CHAPTER 37 RESPIRATION

Chapter Outline

37.1 Gas Exchange Surfaces

A. Respiration is the sequence of events that results in gas exchange between the environment and the body's cells.
    1. **Breathing** includes **inspiration** (bringing air in) and **expiration** (moving air out).
    2. **External respiration** involves gas exchange with the external environment at a respiratory surface.
    3. **Internal respiration** in more complex animals involves gas exchange between the blood and tissue fluid.

B. Diffusion Accompanies Gas Exchange
    1. An effective gas exchange region must be moist, thin, and large in relation to the size of the body.
    2. Some animals are small and shaped to allow their surface to be an adequate gas-exchange surface.
    3. Larger animals are complex and have a specialized gas-exchange surface.
    4. Diffusion improves with vascularization; gas delivery to cells is promoted if the blood contains hemoglobin.

C. Water Environments
    1. It is more difficult for animals to obtain O_2 from water than from air.
        a. Water fully saturated with air contains only a fraction of the O_2 as the same volume of air.
        b. Water is more dense than air; therefore aquatic animals must use more energy to breathe.
        c. Fishes use up to 25% of their energy to breathe; land mammals use only 1–2% of their energy output to breathe.
    2. Hydras and planaria have a large surface area in comparison to their size.
        a. Gas exchange occurs directly across their body surface.
        b. The hydra's outer cell layer contacts the environment; an inner layer exchanges gases with the water in the gastrovascular cavity.
        c. The flat body of planaria permits cells to exchange gases with the external environment.
    3. A tubular shape and vascularized parapodia extensions in polychaete worms provide surface areas for diffusion.
    4. Aquatic animals often pass water over **gills**.
        a. **Gills** are finely divided and vascularized outgrowths of either an outer or inner body surface.
        b. Among clams, water is drawn into the mantle cavity and flows over gills.
        c. Decapod gills are located in brachial chambers under the exoskeleton; water is circulated by special mouthparts.
        d. Fish gills are outward extensions of the pharynx organized into arches.
        e. Ventilation is the result of the combined action of the mouth and gill covers.
        f. When the mouth is open, the opercula are closed and water is drawn in; the mouth then closes and the opercula open, drawing water from the pharynx through gill slits located between the gill arches.
        g. To the outside of the gill arches are gill **filaments** folded into platelike **lamellae**, each of which contains capillaries; the result is a tremendous surface area for gas exchange.
            1) Blood in capillaries of gill lamellae flows in a direction opposite to that of water.
            2) This **countercurrent flow** of water and blood increases the amount of O_2 and CO_2 exchanged.
            3) Such a countercurrent mechanism extracts about 80–90% of the initial dissolved O_2 in the water.

D. Land Environments
    1. Air is a richer source of O_2 than water but air dries out the wet respiratory surfaces; humans lose 350 ml of water per day at 50% relative humidity.
    2. The earthworm is an invertebrate that uses its body surface for respiration.
        a. An earthworm expends energy to secrete mucus and release fluids from excretory pores.
        b. The earthworm is also behaviorally adapted to stay in the moist soil during the day when air is driest.
    3. Terrestrial insects utilize **tracheal systems**.
        a. Oxygen enters a tracheal system at **spiracles**, valvelike openings at each side of the body.
        b. The **tracheae** branch and rebranch to end in tiny **tracheoles** that are in direct contact with body cells.
        c. Larger insects have air sacs located near major muscles to keep air moving in and out of the trachea.
        d. The tracheae effectively deliver adequate oxygen to the cells of insects; the circulatory system has no role in gas transport.
    4. Terrestrial vertebrates have evolved **lungs** for gas exchange.
        a. **Lungs** are vascularized outgrowths of the lower pharyngeal region.
        b. Amphibian lungs are simple, saclike structures, that connect to the external environment by way of two bronchi which connect to a short trachea.
            1) Amphibian gas exchange occurs through a skin kept moist by mucus produced by surface glands.
            2) In the winter, amphibians burrow in mud and all gas exchange occurs across the skin.
            3) Frogs use positive pressure to force air in; nostrils shut and floor of mouth forces air into lungs.
        c. The lining of the lung becomes progressively more finely divided as we move from amphibians to reptiles to birds and mammals.
        d. Human lungs have at least 50 times the skin's surface area.
        e. Reptiles, birds, and mammals use negative pressure to move air into lungs.
            1) Jointed ribs are raised and the muscular diaphragm is flattened to expand the lungs.
            2) As the thoracic cavity expands, the lung volume increases; air flows in due to the difference in air pressure.
            3) By lowering the ribs, pressure is exerted on the lungs, which forces air out.
        f. The lungs of reptiles, amphibians and mammals are not completely emptied during each breathing cycle.
            1) With incomplete ventilation, entering air mixes with used air in lungs.
            2) This conserves moisture but decreases gas-exchange efficiency.
        g. The high oxygen requirements of flying birds requires a **complete ventilation system**.
            1) Incoming air is carried past lungs by a bronchus that takes it to set of posterior air sacs.
            2) Air then passes forward through lungs into a set of anterior air sacs and is finally expelled.
            3) The one-way flow means that oxygen-rich air does not mix with used air; this maximizes gas exchange.

