CHAPTER 34 CIRCULATION

Chapter Outline

34.1 Transport in Invertebrates

A. Transport Mechanisms
   1. Unicellular protozoa make exchanges directly with the environment across the plasma membrane.
   2. Some multicellular animals lack an internal transport system and they can live without it.
   3. The larger invertebrates usually have circulatory systems—either an open system or a closed system.

B. Invertebrates Without a Circulatory System
   1. Sea anemones and planaria are organisms with a sac body plan that makes a circulatory system unnecessary.
   2. Sea anemone cells are part of an external layer or gastrovascular cavity and diffusion supplies all of the nutrients.
   3. Planaria have a trilobed gastrovascular cavity and a small, flat body where diffusion meets these needs.
   4. Pseudocoelomates such as nematodes use the body cavity to transport fluids.
   5. Echinoderms rely on movement of coelomic fluid as a circulatory system.

C. Invertebrates with an Open or a Closed System Circulatory System
   1. In a **circulatory system**, a pumping heart moves one of two types of circulatory fluids.
      a. **Blood** is a circulatory fluid contained within blood vessels
      b. **Hemolymph** is a circulatory fluid which flows into the hemocoel of certain arthropods and molluscs; it is a mixture of blood and interstitial fluid.
   2. Certain arthropods and molluscs have an **open circulatory system**.
      a. Hemolymph is pumped by the heart into the body cavity or sinuses.
      b. Hemolymph bathes the internal organs and then drains back to the heart.
      c. In grasshoppers, a dorsal heart pumps hemolymph into an aorta, which empties into the **hemocoel**.
      d. Hemolymph is colorless (it lacks hemoglobin or other respiratory pigments); a system of tracheae provides oxygen.
   3. Some invertebrates, including earthworms and cephalopods, have a **closed circulatory system** in which blood never leaves the heart or vessels.
      a. Valves prevent any backward flow of the blood as it moves through vessels.
      b. Earthworms have five pairs of anterior lateral vessels that pump blood to every segment.
      c. Blood moves in capillaries where an exchange with tissue fluid takes place before returning in veins.
      d. Earthworms have a red respiratory pigment **hemoglobin** dissolved in the blood, not inside blood cells.
      e. With no special cavity for gas exchange, the gas must diffuse across a moist body wall.

34.2 Transport in Vertebrates

A. Closed Circulatory System
   1. Vertebrates have a closed circulatory system called a **cardiovascular system**.
   2. The muscular **heart** keeps blood circulating through the animal body.
      a. The **atrium** is a chamber of the heart that receives blood.
      b. The **ventricles** pump blood into arteries.
   3. There are three kinds of blood vessels: **arteries** carry the blood away from the heart, **capillaries** are where the exchange with tissue fluid takes place, and **veins** return the blood to the heart.
      a. **Arteries**
         1) have thick walls and are resilient.
         2) expand to accommodate sudden increase in blood volume that results after heart contraction.
         3) divide into small **arterioles.**
      b. **Arterioles** constriction and dilation are regulated by nervous system to regulate blood pressure.
      c. **Capillaries** are microscopic blood vessels with a wall formed of one layer of simple squamous cells.
         1) Capillary beds are so prevalent that, in humans, all cells are within 60–80 μm of a capillary.

2) Only 5% of the capillaries are open at one time; if an animal eats, the capillary beds of the digestive system open.
3) Capillaries are so narrow that red blood cells must pass through them in single file.
4) Gas, nutrient, and waste exchange occurs across the thin walls.

d. The **venules** are vessels that take blood from capillaries and join to form a **vein**.
e. **Veins** transport blood toward the heart.
1) Wall of a vein is much thinner than that of arteries; there is low blood pressure.
2) One-way valves open in direction of heart; close to prevent backflow.

B. Comparison of Circulatory Pathways
1. In vertebrates, there are three different types of circulatory pathways.
2. Fishes have a one-circuit (single-loop circulatory) pathway.
a. Heart has a single atrium and ventricle and pumps the blood under pressure to the gills.
b. Blood in the gills is oxygenated.
c. After passing through gills, blood is under reduced pressure and flow.
3. Other vertebrates have a two-circuit (double-loop circulatory) pathway to breathe air on land.
a. The **systemic circulation** transports the blood to tissues.
b. The **pulmonary circulation** pumps the blood to lungs.
4. In amphibians and most reptiles, the heart has two atria but a single ventricle.
5. The hearts of some reptiles and all birds and mammals are divided into two halves.
a. With two atria and two ventricles, the oxygenated blood is always separate from the deoxygenated blood.
b. The right ventricle pumps blood to the lungs; the ventricle pumps blood to the rest of the body.
c. This arrangement provides adequate blood pressure for both the pulmonary and the systemic circulations.

