically have abundant fat associated with the pericardium. If purchased as a "sheep heart pluck," the sheep heart will have pieces of associated organs, such as lungs, esophagus, etc.

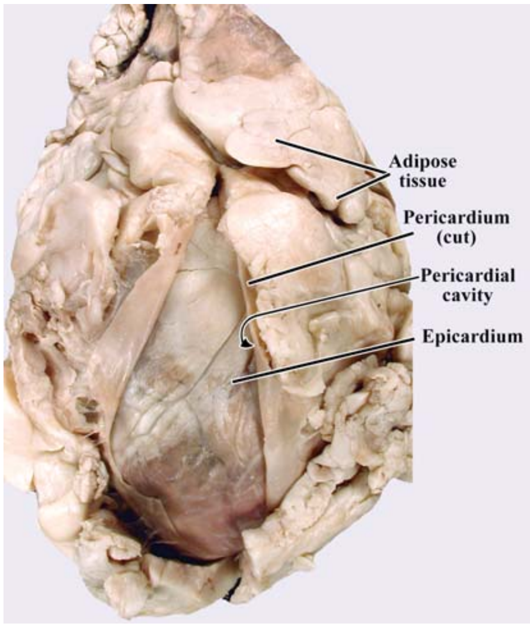

Figure 23.3

The pericardium surrounds the heart. The inner layer of the pericardium is a serous membrane called the parietal layer of the pericardium. The parietal layer continues over the surface of the heart and forms the visceral layer, or epicardium.

GROSS ANATOMY OF THE HEART

Observe the heart's anatomy by studying a **heart model** and the following illustrations and photographs.

The heart is a **four-chambered** organ. The two upper chambers are called **atria**, and the two lower chambers are called **ventricles**. A longitudinal partition, which consists of the **interatrial** and **interventricular septa,** separates the atria and the ventricles and divides the heart into **right and left sides**. The wall between the atria, the **interatrial septum**, partitions the right atrium from the left atrium. The wall between the ventricles, the **interventricular septum**, partitions the right ventricle from the left ventricle. Thus, the heart is a **two-sided pump**. The right side is responsible for receiving blood low in oxygen from the body (systemic circuit) and pumping it to the lungs (pulmonary circuit) where oxygenation occurs. The left side is responsible for receiving oxygenated blood from the lungs (pulmonary circuit) and pumping it to the body (systemic circuit).

The heart works as a pump because of the sequential contractions of its muscle, the myocardium, and the one-way function of its valves. The muscle of the heart is called the **myocardium** and forms the walls of the atria and the ventricles.

Atrial Myocardium

The myocardium of each atrium is called an **auricle** because of its "ear," or "auricle" shape. The atrial myocardium is thin and functions by its contraction to push blood into the ventricles.

Ventricular Myocardium

The myocardium of the ventricles is referred to as **ventricular myocardium**. The myocardium of the left ventricle is **thicker** than that of the right ventricle. The increased thickness of the left ventricle is due to its increased work load of pushing blood through the systemic circuit. The right ventricle pushes blood through the pulmonary circuit, the circuit involved with the gas exchange of the lungs. The pulmonary circuit is short and offers much less resistance than the systemic circuit.

Valves of the Heart

Atrial contraction pushes blood into the ventricles through one-way valves called **atrioventricular (AV) valves**. The atrioventricular valves (located between the atria and ventricles) are the **tricuspid** on the right side and the **mitral** (or **bicuspid**) on the left side. During the contraction of the ventricles the **atrioventricular valves close** preventing blood return back into the atria. Blood is ejected through one-way valves at the bases of the vessels that leave the ventricles. The pulmonary trunk leaves the right ventricle, and the aorta leaves the left ventricle. Valves, the **pulmonary valve** and **aortic valve** (or **semilunar valves**), are located at the bases of the pulmonary trunk and aorta, respectively. When the ventricles relax, the pulmonary and aortic valves (semilunar valves) close and prevent the return of blood into the ventricles.

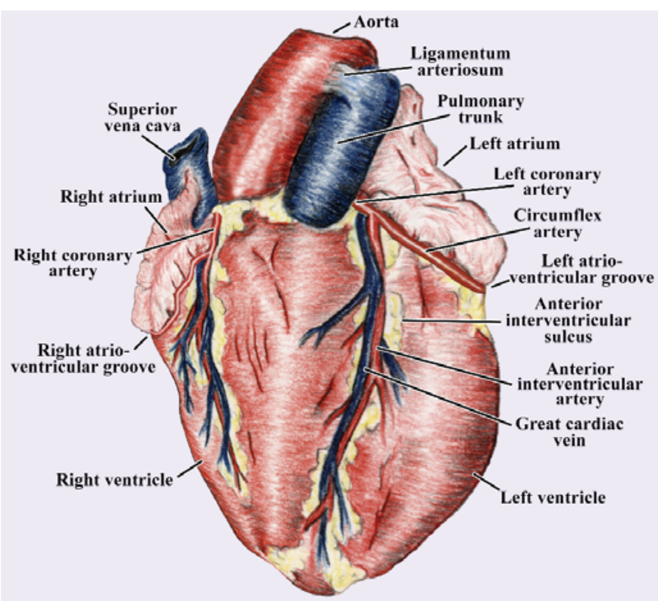

Figure 23.4
Anterior surface of the heart.

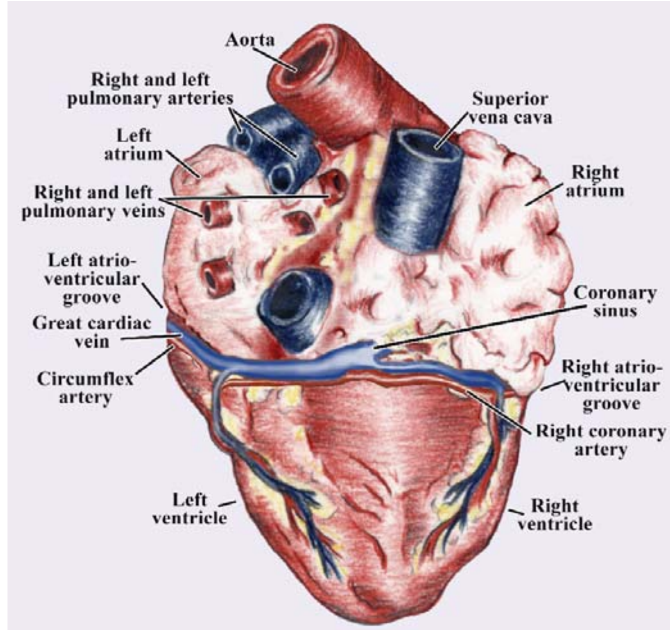

Figure 23.5
Posterior surface of the heart.

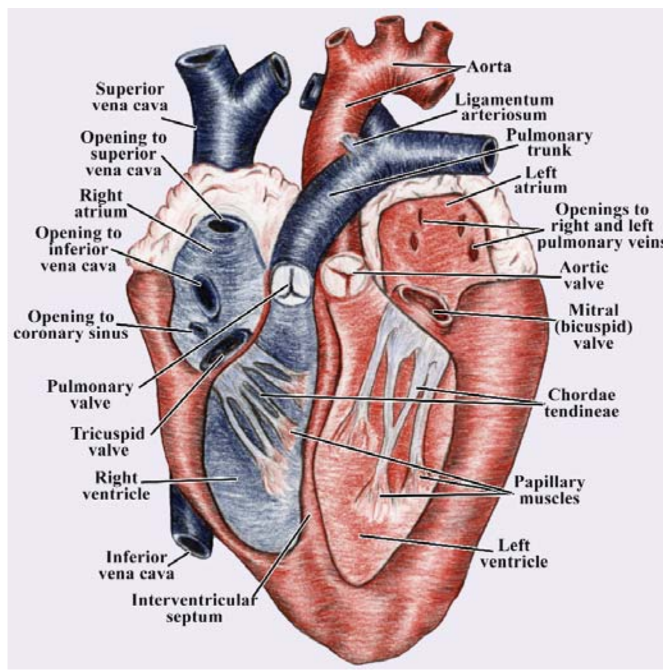

Figure 23.6
Frontal section of the heart showing internal structures.

Right atrium

The right atrium is the superior chamber of the right side of the heart. It receives blood low in oxygen from the general body circulation (systemic circulation) and from the heart muscle itself (coronary circulation).

Superior vena cava

The superior vena cava is the large vein that enters the superior and posterior aspect of the right atrium. It returns blood to the heart from the body regions superior to the heart.

Inferior vena cava

The inferior vena cava is the large vein that enters the inferior and posterior aspect of the right atrium. It returns blood to the heart from the body regions inferior to the heart.

Coronary sinus (entrance)

The coronary sinus is a venous sinus that returns venous blood from the muscle of the heart. It opens into the right atrium just below to the entrance of the inferior vena cava.

Tricuspid valve

The tricuspid valve is located between the right atrium and the right ventricle. Upon ventricular contraction, the tricuspid valve prevents the flow of blood from the right ventricle back into the right atrium. Small tendinous cords, the chordae tendineae, attach to each of the three cusps and anchor the cusps to the myocardium at the papillary muscles.

Right ventricle

The right ventricle receives blood from the right atrium by way of the tricuspid valve. During the contraction of the right ventricle, the closure of the tricuspid valve prevents blood return into the right atrium. The right ventricle functions to eject blood through the pulmonary (semilunar) valve into the pulmonary trunk.

Pulmonary (semilunar) valve

The pulmonary (semilunar) valve is located at the base of the pulmonary trunk. The closure of the valve during ventricular relaxation prevents the return of blood back into the right ventricle.

Pulmonary trunk

The pulmonary trunk is the vessel (artery) that routes blood from the right ventricle toward the lungs for gas exchange.

Left atrium

The left atrium is the superior chamber of the left side of the heart. It receives oxygen-rich blood from the pulmonary veins.

Pulmonary veins

The pulmonary veins return oxygen-rich blood from the lungs to the left atrium.

Bicuspid (mitral) valve

The mitral (bicuspid) valve is located between the left atrium and the left ventricle. Upon ventricular contraction, the mitral valve prevents the flow of blood from the ventricle back into the atrium. Small tendinous cords (chordae tendineae) attach to each of the two cusps and anchor the cusps to the myocardium at the papillary muscles.

Left ventricle

The left ventricle receives blood from the left atrium by way of the mitral (bicuspid) valve. During the contraction of the left ventricle, the closure of the bicuspid valve prevents blood return into the left atrium. The left ventricle functions to eject blood through the aortic (semilunar) valve into the aorta, the primary artery of the systemic circuit.

Aortic (semilunar) valve

The aortic semilunar valve is located in the base (where it exits the left ventricle) of the aorta. The closure of the valve during ventricular relaxation prevents the return of blood back into the ventricle.

Aorta

The aorta is the artery that routes oxygen rich blood from the left ventricle into systemic circulation.

Interventricular septum

The interventricular septum is the wall that separates the right and left ventricles.

Ligamentum arteriosum

The ligamentum arteriosum is the remnant of the ductus arteriosus, a vessel of fetal circulation that shunts blood from the pulmonary trunk to the aorta.

Chordae tendineae

The chordae tendineae are small tendinous cords that attach the cusps of the atrioventricular valves (tricuspid and bicuspid) to the papillary muscles.

Papillary muscles

The papillary muscles are extensions of the ventricular myocardium that attach to the chordae tendineae.

ANSWER WORKSHEET QUESTIONS

Route of Blood Flow through the Heart

The route of the blood through the heart and the structures along the route would be as follows:

Right Side of the Heart

Blood low in oxygen enters the **right atrium** from the **superior** and **inferior vena cavae** and the **coronary sinus**. Blood leaves the right atrium by way of the **tricuspid valve** and enters the **right ventricle**. Blood leaves the **right ventricle** by way of the **pulmonary** (**semilunar valve**) into the **pulmonary trunk**. The pulmonary trunk directs blood into the pulmonary circuit of the **lungs** for gas exchange.

