The Cardiovascular System: The Heart

The heart is located in a specific area of the thoracic cavity known as the mediastinum. The heart rests on the diaphragm and lies at an oblique angle with the superior portion, or base, pointing toward the right shoulder and the inferior portion, or apex, pointing toward the left hip.

The heart is enclosed in a sac called the pericardium, which consists of two layers:

1. **fibrous pericardium** - It is the outer layer composed of tough, dense fibrous connective tissue. The fibrous pericardium functions in protecting the heart, and it anchors the heart to the diaphragm, sternum, and the large blood vessels that enter and leave the heart.

2. **serous pericardium** - It is the inner layer and consists of two layers:
   
   a. **parietal layer** - It lines the inner surface of the fibrous pericardium.

   b. **visceral layer or epicardium** - It lies over and covers the surface of the heart and forms the outer layer of the heart wall.

Between the parietal and visceral layers is the pericardial cavity which is filled with serous fluid. The fluid reduces friction between the layers as the heart beats.

Heart Wall

The wall of the heart is composed of three layers which are richly supplied with blood vessels:

1. **epicardium** - It is the outer layer and functions in protection.

2. **myocardium** - It is the middle layer and makes up the major portion of the heart wall. The myocardium is composed of cardiac muscle tissue and is responsible for the contraction and relaxation of the heart as it beats.

3. **endocardium** - It is the inner layer and is composed of squamous epithelium, specifically called endothelium. It lines the chambers of the heart, covers the valves of the heart, and is continuous with the endothelium of the large blood vessels that enter and leave the heart.
Chambers of the Heart

The interior of the heart is divided into four chambers:

The two upper chambers are the atria, which have thin walls and receive blood from veins. The atria are separated from each other by the interatrial septum. Each atrium has an extension on the superior side called an auricle. The walls of the atria and the auricles contain parallel bundles of muscles called pectinate muscles.

The two lower chambers are the ventricles, which have thick walls and force blood out of the heart by way of arteries. The left ventricle has the thickest walls because it is the major pumping chamber of the heart. The ventricles are separated by the interventricular septum. The walls of the ventricles contain bundles of muscles called papillary muscles. Extending upward from the papillary muscles are threads called chordae tendineae ("heart strings") which attach to the inferior side of the valves located between the atria and the ventricles.

On the surface of the heart the atria and ventricles are separated by a groove called the atrioventricular groove or coronary sulcus. On the front side of the heart, the right and left ventricles are separated by the anterior interventricular sulcus. On the back side of the heart, the right and left ventricles are separated by the posterior interventricular sulcus.

The right atrium receives blood from three veins:

1. superior vena cava - It brings in blood from areas of the body located superior to the diaphragm.

2. inferior vena cava - It brings in blood from areas of the body located inferior to the diaphragm.

3. coronary sinus - It brings in blood from the blood vessels in the myocardium.

The left atrium receives blood from the lungs by way of four pulmonary veins.

Blood leaves the right ventricle by way of the pulmonary trunk and is transported to the lungs.

Blood leaves the left ventricle by way of the aorta and is transported to various parts of the body.
Valves of the Heart

There are two sets of valves in the heart which prevent the backflow of blood into the chambers as the heart contracts and relaxes.

1. atrioventricular (AV) valves - The atrioventricular valves prevent the backflow of blood from the ventricles into the atria. The chordae tendineae attached to the inferior side of the valves prevent them from opening backwards into the atria.

There are two AV valves:

a. tricuspid valve - It is located between the right atrium and right ventricle. It consists of three flaps or cusps covered with endothelium.

b. bicuspid or mitral valve - It is located between the left atrium and left ventricle and it consists of two flaps or cusps covered with endothelium.

2. semilunar valves - They prevent the backflow of blood into the ventricles and they consist of three half-moon or crescent shaped flaps covered with endothelium.

There are two semilunar valves:

a. pulmonary semilunar valve - It is located at the opening between the right ventricle and the pulmonary trunk.

b. aortic semilunar valve - It is located at the opening between the left ventricle and the aorta.
Pathway of Blood Through the Heart

The heart acts as two pumps serving two separate pathways or circuits.

