CHAPTER 36 DIGESTION AND NUTRITION

Chapter Outline

36.1 Digestive Tracts

A. General Digestion
   1. Most animals need to digest food into small molecules that can cross plasma membranes.
   2. Digestion provides the energy needed to carry out routine metabolic activities and maintain homeostasis.
   3. The digestive tract ingests food, breaks down food into small molecules that can cross plasma membranes, absorbs these nutrient molecules, and eliminates nondigestible remains.

B. Incomplete Versus Complete Tracts
   1. Planarians are organisms with an **incomplete gut**.
      a. Planaria are carnivorous and feed largely on smaller aquatic animals.
      b. Digestive system contains only a mouth, a pharynx, and an intestine.
      c. To feed, its pharynx extends far beyond the mouth to suck up minute quantities at one time.
      d. Digestive enzymes in the **gastrovascular cavity** allow some extracellular digestion.
      e. Digestion is finished intracellularly by cells that line the digestive cavity; food then diffuses to nearby cells.
      f. The digestive system lacks regions of specialized function.
      g. The tapeworm relatives of planaria lack a digestive system altogether; they absorb food through a body wall with modified microscopic projections that absorb nutrients from the host.
   2. In contrast, the earthworm has a **complete gut**.
      a. The digestive system is composed of a tube with a mouth and an anus.
      b. Earthworms feed on decayed organic matter in the soil.
      c. Different regions of the gut have specialized functions (e.g., ingestion, mechanical digestion, etc.).
      d. A muscular **pharynx** draws in food with sucking action.
      e. The **crop** is storage area with expansive walls.
      f. The **gizzard** has thick muscular walls to grind food.
      g. Digestion occurs in the intestine, outside of cells or "extracellular."
      h. The surface area for absorption is increased by an intestinal fold called the typhlosole.
      i. The undigested remains exit the body at the anus.

C. Continuous Versus Discontinuous Feeders
   1. Clams are **continuous feeders**, often called **filter feeders**.
      a. Water moves into a mantle cavity through an incurrent siphon and deposits particles on gills.
      b. Ciliary action moves particles to the labial palps which direct them into the mouth and into the stomach.
      c. Digestive enzymes from a digestive gland help amoeboid cells in the tract complete digestion.
   2. Marine fanworms are sessile filter feeders; only small particles are consumed while large particles are rejected.
   3. Baleen whales are active filter feeders; baleen (fringe) filters small krill from water.
   4. Squids are an example of discontinuous feeders.
      a. The head of a squid has ten arms; two arms seize the prey and bring it to the squid's mouth.
      b. Beaklike jaws and a radula (toothy tongue) reduce the food to pieces.
      c. The esophagus leads to a stomach that holds food until digestion is complete.
      d. Discontinuous feeders require a storage region in their gut.

D. Adaptation to Diet
   1. Animals are **herbivores** (eat plants) or **carnivores** (eat animals) or **omnivores** (eat both).
   2. Invertebrates demonstrate a wide variety of diets.

3. Mammal dentition differs according to their mode of nutrition.
    a. Omnivores, including humans, have dentition that accommodates both a vegetable and meat diet.
    b. Omnivore teeth include **incisors** (shearing), **canines** (tearing), **premolars** (grinding), and **molars** (crushing).
    c. Herbivores have large, flat premolars and molars for grinding plant matter.
    d. Grazers (e.g., horses) have sharp incisors for clipping off grass and leaves.
    e. Hard-to-digest plant material requires extensive grinding to disrupt the plant cell walls.
    f. Animals that feed on plants may have long and complex digestive tracts and bacteria in their digestive tracts that can digest cellulose, producing nutrients that an animal can use.
    g. Some grazers have a **rumen** to digest chewed grasses; partially digested cud is then rechewed.
    h. Carnivores' pointed incisors and canines tear off pieces small enough to swallow.
    i. Meat is rich in protein and fatty acids and is easier to digest than plant material.
    j. Carnivores have fewer molars for grinding and a shorter digestive tract with less specialization.

36.2 Human Digestive Tract

A. Human Digestion
    1. The human digestive tract is a complete tube-within-a-tube system.
    2. Each part of the digestive system has a specific function.
    3. Food is never found within the accessory glands, only within the tract itself.
    4. The digestion of food in humans is an extracellular process.
    5. Enzymes are secreted into the digestive tract by nearby glands which never contain food themselves.
    6. Digestion requires a cooperative effort by the production of hormones and the actions of the nervous system.

