2.1 Anatomy & Physiology of Heart

Anatomy of Heart: The heart is composed primarily of cardiac muscle tissue that continuously contracts and relaxes, it must have a constant supply of oxygen and nutrients. Coronary Arteries: The coronary arteries are the network of blood vessels that carry oxygen- and nutrient-rich blood to the cardiac muscle tissue. The blood leaving the left ventricle exits through the aorta, the body’s main artery. Two coronary arteries, referred to as the "left" and "right" coronary arteries, emerge from the beginning of the aorta, near the top of the heart. The initial segment of the left coronary artery is called the left main coronary. This blood vessel is approximately the width of a soda straw and is less than an inch long. It branches into two slightly smaller arteries: the left anterior descending coronary artery and the left circumflex coronary artery. The left anterior descending coronary artery is embedded in the surface of the front side of the heart. The left circumflex coronary artery circles around the left side of the heart and is embedded in the surface of the back of the heart. Just like branches on a tree, the coronary arteries branch into progressively smaller vessels. The larger vessels travel along the surface of the heart; however, the smaller branches penetrate the heart muscle. The smallest branches, called capillaries, are so narrow that the red blood cells must travel in single file. In the capillaries, the red blood cells provide oxygen and nutrients to the cardiac muscle tissue and bond with carbon dioxide and other metabolic waste products, taking them away from the heart for disposal through the lungs, kidneys and liver. When cholesterol plaque accumulates to the point of...
Figure 2.1: Anatomy of Heart

1. Right Coronary  
2. Left Anterior Descending  
3. Left Circumflex  
4. Superior Vena Cava  
5. Inferior Vena Cava  
6. Aorta  
7. Pulmonary Artery  
8. Pulmonary Vein  
9. Right Atrium  
10. Right Ventricle  
11. Left Atrium  
12. Left Ventricle  
13. Papillary Muscles  
14. Chordae Tendineae  
15. Tricuspid Valve  
16. Mitral Valve  
17. Pulmonary Valve  
18. Aortic Valve (Not pictured)
blocking the flow of blood through a coronary artery, the cardiac muscle tissue fed by the coronary artery beyond the point of the blockage is deprived of oxygen and nutrients. This area of cardiac muscle tissue ceases to function properly. The condition when a coronary artery becomes blocked causing damage to the cardiac muscle tissue it serves is called a myocardial infarction or heart attack.

**Superior Vena Cava:** The superior vena cava is one of the two main veins bringing de-oxygenated blood from the body to the heart. Veins from the head and upper body feed into the superior vena cava, which empties into the right atrium of the heart.

**Inferior Vena Cava:** The inferior vena cava is one of the two main veins bringing de-oxygenated blood from the body to the heart. Veins from the legs and lower torso feed into the inferior vena cava, which empties into the right atrium of the heart.

**Aorta:** The aorta is the largest single blood vessel in the body. It is approximately the diameter of your thumb. This vessel carries oxygen-rich blood from the left ventricle to the various parts of the body.

**Pulmonary Artery:** The pulmonary artery is the vessel transporting de-oxygenated blood from the right ventricle to the lungs. A common misconception is that all arteries carry oxygen-rich blood. It is more appropriate to classify arteries as vessels carrying blood away from the heart.
**Pulmonary Vein:** The pulmonary vein is the vessel transporting oxygen-rich blood from the lungs to the left atrium. A common misconception is that all veins carry de-oxygenated blood. It is more appropriate to classify veins as vessels carrying blood to the heart.

**Right Atrium:** The right atrium receives de-oxygenated blood from the body through the superior vena cava (head and upper body) and inferior vena cava (legs and lower torso). The sinoatrial node sends an impulse that causes the cardiac muscle tissue of the atrium to contract in a coordinated, wave-like manner. The tricuspid valve, which separates the right atrium from the right ventricle, opens to allow the de-oxygenated blood collected in the right atrium to flow into the right ventricle.