1. pulmonary circuit - Blood which has a low oxygen concentration and a high carbon dioxide concentration is referred to as deoxygenated blood and it enters the right atrium by way of the superior vena cava and the inferior vena cava. The blood flows through the tricuspid valve and into the right ventricle. The blood leaves the right ventricle through the pulmonary semilunar valve and enters the pulmonary trunk. The pulmonary trunk divides to form the right and left pulmonary arteries, which go to the lungs. The blood flows through smaller branches to the pulmonary capillaries which surround the air sacs or alveoli of the lungs. Carbon dioxide is removed from the blood and oxygen is picked up by the blood of the pulmonary capillaries. The blood is now referred to as oxygenated blood. The capillaries join to form larger vessels which form veins. The oxygenated blood is returned to the left atrium by way of the pulmonary veins.

2. systemic circuit - The oxygenated blood enters the left atrium, passes through the bicuspid valve and into the left ventricle. The blood leaves the left ventricle through the aortic semilunar valve and enters the aorta. From the aorta, the blood enters the arteries which carry oxygenated blood to various parts of the body. In the tissues, the arteries branch to form tissue capillaries where oxygen is removed from the blood, and carbon dioxide, which is a waste product of cells, is picked up by the blood. The blood is now deoxygenated and passes through to veins and returns to the right atrium by way of the superior and inferior venae cavae.

Cardiac Circulation

The wall of the heart has its own blood vessels which bring oxygenated blood to the myocardium and carry carbon dioxide away from the myocardium.

Oxygenated blood is supplied by the first two branches of the aorta known as the left and right coronary arteries.

The left coronary artery runs below the left atrium and divides into two major branches:

1. anterior interventricular artery - It is located in the anterior interventricular sulcus and supplies blood and oxygen to the anterior walls of both ventricles and to the interventricular septum.
2. **circumflex artery** - It distributes blood and oxygen to the posterior walls of the left ventricle and to the left atrium.

The **right coronary artery** runs below the right atrium and divides to form two major branches:

1. **posterior interventricular artery** - It is located in the posterior interventricular sulcus and supplies blood and oxygen to the posterior walls of both ventricles.

2. **marginal artery** - It supplies blood and oxygen to the lateral walls of the right ventricle and to the right atrium.

After passing through the arteries, the blood enters the capillaries where it delivers oxygen and nutrients to the myocardium and picks up carbon dioxide and wastes. The **deoxygenated blood** is collected by three major cardiac veins:

1. **great cardiac vein** - It is located in the anterior interventricular sulcus and receives blood from the anterior portion of the heart.

2. **middle cardiac vein** - It is located in the posterior interventricular sulcus and it receives blood from the posterior portions of the heart.

3. **small cardiac vein** - It is located along the right inferior margin of the heart and receives blood from the lateral walls of the right ventricle.

The cardiac veins join to form the **coronary sinus** which opens into the right atrium.

**Cardiac Cycle**

The cardiac cycle is the contraction, or systole, and relaxation, or diastole, of the atria and ventricles during one heartbeat. During atrial diastole, deoxygenated blood enters the right atrium from various parts of the body by way of the superior and inferior vena cavae and from the myocardium by way of the coronary sinus. Simultaneously, oxygenated blood from the lungs enters the left atrium by way of the pulmonary veins. The atrio-ventricular (AV) valves are open and blood flows freely into the right and left ventricles. The pulmonary and aortic semilunar valves are closed.

The atria undergo systole, which increases the intraatrial pressure and additional blood is forced into the ventricles. The ventricles undergo systole which increases the intraventricular pressure. The blood in the ventricles pushes the AV valves closed and forces the semilunar valves open. **Deoxygenated blood**
is forced out of the right ventricle through the pulmonary semilunar valve and oxygenated blood is forced out of the left ventricle through the aortic semilunar valve. The ventricles undergo diastole and the backflow of blood in the pulmonary trunk and the aorta push the semilunar valves closed. Simultaneously, the atria undergo diastole and fill with blood.

Cardiac Conduction System

Cardiac muscle fibers function like those of skeletal muscles, except the branching networks that spread throughout the heart. When a portion of the net is stimulated, an impulse travels to all of its parts, and the whole structure contracts as a unit.