34.3 Transport in Humans

A. The Human Heart
1. The pumping of the heart keeps the blood moving in arteries.
2. Skeletal muscle contraction is responsible for the blood movement in veins.
3. The **heart** is a cone-shaped, muscular organ about the size of a fist.
4. It is located between lungs directly behind the sternum and is tilted so that apex is directed to left.
5. The **myocardium** is a major portion of the heart consisting mostly of cardiac muscle; its muscle fibers are branched and tightly joined together.
6. The heart lies within a **pericardium** sac that contains **pericardial fluid** which provides cushioning.
7. The **endocardium** lines the inner surface of the heart; it consists of connective tissue and endothelial tissue.
8. An internal wall called the **septum** separates the heart into right and left halves.
9. The heart has two upper, thin-walled **atria** and two lower, thick-walled **ventricles**.
a. The atria receive blood from the venous portion of the cardiovascular system.
b. The atria are much smaller and weaker than the muscular ventricles but hold the same volume of blood.
c. The **ventricles** pump blood into the arterial portion of the cardiovascular system.
10. Heart valves direct the flow of blood and prevent any backward movement.
a. Valves are supported by strong fibrous tendons (**chordae tendineae**) attached to muscular projections of ventricular walls; they prevent valves from inverting.
b. **Atrioventricular valves** between the atria and ventricles prevent any back flow from the ventricle to the atrium.
c. The **right atrioventricular** (**tricuspid**) **valve** on right side of the heart consists of three cusps or flaps.
d. The **left atrioventricular** (**bicuspid** or **mitral**) **valve** on left side consists of two cusps or flaps.

e. **Semilunar valves** resembling half-moons are located between a ventricle and an artery that prevents any back flow from the artery to the ventricle.
    1) The **pulmonary semilunar valve** lies between the right ventricle and the pulmonary trunk.
    2) The **aortic semilunar valve** lies between the left ventricle and the aorta.

B. Path of Blood Through the Heart
1. The route of blood through the heart is as follows.
    a. Oxygen-poor blood enters the right atrium from both the superior vena cava and the inferior vena cava.
    b. The right atrium sends blood through the right atrioventricular (tricuspid) valve to the right ventricle.
    c. The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk and arteries to the lungs.
    d. Oxygen-rich blood returns from the lungs through pulmonary veins and is delivered to the left atrium.
    e. The left atrium sends blood through the left atrioventricular (bicuspid or mitral) valve to the left ventricle.
    f. The left ventricle sends blood through the aortic semilunar valve into the aorta and on to the body proper.
2. The heart is therefore a double pump serving the lungs and body circulations simultaneously.
3. Since the left side has the harder job of pumping blood throughout the body, its walls are thicker.
4. Blood pressure then decreases as the cross-sectional area of the arteries and arterioles increases.

C. The Heartbeat
1. Heart contracts (beats) about 70 times a minute and each heartbeat lasts about 0.85 seconds.
2. The heartbeat or **cardiac cycle** consists of phases.
3. The atria contract first while the ventricles relax (0.15 sec.), then the ventricles contract while atria relax (0.30 sec.), and then all chambers rest (0.40 sec.).
4. **Systole** refers to the contraction of heart chambers and **diastole** is the relaxation of heart chambers.
5. The heart is in diastole about 50% of the time.
6. The short systole of the atria is needed only to send blood into the ventricles.
7. When the term "systole" is used alone, it refers to left ventricle systole.
8. When the heart beats, the familiar **lub-dub** sound is heard as the valves of the heart close.
    a. **Lub** is caused by the vibrations of the heart when the atrioventricular valves close.
    b. **Dub** is heard when the vibrations occur due to the closing of semilunar valves.
9. A **pulse** is a wave effect that passes down the walls of arterial blood vessels when the aorta expands and then almost immediately recoils following ventricular systole.
10. Since there is one arterial pulse per ventricular systole, the arterial pulse rate can be used to determine the heart rate.
11. Rhythmic contraction of the heart is due to the cardiac conduction system.
    a. The **sinoatrial (SA) node** is the "pacemaker" found in the upper dorsal wall of the right atrium; it initiates the heartbeat by sending out an excitatory impulse every 0.85 seconds to cause the atria to contract.
    b. The **atrioventricular (AV) node** is found in the base of the right atrium very near the septum; when stimulated by impulses from the SA node, it sends out impulses through the septum to cause the ventricles to contract.
    c. Although the beat of the heart is intrinsic, it is regulated by the nervous system which can increase or decrease the heartbeat rate.
12. An **electrocardiogram** (ECG) is a recording of the electrical changes that occur in the myocardium during a cardiac cycle; it is used as a diagnostic tool to identify abnormal cardiac function.
13. Normal Cardiac Cycle
    a. The **P wave** represents excitation and occurs just before atrial contraction.
    b. The **QRS complex** signals that the ventricles are about to contract.
    c. The electrical changes that occur as the ventricular muscle fibers recover produce the **T wave**.
14. Ventricular fibrillation is uncoordinated contraction of the ventricles; with the application of a strong electric current, the SA node may reestablish a coordinated beat.

