Section D: The Mammalian Digestive System

1. The oral cavity, pharynx, and esophagus initiate food processing
2. The stomach stores food and performs preliminary digestion
3. The small intestine is the major organ of digestion and absorption
4. Hormones help regulate digestion
5. Reclaiming water is major function of the large intestine
Introduction

• The general principles of food processing are similar for a diversity of animals, including the mammalian system which we will use as a representative example.

• The mammalian digestive system consists of the alimentary canal and various accessory glands that secrete digestive juices into the canal through ducts.

  • **Peristalsis**, rhythmic waves of contraction by smooth muscles in the walls of the canal, push food along.

  • **Sphincters**, muscular ringlike valves, regulate the passage of material between specialized chambers of the canal.

  • The accessory glands include the **salivary glands**, the **pancreas**, the **liver**, and the **gallbladder**.
• After chewing and swallowing, it takes 5 to 10 seconds for food to pass down the esophagus to the stomach, where it spends 2 to 6 hours being partially digested.

• Final digestion and nutrient absorption occur in the small intestine over a period of 5 to 6 hours.

• In 12 to 24 hours, any undigested material passes through the large intestine, and feces are expelled through the anus.
1. The oral cavity, pharynx, and esophagus initiate food processing

- Both physical and chemical digestion of food begins in the mouth.
  - During chewing, teeth of various shapes cut, smash, and grind food, making it easier to swallow and increasing its surface area.
  - The presence of food in the oral cavity triggers a nervous reflex that causes the salivary glands to deliver saliva through ducts to the oral cavity.
  - Salivation may occur in anticipation because of learned associations between eating and the time of day, cooking odors, or other stimuli.
• Saliva contains a slippery glycoprotein called mucin, which protects the soft lining of the mouth from abrasion and lubricates the food for easier swallowing.
  
• Saliva also contains buffers that help prevent tooth decay by neutralizing acid in the mouth.
  
• Antibacterial agents in saliva kill many bacteria that enter the mouth with food.
• Chemical digestion of carbohydrates, a main source of chemical energy, begins in the oral cavity.
  • Saliva contains salivary amylase, an enzyme that hydrolyzes starch and glycogen into smaller polysaccharides and the disaccharide maltose.
• The tongue tastes food, manipulates it during chewing, and helps shape the food into a ball called a bolus.
  • During swallowing, the tongue pushes a bolus back into the oral cavity and into the pharynx.
• The **pharynx**, also called the throat, is a junction that opens to both the esophagus and the trachea (windpipe).

  • When we swallow, the top of the windpipe moves up such that its opening, the glottis, is blocked by a cartilaginous flap, the **epiglottis**.

  • This mechanism normally ensures that a bolus will be guided into the entrance of the esophagus and not directed down the windpipe.
(1) When not swallowing, the esophageal sphincter muscles is contracted, the epiglottis is up, and the glottis is open, allowing airflow to the lungs.

(2) When a food bolus reaches the pharynx, (3) the larynx moves upward and the epiglottis tips over the glottis, closing off the trachea.

(4) The esophageal sphincter relaxes and the bolus enters the esophagus.

(5) In the meantime, the larynx moves downward and the trachea is opened, (6) where it is pushed by peristalsis to the stomach.
• The esophagus conducts food from the pharynx down to the stomach by peristalsis.
  
  • The muscles at the very top of the esophagus are striated and therefore under voluntary control.
  
  • Involuntary waves of contraction by smooth muscles in the rest of the esophagus then takes over.
2. The stomach stores food and performs preliminary digestion

- The stomach is located in the upper abdominal cavity, just below the diaphragm.
  - With accordionlike folds and a very elastic wall, the stomach can stretch to accommodate about 2 L of food and fluid, storing an entire meal.
  - The stomach also secretes a digestive fluid called **gastric juice** and mixes this secretion with the food by the churning action of the smooth muscles in the stomach wall.
• Gastric juice is secreted by the epithelium lining numerous deep pits in the stomach wall.

• With a high concentration of hydrochloric acid, the pH of the gastric juice is about 2 - acidic enough to digest iron nails.

• This acid disrupts the extracellular matrix that binds cells together.

• It kills most bacteria that are swallowed with food.

• Also present in gastric juice is pepsin, an enzyme that begins the hydrolysis of proteins.

• Pepsin, which works well in strongly acidic environments, breaks peptide bonds adjacent to specific amino acids, producing smaller polypeptides.
• Pepsin is secreted in an *inactive* form, called **pepsinogen** by specialized chief cells in gastric pits.

• Parietal cells, also in the pits, secrete hydrochloric acid which converts pepsinogen to the active pepsin only when both reach the lumen of the stomach, minimizing self-digestion.

• Also, in a positive-feedback system, activated pepsin can activate more pepsinogen molecules.
• The stomach’s second line of defense against self-digestion is a coating of mucus, secreted by epithelial cells, that protects the stomach lining.

• Still, the epithelium is continually eroded, and the epithelium is completely replaced by mitosis every three days.

• Gastric ulcers, lesions in the stomach lining, are caused by the acid-tolerant bacterium *Heliobacter pylori*.

  • Ulcers are often treated with antibiotics.
• About every 20 seconds, the stomach contents are mixed by the churning action of smooth muscles.

• As a result of mixing and enzyme action, what begins in the stomach as a recently swallowed meal becomes a nutrient-rich broth known as **acid chyme**.
• Most of the time the stomach is closed off at either end.

• The opening from the esophagus to the stomach, the cardiac orifice, normally dilates only when a bolus driven by peristalsis arrives.

• The occasional backflow of acid chyme from the stomach into the lower esophagus causes heartburn.