**Right Ventricle:** The right ventricle receives de-oxygenated blood as the right atrium contracts. The pulmonary valve leading into the pulmonary artery is closed, allowing the ventricle to fill with blood. Once the ventricles are full, they contract. As the right ventricle contracts, the tricuspid valve closes and the pulmonary valve opens. The closure of the tricuspid valve prevents blood from backing into the right atrium and the opening of the pulmonary valve allows the blood to flow into the pulmonary artery toward the lungs.

**Left Atrium:** The left atrium receives oxygenated blood from the lungs through the pulmonary vein. As the contraction triggered by the sinoatrial node progresses through the atria, the blood passes through the mitral valve into the left ventricle.
**Left Ventricle:** The left ventricle receives oxygenated blood as the left atrium contracts. The blood passes through the mitral valve into the right ventricle. The aortic valve leading into the aorta is closed, allowing the ventricle to fill with blood. Once the ventricles are full, they contract. As the left ventricle contracts, the mitral valve closes and the aortic valve opens. The closure of the mitral valve prevents blood from backing into the left atrium and the opening of the aortic valve allows the blood to flow into the aorta and flow throughout the body.

**Papillary Muscles:** The papillary muscles attach to the lower portion of the interior wall of the ventricles. They connect to the chordae tendineae, which attach to the tricuspid valve in the right ventricle and the mitral valve in the left ventricle. The contraction of the papillary muscles opens these valves. When the papillary muscles relax, the valves close.

**Chordae Tendineae:** The chordae tendineae are tendons linking the papillary muscles to the tricuspid valve in the right ventricle and the mitral valve in the left ventricle. As the papillary muscles contract and relax, the chordae tendineae transmit the resulting increase and decrease in tension to the respective valves, causing them to open and close. The chordae tendineae are string-like in appearance and are sometimes referred to as "heart strings."

**Tricuspid Valve:** The tricuspid valve separates the right atrium from the right ventricle. It opens to allow the de-oxygenated blood collected in the right atrium to flow into the right ventricle. It closes as the right ventricle contracts,
preventing blood from returning to the right atrium; thereby, forcing it to exit through the pulmonary valve into the pulmonary artery.

**Mitral Valve:** The mitral valve separates the left atrium from the left ventricle. It opens to allow the oxygenated blood collected in the left atrium to flow into the left ventricle. It closes as the left ventricle contracts, preventing blood from returning to the left atrium; thereby, forcing it to exit through the aortic valve into the aorta.

**Pulmonary Valve:** The pulmonary valve separates the right ventricle from the pulmonary artery. As the ventricles contract, it opens to allow the deoxygenated blood collected in the right ventricle to flow to the lungs. It closes as the ventricles relax, preventing blood from returning to the heart.

**Aortic Valve:** The aortic valve separates the left ventricle from the aorta. As the ventricles contract, it opens to allow the oxygenated blood collected in the left ventricle to flow throughout the body. It closes as the ventricles relax, preventing blood from returning to the heart.
Physiology of Heart

The heart is the muscular organ of the circulatory system that constantly pumps blood throughout the body. Approximately the size of a clenched fist, the heart is composed of cardiac muscle tissue that is very strong and able to contract and relax rhythmically throughout a person's lifetime \[14\].

The heart has four separate compartments or chambers. The upper chamber on each side of the heart, which is called an atrium, receives and collects the blood coming to the heart. The atrium then delivers blood to the powerful lower chamber, called a ventricle, which pumps blood away from the heart through powerful, rhythmic contractions.

The human heart is actually two pumps in one. The right side receives oxygen-poor blood from the various regions of the body and delivers it to the lungs. In the lungs, oxygen is absorbed in the blood. The left side of the heart receives the oxygen-rich blood from the lungs and delivers it to the rest of the body.

**Systole:** The contraction of the cardiac muscle tissue in the ventricles is called systole. When the ventricles contract, they force the blood from their chambers into the arteries leaving the heart. The left ventricle empties into the aorta and the right ventricle into the pulmonary artery. The increased pressure due to the contraction of the ventricles is called systolic pressure.
Figure 2.2: Physiology of Heart

1. Sinoatrial node (SA node) 2. Atrioventricular node (AV node)
3. Common AV Bundle 4. Right & Left Bundle Branches

Figure 2.3: Electrical Conduction System

1. Sinoatrial node (SA node) 2. Atrioventricular node (AV node)
3. Common AV Bundle 4. Right & Left Bundle Branches
Diastole: The relaxation of the cardiac muscle tissue in the ventricles is called diastole. When the ventricles relax, they make room to accept the blood from the atria. The decreased pressure due to the relaxation of the ventricles is called diastolic pressure.