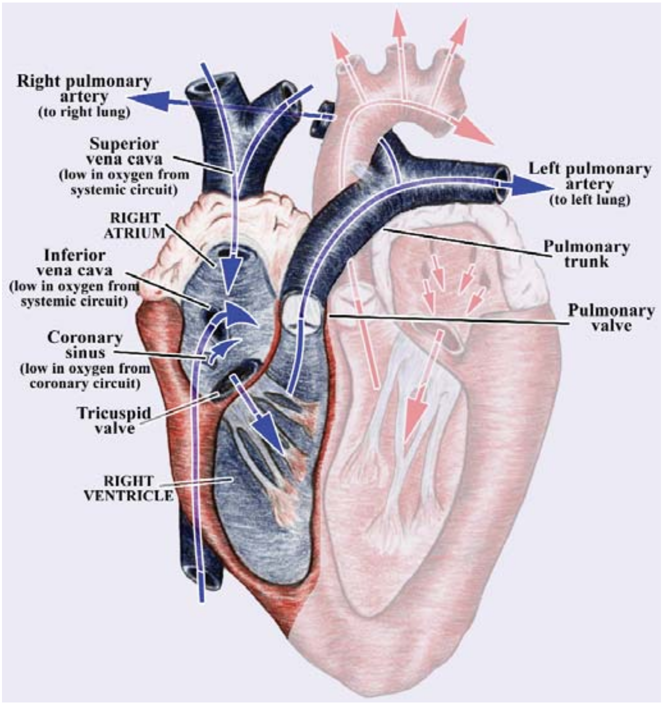

Figure 23.7

Route of blood flow through the right side of the heart.

23

Left Side of the Heart

Oxygen rich blood enters the **left atrium** from the **right and left pulmonary veins**. Blood leaves the left atrium by way of the **mitral** (**bicuspid**) **valve** and enters the **left ventricle**. Blood leaves the **left ventricle** by way of the **aortic** (**semilunar**) **valve** into the **aorta**. The aorta directs blood into the **systemic circuit of the body**.

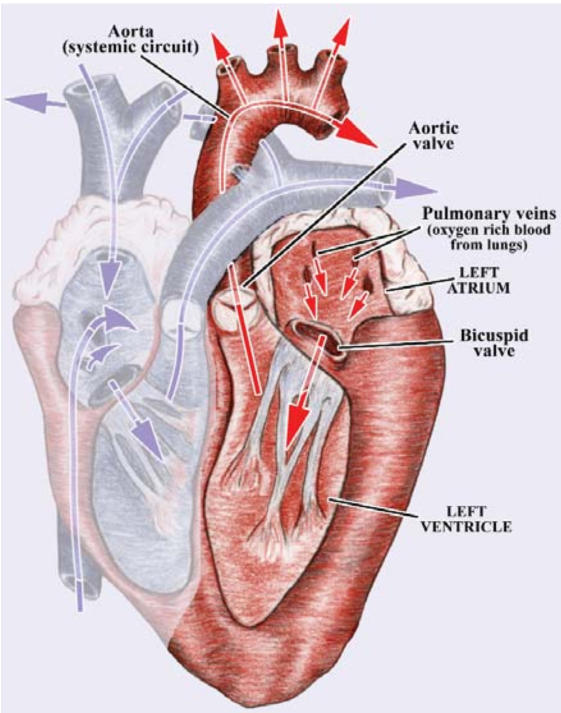

Figure 23.8
Route of blood flow through the left side of the heart.

ANSWER WORKSHEET QUESTIONS

Coronary Circulation

The coronary circuit is the circulatory pathway through the myocardium of the heart.

Coronary Arteries

Oxygen rich blood leaves the aorta and enters the two coronary arteries, the **right and left coronary arteries**. The coronary arteries exit the aorta from the **aortic sinuses**, small dilations located opposite each cusp of the aortic (semilunar) valve. Two of the arotic sinuses, the **right anterior** and the **left anterior**, give rise to the right and left coronary arteries, respectively.

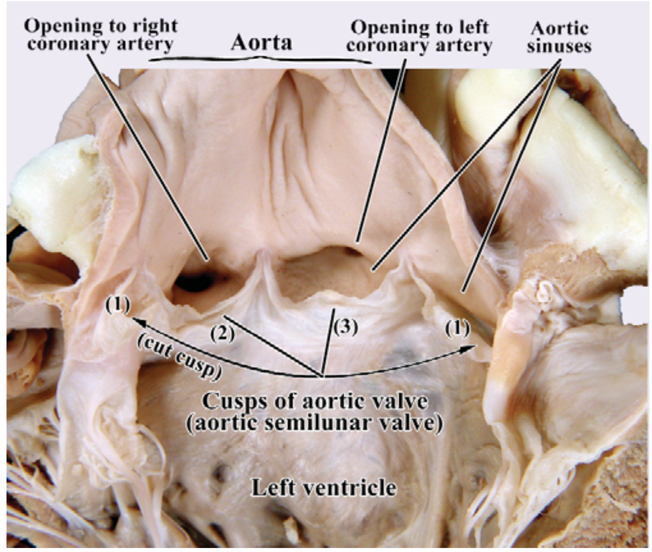

Figure 23.9
The right and left coronary arteries exit the aorta from the coronary sinuses, small dilations located opposite each cusp of the aortic (semilunar) valve. Photograph shows the origins of the right and left coronary arteries in a dissected sheep heart.

Right Coronary Artery

The right coronary artery originates at the right anterior aortic sinus. It follows the right atrioventricular sulcus, the groove between the right atrium and the right ventricle, to the posterior interventricular sulcus. At the posterior interventricular sulcus, it continues to the apex of the heart as the posterior interventricular artery. A small branch, the marginal artery, is formed from the right coronary artery along the margin of the right ventricle.

Left coronary artery

The left coronary artery originates at the left anterior aortic sinus. It branches into the anterior interventricular artery and the circumflex artery. The anterior interventricular artery follows the anterior interventricular sulcus toward the apex of the left ventricle. The circumflex artery follows the left atrioventricular sulcus, the groove between the left atrium and the left ventricle. Along its route it gives off branches and then terminates before reaching the posterior interventricular sulcus.

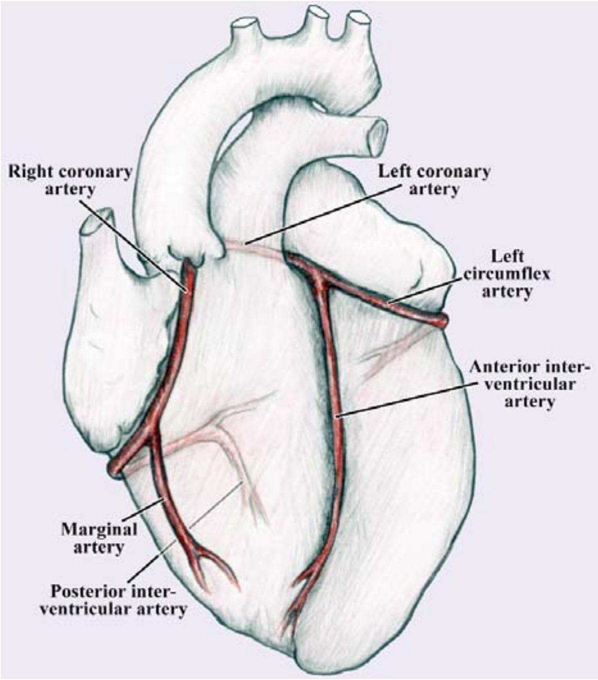

Figure 23.10

Oxygen rich blood leaves the aorta and enters the two coronary arteries, the right and left coronary arteries, which distribute oxygen-rich blood into the myocardium.

Coronary Veins

The venous system of the cardiac circuit collects blood that leaves the capillaries of the myocardium. Capillaries are the vessels that function as the sites of vascular exchange. Venous blood enters three major veins, the (**1**) **great cardiac vein**, the (**2**) **middle cardiac vein**, and the (**3**) **small cardiac vein**, which merge into the large **coronary sinus**.

Coronary sinus

The coronary sinus is a large thin walled vein that receives venous return from the three major veins, the (**1**) **great cardiac vein**, the (**2**) **middle cardiac vein**, and the (**3**) **small cardiac vein**. The coronary sinus opens into the right atrium just below the inferior vena cava.

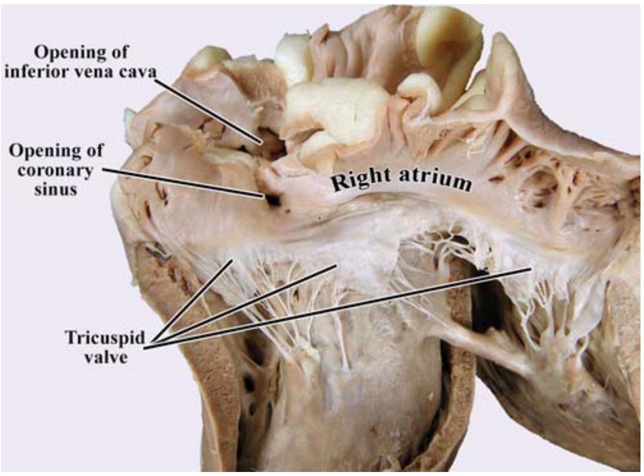

Figure 23.11

The coronary sinus delivers venous blood from the coronary circuit into the right atrium. Photograph shows the opening of the coronary sinus in a dissected sheep heart.

Great cardiac vein

The great cardiac vein is located in the anterior interventricular sulcus and directs venous blood into the coronary sinus.

Middle cardiac vein

The middle cardiac vein is located in the posterior interventricular sulcus and directs venous blood into the coronary sinus.

Small cardiac vein

The small cardiac vein is located along the margin of the right ventricle. It directs venous blood into the coronary sinus.

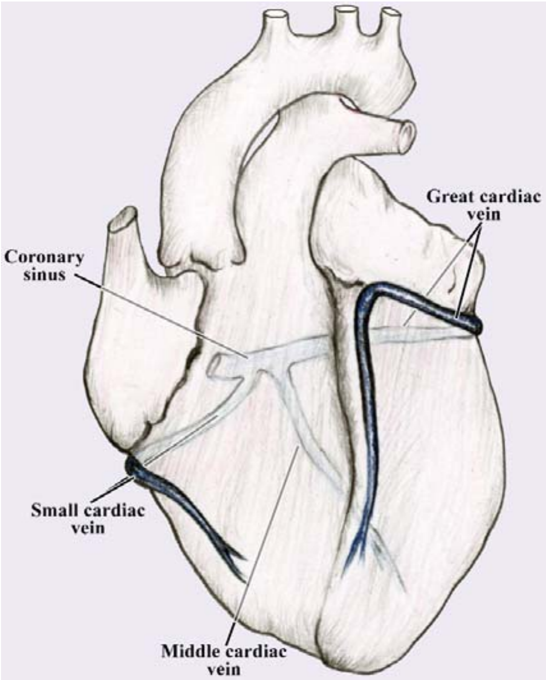

Figure 23.12

The venous system of the cardiac circuit collects blood that leaves the capillaries of the myocardium. Blood is collected into three major veins that enter the large thin walled vessel, the coronary sinus. The coronary sinus enters the right atrium.

ANSWER WORKSHEET QUESTIONS

SHEEP HEART DISSECTION

Because of its small size, ease of storage, and most important, its anatomical similarities to the human heart, the preserved sheep heart is ideal for dissection. Because the sheep is a quadruped, directional terms of reference are obviously different for the sheep heart than for the human (biped). Liberty is taken and direction terms that apply to the heart in biped orientation are used (for example, the term anterior that used for a biped, is substituted for the term cranial that is used for a quadruped).

SAFETY PRECAUTIONS

- Protective gloves must be worn.
- Protective goggles must be worn.
- Rinse the specimen in running water to remove as much preservative as possible.
- Exercise care not to cut yourself when dissecting or cleaning instruments.
- Obtain medical attention if cuts or puncture wounds occur.
- Consult the manufacture's material safety data sheets (MSDS) for any concerns regarding exposure to preservative fluids or fumes.
- Upon completion of the dissection clean your work area and place specimen in an appropriate discard container.

EXTERNAL ANATOMY

LAB ACTIVITY 2

Obtain a sheep heart and rinse it under running tap water to wash off the excess preservative. Study the heart's anatomy by comparing the heart to the following illustrations and photographs.

DORSAL VIEW

External Anatomy

- Do not make any dissection incisions until this section on external anatomy is completed.
- Sheep hearts are packed and shipped in a variety of containers. It is possible that the heart you select for study has been altered in its external shape due to being tightly packed for shipment.
- Sheep hearts may not have all of their external vessels. Frequently, vessels are removed or cut short during processing.