D. Vascular Pathways
    1. The human cardiovascular system has two major circular pathways.
    2. The Pulmonary Circuit
        a. The **pulmonary circuit** circulates blood to the lungs where blood is oxygen-rich.
        b. Oxygen-poor blood from the body collects in the right ventricle, which pumps it to **pulmonary trunk.**
        c. The pulmonary trunk divides into right and left pulmonary arteries to carry blood to each lung.
        d. In the lungs, carbon dioxide (CO_2) is unloaded and O_2 is picked up by blood.
        e. Oxygen-rich blood from the lungs is returned through **pulmonary veins** to the left atrium.
    3. The Systemic Circuit
        a. The **aorta** and **vena cavae** are main pathways for blood in **systemic circuit.**
        b. Transport of oxygenated blood moves from the left ventricle through the aorta out to all tissues.
        c. Deoxygenated blood returns from all tissues via vena cava.
        d. In a systemic circuit, arteries contain bright red oxygen-rich blood; the veins contain dull red oxygen-poor blood that appears blue when viewed through the skin.
    4. The **coronary arteries** serve the heart muscle itself.
        a. **Coronary arteries** originate from the base of the aorta just above the aortic semilunar valve.
        b. Coronary arteries lie on the external surface of the heart; they branch into arterioles and capillaries.
        c. Capillary beds enter the venules that join to form the cardiac veins.
        d. **Coronary veins** collect oxygen-poor blood from the capillaries and empty into the right atrium.
    5. The **portal system** is a pathway of blood flow that begins and ends in capillaries.
        a. The **hepatic portal vein** transports blood from capillaries in small intestinal villi to capillaries in liver.
        b. The hepatic vein leaves the liver and enters the inferior vena cava.

E. Blood Pressure
    1. **Systolic pressure** results from blood being forced into the arteries during ventricular systole.
    2. **Diastolic pressure** is pressure in arteries during ventricular diastole.
    3. Human **blood pressure** is measured as the force pushing against the wall of the brachial artery of the upper arm.
        a. Blood pressure is measured by a **sphygmomanometer** which has a pressure cuff.
        b. Clinical blood pressure measures pressures produced by contraction and relaxation of right ventricle.
        c. Blood pressure is stated in millimeters of mercury (e.g., 120/80 mm Hg) for systolic/diastolic.
    4. As blood flows from the aorta into arteries and arterioles, the blood pressure falls.
    5. The difference in pressure between systolic and diastolic pressures gradually diminishes.
    6. Capillaries have a slow, even blood flow due to the high total cross-sectional area.
        a. The total length of human capillaries is estimated at 60,000 miles.
        b. Most of this distance is due to quantity of capillaries.
    7. Blood pressure in the veins is low and cannot move blood back to heart, especially from the limbs.
    8. Skeletal muscle contraction on the walls of veins with **valves**, preventing backflow of blood, is responsible for the flow of blood in veins.
    9. **Varicose veins** are abnormal dilations that develop when the valves become weak and ineffective.

34.4 Cardiovascular Disorders

A. Cardiovascular Disease
    1. Cardiovascular disease (CVD) is the leading cause of untimely death in Western countries.
    2. The risk of CVD can be reduced by following guidelines for a heart-healthy life-style.