The cardiac muscles do not need nerve impulses to contract. Contraction occurs through an intrinsic cardiac conduction or nodal system within the heart. The conduction system is composed of specialized muscle tissue that generates and distributes the electrical impulses which stimulate the cardiac muscle fibers to contract. The nodal system consists of the sinoatrial node (SA node), the atrioventricular node (AV node), the atrioventricular bundle, the bundle branches, and the Purkinje fibers.

The sinoatrial node is also known as the pacemaker of the heart. It consists of a small mass of specialized tissue located in the posterior wall of the right atrium just inferior to the opening of the superior vena cava. The SA node initiates each cardiac cycle and sets the basic heart rate and sinus rhythm (rhythmic contractions) of the heart. The impulse from the SA node spreads over both atria, causing them to contract. The impulse then passes along conducting fibers to the atrioventricular node which is located in the inferior portion of the interatrial septum just above the tricuspid valve. From the AV node, the impulse travels to a group of large fibers that make up the atrioventricular bundle in the interatrial septum. The fibers of the bundle enter the top of the interventricular septum and divide into the right and left bundle branches which run down both sides of the septum. About half way down the septum, the branches form the enlarged Purkinje fibers. The Purkinje fibers pass into the papillary muscles and downward to the apex of the heart, around the ends of the ventricles and over their lateral walls. Many small branches from the Purkinje fibers enter the cardiac muscle fibers. Contraction of the ventricles is stimulated by the Purkinje fibers.
Cardiac Output

Cardiac output is the amount of blood forced out by the ventricles per minute.

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\text{cardiac output (CO)} = \text{heart rate (HR)} \times \text{stroke volume (SV)}
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\begin{align*}
\text{(ml/min)} & \quad \text{(beats/min)} & \quad \text{(ml/beat)} \\
\text{Heart rate} & = \text{average resting heart rate of 75 beats/min} \\
\text{Stroke volume} & = \text{volume of blood pumped out by the ventricles with each beat (70 ml/beat)}
\end{align*}
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Stroke volume is the difference between the volume of blood that enters a ventricle during diastole (end diastolic volume or EDV) and the volume of blood left in a ventricle following systole (end systolic volume or ESV).

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\text{SV (ml/beat)} = \text{EDV (120 ml)} - \text{ESV (50 ml)}
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\text{SV} = 70 \text{ ml/beat}
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\text{CO (ml/min)} = 75 \text{ beats/min} \times 70 \text{ ml/beat} = 5,250 \text{ ml/min} \text{ or } 5.25 \text{ L/min}
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Cardiac output increases when either heart rate or stroke volume, or both increase, and decreases when either or both decrease.

Frank-Starling Law of the Heart - stroke volume is controlled by the degree to which cardiac muscle fibers are stretched just before they contract. An increase in the volume of blood increases the stroke volume and the force of contractions increases.

Regulation of the Cardiac Cycle

Factors such as exercise, stress, age, sex, chemicals, and body temperature may affect the cardiac cycle. The sympathetic and parasympathetic divisions of the autonomic nervous system (ANS) aid in returning the heart rate to normal.

The cardiac centers are located in the medulla oblongata. The sympathetic center (fight-or-flight) or cardioacceleratory center, and the parasympathetic center (resting and digesting) or cardioinhibitory center have postganglionic fibers that synapse with the SA and AV nodes and the myocardium in order to regulate the heart rate under these conditions.
Electrocardiogram

An electrocardiogram (ECG) is a recording of the electrical changes that occur in the myocardium during a cardiac cycle. The changes result from the depolarization and repolarization associated with the contraction of muscle fibers.

The first wave of the ECG is the P wave. It represents atrial depolarization. It is the spread of an impulse from the SA node through the atria. A fraction of a second after the P wave begins, the atria contract.

The largest and longest wave is the QRS complex. It represents depolarization of the ventricles and occurs just before the ventricles contract. Atrial repolarization occurs during depolarization of the ventricles and is not observed in the ECG because ventricular depolarization is much stronger and masks it out.

The last wave is the T wave. It indicates repolarization of the ventricles.