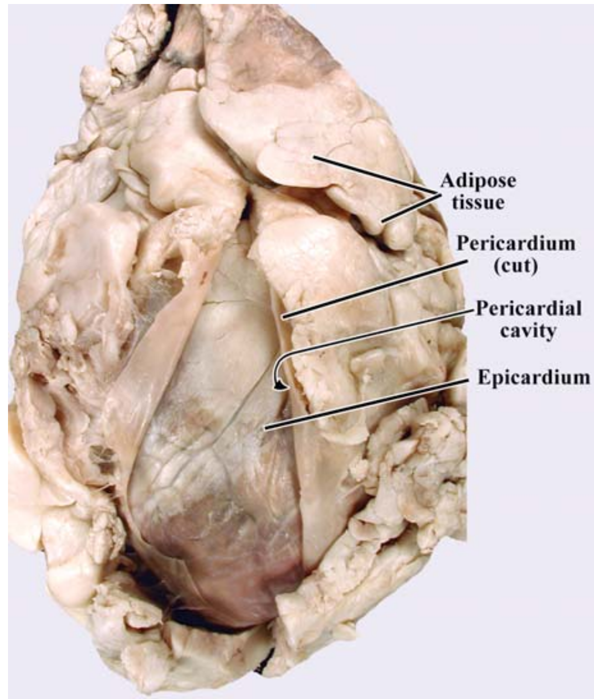

Figure 23.13

The pericardial sac, or pericardium surrounds the heart. A serous-fluid filled cavity, the pericardial cavity, is located between the pericardium and the epicardium.

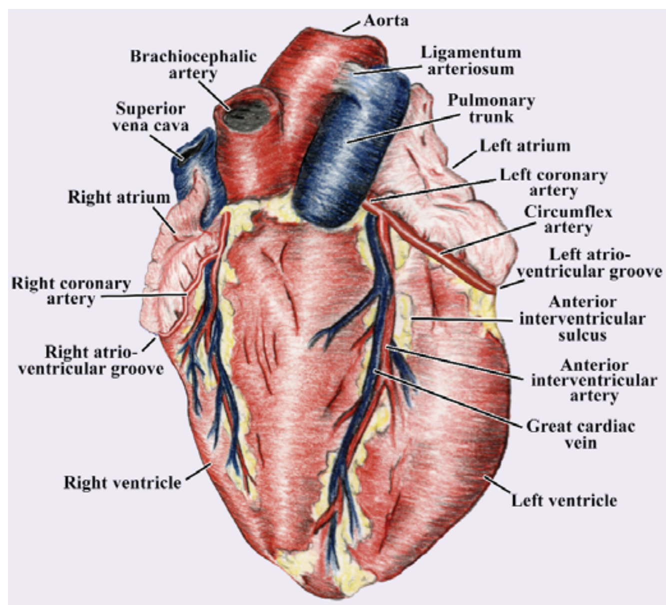

Figure 23.14

Illustration of the anterior surface of the sheep heart.

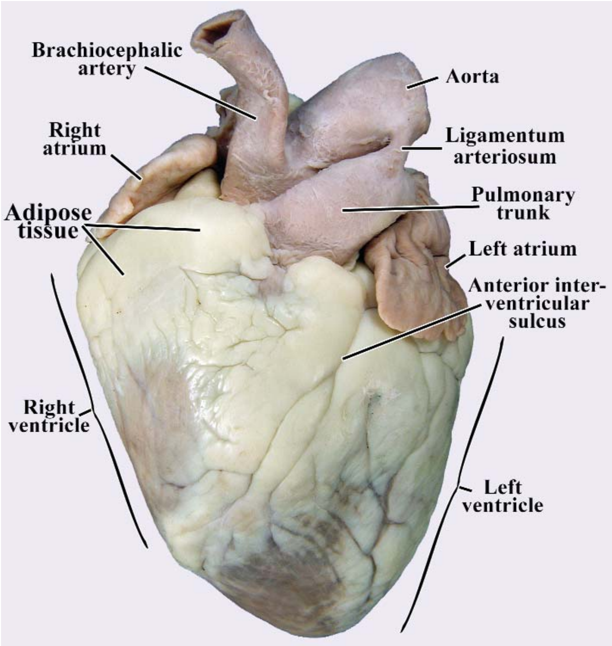

Figure 23.15
Photograph of the anterior surface of the sheep heart.

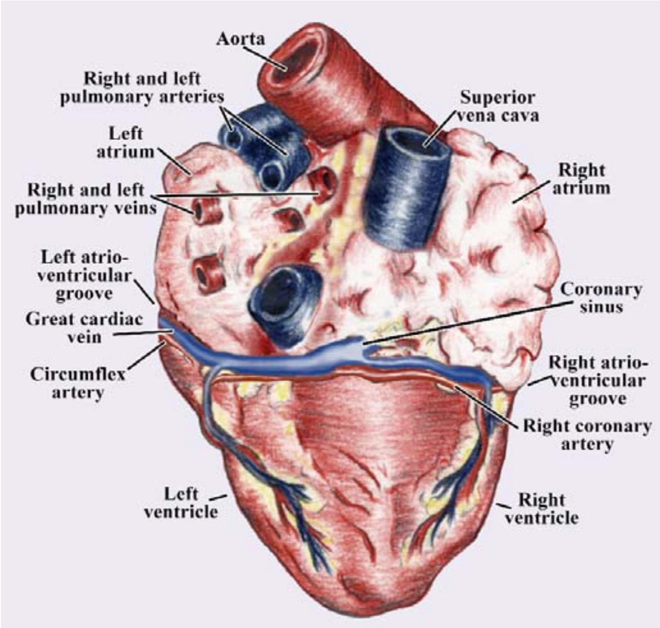

Figure 23.16
Illustration of the posterior surface of the sheep heart.

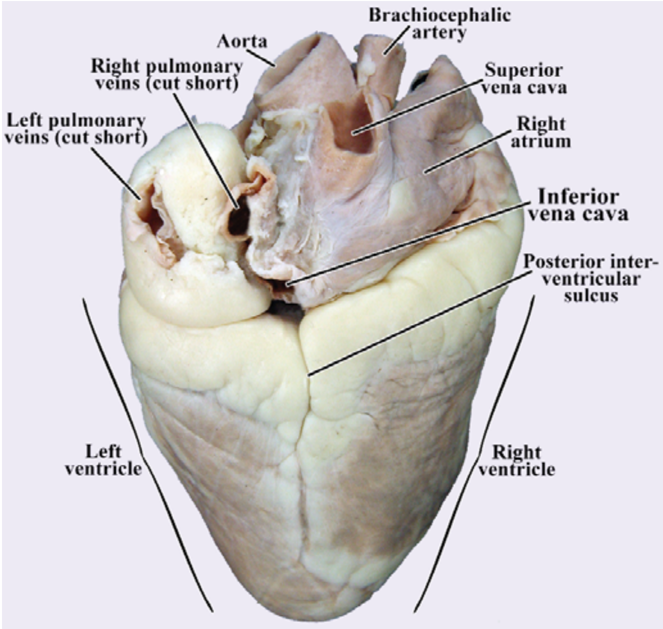

Figure 23.17
Photograph of the posterior surface of the sheep heart.

Pericardium, Epicardium, Myocardium, and Endocardium

Pericardium

The heart is surrounded by a sac called the pericardial sac, or the pericardium. The preserved sheep hearts may be purchased with the pericardium present. If the pericardium is not present, some cut remnants of the pericardium may be located around the bases of the major vessels. The inner surface of the pericardium is called the parietal layer of the pericardium, and is a serous membrane.

Epicardium

The epicardium (visceral layer of the pericardium) is a very thin serous covering on the surface of the heart. Pick the ventricular myocardium with a sharp probe to separate the epicardium from the underlying myocardium (muscle).

Myocardium

The myocardium is the muscle of heart.

Endocardium

The endocardium is the internal lining of the heart. It is the innermost layer of cells and their associated basement membrane.

Anterior aspect

Locate the anterior surface of the heart by identifying the **anterior interventricular sulcus**, which is a shallow groove that follows the internal **interventricular septum**, the wall between the right and left ventricles.

Superior aspect

Locate the superior aspect of the heart by identifying the fatty region with blood vessels. Some blood vessels may be partially obscured in the fat. Also, the atria are located superiorly.

Inferior aspect

The inferior aspect of the heart is identified by the location of the muscular ventricles.

Atrial myocardium

The muscular walls of the atria appear as two wrinkled "ear-like flaps" called the auricles. The auricles are slightly expandable, and their contraction provides the final push for ventricular filling.

Ventricular myocardium

The ventricular myocardium makes up the muscular ventricles of the heart.

Right side and left side

Locate the interventricular sulcus and notice that the ventricles are not divided equally. The left ventricle is more muscular than the right ventricle. The left ventricle is more muscular because it pumps blood throughout the body (systemic circuit), whereas the right side pumps only to the lungs (pulmonary circuit).

Locate the **pulmonary trunk** at the anterior, superior portion of the right ventricle. It points slightly to the left as it exits the ventricle.

Locate the **aorta** at the superior portion of the left ventricle. It is usually cut short, but because of its thick wall and large opening, it is easy to identify.

ANSWER WORKSHEET QUESTIONS

Blood Vessels Associated with the Heart

Identify the following major blood vessels. Removal of some of the fatty tissue may be necessary. Arteries conduct blood **away** from the heart and have **thicker walls** than the veins. Arteries have thicker walls because their blood pressure is higher than that of their companion veins.

Superior and Inferior Vena Cavae

The superior and inferior vena cavae return oxygen-poor blood from the systemic circulatory system to the right atrium. They are difficult to locate because their walls are thin and collapsed. If you cannot locate them now, locate them later during the dissection exercise.

Pulmonary trunk

The pulmonary trunk routes oxygen-poor blood from the right ventricle toward the lungs. Turn the heart to its anterior aspect and locate the right ventricle. Identify the pulmonary trunk by locating its origin at the anterior, superior, medial aspect of the ventricle. If the pulmonary trunk is not cut too short, you should follow it away from the heart and locate its two branches, the **right and left pulmonary arteries** and the **ligamentum arteriosum**. The ligamentum arteriosum, which connects with the aorta just before the pulmonary trunk branches, is the remnant of an artery of fetal circulation called the **ductus arteriosus**.

Pulmonary Veins

The pulmonary veins route oxygen-rich blood from the lungs to the left atrium. Turn the heart to its posterior aspect and locate the left auricle. If there is a large portion of the auricle cut away, the pulmonary veins are probably not present. If the auricle is intact, the pulmonary veins are located posterior and inferior to the left auricle. They are difficult to locate because they are very thin-walled, collapsed, and obscured by fat. If you cannot locate them now, locate them later during the dissection exercise.

Aorta

The aorta routes oxygen-rich blood from the left ventricle to the circulation of the body (systemic circulation). Turn the heart to its anterior aspect and locate the left ventricle. The aorta exits the superior aspect of the left ventricle (just posterior to the origin of the pulmonary trunk). It is thick-walled and projects toward the left side of the heart. Identify its first branch, the brachiocephalic artery, which originates slightly above the base of the aorta.

ANSWER WORKSHEET QUESTIONS

INTERNAL ANATOMY (DISSECTION)

There are two common methods for the dissection of the sheep heart.

- One method (described as "**Frontal Section**") involves a single cut (frontal section) which divides the heart into anterior and posterior portions.
- The other method (described as "**Route of Blood**") involves several cuts which independently open the right side and the left sides of the heat to follow the route of blood flow.

SAFETY PRECAUTIONS

- Protective gloves must be worn.
- Protective goggles must be worn.
- Rinse the specimen in running water to remove as much preservative as possible.
- Exercise care not to cut yourself when dissecting or cleaning instruments.
- Obtain medical attention if cuts or puncture wounds occur.
- Consult the manufacture's material safety data sheets (MSDS) for any concerns regarding exposure to preservative fluids or fumes.
- Upon completion of the dissection clean your work area and place specimen in an appropriate discard container.

LAB ACTIVITY 3

Dissection - Frontal Section

Cut the heart so that two equal portions, one anterior and one posterior, are obtained (frontal section). Make the cut along a frontal plane which extends from the right atrium to the left atrium to the apex of the left ventricle. Make sure that the cut divides the heart into equal anterior and posterior portions.