37.2 Human Respiratory System

A. Structure
    1. The human **respiratory system** includes everything that conducts air to and from the **lungs**; **the** lungs lie deep within the thoracic cavity for protection from drying out.
    2. Air moves into the nose, then flows past the **pharynx** to the **trachea**, **bronchi** and **lungs**.
        a. This process filters debris, warms air, and adds moisture.
        b. When the air reaches the lungs, it is at body temperature and saturated with water.
        c. The trachea and bronchi are lined with cilia that beat upward carrying mucus, dust, and any food particles that went the wrong route.
        d. The **hard** and **soft palates** separate nasal cavities from mouth.
        e. The air and food passages cross in pharynx; the real danger of choking is offset by providing an alternative path for breathing during congestion, and also increasing air intake during exercise.
        f. Air flows past the pharynx through the **glottis** and into the **larynx**, which is protected by the epiglottis.

g. At the edges of the glottis are **vocal cords**; as air passes across them, these tissues vibrate creating sounds.
h. From the larynx, air flows down the **trachea** to the **bronchi**.
    1) The larynx is held open by cartilage that forms the Adam's apple.
    2) The **trachea** walls are reinforced with C-shaped rings of cartilage.
    3) As food is swallowed, the larynx rises and the glottis is closed by a flap of tissue called the **epiglottis**.
    4) A backward movement of soft palate covers the entrance to the nasal passages; this directs food downward.
i. The trachea divides into two **bronchi**; C-shaped rings of cartilage diminish as bronchi branch.
j. Within the lungs, each bronchus branches into numerous **bronchioles** that conduct air to **alveoli**.
k. **Alveoli** are microscopic air sacs.

B. Breathing
1. Humans breathe using negative pressure similar to all other mammals.
2. During **inhalation**, lowering the diaphragm and raising the ribs forms a negative pressure by increasing the volume of the thoracic cavity; the air–under greater outside pressure–flows into the lung.
3. Increases in the CO_2 and H^+ concentrations in the blood are the primary stimuli increasing the breathing rate.
    a. The chemical content of blood is monitored by **chemoreceptors** sensitive to increases in CO_2 and H^+ concentrations of the blood, but minimally sensitive to decreases in O_2 concentration.
    b. The **aortic bodies** are chemoreceptors located in the wall of the aortic arch.
    c. **Carotid bodies** are chemoreceptors located in the wall of the carotid arteries.
4. Information from these goes to a respiratory center in the **medulla oblongata** increasing the breathing rate when CO_2 or H^+ concentrations increase; this respiratory center is sensitive to blood reaching brain.

