Human Circulatory and Respiratory Systems

1. The human circulatory system serves several purposes.
   a. Nutrient and waste transport
      i. Nutrients enter the blood through the wall of the small intestine.
      ii. Those nutrients are carried to all body cells.
      iii. Cells release wastes into the blood. These are carried to the liver and kidney.
   b. Oxygen and carbon dioxide transport
      i. Oxygen (O_2) transport
         (1) Oxygen diffuses into blood through gills or lungs and is picked up by a protein called **hemoglobin** in red blood cells. It must be delivered to all cells of the body.
         (2) Blood plasma holds a maximum of 3 ml O_2/L while whole blood is able to carry 200 ml O_2/L
         (3) Hemoglobin makes the difference.
            (a) This protein carries oxygen in the blood of most animals.
            (b) Hemoglobin picks up oxygen in lungs and becomes bright red in color
            (c) Hemoglobin releases oxygen at tissues and becomes dark red in color. It looks blue under the skin because of the way light passes through the skin.
         (4) The fluid surrounding tissues and cells has a lower [O_2] than blood so oxygen diffuses from the blood into the fluid surrounding the tissues. This diffusion occurs in the capillaries.
         (5) At rest, only about 20% of the oxygen in blood is unloaded. When it's needed (like during exercise) the rest of the oxygen can be unloaded.
         (6) Blood contains reserves for 4-5 minutes without breathing. After that time, cells begin to die.
      ii. **Anemia** is the most common blood disorder caused by a decrease in the number of red blood cells (RBCs) or less than the normal quantity of hemoglobin in the blood
         (1) The most common cause of anemia is iron deficiency. Hemoglobin requires iron to function properly, so a lack of iron means insufficient hemoglobin can be made so less oxygen can be carried.
         (2) Oxygen is needed for cells to produce energy from food so the principle symptom is fatigue. Other symptoms can include rapid heart rate, dizziness, and lack of concentration.
      iii. Carbon monoxide (CO)
         (1) Hemoglobin binds to carbon monoxide (CO) but the binding is not easily reversible.
         (2) In the presence of CO, hemoglobin is less able to carry oxygen and suffocation results.
      iv. Carbon dioxide (CO_2) transport
         (1) Carbon dioxide, the waste from cellular respiration, is released by cells into the blood. This is carried back to the gills or lungs and released.
         (2) The lower [CO_2] in the alveoli causes CO_2 to diffuses into the alveoli and it is exhaled.

c. Temperature regulation
   i. For most vertebrates, body temperature varies with environmental temperature. Mammals and birds are exceptions in that they maintain constant body temperature.
   ii. Heat is distributed by circulating blood and temperature can be adjusted by directing flow to the body interior or to the extremities.
   iii. Body temperature can be decreased by dissipating heat to the environment.
   iv. Heat can be conserved by directing blood from the extremities to the interior of the body.

d. Hormone circulation - Body activities are coordinated by hormones produced in endocrine glands and circulated throughout the body in blood.

e. Immune system - several types of cells and proteins in the immune system are transported in the blood.

2. The circulatory system contains different types of blood vessels.
   a. **Arteries** carry blood away from heart.
      i. They contain muscular layers which allow them to withstand high pressure.
      ii. Arteries are elastic to allow them to expand and recoil when receiving blood from heart.
   b. Arteries branch into smaller vessels called **arterioles**.
      i. These vessels are also elastic and have muscles that control their diameters.
         (1) **Vasoconstriction** is the contraction of the muscular layer causes the diameter to narrow, decreasing blood flow.
         (2) **Vasodilation** is the relaxation of the muscular layer causes the diameter to increase, increasing blood flow.
         (3) Sphincter muscles (called precapillary sphincters) in arterioles can open and close specific capillary beds as needed.
         (4) The change in blood flow can cause the skin to appear flushed or pale depending on if the blood flow is increased or decreased, respectively.
   c. The smallest blood vessels, typically less than 1 mm long, are called **capillaries**.
      i. The diameter is so small that red blood cells must travel through in single file.
      ii. Very thin walls allow exchange of materials between blood and all cells of the body. The huge surface area of capillaries slows down the flow of blood to allow time for exchange of materials in the blood with the extracellular fluid.
      iii. Blood releases oxygen and nutrients, and picks up carbon dioxide and wastes.
      iv. Most of the exchange in capillaries happens because of blood pressure.
         (1) At the arterial end of capillaries blood pressure forces fluid out and into the surrounding tissues. As blood moves through the capillary, the blood pressure decreases so that near the venous end, less is leaking into the surrounding tissues.
         (2) As blood flows through the capillary and fluid moves out, the blood that remains behind becomes more concentrated. Osmosis then causes fluid to move back into the capillary near the venous end.
         (3) During the exchange, some fluid is also removed from the blood. Most fluid reenters the blood by osmosis but some does not.
            (a) The remaining fluid is returned to blood by a network of tubes called the **lymphatic system**, which connects to the circulatory system at veins on the side of the neck.
            (b) Lymphatic vessels contain one-way valves as in veins to aid the movement of lymphatic fluid.