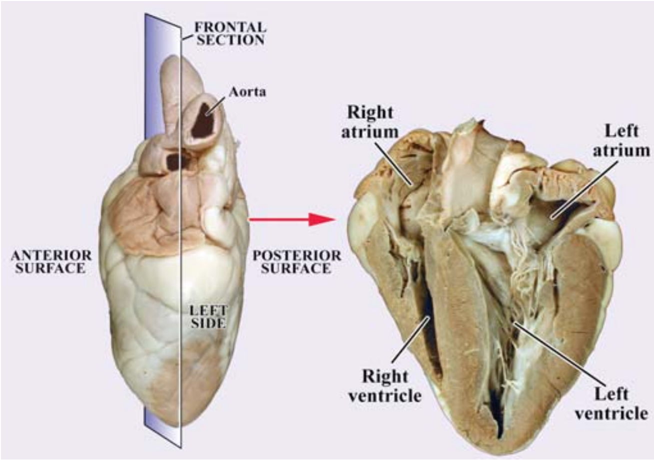

Figure 23.18

Cut the heart so that two equal portions, one anterior and one posterior, are obtained (frontal section).

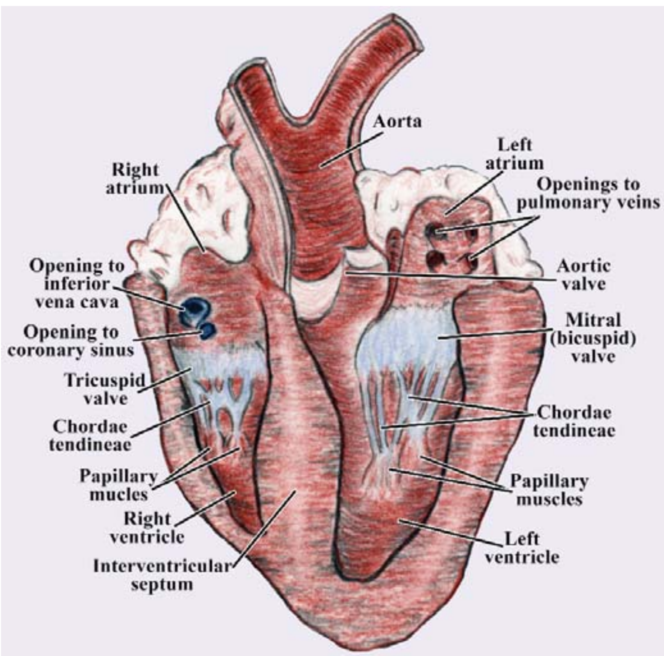

Figure 23.19

Illustration of a frontal section showing the posterior portion of the sheep heart.

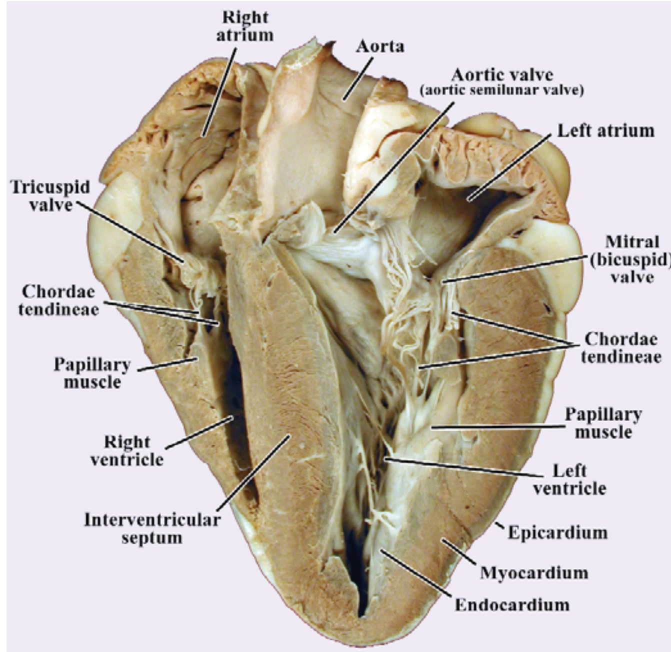

Figure 23.20

Photograph of a frontal section showing the posterior portion of the sheep heart.

ANSWER WORKSHEET QUESTIONS

LAB ACTIVITY 4

Dissection - Route of Blood Flow

This method independently opens the right and the left sides of the heart.

Dissection of the Right Side of Heart

Use **scissors** to make an incision into the anterior wall of the pulmonary trunk. Cut the pulmonary trunk along its anterior wall toward the right ventricle. Continue into the right ventricle (stay in the ventricle!) and cut downward to its bottom. Now continue the cut upward until you cut through the superior surface right atrium.

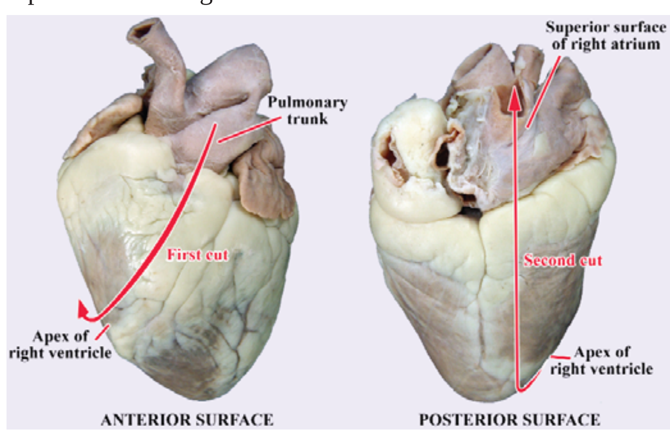

Figure 23.21

Dissection of the right side of the sheep heart.

23

Observe the following illustrations and photographs for the identification of the internal structures of the right side of the heart.

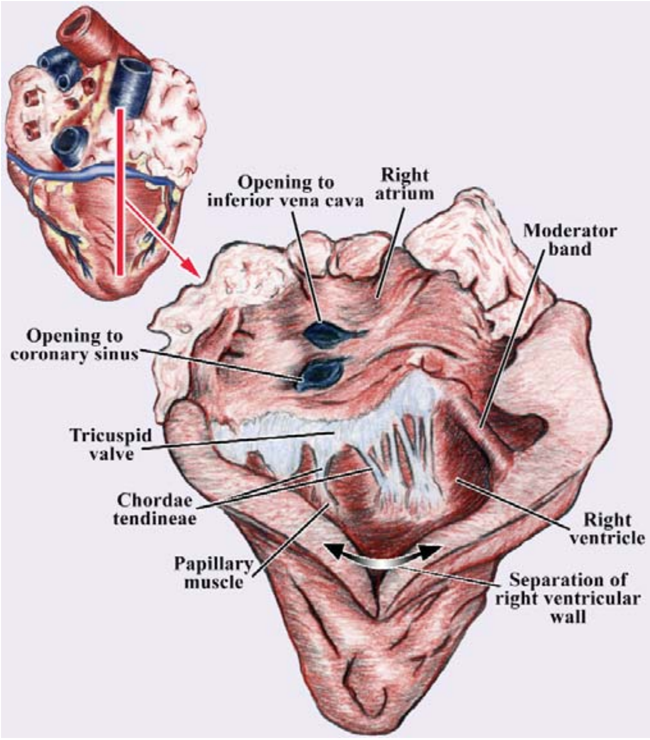

Figure 23.22

Illustration showing posterior surface of the heart cut to expose the right atrium and right ventricle.

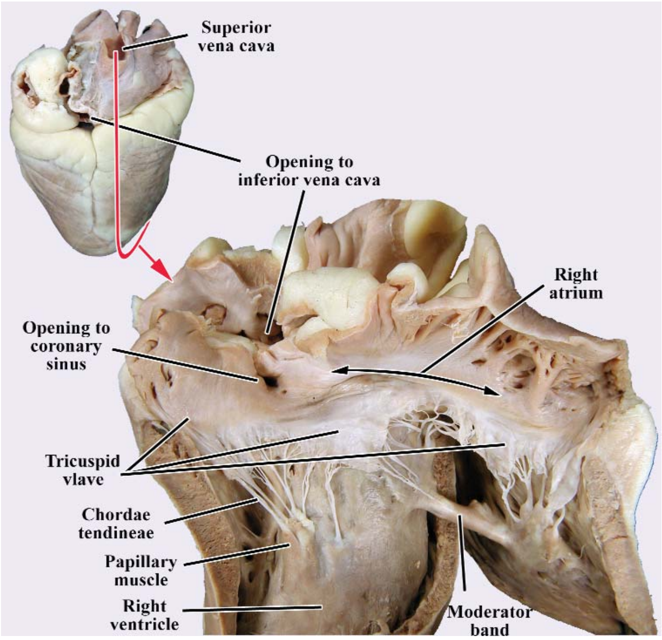

Figure 23.23

Photograph of sheep heart dissection showing posterior surface of the heart cut to expose the right atrium and right ventricle.

Right atrium

Pull the cut of the posterior surface open to expose the interior of the right atrium and the right ventricle. Identify the entrances of the **superior vena cava**, **inferior vena cava**, and **coronary sinus**. The location of the vessels can be determined by carefully inserting a blunt probe into the entrances.

Tricuspid valve

The tricuspid valve is located between the right atrium and ventricle. Identify the **three cusps** of the valve (the cut goes through one cusp). Identify the **chordae tendineae** (tendinous chords) and **papillary muscles**. The chordae tendineae attach the free-edges of the cusps of the valve to the myocardium at modified muscle sites called papillary muscles. When the ventricle contracts, blood exerting pressure upon the valve cusps pushes them back toward the atrium. The chordae tendineae and papillary muscles stop the cusps in the closed position preventing the back flow of blood.

Right ventricle

The right ventricle is the **ejection chamber** of the right side. The right ventricle extends superiorly and anteriorly to the **pulmonary** (**semilunar**) **valve** located at the **base of the pulmonary trunk**. When pressure in the right ventricle is greater than pressure in the pulmonary trunk, the pulmonary valve opens and blood is ejected from the ventricle.

Moderator band

The moderator band is a small extension of the myocardium located between the **interventricular septum and the anterior ventricular wall**. The moderator band functions in **preventing over distention** of the right ventricular wall.

Pulmonary trunk

The pulmonary trunk is the artery that carries blood from the superior, anterior portion of the right ventricle. The pulmonary trunk routes oxygen-poor blood into its two branches, the **right and left pulmonary arteries**, which deliver blood to the lungs for oxygenation.

Pulmonary (semilunar) valve

The pulmonary semilunar valve is located at the **base** (point of origin) of the **pulmonary trunk**. Follow the dissection through the pulmonary trunk and identify the three semilunar cusps of the valve (the cut goes through one cusp). When the right ventricle contracts, and its pressure is greater than pressure in the pulmonary trunk, the pulmonary valve opens. The pulmonary valve closes upon ventricular relaxation, when pressure in the right ventricle is less than pressure in the pulmonary trunk. Closure of the pulmonary valve prevents blood return into the right ventricle.

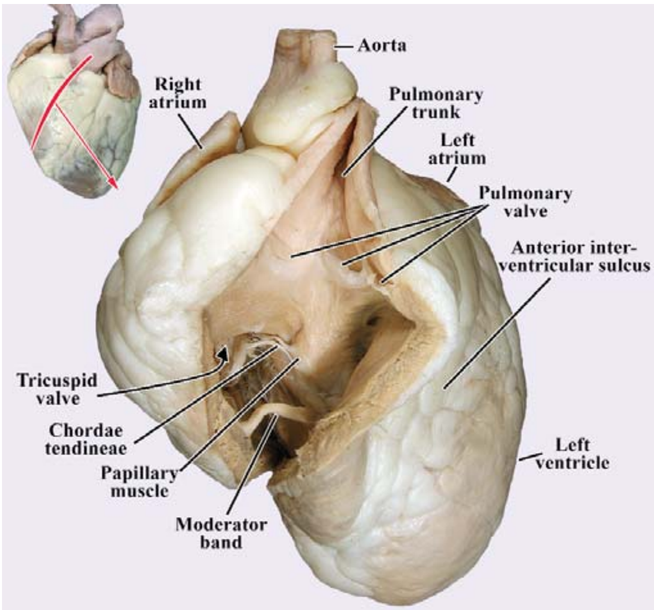

Figure 23.24

Photograph of the sheep heart showing the structure of the pulmonary (semilunar) valve. The pulmonary valve prevents the return of blood to the right ventricle.

ANSWER WORKSHEET QUESTIONS

Dissection of the Left Side of the Heart

Use **scissors** and cut through the superior wall of the left atrium. Extend the incision downward to the apex of the left ventricle.