B. Hypertension
    1. An estimated 20% of Americans suffer from **hypertension** or high blood pressure.
    2. Women have this condition if their blood pressure is significantly higher than 160/95; men under the age of 45 if over 130/90, and beyond the age of 45 if above 140/95.
    3. The diastolic pressure is emphasized when medical treatment is considered.
    4. Hypertension may not be detected until a stroke or heart attack occurs.

5. Two genes are involved in hypertension for some individuals.
    a. One gene codes for angiotensinogen, a plasma protein converted to a vasoconstrictor byproduct of a second gene.
    b. Persons with this form of hypertension may one day be cured by gene therapy.

C. Atherosclerosis
1. Hypertension is seen in individuals with **atherosclerosis,** formerly called arteriosclerosis.
2. Soft masses of fatty materials, mostly cholesterol, accumulate beneath the inner linings of arteries.
3. As this plaque accumulates, it protrudes into a vessel and interferes with blood flow.
4. Atherosclerosis develops in early adulthood but the symptoms may not appear until age 50 or older.
5. Plaque can cause a blood clot to form on irregular arterial walls.
6. As long as a clot remains stationary, it is a **thrombus**.
7. If a clot dislodges, it is an **embolus**, a blood clot that moves in the blood.
8. In some families, atherosclerosis is inherited as **familial hypercholesterolemia**.

D. Stroke and Heart Attack
1. Stroke, heart attack, and aneurysm are associated with hypertension and atherosclerosis.
2. **Strokes** can result in paralysis or death; a small cranial arteriole bursts or is blocked by an embolus.
    a. Stroke is also called a cardiovascular accident (CVA).
    b. Whether paralysis or death occurs depends on the extent of the portion of the brain that lacks O_2.
    c. Warning symptoms that foretell stroke include: numbness in hands or face, difficulty speaking, blindness in one eye, etc.
3. A myocardial infarction (MI) is also called **heart attack**.
    a. This occurs when a portion of heart muscle dies due to a lack of O_2.
    b. A partially blocked coronary artery causes **angina pectoris** causing pains or a flash of burning.
    c. Nitroglycerin and related drugs dilate the blood vessels and relieve pain.
    d. One cause of heart attacks is blockage of the coronary arteries due to a thromboembolism.

34.5 Blood, a Transport Medium

A. The blood of mammals has two components: plasma and formed elements (cells and platelets).
1. **Plasma** contains water and many types of molecules, including nutrients, wastes, salts, and proteins.
2. Salts and proteins buffer the blood.
    a. They effectively keep the blood pH near 7.4.
    b. They maintain the blood osmotic pressure so water has a tendency to enter capillaries.
3. Some plasma proteins are involved in blood clotting.
4. Some plasma proteins assist in transporting large organic molecules in the blood.
    a. Lipoproteins that transport cholesterol are globulins.
    b. **Albumin**, a common plasma protein, transports bilirubin, a breakdown product of hemoglobin.

B. Formed Elements
1. Formed elements are of three types: red blood cells (RBCs), white blood cells (WBCs), and platelets.
2. Red Blood Cells
    a. **Red blood cells** (**erythrocytes**) are small biconcave disks.
    b. When mature, RBCs lack a nucleus and contain hemoglobin.
    c. There are 6 million RBCs per mm^3 of whole blood.
    d. Each RBC contains about 250 million hemoglobin molecules.
        1) **Hemoglobin** contains four globin protein chains, each with an iron-containing heme group.
        2) The iron atom of a heme group loosely binds with an O_2 molecule; thus, blood carries oxygen.
        3) Anemia is either a lack of enough RBC or insufficient hemoglobin; an individual suffers from a tired, run-down feeling.
    e. RBCs are manufactured in the red bone marrow of the skull, ribs, vertebrae, and the ends of long bones.
    f. The growth factor **erythropoietin** is produced when an enzyme from the kidneys acts on a precursor made by the liver and stimulates production of red blood cells; as a drug it helps people with anemia.
    g. Before being released from bone marrow, the RBCs lose their nucleus and synthesize hemoglobin.
    h. Red blood cells have a life span of about 120 days; then they are destroyed chiefly in liver and spleen.

i. When the RBCs are destroyed, the hemoglobin is released; the iron is recovered and returned to bone marrow where it is reused.
j. The heme portions undergo chemical degradation and are excreted by the liver as bile pigments; it colors the feces.