(c) Blockage of the lymphatic systems leads to the retention of water in the tissues. The resulting swelling is called **edema**.

(d) Starvation edema can occur in cases of prolonged malnutrition. Starved for protein, cells begin to digest proteins from the blood, decreasing their concentration. This results in less water moving back into the blood from surrounding tissues by osmosis, causing swelling

d. Capillaries merge to form larger vessels called **venules** which, in turn, merge into veins.

e. **Veins** are large vessels that carry blood back to the heart.

i. Blood pressure decreases drastically as blood moves through the capillaries and the pressure is too low to allow the return of blood to the heart from the lower body.

ii. The flow of blood is aided by the contraction of skeletal muscles and one-way valves that prevent blood from flowing backward in the veins.

f. As in all mammals, the human heart is a double pump with four chambers containing completely separated ventricles.

g. The left side of the heart achieves s**ystemic circulation**, pumping oxygenated blood to the body tissues while the right side of the heart pumps deoxygenated blood to the lungs in **pulmonary circulation**. The left ventricle is much more muscular than the right as it must move blood through the whole body.

i. The right ventricle pumps blood to the lungs through the pulmonary arteries. The pressure of blood leaving the ventricle opens a **semilunar valve** at the entrance to the pulmonary artery. This valve closes when the ventricle relaxes to prevent the backflow of blood into the ventricle.

ii. In the lungs, the blood absorbs O_2 and releases CO_2 before returning to the left atrium via the pulmonary veins.

iii. The oxygen-rich blood from the lungs enters the left atrium.

iv. This blood moves into the left ventricle as the ventricle relaxes and the left atrium contracts. Between the atrium and ventricle is an **atrioventricular (or AV) valve**. The valve opens as blood moves into the ventricle but closes when the ventricle contracts to prevent the flow of blood back into the atrium. There is another AV valve between the right atrium and right ventricle.

(1) The sounds of the heartbeat are caused by the closing of the heart valves.

(a) The first sound (lub) is caused by blood hitting the AV valves as they close.

(b) The second sound (dub) is caused by blood hitting the semilunar valves as they close.

(c) If the valves do not close properly, some blood can pass through the valves and cause a heart murmur. The heart must work harder to get the same volume of blood circulating. This can be corrected by replacing the valve.

v. The left ventricle then contracts, pumping blood into the aorta. The aorta branches into arteries to distribute oxygen-rich blood throughout the body.

(1) The first branches from the aorta form the coronary arteries he heart itself. These arteries can become blocked, producing a heart attack.

vi. Oxygen-poor blood from the lower body returns to the right atrium through the inferior vena cava and from the upper body through the superior vena cava.

vii. Blood from the upper body enters the heart through the superior vena cava while blood from the lower body enters through the inferior vena cava.

h. Muscle cells in the heart can all contract on their own but to produce a useful, regular heartbeat but they must be coordinated.

i. Nerve signals from the brain influence the heart rate, slowing or speeding it. If all the nerves to the heart are cut it will continue to beat but the cells will become uncoordinated.

ii. This coordination is accomplished by the pacemaker which causes all the cells to contract together. The **pacemaker** (or SA node) is a group of cells in the wall of the right atrium near the superior vena cava called the sinoatrial node (SA node) that produces electrical signals that spread quickly throughout the atria. These signals ensure that the two atria contract in unison.

iii. To be filled with blood from the atria, the ventricles must contract slightly later than the atria. Another group of cells called the atrioventricular (AV) node receives the signal from the SA node but delays it for about 0.1 s before passing it along to the ventricles. This ensures that the atria finish contracting before the ventricles contract.

i. Blood pressure

i. When the heart relaxes between beats (diastole) the arterial pressure drops to about 80 mm Hg. This is called diastolic pressure. The pressure does not drop to 0 because the arterial walls are elastic and squeeze the blood. The 80 mm Hg diastolic pressure keeps blood flowing between beats.