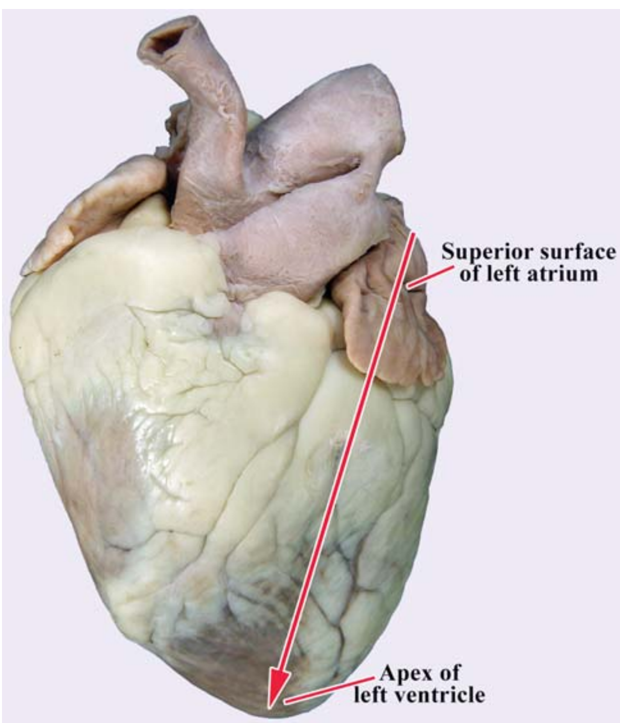

Figure 23.25

Photograph showing the incision for opening the left side of the heart.

Observe the following illustrations and photographs for the identification of the internal structures of the left heart.

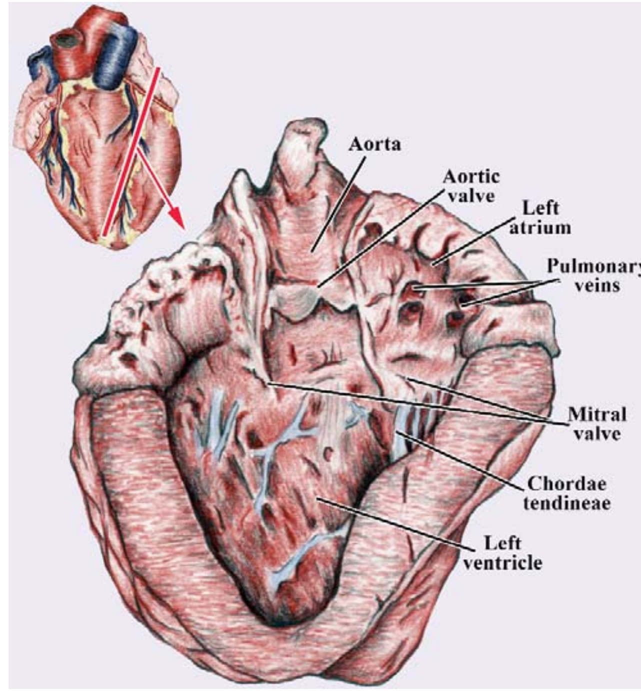

Figure 23.26

Illustration showing the left side of the heart.

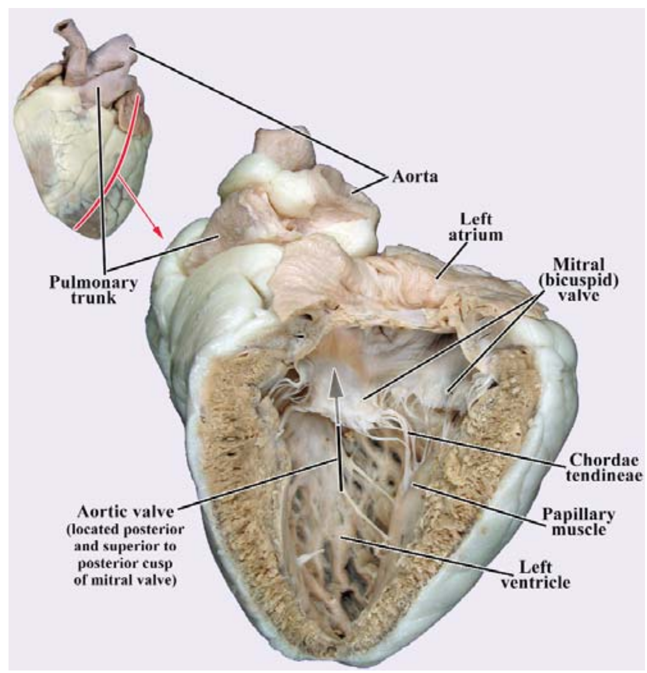

Figure 23.27

Photograph of the sheep heart dissection showing the left side of the heart.

Left atrium

Expose the interior of the left atrium and locate the entrance of the pulmonary veins. If a large portion of the auricle is missing, the pulmonary veins were probably removed during processing.

Bicuspid (mitral) valve

The mitral (bicuspid) valve is located between the left atrium and ventricle. Identify the two cusps of the valve (the cut goes through one cusp). Identify the **chordae tendineae** (tendinous chords) and **papillary muscles**. The chordae tendineae attach the free-edges of the cusps of the valve to the myocardium at modified muscle sites called papillary muscles. When the ventricle **contracts** ventricular pressure becomes **greater than atrial pressure** and the mitral valve **closes**. The chordae tendineae and papillary muscles hold the cusps in their closed position.

Left ventricle

Turn the heart to observe the superior and medial aspect of the ventricle. Compare the thickness of the left ventricular wall to the right ventricular wall. Oxygenated blood is pumped throughout the body by the left ventricle (systemic circulation). Thus, the left ventricular wall is more massive than the right. Observe the aortic (semilunar) valve at the base of the aorta. When pressure in the left ventricle is greater than pressure in the aorta, the aortic (semilunar) valve opens and blood is ejected from the ventricle.

Trabeculae carneae

The trabeculae carneae are bands, or projections, of the heart muscle from the inner surface of the ventricle.

Aortic semilunar valve

The aortic semilunar valve is located at the base of the aorta. **Cut through the posterior cusp of the tricuspid valve** and identify the three semilunar cusps (the dissection cuts through one cusp). The aortic (semilunar) valve is stronger, thicker, and larger than the pulmonary (semilunar) valve. The aortic valve opens during left ventricular contraction, when ventricular pressure is greater than the pressure in the aorta. The aortic valve closes when the left ventricle relaxes, and its pressure is less than the pressure in the aorta. The closure of the valve prevents blood return into the left ventricle. Blood in the aorta continues into the systemic circuit.

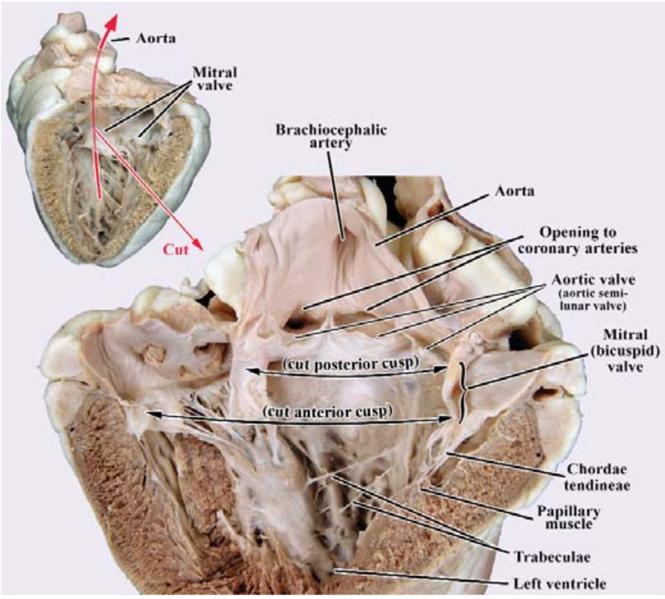

Figure 23.28

The aortic valve is exposed by cutting its posterior cusp. The arotic valve functions to prevent blood return to the left ventricle upon ventricular relaxation.

ANSWER WORKSHEET QUESTIONS

LAB ACTIVITY 5

Valves of the Heart

Observe the valves of the heart from their superior view.

- If a frontal section dissection was performed, hold the two halves together and cut away the atria and the associated vessels.
- If the "route of blood" dissection was performed, cut away the atria and the associated vessels.

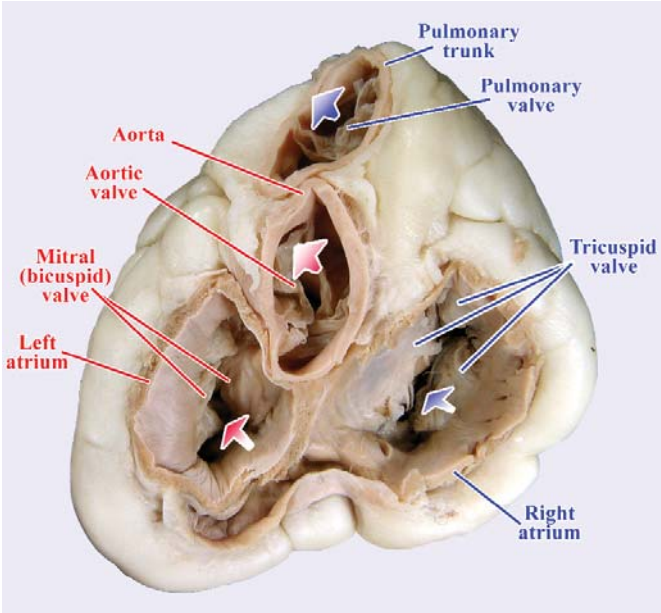

Figure 23.29

Photograph of the superior surface of the ventricles after the removal of the atria and vessels. Removal of the atria exposes the superior surfaces of the four one-way valves of the heart.

The valves of the heart are one-way valves that are opened and closed by pressure/flow of blood. Blood flowing in the direction of their cusps opens the valves. The valves close when blood is pushed against their cusps.

Atrioventricular valves (AV valves)

Observe that the cusps of the atrioventricular valves, the mitral and tricuspid valves, face toward the ventricles. Thus, the AV valves prevent back flow of blood into the atria. The free-edges of the cusps are attached to tendinous cords, the chordae tendineae. The chordae tendineae attach to modified muscle tissue of the myocardium, the papillary muscles. The chordae tendineae and papillary muscles support the free-edges of the atrioventricular valves, preventing their **prolapse**, or displacement into the atria. The **mitral valve** is most often involved in prolapse because of the increased left ventricular pressure.

The atrioventricular valves are **open** when pressure in the **atria is greater than pressure in the ventricles**. Thus, the atrioventricular valves allow filling of the ventricles. The atrioventricular valves are **closed** when pressure in the **ventricles is greater than in the atria**. Thus, the atrioventricular valves prevent back flow of blood from the ventricles into the atria.

Pulmonary and Aortic Valves (semilunar, or SL, valves)

Observe that the cusps of the pulmonary and aortic valves face outward from the ventricles into the pulmonary trunk and aorta, respectively. Thus, the semilunar valves prevent the back flow of blood into the ventricles. The pulmonary and aortic valves are not supported by chordae tendineae or papillary muscles.

The pulmonary and aortic valves (semilunar valves) are **open** when **pressure in the ventricles is greater than the pressure in the exiting vessels**, the pulmonary trunk and aorta, respectively. Thus, the pulmonary and aortic valves allow emptying of blood (blood ejection) from the ventricles. The pulmonary and aortic valves are **closed** when pressure in the exiting vessels, the pulmonary trunk and aorta, respectively, is **greater than in the ventricles**. Thus, the pulmonary and aortic valves prevent the back flow of blood from the exiting vessels into the ventricles.

ANSWER WORKSHEET QUESTIONS

LAB ACTIVITY 6

Ventricular Walls

Observe the thickness and design of the ventricles of the heart by sectioning the ventricles in cross section.

- If a frontal section dissection was performed, hold the two halves together and cut the ventricles in cross section.
- If the "route of blood" dissection was performed, cut the ventricles in cross section.

Observe that the myocardium of the left ventricle is thicker than that of the right ventricle. Also, notice that the wall of the left ventricle is circular in design making its contraction very efficient. Compared to the wall of the right ventricle that has a flap-like design, the left ventricle is more efficient and stronger.

It might appear that the two ventricles have different volumes. However, the volume of the right ventricle is normally the same as the volume of the left ventricle. Thus, under resting conditions, the same volume of blood pumped from the right ventricle to the pulmonary circuit, is retuned to the left ventricle. The left ventricle pumps the same volume of blood into the systemic circuit, and the same volume is returned to the right ventricle.