B. Mouth
    1. Human dentition has many specializations because humans are omnivores.
    2. Food is chewed in the mouth and mixed with saliva.
        a. Three pairs of **salivary glands** secrete saliva by way of ducts into the mouth.
        b. **Salivary amylase** is the enzyme that begins starch digestion; maltose is the common end product.

$$\text{starch} + H_2O \xrightarrow{\text{salivary amylase}} \text{maltose}$$

        c. Food is manipulated by a muscular tongue containing both touch and pressure receptors.
        d. **Taste buds** are located primarily on the tongue but also on the surface of the mouth; chemical receptors are stimulated by the chemical composition of food.
        e. Food is chewed and mixed with saliva to form a bolus in preparation for swallowing.

C. The Pharynx and the Esophagus
    1. The digestive and respiratory passages come together in the pharynx, and then separate.
        a. During swallowing, the pathway of air to the lungs could be blocked if food entered the trachea.
        b. The **epiglottis** covers the opening into the **trachea** as muscles move a bolus of food through the pharynx into the esophagus.
    2. The **esophagus** is a muscular tube that moves swallowed food to the **stomach** by **peristalsis**.

D. Stomach
    1. The **stomach** stores liters of partially digested food, freeing humans from continual eating.
    2. Pioneer work by Dr. William Beaumont revealed much of the stomach's functions in the mid-1800s.
        a. The French-Canadian fur trapper Alexis St. Martin had an opening (**fistula**) through which Dr. Beaumont could observe his stomach.
        b. He collected the **gastric juice** produced by cells of **gastric glands**.
        c. Walls of the stomach contract vigorously and mix food with juices secreted when the food enters.
        d. Beaumont found that gastric juice contains hydrochloric acid and another digestive substance, pepsin.
        e. He discovered gastric juices are produced independently of the protective mucous secretions.
        f. His careful work pioneered the study of the physiology of digestion.
    3. **Hydrochloric acid (HCl)** lowers pH of the gastric contents to about 2.
        a. The epithelial lining of the stomach has millions of gastric pits leading to gastric glands.
        b. This acid kills most bacteria and other microorganisms.
        c. The low pH also stops the activity of salivary amylase and promotes the activity of pepsin.

4. **Pepsin** is a hydrolytic enzyme that acts on proteins to produce peptides.

$$\text{protein} + H_2O \xrightarrow{\text{pepsin}} \text{peptides}$$

5. A thick layer of mucus protects the wall of the stomach and the first part of the duodenum from **HCl** and **pepsin**.
6. Ulcers develop when the lining is exposed to digestive action; recent research indicates this is usually due to infection by *Helicobacter pylori* bacteria.
7. Stomach contents, a thick, soupy mixture, are called **chyme**.
8. At the base of the stomach is a narrow opening controlled by a **sphincter** (a circular muscle valve).
   a. When the sphincter relaxes, chyme enters the **duodenum**; a neural reflex causes the sphincter to contract, closing off the opening.
   b. The **duodenum** is the first part of the **small intestine**.
   c. The sphincter relaxes and allows more chyme to enter the duodenum.
   d. The slow, rhythmic pace with which chyme exits the stomach allows for thorough digestion.

E. Small Intestine
1. The human **small intestine** is a coiled muscular tube about three meters long.
2. As chyme enters the duodenum, proteins and carbohydrates are partly digested but no fat digestion occurs.
3. Additional digestion is aided by secretions from the **liver** and the **pancreas**.
   a. **Bile** is a secretion of the **liver** temporarily stored in the **gallbladder** before being sent to duodenum.
   b. Bile emulsifies fat; bile is a green byproduct of the breakdown of hemoglobin.
   c. Bile contains bile salts that help in the emulsification of fat.
      1) Emulsification breaks fat globules into microscopic droplets.

$$\text{fat} \xrightarrow{\text{bile salts}} \text{fat droplets}$$

      2) This increases fat digestion by increasing the surface area of fat globules exposed to enzymes.
   d. **Pancreatic juice** is secreted by the **pancreas** and contains the following:
      1) sodium bicarbonate [$NaCO_3$] that neutralizes acidity of chyme; the pH of small intestine is slightly basic;
      2) pancreatic amylase that digests starch to maltose;

$$\text{starch} + H_2O \xrightarrow{\text{pancreatic amylase}} \text{maltose}$$

      3) trypsin and other enzymes that digest protein to peptides; and

$$\text{protein} + H_2O \rightarrow \text{peptides}$$

      4) lipase that digests fat droplets to glycerol and fatty acids.

$$\text{fat droplets} + H_2O \xrightarrow{\text{lipase}} \text{glycerol} + \text{fatty acids}$$

   e. Epithelial cells of villi produce intestinal enzymes attached to the plasma membrane of microvilli.
   f. Intestinal secretions complete the digestion of peptides and sugars; peptides are digested by peptidases into amino acids

$$\text{peptides} + H_2O \xrightarrow{\text{peptidases}} \text{amino acids}$$

   g. and maltose from the first step in starch digestion is converted by maltase to glucose

$$\text{maltose} + H_2O \xrightarrow{\text{maltase}} \text{glucose} + \text{glucose}$$