C. Gas Exchange and Transport
1. Gas exchange between the air in the alveoli and the blood in the pulmonary capillaries is primarily by diffusion.
2. Atmospheric air contains little CO_2, but blood flowing in the pulmonary capillaries has a higher concentration of CO_2.
3. CO_2 diffuses from higher concentration in the blood across the walls of alveolar capillaries to lower concentration in the air in the alveoli.
4. The blood coming into pulmonary capillaries is oxygen poor and the alveolar air is oxygen rich.
5. Oxygen diffuses from higher concentration in alveoli across the walls of the alveolar capillaries to the lower concentration in blood.

D. Transport of Oxygen and Carbon Dioxide
1. Most O_2 entering pulmonary capillaries combines with **hemoglobin** (Hb) to form **oxyhemoglobin** (HbO_2).

$$\underset{\text{deoxyhemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2} \rightarrow \underset{\text{oxyhemoglobin}}{HbO_2}$$

2. Each **hemoglobin** molecule has four polypeptide chains; each chain folds over an iron-containing heme.
    a. Each RBC has 250 million hemoglobin molecules.
    b. Each RBC can carry a billion molecules of O_2 oxyhemoglobin.
    c. The iron atom of a heme group loosely binds with an O_2 molecule.
3. Oxygen-binding ability of hemoglobin can be graphed.
    a. The percentage of oxygen-binding sites of hemoglobin carrying O_2 varies with **partial pressure** of O_2 (PO_2) in immediate environment.
    b. The **partial pressure** is the amount of pressure exerted by a particular gas among all of the gases present.
    c. At a normal partial pressure of O_2 in lungs, hemoglobin becomes practically saturated with O_2.
    d. But at the O_2 partial pressures in the tissues, oxyhemoglobin quickly unloads much of its O_2.

$$HbO_2 \rightarrow Hb + O_2$$

    e. The acid pH and warmer temperature of the tissues also promote this dissociation.

4. In tissues, some hemoglobin combines with CO_2 to form **carbaminohemoglobin**.
5. However, most CO_2 is transported in form of **bicarbonate ion** (HCO_3^-).
    a. First CO_2 combines with water, forming **carbonic acid** (H_2CO_3).
    b. Then this dissociates to a H^+ and a HCO_3^-

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

carbonic acid bicarbonate ion

    c. **Carbonic anhydrase**, an enzyme in red blood cells, speeds this reaction.
    d. Release of H^+ ions could drastically lower blood pH; however, the hydrogen ions are absorbed by the globin portions of hemoglobin and the HCO_3^- diffuses out of the RBCs and into the plasma.
    e. Hemoglobin combines with H^+ ions as **reduced hemoglobin** (**HHb**); HHb plays a vital role in maintaining normal blood pH.
    f. As blood enters the pulmonary capillaries, most of the CO_2 is in plasma as HCO_3^-.
    g. The little free CO_2 remaining diffuses out of the blood across the walls of the pulmonary capillaries and into alveoli.
    h. Any decrease in plasma CO_2 concentration causes the following reaction also catalyzed by carbonic anhydrase:

$$H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow CO_2 + H_2O$$

    i. At same time, hemoglobin unloads H^+ and HHb becomes Hb.

37.3 Respiration and Health

A. Upper Respiratory Tract Infections (URI)
    1. The entire respiratory tract has a warm, wet, mucous membrane lining exposed to environmental air.
    2. The upper respiratory tract consists of nose, pharynx and larynx.
    3. **Strept throat** is a severe infection caused by the bacteria *Streptococcus pyogenes* resulting in a high fever and difficulty swallowing and it can lead to a systemic infection.
    4. **Sinusitis** is infection of the sinuses; 1–3% of upper respiratory infections are accompanied by sinusitis.
    5. **Tonsillitis** occurs when the tonsils and adenoids of the pharynx are inflamed as a first line of defense.
    6. **Laryngitis** is an infection of the larynx causing hoarseness and an inability to talk.
    7. Persistent hoarseness without any upper respiratory infection is one of the warning signs of **cancer**.