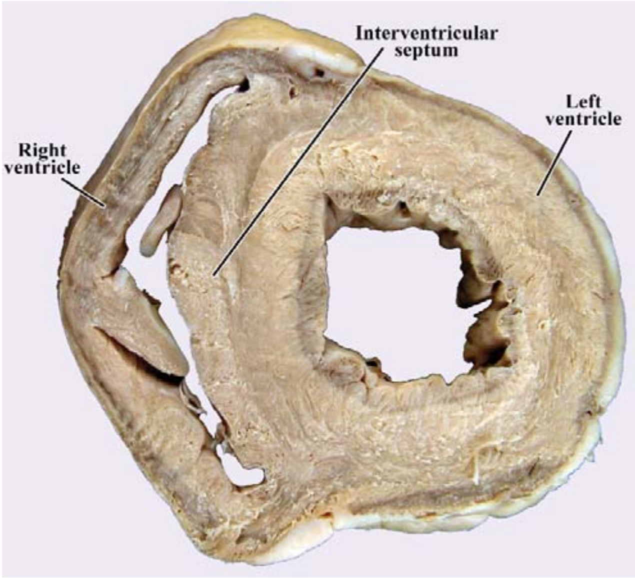

Figure 23.30

Photograph of a cross section across the ventricles of the preserved sheep heart. The left ventricle is designed structurally and in the thickness of the myocardium to produce the most blood pressure.

ANSWER WORKSHEET QUESTIONS

ELECTRICAL EVENTS OF THE HEART

The electrical activity of the heart is graphically recorded as an **electrocardiogram** (or **ECG**). Non-electrical events such as heart sounds are converted by transducers into electrical signals and are graphically recorded. Several systems are available for graphically recording electrical activity. Some systems can record only one event (such as the electrical activity produced by the heart, an ECG), and others can record several events at the same time (such as an ECG, heart sounds, pulse, and respiration). Each event is recorded on a "channel." Thus, systems are described as either single channel or multichannel systems. Multichannel systems usually range from two to four channels and have the advantage of allowing immediate correlations (real time) among the recorded events.

Instrumentation in laboratories varies greatly. Thus, it is impossible to include instructions for all the instrumentation that might be found in laboratories.

Electrocardiogram

Electrocardiographs are medical instruments specifically designed to record electrocardiograms. The electrocardiogram is a recording of the electrical activity produced by the heart by the depolarization and repolarization of its excitable tissues (nodes, conduction, and contraction tissues). As the heart's tissues undergo electrical changes (action potentials), the electrical potentials are transmitted through the tissues of the body. At specific sites on the body, electrodes (leads) are attached for analysis of the electrical potentials. Leads usually include the locations of the wrists, ankles, and chest. The number and combinations of leads used during an ECG is usually used to describe the ECG. For example, a diagnostic ECG is a 12 lead ECG (includes tracings from leads identified as I, II, III, VR, VL, VF, V1, V2, V3, V4, V5, and V6). For the purpose of understanding the conduction system of the heart, this study is limited to the ECG tracing called Lead I (or, I).

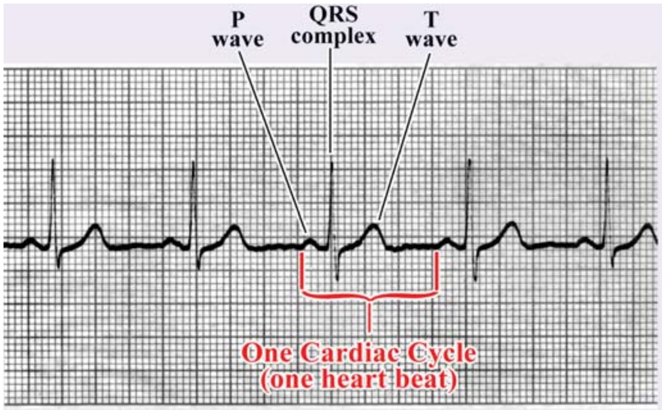

Figure 23.31

Photograph of an ECG tracing (L I) from a medical electrocardiograph.

Conduction System of the Heart

The electrical activity of the heart (intrinsic) is generated and transmitted through its conduction system and myocardium (muscle).

Located in the right atrial myocardium just inferior to the opening of the superior vena cava is a mass of cells called the **sinoatrial node** (**SA node, or sinus node**), or the **pacemaker** of the heart. The depolarization of the sinoatrial node initiates each cardiac cycle. A cardiac cycle is one heartbeat, or one filling and ejection phase of the heart. Once the depolarization impulse is initiated, depolarization spreads over the atrial myocardium resulting in **atrial contraction** (**systole**). Located near the inferior portion of the interatrial septum is the **atrioventricular node** (**AV node**), which is depolarized along with the last portion of the atrial myocardium. The depolarization wave leaves the AV node by a tract of conducting fibers called the **atrioventricular bundle** (**bundle of His**) that enters the **interventricular septum**. The bundle of His forms the **right and left bundle branches,** which conduct the depolarization into **Purkinje fibers.** The **Purkinje fibers** conduct the depolarization into the **ventricular myocardium**. The depolarization of the ventricular myocardium results in contraction of the **ventricles** (**systole**).

ANSWER WORKSHEET QUESTIONS

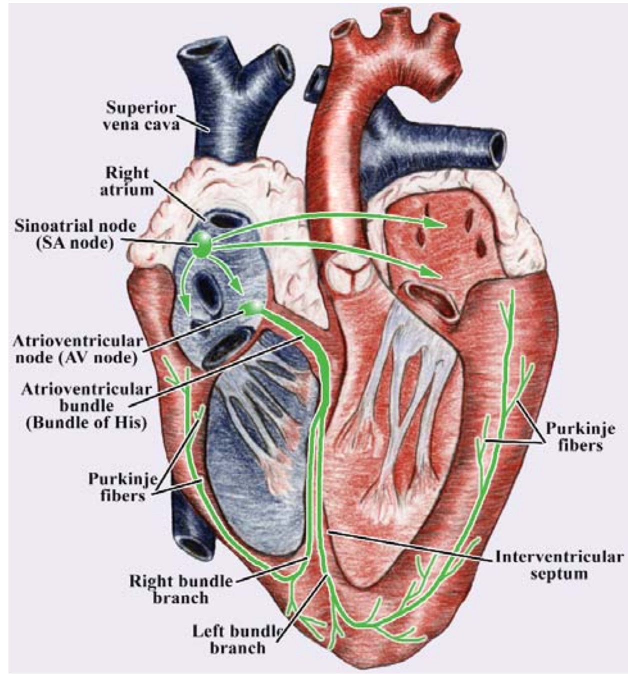

Figure 23.32

The conduction system of the heart.

ECG Waves

The recording of the electrical events that are produced by the heart is called an electrocardiogram (ECG). A normal electrocardiogram shows three distinctive waves: (**1**) the **P wave,** (**2**) the **QRS complex** (**Q wave**, **R wave**, and **S wave**), and (**3**) the **T wave**.

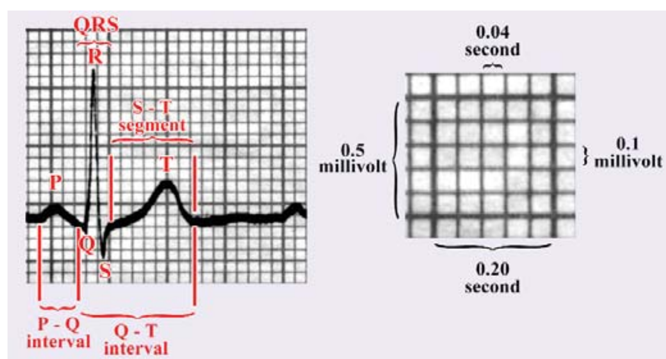

Figure 23.33

An ECG tracing (from Lead I) showing waves and significant intervals.

P wave

The P wave, a small upward wave, is the first ECG wave of a cardiac cycle. The P wave begins with the depolarization of the SA node and represents the depolarization of the atrial myocardium.

QRS complex

The QRS complex follows the P wave. It is composed of the Q, R, and S waves. The Q wave is seen as the first downward deflection, the R wave as the following large upward deflection, and the S wave as the next downward deflection. The combination of the Q, R, and S waves is the QRS complex. The wave pattern represents the depolarization of the ventricular myocardium (and its conduction pathway).

T wave

The T wave follows the QRS complex. It is an upward deflection and represents the repolarization of the ventricles.

P-Q interval

The P-Q interval is the time beginning with the depolarization of the SA node (start of P wave) to the beginning of ventricular depolarization.

Q-T interval

The Q-T interval is the time from the beginning of ventricular depolarization through ventricular repolarization.

S-T segment

The S-T segment is the time when the ventricles are completely depolarized.

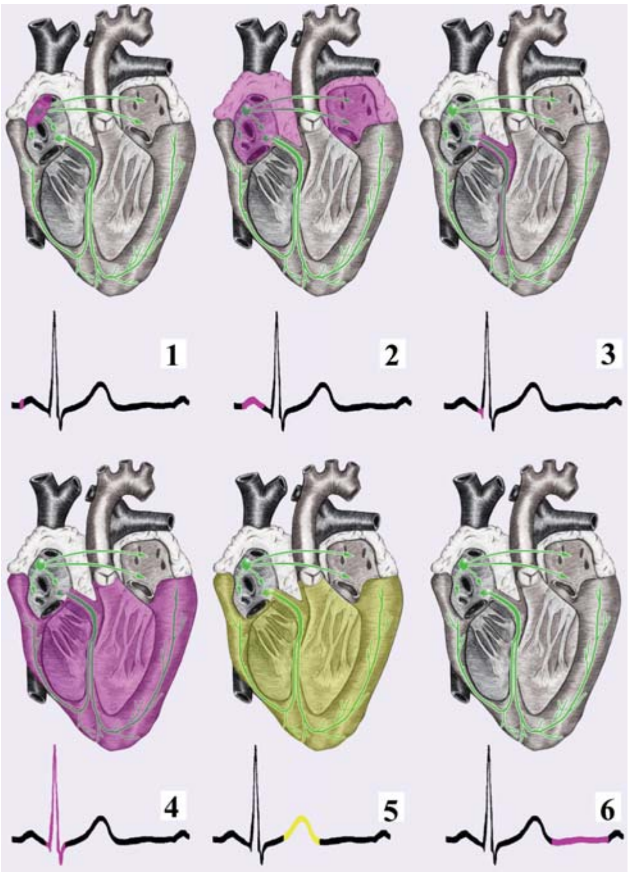

Figure 23.34

Correlation of the ECG waves to colored related areas of the heart.

ANSWER WORKSHEET QUESTIONS

CARDIAC CYCLE

A cardiac cycle is one heartbeat, or one filling and ejection phase of the heart. A normal ECG, or a normal **sinus rhythm**, is characterized by having the three sequential waves, the P wave, the QRS complex, and the T wave in their normal intervals and shapes, with a range of 60 - 100 beats per minute. The average heart rate is **75 beats per minute**. If the heart is beating at 75 beats per minute, it takes **0.8 second for each beat**. The response of the heart in a cardiac cycle is as follows:

At the end of the previous cardiac cycle (following the T wave), the heart is in its resting period. In its resting period both the atria and the ventricles are filling with blood. Atrial filling began immediately upon atrial diastole (relaxation, after the P wave) in the **previous** cardiac cycle. Venous return produces an atrial pressure that is higher than pressure in the relaxed ventricles. Ventricular filling began immediately upon ventricular diastole (relaxation, after the T wave) in the **previous** cardiac cycle. The atrioventricular valves (mitral and tricuspid) are open.

The previous cardiac cycle ends with the beginning of the P wave of the next cardiac cycle. The **P wave** begins with the depolarization of the SA node and shows the depolarization of the atrial myocardium. Depolarization of the atrial myocardium **results** in **atrial contraction** (**systole**), which begins about the middle of the P wave. Atrial systole lasts for 0.1 second and provides the final push of blood into the ventricles prior to their contraction. Atrial diastole (relaxation) lasts for 0.7 second. During atrial diastole the atria begin to fill due to the pressure of venous return. The pressure in the pulmonary trunk and the aorta is higher than ventricular pressure, and the pulmonary and aortic (semilunar) valves are closed.

