

## Digestive System

1. General
  - a. Animals obtain energy by breaking food molecules into smaller pieces.
  - b. The basic fuel molecules are amino acids, lipids and sugars
  - c. Digestion is the chemical breakdown of large food molecules into smaller molecules that can be used by cells. The processing of food has four basic steps:
    - i. Ingestion
    - ii. Digestion
    - iii. Absorption
    - iv. Elimination
  - d. Digestion occurs in two different ways
    - i. Mechanical digestion - breaking food into smaller pieces.
    - ii. Chemical digestion - breaking food into smaller molecules.
  
2. Food enters the digestive tract through the mouth.
  - a. Chewing breaks food into smaller particles so that chemical digestion can occur faster.
  - b. Teeth are important to animal digestion for capturing, tearing, and chewing food.
    - i. Carnivores possess pointed teeth for capture, cutting and shearing.
    - ii. Herbivores have large, flat teeth suited for grinding plant materials.
    - iii. Omnivores have both types, front like carnivores, back like herbivores.
  - c. Food is moistened and lubricated in the mouth.
    - i. Tongue mixes food with saliva.
    - ii. Saliva is secreted by salivary glands.
    - iii. Contains the enzyme salivary amylase to begin the breakdown of starch.
    - iv. There is continuous secretion to keep the mouth moist and to lubricate food.
    - v. Secretion of saliva is stimulated by the presence of food.
  
3. Food passes to the stomach through the esophagus.
  - a. Mucous lubricates and helps hold the chewed food together in a clump called a bolus.
  - b. The tongue is muscular and is used to move food. It pushes food to the back of the mouth where it is swallowed. As the tongue moves the bolus to the back of the mouth, the swallowing reflex takes over to move the bolus down the esophagus.
  - c. The respiratory and digestive passages meet in the pharynx. They separate posterior to the pharynx to form the esophagus (leading to the stomach) and the trachea (leading to the lungs). When swallowing, the epiglottis automatically moves up to block the passage to the trachea so that food does not end up in the lungs.
  - d. The bolus is moved to the stomach by peristalsis (rhythmic muscle contractions).
  - e. A muscle called the cardiac sphincter controls the movement of food from the esophagus to the stomach.
  - f. This muscle prevents food in the stomach from reentering the esophagus. Sometimes acid does splash up into the esophagus causing what we call heartburn.
  
4. Preliminary digestion occurs in the stomach
  - a. The lining of the stomach is highly folded and expands as it fills with food.
  - b. The stomach has an extra layer of muscle to churn food. The mixture of partly digested food and gastric juice is called chyme.

- c. Cells of the stomach lining secrete hydrochloric acid (HCl) which keeps the stomach contents at a pH of about 2, helping to digest proteins. The low pH also kills most bacteria. The cells of the lining are protected by a coating of mucous that is constantly replaced as the acid destroys it.
  - d. They also secrete pepsinogen, a protein digesting enzyme. Inactive pepsinogen is cleaved to form pepsin - the active form of the enzyme. This is important to protect the cells that produce pepsin from being digested themselves. Pepsin is most active in a pH of 2.
  - e. The stomach produces about 2 L of acid and gastric secretions per day. Seeing, smelling, tasting, or thinking about food can result in the secretion of gastric juice.
  - f. Pepsin cuts proteins into short pieces and they are not further digested until they reach the small intestine.
  - g. There is no digestion of carbohydrates or fats in stomach.
  - h. If the stomach lining is not protected, gastric juice can dissolve a hole through it, causing a gastric ulcer. Most gastric ulcers are caused by certain bacteria which can survive in the acidic environment of the stomach. The growth of the bacteria on the stomach lining cause an irritation and results in the production of too much acid. Duodenal (intestinal) ulcers are more common, resulting when excessive acidic chyme is passed to the duodenum.
  - i. Very little absorption occurs in the stomach, with some exceptions such as water, aspirin and alcohol. All other absorption occurs in the intestine.
5. Other digestion and absorption of molecules take place in the small intestine.
- a. The duodenum is the first part of the small intestine. The passage of food from the stomach to the small intestine is regulated by a muscle called the pyloric sphincter, which allows chyme to enter the duodenum in small spurts.
  - b. The capacity of the small intestine is limited and digestion takes time so only small amounts of chyme are permitted to enter at a time.
  - c. The small intestine is where most digestion occurs.
    - i. The length is approximately three meters. The first part, the duodenum, is about the first 25 centimeters. The other two sections are the jejunum and ileum.
    - ii. At this point, proteins and carbohydrates are only partially digested and lipid digestion has not begun.
    - iii. In the duodenum, chyme, pancreatic enzymes, and bile from the liver and gallbladder are mixed.
    - iv. The presence of food in the duodenum also triggers the release of various hormones
      - (1) The intestine must be protected from the acid contained in gastric juice. When chyme enters the small intestine, the cells of the duodenum release the hormone secretin. This hormone stimulates the pancreas to produce sodium bicarbonate, which neutralizes the acidic chyme and shuts off pepsin. It also stimulates the liver to secrete bile.
      - (2) Another hormone (CCK, cholecystokinin), stimulates the gallbladder to release bile and the pancreas to produce pancreatic enzymes.
      - (3) Another hormone (GIP, gastrin inhibitory protein) inhibits gastric glands in the stomach and inhibits the mixing and churning movement of stomach muscles. This slows the rate of stomach emptying when the duodenum contains food.