3. White Blood Cells
   a. **White blood cells** (**leukocytes**) differ from RBCs in being larger and in having a nucleus.
   b. WBCs lack hemoglobin and appear translucent without staining.
   c. **Granular leukocytes** contain conspicuous granules in their cytoplasm and have a lobed nucleus.
      1) **Neutrophils** have granules that stain slightly pink; they are amoeboid, spherical cells that readily squeeze through capillary walls and phagocytize foreign material.
      2) **Eosinophils** have granules that take up the red dye eosin.
      3) **Basophils** have granules that take up a basic dye, staining them deep blue.
   d. A newly discovered stem cell growth factor (SGF) increases the production of all WBCs, which helps patients with low immunity.
   e. **Agranular leukocytes** lack granules in their cytoplasm and have a circular or indented nucleus.
      1) **Monocytes** are amoeboid and able to enter tissues where they transform into **macrophages**.
      2) **Macrophages** release white blood cell growth factors that increase the number of leukocytes.
      3) **Pus** is a thick, yellowish fluid that contains a large proportion of dead WBCs that have fought infection.
      4) **Lymphocytes** play a key role in fighting infection and include two types.
         a) **T cells** are lymphocytes that directly attack virus-infected cells.
         b) **B cells** can be stimulated to produce one type of **antibody** specific for one type of antigen.
      5) An **antigen** is any substance stimulating production of antibodies; antigen is foreign to the body.
      6) **Antibodies** combine with antigens to promote their being phagocytized by a macrophage.
      7) A person is actively immune when many B cells produce specific antibody for an infection.

4. Platelets
   a. **Platelets** (**thrombocytes**) result from fragmented giant cells (**megakaryocytes**) in the bone marrow.
   b. 200 billion platelets are produced a day; blood contains 150,000–300,000 platelets per mm^3.
   c. Platelets are involved in blood clotting or coagulation.
   d. At least 12 clotting factors in the blood participate in blood clotting.
   e. Hemophilia is an inherited disorder where the liver is unable to produce one of the clotting factors.
   f. Minor bumps can cause internal bleeding; bleeding into the brain causes death in hemophilia.
   g. Vitamin K is necessary to produce prothrombin; deficiency of vitamin K causes hemorrhagic disorders.

5. Blood Clotting
   a. When a blood vessel is damaged, platelets clump at the site of the puncture and partially seal the leak.
   b. The platelets and damaged tissue cells release a **clotting factor** called **prothrombin activator**.
   c. With calcium ions, prothrombin activator catalyzes a reaction converting **prothrombin** to **thrombin**.
   d. Thrombin acts as an enzyme to sever two amino acid chains from each fibrinogen molecule.
   e. These activated fragments join end-to-end forming long threads of **fibrin**.
   f. Fibrin threads wind around the platelet plug and provide a framework for a clot.
   g. RBCs are trapped within the fibrin threads, making the clot appear red.
   h. When blood vessel repair is initiated, **plasmin** destroys the fibrin network and restores plasma fluidity.
   i. When clotting occurs in test tube, a fluid **serum** collects above a clot; it has same composition as plasma except fibrinogen.

C. Capillary Exchange
   1. Two forces control the movement of fluid through the capillary walls.
      a. **Osmotic pressure** tends to cause water to move from tissue fluid to the blood.
      b. **Blood pressure** tends to cause water to move from the blood to tissue fluid.

    c. At the arterial end of a capillary, blood pressure is higher than osmotic pressure: water exits and moves into tissues.
    d. Along the capillary, O_2 and nutrients diffuse out into the tissue fluid, while CO_2 and other metabolic wastes diffuse into the capillaries from the tissue fluid.
2. Midway along a capillary, there is no net movement of water.
3. The **tissue fluid** is intercellular fluid that surrounds the cells; the circulatory system exchanges materials with this fluid.
4. The exchange between the blood and tissue fluid occurs by diffusion through the one-cell-thick capillary walls.
    a. At the venule end, osmotic pressure is higher than blood pressure and water moves back into blood.
    b. Almost the same amount of fluid that left the capillary returns to it; there is always some excess tissue fluid collected by the lymphatic capillaries.
5. The tissue fluid within lymphatic vessels is **lymph**.
6. Lymph returns to the systemic venous blood when lymphatic vessels enter the subclavian veins in the shoulder.
7. Not all capillary beds are open at the same time; precapillary sphincters shunt blood along various pathways.
8. Through capillary dilation and constriction, blood also distributes heat to body parts and conserves heat when cold.