ii. When the ventricles contract (systole) the pressure in the arteries leaving the heart rises to about 120 millimeters of mercury (mm Hg). This is called systolic pressure.

iii. Normal values: systolic/diastolic = 120/80 mm Hg.

iv. Blood pressure is monitored by the medulla oblongata through sensors in the aorta and carotid arteries. Vasoconstriction can be used to increase blood pressure and vasodilation can be used to lower it as needed.

j. Cardiac output

i. Cardiac output (CO) is the volume of blood pumped by each ventricle per minute. Stroke volume (SV) is the volume of blood pumped per cycle.

ii. Cardiac output = rate of heart beat (HR) x stroke volume

iii. It is normally about 5 L/min in humans. Doubling the HR or the SV will double the CO.

iv. It can be increased with exercise. Exercise increases stroke volume over time so that the heart can pump more blood with fewer strokes. A lower heart rate decreases the risk of heart disease. In humans, HR can rise to ~200 beats/min during exercise. Faster rates are inefficient because the heart does not have time to fill completely. SV can increase about 50% with exercise, to 100 to 120 mL.

v. This allows the exercise CO to increase to 20-24 L/min. A healthy heart beats more slowly but as a higher stroke volume.

k. **Heart disease** is the leading cause of death in North America.

i. **Atherosclerosis** is a disease in which the wall of an artery thickens as fatty material builds up on it.

(1) A diet high in fat and cholesterol results in increased concentrations of these in the blood, which then deposit on the wall of the arteries.

(2) The diameter narrows which increases pressure and decreases flow. If the artery is blocked completely it can cause a heart attack or stroke.

(3) The condition can be improved by decreasing fat and cholesterol while increasing fiber in the diet and with exercise. In advanced cases, medication or even surgery can be required.

ii. High blood pressure (hypertension)

(1) High blood pressure is associated with cardiovascular disease and can be caused by a high salt diet or stress.
(2) In males under 45 years, pressures greater than 130/90 are considered to be high. In males over 45 years, pressures greater than 140 /95 are high. Females are becoming more and more at risk of high blood pressure.
(3) The stress of the heart having to work harder can cause a heart attack.

iii. An **aneurysm** is a localized, blood-filled balloon-like bulge in the wall of a blood vessel.
(1) As the aneurysm increases in size, the risk of rupture increases. A rupture results in severe hemorrhage which can lead to death.
(2) Aneurysms can be hereditary or caused by disease, both of which cause the wall of the blood vessel to weaken.

iv. Heart murmurs are any abnormal heart sound.
(1) These can be the result of narrowing or leaking heart valves, or the presence of abnormal passages through which blood flows in or near the heart.

v. **Angina** and **heart attack**.
(1) Angina is chest pain due to lack of oxygen to the heart muscle. The main cause coronary artery disease, due to atherosclerosis of the coronary arteries. The symptoms are usually described as a pressure, heaviness, tightness, squeezing, burning, or choking sensation.
(2) If the oxygen deprivation to the heart is severe enough to interrupt blood supply to the heart, myocardial infarction (heart attack) results.

3. The average adult human has about 5L of blood, consisting of plasma and blood cells.

a. About 55% of blood volume is **plasma**, the fluid portion of blood.

i. Plasma contains a variety of dissolved materials including gases, glucose, amino acids, ions and vitamins. The plasma also contains wastes and hormones.

ii. Proteins
(1) Albumin acts as a solute in plasma to regulate the movement of water into and out of blood by osmosis.
(2) Proteins that carry lipids (HDL and LDL).
(3) Fibrinogen needed for blood clotting.

b. Cells account for about 45% of blood volume.

i. **Red blood cells** (RBCs) or erythrocytes (~4-5 million/mm^3)
(1) Red blood cells are continuously produced in the red marrow of the skull, ribs, vertebrae, and ends of the long bones.
(2) Cells are shaped like biconcave disks to increase surface area. This surface area increases the rate of exchange between RBCs and tissue. They lack a nucleus to have more space for hemoglobin so they can carry more oxygen.
(3) RBCs have membrane glycoproteins of specific types which allow us to divide them into the 4 blood types.
(4) They live for between 3 and 4 months. Dead RBCs are removed by the liver and spleen.

ii. **White blood cells** (WBCs) or leukocytes (4,000 - 11,000/microliter)
(1) Leukocytes are less than 1% of total blood cells but are an important part of the immune system.
(2) They circulate in blood and can exit into the fluid surrounding the tissues.

iii. **Platelets** (200,000 - 500,000/microliter)
   (1) Platelets are tiny cells that play important role in blood clotting.
   (2) When a vessel is damaged, platelets stick to the exposed inner wall of the vessel. They release a protein which makes other platelets stick to them, forming a plug to stop any bleeding.
   (3) The clumping platelets also release a protein which causes a blood protein called fibrinogen to convert to fibrin.
   (4) Fibrin is a thread-like protein that forms a net (or mesh) to cover the injury and trap RBCs and other platelets.
   (5) Other proteins (called **clotting factors**) are also involved. A defect in any one of the clotting factors causes hemophilia, a disorder in which blood clotting does not occur properly and excessive bleeding can result from even minor injuries.