Electrical Conduction System: The heart is composed primarily of muscle tissue. A network of nerve fibers coordinates the contraction and relaxation of the cardiac muscle tissue to obtain an efficient, wave-like pumping action of the heart.

The Sinoatrial Node (often called the SA node or sinus node) serves as the natural pacemaker for the heart. Nestled in the upper area of the right atrium, it sends the electrical impulse that triggers each heartbeat. The impulse spreads through the atria, prompting the cardiac muscle tissue to contract in a coordinated wave-like manner.

The impulse that originates from the sinoatrial node strikes the Atrioventricular node (or AV node) which is situated in the lower portion of the right atrium. The atrioventricular node in turn sends an impulse through the nerve network to the ventricles, initiating the same wave-like contraction of the ventricles.

The electrical network serving the ventricles leaves the atrioventricular node through the Right and Left Bundle Branches. These nerve fibers send impulses that cause the cardiac muscle tissue to contract.
2.2 Anatomy & Physiology of Lungs

Awake or asleep, conscious or unconscious, our bodies breathe automatically without thought on our part. When we are quiet our bodies breathe 15 times a minute on average. Every day an average, moderately active person breathes about 20,000 liters of air\[^{14}\].

**Respiratory System**: The exchange of gases in any biological process is termed as respiration. To sustain life, the human body must take in oxygen which combines with carbon, hydrogen, and various nutrients to produce heat and energy for the performance of work. The entire process of taking in oxygen from the environment, transporting the oxygen to the cells, removing the carbon dioxide from the cells, and exhausting this waste product into the atmosphere must be considered within the definition of respiration. Two types of respiration are identified:

1. Internal respiration
2. External respiration

In human body, the tissue cells are generally not in direct contact with their external environment\[^{7}\]. Instead, the cells are batched (covered) in fluid. This tissue fluid can be considered as the internal environment of the body. The cells absorb oxygen from this fluid. The circulating blood is the medium by which oxygen is brought to the internal environment. Carbon dioxide is carried from the tissue fluids by the same mechanism. The exchange of gases
between the blood and the external environment takes place in the lungs and is termed external respiration.

**The Anatomy of Lungs:** The function of the lungs is to oxygenate the blood and to eliminate carbon dioxide in a controlled manner. During inspiration fresh air enters the respiratory tract, becomes humidified and heated to body temperature, and is mixed with the gases already present in the region comprising the trachea and bronchi (see Figure 2.4). This gas is then mixed further with the gas residing in the alveoli to the pulmonary capillary blood supply, whereas carbon dioxide diffuses from the blood to the alveoli. The oxygen is carried from the lungs and distributed among the various cells of the body by the blood circulation system, which also returns the carbon dioxide to the lungs. The entire process of inspiring and expiring air, exchange of gases, distribution of oxygen to the cells, and collection of CO$_2$ from the cells forms what is known as pulmonary function tests.

**The Physiology of Lungs:** Air enters the lungs through the air passages, which include the nasal cavities pharynx, larynx, trachea, bronchi, and bronchioles, as shown in figure 2.4.

The lungs are elastic bags located in a closed cavity, called the thorax or thoracic cavity. The right lung consists of three lobes (upper, middle, and lower), and the left lung has two lobes (upper and lower). The larynx, sometimes called the “voice box” (because it contains the vocal cords), is connected to the bronchi through the trachea, sometimes called the “windpipe.”
Figure 2.4: The respiratory tract.
Above the larynx is the epiglottis, a valve that closes whenever a person swallows, so that food and liquids are directed to the esophagus (tube leading to the stomach) and into the stomach rather than into the larynx and trachea.