5. Large molecules of carbohydrates, proteins and fats are broken into small molecules absorbed by villi.

F. Absorption by Villi
1. The mucous membrane lining has ridges and furrows; these surfaces are covered by **villi**.
   a. **Villi** are fingerlike projections whose surface cells are covered by **microvilli**.
   b. **Microvilli** are minute projections, called a brush border on the surface of cells of the intestinal villi.

c. Ridges, furrows, villi, and microvilli greatly increase the effective surface area of the small intestine.
2. The small intestine is specialized for absorption by the huge number of villi that line the intestinal wall.
3. If the small intestine was merely a smooth tube, it would have to be 500–600 m long to have a comparable surface area.
4. Each villus contains blood vessels and a lymphatic **lacteal**.
5. A **lacteal** is lymphatic vessel in an intestinal villus that aids in absorption of fats.
6. Sugars and amino acids enter villi cells and are absorbed into bloodstream.
7. Glycerol and fatty acids enter villi cells; reassembled into fat molecules, they move into lacteals.
8. Absorption involves diffusion and active transport requiring the expenditure of cellular energy.

G. Control of Digestive Juices
1. **Gastrin** is produced by cells in the gastric glands of the stomach wall; gastrin stimulates gastric glands and increases gastric motility; its secretion is stimulated by a meal rich in protein.
2. **Secretin** is produced by cells in the duodenal wall; secretin stimulates the pancreas to secrete fluids rich in $NaCO_3$ into the duodenum; secretion is stimulated by acid chyme.
3. **Cholecystokinin (CCK)** produced by the duodenal wall stimulates the pancreas to increase pancreatic juice and the liver to increase the output of bile; it also causes the gallbladder to release bile; secretion of CCK is stimulated by fats.
4. **Gastric inhibitory peptide (GIP)** from the duodenal wall inhibits both gastric gland secretion and stomach motility.

H. Accessory Organs
1. Pancreas
a. The **pancreas** lies deep within the abdominal cavity, just below the stomach, and rests on the posterior abdominal wall.
b. It is an elongated and somewhat flattened organ.
c. As an endocrine gland, it secretes glucagon and insulin hormone into the bloodstream.
d. As an exocrine gland, it secretes pancreatic juice.
1) Pancreatic juice contains sodium bicarbonate that neutralizes acidic chyme.
2) Pancreatic enzymes digest carbohydrates, fats and proteins.
2. The **liver** is a large glandular organ that fills the top of abdominal cavity, just below the diaphragm.
a. Liver has numerous functions:
1) The liver detoxifies blood by removing and metabolizing poisonous substances.
2) The liver makes plasma proteins including albumin and fibrinogen.
3) The liver destroys old red blood cells and converts hemoglobin to bilirubin and biliverdin in bile.
4) It produces bile stored in the **gallbladder** before it enters the duodenum to emulsify fats.
5) It stores glucose as glycogen and breaks down glycogen to maintain a constant blood glucose concentration.
6) The liver produces urea from amino groups and ammonia.
b. Blood vessels from both the large and small intestines lead to the liver as the hepatic portal vein.
c. The liver maintains the blood glucose level at 0.1% by removing glucose from the hepatic portal vein to store as glycogen; when needed, glycogen is broken down and glucose re-enters the hepatic vein.
d. Amino acids can be converted to glucose but deamination (removal of amino groups) must occur.
e. Using complex metabolic pathway, the liver converts amino groups to urea.
f. Urea is the most common human nitrogenous waste; it is transported by the blood to the kidneys.
3. Liver Disorders
a. Jaundice is a symptom involving a yellowish skin due to a large amount of bilirubin in blood.
b. In *hemolytic jaundice,* the RBCs are broken down in abnormally large amounts.
c. In *obstructive jaundice,* there is blockage of the bile ducts (gallstones) or damage to liver cells.
d. *Viral hepatitis* is a viral liver infection.
1) Hepatitis A results from eating contaminated food.
2) Hepatitis B and C are spread by blood transfusions, kidney dialysis, and unsterile needle use.
3) All three can be caused from sexual contact.
e. Cirrhosis is a chronic disease where the liver tissue is replaced by fatty tissue and then scar tissue; alcoholics provide too much alcohol for the liver to break down.