B. Lower Respiratory Tract Disorders
    1. **Acute bronchitis** is an infection of the primary and secondary bronchi and is usually preceded by a viral URI.
    2. **Pneumonia**
        a. Pneumonia is usually caused by a bacterial or viral lung infection.
        b. The bronchi and alveoli fill with fluid.
        c. Pneumonia can be localized in specific lobules.
        d. AIDS patients are subject to a rare form of pneumonia caused by the protozoan *Pneumocystis carinii.*
    3. **Pulmonary Tuberculosis**
        a. Tuberculosis is caused by the tubercle bacillus, a type of bacterium.
        b. A TB skin test is a highly diluted extract of the bacilli injected into the patient's skin; if a person has been exposed, the immune response will cause an area of inflammation.
        c. Bacilli that invade lung tissue are isolated by the lung tissue in tiny capsules called tubercles.
        d. If the person is highly resistant, the imprisoned bacteria die.
        e. If the person is not resistant, the bacteria can eventually be liberated.
        f. A chest X ray detects active tubercles.
        g. Appropriate drug therapy can ensure localization and the eventual destruction of live bacteria
        h. Resurgence has accompanied increases in AIDS, homeless, and poor.
        i. The new strains are resistant to standard antibiotics.

C. Pulmonary Disorders
    1. **Pulmonary Fibrosis**
        a. Inhaling particles of silica, coal dust, fiberglass and asbestos can lead to **pulmonary fibrosis**.
        b. These agents result in a build up of fibrous connective tissue; then the lungs cannot inflate properly.
        c. Asbestos was used widely for fireproofing and widespread exposure occurred; it is estimated that a possible 2 million deaths could be caused by asbestos between 1990 and 2020.

2. **Chronic Bronchitis**
    a. Airways are inflamed and filled with mucus; often a cough brings mucus up.
    b. The bronchi degenerate, losing cilia and normal cleansing action and making an infection likely.
    c. Smoking cigarettes and cigars is the most common cause but other pollutants are also involved.
3. **Emphysema**
    a. Emphysema is a chronic and incurable disorder; it involves distended and damaged alveoli.
    b. The lungs often balloon due to trapped air and ineffective alveoli.
    b. Emphysema is often preceded by chronic bronchitis.
    c. The elastic recoil of the lungs is reduced and the airways are narrowed, making expiration difficult.
    d. Since the surface area for gas exchange is reduced, insufficient O_2 reaches the heart and the brain.
    e. This triggers the heart to work furiously to force more blood through lungs; this can then lead to a heart condition.
    f. Lack of oxygen to the brain makes the patient feel depressed, sluggish, and irritable.
    g. Exercise, drug therapy, and supplemental oxygen may relieve the symptoms and slow the progress.
4. **Asthma**
    a. Asthma is a disease of the bronchi and bronchioles; it causes wheezing, breathlessness and a cough.
    b. The airways are sensitive to specific allergens (e.g., pollen, dust, cold air, etc.)
    c. Exposure to the irritant causes the smooth muscle in bronchi to spasm; chemical mediators given off by the immune cells in the bronchioles result in the spasms.
    d. Bronchial inflammation reduces the diameter of the airways.
    e. Special Inhalers can control the inflammation and sometimes prevent an attack; other inhalers can stop muscle spasms.
5. **Lung Cancer**
    a. Formerly more common in men, lung cancer now surpasses breast cancer as cause of death in women due to smoking.
    b. **Lung cancer** develops in the lung tissue in steps.
        1) First, a thickening and callusing of the cells lining the bronchi appears.
        2) Cilia are lost so it becomes impossible to prevent dust and dirt from settling in the lungs.
        3) Next, cells with atypical nuclei appear in the callused lining.
        4) A tumor consisting of disordered cells with atypical nuclei develops as **cancer *in situ*** (cancer at one location).
        5) When some tumor cells break free and penetrate other tissue (**metastasis**), the cancer spreads.
        6) A tumor may grow until the bronchus is blocked, cutting off the air supply to the lungs.
        7) The entire lung then collapses; the trapped secretions become infected causing pneumonia or lung abscess.
    c. The only treatment is surgery (pneumonectomy) where a lobe or whole lung is removed before the cancer has been able to spread.