The **QRS complex** follows the P wave. It begins with the small downward slope of the Q wave. The Q wave is produced by the depolarization of the interventricular septum. During the R and S waves, ventricular depolarization spreads upward from the apex of the ventricles. Ventricular depolarization **results** in **ventricular contraction** (**systole**), which lasts for 0.3 seconds. (Ventricular diastole lasts for 0.5 second). When increased ventricular pressure exceeds atrial pressure, the **atrioventricular valves** (**AV, or bicuspid and tricuspid**) **close**. The first heart sound, described as **lub**, is associated with the closure of the atrioventricular valves. For a brief period of time, the ventricles are in isovolumetric contraction as their volume does not change because both the atrioventricular valves and semilunar valves are closed. The pulmonary and aortic (semilunar) valves **open** when ventricular pressure **is greater than** the pressure in the pulmonary trunk and the aorta. Opening of the pulmonary and aortic (semilunar) valves allows blood ejection into systemic circulation. Elastic blood vessels expand to accommodate the increased blood volume.

The **T wave** is produced as the ventricles repolarize and their myocardium enters relaxation (diastole). When ventricular pressure is **less** than the pressure in the pulmonary trunk and the aorta, the **pulmonary and aortic** (**semilunar**) **valves close**. The second heart sound, described as **dup**, is associated with the closure of the semilunar valves. When ventricular pressure is **less** than atrial pressure, the **atrioventricular valves** (bicuspid and tricuspid) **open**.

The elastic blood vessels have reach maximal expansion with blood ejection. With the closure of the pulmonary and aortic (semilunar) valves blood ejection is stopped. The elastic arteries recoil and blood is circulated through the systemic circuit back toward the right atrium. The circulation of blood is now driven by the recoil of the elastic arteries. The expansion and recoil of the elastic arteries are described as the **pulse**.

23

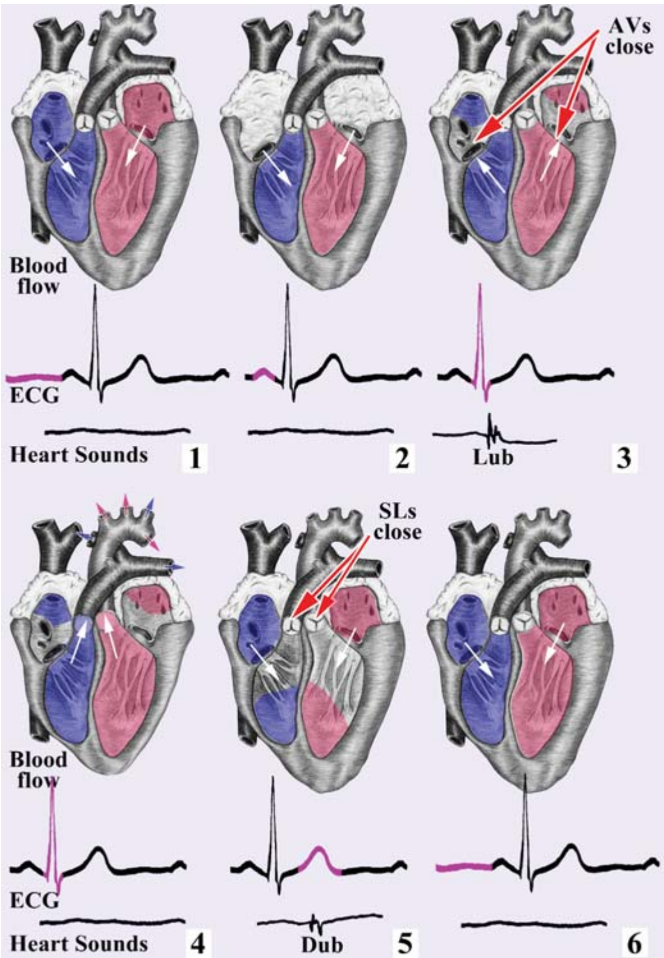

Figure 23.35

Relationships between ECG, blood flow, and heart sounds.

1 Heart is in diastole (period of rest). From the previous cardiac cycle, the ventricles have just finished blood ejection, and their pressure is low. Venous return brings blood into the atria and the ventricles.

2 P wave shows atrial depolarization, and the atrial enter systole (contraction). Atrial systole provides final push of blood into ventricles.

3 QRS shows depolarization of ventricles and ventricles enter systole (contraction). Ventricular pressure begins to increase and the AV valves close producing first heart sound, the dub. Atria enter diastole (relaxation), and they begin to receive blood from venous circulation.

4 Ventricular contraction continues to increase pressure. For a short time, the ventricles are in isovolumetric contraction, as their volume does not change until the semilunar valves open. Opening of semilunar valves occurs when ventricular pressure is greater than the pressure in the exiting vessels, the pulmonary trunk and aorta. Blood is ejected from the ventricles.

5 T wave shows repolarization of ventricles and the ventricles enter diastole (relaxation). Ventricular pressure drops lower than the pressure in the exiting vessels, and the semilunar valves close. Closing of the semilunar valves produces the second heart sound, the dub.

6 Heart enters diastole and blood continues to fill the atria and ventricles due to pressure of venous return.

ANSWER WORKSHEET QUESTIONS

Auscultation of Heart

Auscultation is the term used to describe listening to sounds of the body, such as the sounds of heart, respiratory sounds, and sounds of the gastrointestinal tract. Auscultation of the heart is useful in detecting abnormal valve sounds and leaks between the right and left sides of the heart, or blood vessels.

Because of valve location and chamber resonance, the sound associated with the closure of each valve of the heart is best auscultated at a specific site on the anterior chest wall.

- **Aortic semilunar valve**
  The aortic semilunar valve can best be heard at the second intercostal space at the right sternal margin.
- **Pulmonary semilunar valve**
  The pulmonary semilunar valve can best be heard at the second intercostal space at the left sternal margin.
- **Bicuspid (mitral) valve**
  The bicuspid (mitral) valve can best be heard at the fifth intercostal space vertically in line with the middle of the clavicle.
- **Tricuspid valve**
  The tricuspid valve can best be heard at the fifth intercostal space at the right sternal margin.

LAB ACTIVITY 7

Obtain a **stethoscope** and **clean the earpieces** with an alcohol pad. Use the above illustration and listen to your chest for sounds associated with the closure of the valves. Success in detecting subtle differences among the four regions takes a good-quality stethoscope, critical listening, patience, and a very quiet room.

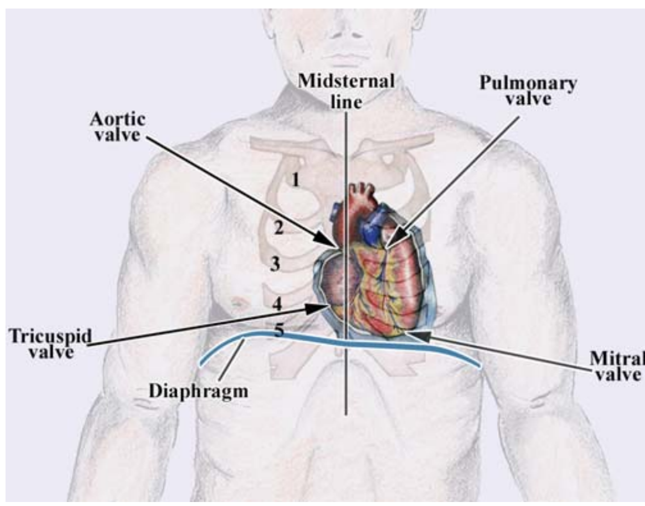

Figure 23.36

The sound associated with the closure of each valve of the heart is best auscultated at these sites on the anterior chest wall.

ANSWER WORKSHEET QUESTIONS

CARDIAC MUSCLE

Cardiac fibers form the **myocardium** (heart muscle). The rod-like fibers are short, striated, mostly uninucleate (some are binucleate), and form chains (as the individual fibers are joined end-to-end at intercalated discs) that branch.

The transverse tubules (T tubules), the small **excitable** tubules continuous with the sarcolemma, of cardiac muscle cells are short. Cardiac muscle does not have **terminal cisternae**, the sac-like ends of the network of sarcoplasmic reticulum that surrounds the myofibrils. Thus, cardiac muscle does not form triads. A triad is the relationship between a T tubule and a pair of terminal cisternae, as found in skeletal muscle.

Contraction is dependent upon the presence of **calcium ions**. Calcium ions bond to **troponin** resulting in exposure of actin (thin filaments). Depolarization of the fiber triggers the release of **calcium ions from the sarcoplasmic reticulum**. However, muscle depolarization **opens calcium ion channels in the sarcolemma** allowing a greater **influx of extracellular calcium ions** than supplied by the sarcoplasmic reticulum. Contraction is terminated by the removal of calcium ions back into the sarcoplasmic reticulum and to the extracellular environment.

Intercalated discs are unique to cardiac muscle. They are formed at adjacent ends of cardiac muscle fibers by the close association of the two fibers plasma membranes. Intercalated discs house **gap junctions** and **desmosomes**. Gap junctions allow the transmission of small ions and function as a **direct electrical connection**. Desmosomes are junctions that provide **mechanical connections** between adjacent fibers. Thus, depolarization, contraction, and the transmission of tension involve **all of the junctioned fibers** in the myocardium.

The heart houses a group of self-excitable fibers called the heart's "**pacemaker**," or **sinoatrial node** (**SA node**). The pacemaker cells undergo spontaneous depolarization. However, the rate of their depolarization is controlled by the **autonomic nervous system**. Thus, **neuromuscular junctions** are present only where neural regulation occurs. Depolarization spreads from the pacemaker fibers to adjacent cardiac fibers through **gap junctions**.

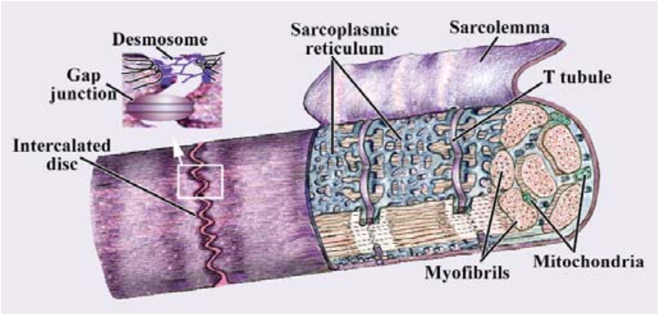

Figure 23.37

Cardiac muscle fibers form the myocardium (heart muscle). The rod-like fibers are short, striated, and are mostly uninucleate. Fibers are joined end-to-end at specialized sites called intercalated discs. Intercalated discs contain jap junctions and desmosomes and organized the fibers into long chains that show extensive branching.

Characteristics	Cardiac Muscle
Appearance and Shape of Cells	Fibers are: joined form branching chains striated, short, uninucleate (mostly), cylindrical
Contraction controlled by	Autonomic nervous system, and hormones
Neuromuscular junctions present	Only at ANS regulatory sites
Sarcomeres present	Yes
T tubules present	Yes, at Z lines
Sacroplasmic reticulum	Yes, but not well developed
Troponin present	Yes, associated with actin (thin filaments)
Calcium delivery from sarcoplasmic reticulum	Yes, and additionally from extracellular fluid
Calcium regulation	Calcium ions bond to troponin on thin filament (actin). Removal of calcium back to SR and extracellular environment terminates contraction

Figure 23.38

Characteristics of cardiac muscle.

LAB ACTIVITY 8

Observe a tissue preparation labeled "**Cardiac Muscle**," or "**Muscle, three types**." Identify the **branched cardiac fibers** and the darkly stained **intercalated disks.**

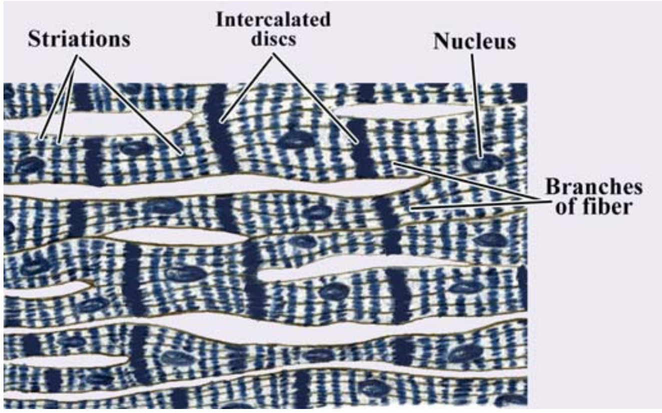

Figure 23.39

Cardiac muscle tissue consists of branching cells that are joined at end-to-end junctions called intercalated discs.