- v. Digestion continues and absorption occurs in all three sections of the small intestine.
  - (1) Digestive enzymes secreted by the cells of the small intestine digest lactose, sucrose and other sugars. Some adults lose the ability to produce lactase, resulting in the condition called lactose intolerance.
  - (2) Absorption of food in the intestine.
    - (a) The walls of the small intestine are covered with small projections called villi. These increase the surface area of the small intestine to increase absorption.
    - (b) The villi themselves are covered with many tiny projections called microvilli, which increase the surface area still further.
    - (c) The molecules resulting from the digestion of proteins and carbohydrates are absorbed by cells of the intestinal lining.
    - (d) The villi contain capillaries, tiny blood vessels which allows efficient transfer of these molecules to the blood.
    - (e) The products of fat digestion are absorbed through the villi into the lymphatic system. They enter the blood stream near the neck where the lymphatic system joins the circulatory system.
  
- 6. The pancreas secretes enzymes, bicarbonate and hormones.
  - a. The pancreas is located below the stomach.
  - b. Secretions of the pancreas reach the duodenum via the pancreatic duct. The fluid contains
    - i. The protein digesting enzyme trypsin.
    - ii. The starch digesting enzyme pancreatic amylase.
    - iii. The fat digesting enzyme lipase.
    - iv. Bicarbonate to neutralize HCl from the stomach.
  - c. The pancreas also produces hormones that regulate levels of sugar in the blood. These hormones, insulin and glucagon, are produced by clusters of cells called islets of Langerhans. See the Liver below.
  
- 7. The liver produces bile and regulates blood composition.
  - a. Role in Digestion
    - i. Old red blood cells are destroyed by the liver and the hemoglobin from these cells is used to make bile. The remains of the red blood cells are eliminated with feces and give it its characteristic brown color.
    - ii. Bile is stored and concentrated in gall bladder. The presence of fatty food in the duodenum triggers the gallbladder to release bile.
    - iii. Bile travels through the common bile duct to the duodenum.
    - iv. Bile salts are soluble in both lipids and water. This enables them to break apart fat droplets in chyme to create smaller droplets. This increases the surface area for lipase to work on and increases the speed of their digestion.
    - v. Cholesterol can bind bile together causing crystals to form. If these crystals become large enough they can block the common bile duct.
    - vi. If the common bile becomes blocked, bile salts can accumulate in the skin and produce a yellow color in a condition called jaundice.

- b. Regulation of blood composition.
  - i. Another role of the liver is to remove toxins from the blood.
  - ii. The liver absorbs or chemically modifies toxic substances to prevent them remaining in circulation.
  - iii. Ammonia produced by the digestion of proteins is converted to a less toxic compound (urea) by the liver. Urea is removed from the blood by the kidneys and eliminated in urine.
  - iv. Alcohol and drugs are metabolized by liver cells into less harmful compounds. Other toxins, pesticides, and carcinogens are also detoxified.
  - v. These less harmful compounds are returned to the blood and are removed by the kidneys.
  - vi. If the liver is chronically exposed to toxins, the cells become damaged and die. The result is cirrhosis of the liver.
- c. Regulation of blood glucose levels.
  - i. It is important to maintain a constant concentration of blood glucose so that cells have a steady supply. This is especially important for brain cells which store little glucose, and cannot use fat or amino acids as an energy source.
  - ii. Vertebrates eat sporadically when food is available and, often, a period of fasting occurs between meals. Also, most food is digested rapidly, and the resulting molecules (including glucose) enter the blood stream. Without some control, the level of glucose (and other compounds) in the blood would be quite variable.
  - iii. The liver removes glucose from blood, converting it into glycogen. Glycogen is stored in both the liver and in skeletal muscle.
  - iv. The conversion of glucose to glycogen is stimulated by the pancreatic hormone, insulin. If blood glucose is high (such as after eating) the release of insulin from the pancreas causes the liver to store glucose. If blood glucose level is low (such as between meals), the opposing pancreatic hormone glucagon causes the liver to secrete glucose into the blood.
  - v. The liver stores enough glycogen for about 12-18 hours of fasting. If food is still unavailable after that, amino acids (from muscles) and fats (from fat stored in fat cells) are used as a source of energy.

8. The large intestine concentrates solids by reabsorbing water.
- a. The large intestine or colon comprises last meter of the digestive tract.
  - b. It has no digestive function, but functions to absorb water. If water is not absorbed, as can happen during certain bacterial infections, diarrhea can result, causing dehydration and salt loss.
  - c. The daily total volume of food and water we take in from eating is about 2 L (including about 800 g of solids). The body adds about 7 L of its own fluids making a total of 9 L.
    - i. 1.5 L saliva and salivary enzymes
    - ii. 2 L of gastric secretions
    - iii. 1.5 L of pancreatic secretions
    - iv. 0.5 L of bile from the liver
    - v. 1.5 L of intestinal secretions
  - d. Nearly all fluids and solids are absorbed so that only 50 g of solids and 100 mL of liquid leave as feces. The large intestine (along with some absorbed by the small intestine) recovers about 90% of the water that enters the digestive system. Remember that this is very important for a terrestrial vertebrate.

- e. Undigested material is compacted and stored until the colon is full. When the colon is full, a signal to empty it is sent by sensors in the walls of the colon.
- f. Bacteria (mostly *E. coli*) live and reproduce in the colon. Anaerobic digestion (fermentation) of material by these bacteria produces gas in the colon. They also produce vitamins for the host, including vitamin K some B vitamins. Bacteria are lost when feces is eliminated, making exposure to feces dangerous.
- g. Fiber (cellulose) tends to fill up the colon and cause it to be emptied. Low fiber diets result in slower passage of food through colon and have been linked to colon cancer.
- h. The rectum is the last section of the large intestine. Feces pass into the rectum by peristaltic contractions and material exits through the anus, a sphincter muscle.
- i. Feces is composed of approximately 75% water and 25% solids. One third of the solids is intestinal bacteria, 2/3 is undigested materials.