4. Human lungs, like those of other mammals, contain the respiratory surface for gas exchange.
   i. Air normally enters through the nostrils. The nostrils are lined with hairs to filter out dust and the nasal passage warms and moistens the air.
   ii. From the nose, air enters the **trachea** (or windpipe), which branches into two **bronchi**, one leading to each lung.
   iii. Bronchi further branch into smaller and smaller tubes. The narrowest ones are called **bronchioles**.
   iv. The bronchioles end in clusters of tiny air sacs called **alveoli** (each human lung contains about 350 M alveoli).
      (1) All gas exchange occurs across the thin walls of the alveoli. Each alveolus is surrounded by a web of capillaries so that O_2 can be quickly absorbed into the blood and CO_2 can be quickly eliminated from the blood.
      (2) Branching and alveoli provide a huge total surface area. In humans, this is about 100 m^2.
   v. Air flow in the lung
      (1) **Inhalation**
         (a) Rib intercostal muscles contract, expanding the ribcage.
         (b) The diaphragm contracts and lowers, increasing the volume of the chest (thoracic) cavity.
         (c) The increased volume causes a decrease in pressure in the lungs so that air flows in.
      (2) **Exhalation**
         (a) The diaphragm and intercostal muscles relax.
         (b) The volume of the thoracic cavity and lungs decreases, increasing the pressure.
         (c) The increase in pressure forces air out.
   vi. Air volumes of human lungs
      (1) Healthy lungs are flexible so that they can expand to fill with air and then contract to force air out.
      (2) This flexibility also allows us to take in more air when our level of activity increases and we need more oxygen. In other words, during normal breathing, the total lung capacity is not used.
      (3) **Tidal volume** (TV) is the volume of air inhaled and exhaled in a single breath. This is about about 500 ml of air but can be increased to 3000 ml during exercise.

(4) **Respiratory rate** is the number of breaths per unit time (usually, one minute).

(5) Total lung ventilation (the total amount of air moved in and out of the lungs each minute) depends upon 2 factors:

(i) The size of each breath (tidal volume); and,

(ii) The number of breaths/minute (respiratory rate).

(b) For an average human adult this is 5 L/min, but can be as high as 130 L/min with training.

5. Control of breathing.
   a. Breathing is an automatic process controlled by a part of the brain called the **breathing control center**.
   b. Nerve signals are sent to the diaphragm and intercostal muscles, triggering inhalation.
   c. When the signals stop, exhalation begins.
   d. The automatic control can be voluntarily overridden.
   e. When breathing stops, [CO_2] increases and is detected by the special cells in the aorta and carotid artery.
   f. They send impulses to the breathing control center to start breathing.
   g. In hyperventilation, so much CO_2 is removed from the blood that the breathing control center sends a stop breathing message.

6. Breathing disorders
   a. Allergens trigger the release of histamine which constricts muscles to narrower the diameter of the bronchioles. This results in lower air flow.
   b. **Bronchitis**
      i. An inflammation of the airways that causes mucous to accumulate. The normal cleansing activity of cilia is reduced and not sufficient to remove the mucous. Coughing attempts to clear the mucus.
      ii. Smoking and other irritants increase mucus secretion and diminish cilia function.
   c. **Emphysema**
      i. Emphysema occurs when the alveolar walls become less flexible. Damage to the walls also reduces the amount of surface area available for gas exchange.
      ii. Emphysema is associated with environmental conditions, diet, infections, and genetics. It can result from chronic bronchitis when the airways become clogged with mucous and air becomes trapped within the alveoli.
   d. Effects of cigarette smoke
      i. Cigarette smoke prevents the cilia from beating and stimulates mucus secretion.
      ii. Coughing expels excess mucous but contributes to bronchitis and emphysema.
      iii. Cigarette smoke contains compounds that are modified in the body to form carcinogens. Smoking causes 80% of lung cancer deaths.