23

The intercalated discs are formed by the end-to-end junctions of the fibers. Each fiber usually contains a single nucleus (some are binucleate). Identify the **striations** which appear as alternating light and dark bands.

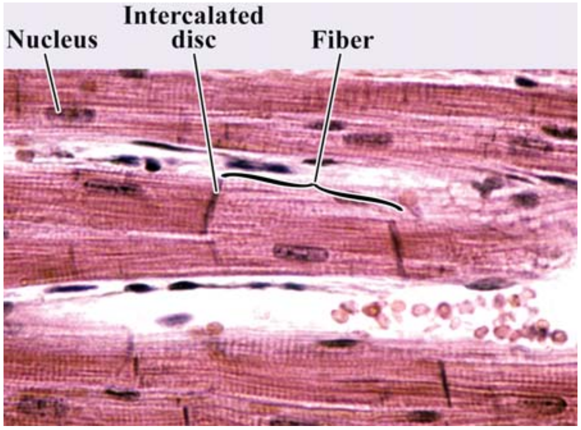

Figure 23.40

High power photograph of cardiac muscle tissue.

ANSWER WORKSHEET QUESTIONS

CARDIAC MUSCLE CELLS - ACTION POTENTIAL

The action potential of cardiac muscle cells begins when the membrane potential reaches threshold. The action potential is divided into three general segments, (**1**) **rapid depolarization**, (**2**) **slow depolarization**, and (**3**) **repolarization**.

Rapid Depolarization

At threshold fast-sodium ion channels of the sarcolemma (plasma membrane) open, and sodium ions rapidly diffuse into the cell. The fast-sodium ion channels remain open for only a few milliseconds resulting in a rapid depolarization of the sarcolemma to about 30 millivolts. The depolarization spreads down the short T tubules and results in the release of calcium ions from the sarcoplasmic reticulum. Calcium ions bind to troponin and contraction begins.

Slow Depolarization

As a result of the depolarization initiated by fast-sodium channels, slow-calcium ion channels of the sarcolemma open. For an extended time of about 180 milliseconds calcium channels allow the diffusion of calcium ions from the extracellular environment. The relatively constant influx of calcium ions for this extended time results in the membrane potential remaining a relatively stable level, a **plateau**. The influx of calcium ions results in additional release of calcium from the sarcoplasmic reticulum. Increased tension results as additional calcium ions bind additional troponin, resulting in increased cross-bridge interaction.

Repolarization

Repolarization occurs upon the closure of the slow-calcium ion channels and the opening of potassium ion channels. Calcium ions are pumped back into the sarcoplasmic reticulum and the extracellular environment. The outward movement of potassium, and the decrease in calcium ion concentration returns the sarcolemma to its resting membrane potential.

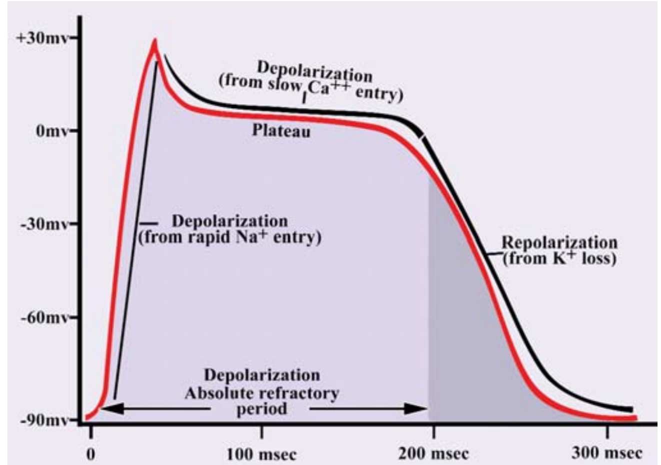

Figure 23.41

Overview of the action potential of cardiac muscle cells. The action potential is divided into three general segments, (1) rapid depolarization, (2) slow depolarization, and (3) repolarization.

ANSWER WORKSHEET QUESTIONS

CARDIAC CONDUCTION FIBERS

In addition to the contractile fibers of cardiac tissue, fibers that function in the generation and conduction of action potentials are located in the heart. Specialized myocardial conduction fibers include nodal and conduction fibers. Nodal fibers, such as found in the sinoatrial and atrioventricular nodes are mostly concerned with the generation of cardiac action potentials. Conduction pathways such as the atrioventricular bundle (bundle of His), the bundle branches, and Purkinje fibers, function to rapidly spread action potentials throughout the contractile cells.

LAB ACTIVITY 9

Observe a preparation labeled "**Purkinje Fibers**." Purkinje fibers are commonly found in bundles just beneath the endocardium. Purkinje fibers are modified myocardial cells that function in conduction of action potentials directly to the contractile cells. Purkinje fibers are larger than contractile cells and have fewer myofibrils. Their myofibrils are located near the periphery of the cells, thus, producing cells with a relatively clear central area. Purkinje fibers usually contain two nuclei.

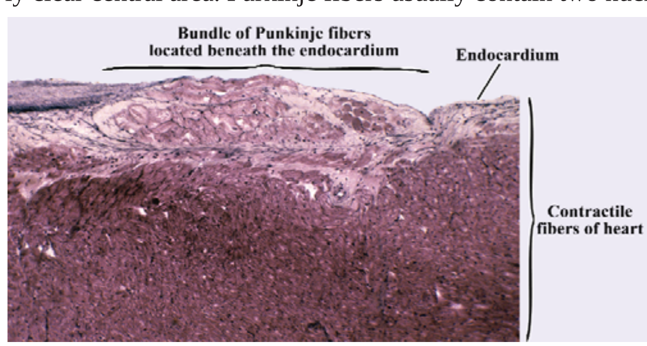

Figure 23.42

Low power photograph of a bundle of Purkinje fibers located beneath the endocardium of the heart.

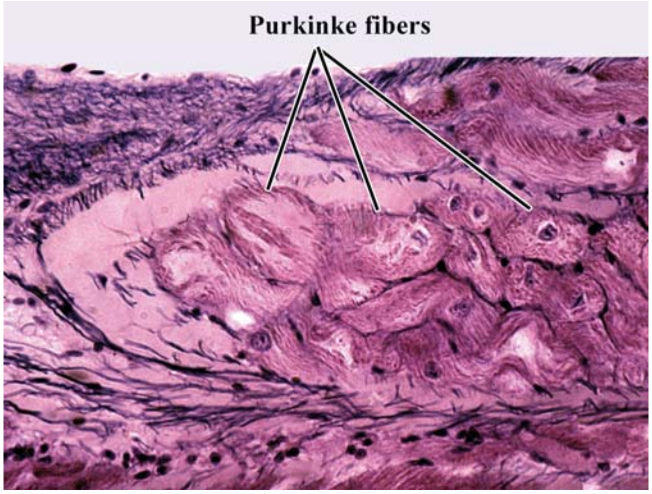

Figure 23.43

High power photograph of Purkinje fibers (from previous photographed specimen). Purkinje fibers are modified myocardial cells that function in conduction of action potentials. Purkinje fibers are larger than contractile cells and have fewer myofibrils.

ANSWER WORKSHEET QUESTIONS

CARDIAC OUTPUT

Cardiac output is the volume of blood ejected by each ventricle in one minute. Cardiac output is calculated by multiplying **stroke volume** by **heart rate**.

Stroke volume

Stroke volume is the volume of blood ejected by each ventricle by a single cardiac cycle, or heart beat. Stroke volume is calculated by subtracting **end systolic volume** from **end diastolic volume**.

End Diastolic Volume

The end diastolic volume is the volume of blood in each ventricle at the end of its relaxation and filling phase, diastole. The end of diastole is marked by the beginning of systole, or the contraction phase.

End Systolic Volume

The end systolic volume is the volume of blood remaining in each ventricle at the end of the contraction phase, systole.

Stroke Volume

Stroke volume is the volume of blood ejected by each ventricle by a single cardiac cycle. Stroke volume (SV) is calculated by subtracting the volume of blood remaining in the ventricle upon completion of its contraction (end systolic volume, ESV) from the volume of blood in the ventricle at the beginning of its contraction (end diastolic volume, EDV), or SV = EDV - ESV.

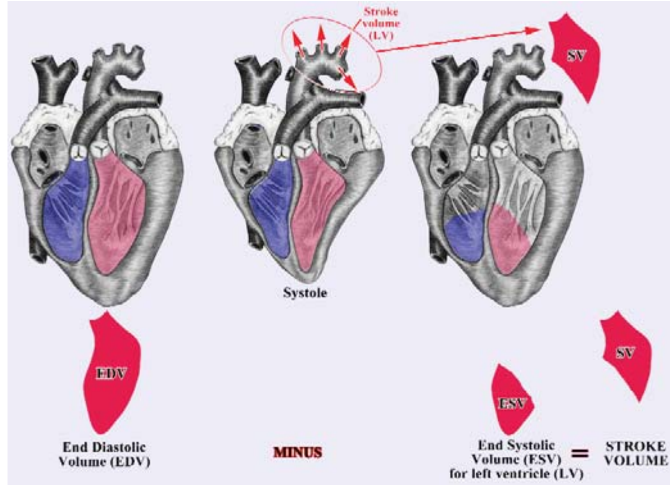

Figure 23.44

Stroke volume is equal to end diastolic volume minus end systolic volume (of each ventricle). This illustration shows the calculation of stroke volume for the left ventricle.

Stroke volume changes to meet the demands of the body. Volume changes of stroke volume are functions of volume changes to the end diastolic volume and the end systolic volume.

Changes Affecting the End Diastolic Volume

Volume changes to the end diastolic volume include changes produced as a result of **filling time** and **venous return**.

Filling time

Filling time is a function of heart rate. The slower the rate the more time available for ventricular filling (results in a decrease of EDV), the faster the rate the less time for ventricular filling (results in an increase of EDV).

Venous return

Venous return is the amount of blood returning to the ventricles from systemic circulation. Factors influencing venous return include blood pressure, vascular resistance, skeletal muscle pumping mechanism, heart rate, etc.

Changes Affecting the End Systolic Volume

Three factors that influence the end systolic volume are (**1**) **preload**, (**2**) **contractility**, and (**3**) **afterload**.

Preload

Preload is the based upon the volume of blood entering (loading) the ventricles. Filling of the ventricles stretches the myocardium, and at the myofilament level results in an outward sliding of the thin filaments along the thick filaments. In cardiac muscle (as opposed to skeletal muscle), the outward movement of the thin filaments results in a better alignment of the cross-bridges resulting in **increased** force of contraction. This mechanism is called **Starling's Law of the Heart**. Increased force of contraction results in an increase of stroke volume (within limits) as more blood is forced from the ventricles.

Contractility

Contractility is the ability of the ventricles to change force of contraction. Several factors that influence contractility are (**1**) **stimulation by the sympathetic division** (flight or fight response) of the ANS, (**2**) **hormones** (especially, epinephrine, glucagon, and thyroxine), and (**3**) **electrolyte balance** (especially, involving changes in potassium and calcium ions).

Afterload

Afterload is the tension the ventricles must produce to open the aortic and pulmonary valves. Afterload is a function of the blood pressure in the exiting vessels of the ventricles. The greater the pressure in the exiting vessels, the greater the tension (afterload) of the ventricles required to open their valves. The primary factor that influences afterload is increased resistance of circulation.

ANSWER WORKSHEET QUESTIONS

Heart Rate

Heart rate is primarily controlled by the autonomic nervous system (ANS). The parasympathetic division (the cardioinhibitory center) decreases heart rate, and the sympathetic division (the cardioacceleratory center) increases heart rate. The parasympathetic and sympathetic centers are located in the medulla oblongata. The cardioinhibitory center is the dominate control center. The cardioacceleratory center increases stimulation to the heart when the body is subjected to factors such as emotional and physical crises, and decreased blood pressure. Other factors, such as hormone levels (especially, epinephrine, glucagon, and thyroxine) and electrolyte balance (especially, Na^+, K^+, and Ca^{++}) also influence heart rate. The normal range for the heart's rate of beat is between 60 - 100 beats per minute, with most people averaging between 70 - 80 beats per minute (bpm). **Bradycardia** is defined as a slow heart rate, usually less than 60 bpm. **Tachycardia** is defined as a fast heart rate, usually over 100 bpm.

ANSWER WORKSHEET QUESTIONS