The trachea is about 1.5 to 2.5 cm in diameter and approximately 11 cm long, extending from the larynx to the upper boundary of the chest. Here it bifurcates (forks) into the right and left main stem bronchi. Each bronchus enters into the corresponding lung and divides like the limbs of a tree into smaller branches. The branches are of unequal length and at different angles, with over 20 of these nonsymmetrical bifurcations normally present in the human body. Farther along these branching, where the diameter is reduced to about 0.1 cm, the air-conducting tubes are called bronchioles. As they continue to decrease in size to about 0.05 cm in diameter, they form the terminal bronchioles, which branch again into the respiratory bronchioles, where some alveoli are attached as small air sacs in the wall of lung. After some additional branching, these air sacs increase in number, becoming the pulmonary alveoli. The alveoli are each about 0.02 cm in diameter. It is estimated that, all told, some 300 million alveoli are found in the lungs (see Figure 2.5).

Beyond about the tenth stage of branching, the bronchioles are embedded within alveolar lung tissue; and with the expansion and relaxation of the lung, their diameters are greatly affected by the lung size or lung volume. Up to this point, the diameter of the air sacs is more affected by the pleural pressure, the pressure inside the thorax.
Figure 2.5: Alveoli and capillary network
Breathing is accomplished by musculature that literally changes the volume of the thoracic cavity and, in so doing, creates negative and positive pressures that move air into and out of the lungs. Two sets of muscles are involved: those in and near the diaphragm that cause the diaphragm to move up and down, changing the size of the thoracic cavity in the vertical direction, and those that move the rib cage up and down to change the lateral of the thorax.

The *diaphragm* is a special dome-or bell-shaped muscle located at the bottom of the thoracic cavity, which, when contracted, pulls downward to enlarge the thorax. This action is the principal force involved in inspiration.

Normal expiration is essentially passive, for, on release of the inspiratory muscles, the elasticity of the lungs and the rib cage, combined with the tone of the diaphragm, reduces the volume of the thorax, thereby developing a positive pressure that forces air out of the lungs. In forced expiration a set of abdominal muscles pushes the diaphragm upward very powerfully while the internal intercostals muscles pull the rib cage downward and apply pressure against the lungs to help force air out.

During normal inspiration the pressure inside the lungs, the *intraalveolar pressure*, is about -3 mm Hg, whereas during expiration the pressure becomes about +3 mm Hg. The ability of the lungs and thorax to expand during breathing is called the compliance, which is expresses as the volume increase in the lungs per unit increase in *intra-alveolar pressure*. The resistance to the flow of air into and out of the lungs is called *airway resistance*.
Blood, from the body tissues and their capillaries is brought via the superior and inferior vena cava into the right atrium of the heart, which in turn, empties into the right ventricle. The right ventricle pumps the blood into and through the lungs in a pulsating fashion, with a systolic pressure of about 20 mm Hg and a diastolic pressure of 1 to 4 mm Hg. By perfusion, the blood passes through the pulmonary capillaries, which are in the walls of the air sacs, wherein oxygen is taken up by the red blood cells and hemoglobin. The compound formed by the oxygen and the hemoglobin is called oxyhemoglobin. At the same time, carbon dioxide is removed from the blood into the alveoli.

From the pulmonary capillaries, the blood is carried through the pulmonary veins to the left atrium. From here it enters the left ventricle, which pumps the blood out into the aorta at pressures of 120/80 mm Hg. It is then distributed to all the organs and muscles of the body. In the tissues, the oxyhemoglobin gives up its oxygen while carbon dioxide diffuses into the blood from the tissue and surrounding fluids. The blood then flows from the capillaries into the venous system back into the superior and inferior vena cava.

The interchange of the oxygen from the lungs to the blood and the diffusion of carbon dioxide from the blood to the lungs take place in the capillary surface of the alveoli. The alveolar surface area is about 80 m², of which more than three-fourths is capillary surface. Hyperventilation refers to abnormally prolonged, rapid, or deep breathing. Hyperventilation is also the condition produced by over breathing. Dyspnea is the sensation of inadequate or distressful respiration, a condition of abnormal breathlessness. Hypercapnia
is an excess amount of CO$_2$ in the system, and *hypoxia* is a shortage of oxygen.

Both hypercapnia and hypoxia can result from inadequate ventilation.