I. Large Intestine
    1. The **large intestine** is the region following the small intestine.
    2. It has four parts: the cecum, colon, rectum, and anal canal.
    3. Appendix
        a. Th appendix is a fingerlike projection extending from the **cecum,** a blind sac at the junction of small and large intestine.
        b. It may play a role in fighting infections.
        c. If infected appendix bursts, it results in general abdominal infection (**peritonitis**).
    4. About 1.5 liters of water enter the digestive tract daily from drinking and another 8.5 liters enter from various secretions.
        a. About 95% of this total liquid is reabsorbed by the small intestine; most of the remainder is absorbed by cells of the colon.
        b. If the water is not reabsorbed, it causes **diarrhea** which can cause a serious dehydration and ion loss.
    5. The large intestine functions in ion regulation, absorbing salts plus the vitamin K produced by intestinal bacteria.
    6. The large intestine terminates at the **anus**, an external opening.
    7. Feces
        a. Feces consists of about 75% water and 25% solid matter.
        b. One-third of the the solid matter is intestinal bacteria.
        c. The remainder is undigested wastes, fats, organic material, mucus, and dead cells from the intestinal lining.
    8. Intestinal **polyps** are small growths arising from epithelial lining.
        a. Whether they are benign or cancerous, polyps can be removed surgically.
        b. A low-fat, high-fiber diet promotes regularity and may provide protection against mutagenic agents.

36.3 Nutrition

A. A **balanced diet**, required for good health, includes a properly proportioned variety of foods.
B. Vitamins
    1. **Vitamins** are essential organic compounds the body cannot make but still requires for metabolic activities.
    2. Many vitamins are portions of coenzymes: niacin is part of NAD^+ and riboflavin is a part of FAD.
    3. Coenzymes are needed in small amounts because they are used over again and again.
    4. Vitamin A is not a coenzyme but a precursor for the visual pigment that prevents night blindness.
    5. Lack of vitamins results in vitamin deficiencies.
    6. The 13 vitamins are divided into those that are fat soluble and those that are water soluble.
C. Antioxidants
    1. Cell metabolism generates **free radicals**, unstable molecules with an extra electron; O_3^- is a common free radical.
    2. Free radicals stabilize by eventually donating electrons to another molecule; this damages cellular molecules.
    3. Free radicals damage DNA, proteins, and other molecules by donating an electron; this may cause cancer or plaque in arteries.
    4. Vitamins C, E, and A—abundant in fruits and vegetables—are antioxidants that defend against free radicals.
    5. Supplements do not replace fruits and vegetables that also contain many other beneficial compounds.
D. Vitamin D
    1. Skin cells contain a precursor cholesterol molecule converted to vitamin D by UV light exposure.
    2. Only a small amount of UV is needed to cause this change.
    3. Vitamin D leaves the skin and is modified in the kidneys and then in the liver until it becomes calcitriol.
    4. Calcitriol circulates throughout the body regulating calcium uptake and metabolism.
    5. Calcitriol promotes absorption of calcium by the intestines.
    6. The lack of vitamin D leads to rickets in children; poor mineralization of the skeleton causes bowing of the legs.
    7. Most milk is fortified with vitamin D to prevent rickets.

E. Minerals
    1. We require **macrominerals** (e.g., calcium, phosphorus) in amounts of over 100 mg per day.
        a. They are constituents of cells and body fluids and structural components of tissues.
        b. Calcium is needed to build bones and teeth and for nerve conduction and muscle contraction.
    2. **Microminerals** are elements (e.g., zinc, iron) recommended in amounts less than 20 mg per day.
        a. These microminerals are more likely to have very specific functions.
        b. Iron is needed to produce hemoglobin; adult females need more due to menstrual loss of blood.
        c. Iodine is used to produce thyroxin, a hormone of the thyroid glands.
        d. Minute amounts of molybdenum, selenium, chromium, nickel, vanadium, silicon, and arsenic are essential.
        e. Some individuals may not receive enough calcium, stress can cause a magnesium deficiency, and a vegetarian diet may be short on zinc.

G. Calcium
    1. Calcium supplements counteract the osteoporosis that afflicts 25% of older men and 50% of older women.
    2. Porous bones break easily due to lack of calcium.
    3. After menopause, bone-eating cells called osteoclasts are more active than bone-forming osteoblasts.
    4. Calcium supplements have been shown to slow bone loss in the elderly.
    5. Intake of 1,000–1,500 mg calcium/day is recommended; therefore supplemental calcium is usually necessary.
    6. Exercise is also effective in building bone mass.

G. Sodium
    1. The recommended daily intake of sodium is 400–3,300 mg; average American intake is 4,000–4,700 mg.
    2. A high sodium intake has been linked to hypertension in some people.
    3. One third of our sodium intake is found naturally in foods; another third is added in processing.
    4. We add one-third of our salt intake in cooking or as table salt.