• At the opening from the stomach to the small intestine is the pyloric sphincter, which helps regulate the passage of chyme into the intestine.

• A squirt at a time, it takes about 2 to 6 hours after a meal for the stomach to empty.
3. The small intestine is the major organ of digestion and absorption

- With a length of over 6 m in humans, the small intestine is the longest section of the alimentary canal.

- Most of the enzymatic hydrolysis of food macromolecules and most of the absorption of nutrients into the blood occurs in the small intestine.
• In the first 25 cm or so of the small intestine, the **duodenum**, acid chyme from the stomach mixes with digestive juices from the pancreas, liver, gall bladder, and gland cells of the intestinal wall.

• The pancreas produces several hydrolytic enzymes and an alkaline solution rich in bicarbonate which buffers the acidity of the chyme from the stomach.
• The liver performs a wide variety of important functions in the body, including the production of bile.

• Bile is stored in the gallbladder until needed.

• It contains bile salts which act as detergents that aid in the digestion and absorption of fats.

• Bile also contains pigments that are by-products of red blood cell destruction in the liver.

• These bile pigments are eliminated from the body with the feces.
Specific enzymes from the pancreas and the duodenal wall have specific roles in digesting macromolecules.

<table>
<thead>
<tr>
<th>Oral cavity, pharynx, esophagus</th>
<th>(a) Carbohydrate digestion</th>
<th>(b) Protein digestion</th>
<th>(c) Nucleic acid digestion</th>
<th>(d) Fat digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysaccharides (starch, glycogen)</td>
<td>Salivary amylase</td>
<td>Proteins</td>
<td>DNA, RNA</td>
<td>Fat globules</td>
</tr>
<tr>
<td>Smaller polysaccharides, maltose</td>
<td></td>
<td>Small polypeptides</td>
<td>Nucleases</td>
<td>Bile salts</td>
</tr>
</tbody>
</table>

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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trypsin, Chymotrypsin</td>
<td>Nucleases</td>
<td>Bile salts</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Nucleotides</td>
<td>Fat droplets (emulsified)</td>
</tr>
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<td></td>
<td></td>
<td>Aminopeptidase, Carboxypeptidase</td>
<td></td>
<td>Lipase</td>
</tr>
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<td></td>
<td></td>
<td>Amino acids</td>
<td></td>
<td>Glycerol, fatty acids, glycerides</td>
</tr>
</tbody>
</table>

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<tr>
<th>Lumen of small intestine</th>
<th>Polysaccharides</th>
<th>Polypeptides</th>
<th>DNA, RNA</th>
<th>Fat globules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltose and other disaccharides</td>
<td>Trypsin, Chymotrypsin</td>
<td>Nucleases</td>
<td>Bile salts</td>
<td></td>
</tr>
<tr>
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<td></td>
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</tr>
</tbody>
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<th>Epithelium of small intestine (brush border)</th>
<th>Disaccharidases</th>
<th>Small peptides</th>
<th>Nucleotidases</th>
<th>Nucleosidases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monosaccharides</td>
<td>Dipeptidases</td>
<td>Nucleosides</td>
<td>Nitrogenous bases, sugars, phosphates</td>
<td></td>
</tr>
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Fig. 41.17

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The digestion of starch and glycogen, begun by salivary amylase in the oral cavity, continues in the small intestine.

- Pancreatic amylases hydrolyze starch, glycogen, and smaller polysaccharides into disaccharides.
- A family of disaccharidases hydrolyze each disaccharide into monomers.
  - Maltase splits maltose into two glucose molecules.
  - Sucrase splits sucrose, a sugar found in milk, into glucose and fructose.
- These enzymes are built into the membranes and extracellular matrix of the intestinal epithelium which is also the site of sugar absorption.
• Digestion of proteins in the small intestine completes the process begun by pepsin.
  
  • Several enzymes in the duodenum dismantle polypeptides into their amino acids or into small peptides that in turn are attacked by other enzymes.
    
    • **Trypsin** and **chymotrypsin** attack peptide bonds adjacent to specific amino acids, breaking larger polypeptides into shorter chains.
    
    • **Dipeptidase**, attached to the intestinal lining, split smaller chains.
    
    • **Carboxypeptidases** and **aminopeptidase** split off one amino acid from the carboxyl or amino end of a peptide, respectively.

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Many of the protein-digesting enzymes, such as aminopeptidase, are secreted by the intestinal epithelium, but trypsin, chymotrypsin, and carboxypeptidase are secreted in inactive form by the pancreas.

Another intestinal enzyme, **enteropeptidase**, converts inactive trypsinogen into active trypsin.

Active trypsin then activates the other two.
• The digestion of nucleic acids involves a hydrolytic assault similar to that mounted on proteins.
  • A team of enzymes called nucleases hydrolyzes DNA and RNA into their component nucleotides.
  • Other hydrolytic enzymes then break nucleotides down further into nucleosides, nitrogenous bases, sugars, and phosphates.
• Nearly all the fat in a meal reaches the small intestine undigested.

• Normally fat molecules are insoluble in water, but bile salts, secreted by the gallbladder into the duodenum, coat tiny fats droplets and keep them from coalescing, a process known as emulsification.

• The large surface area of these small droplets is exposed to lipase, an enzyme that hydrolyzes fat molecules into glycerol, fatty acids, and glycerides.
• Most digestion occurs in the duodenum.

• The other two sections of the small intestine, the **jejunum** and **ileum**, function mainly in the absorption of nutrients and water.

• To enter the body, nutrients in the lumen must pass the lining of the digestive tract.
  
  • The small intestine has a huge surface area - 300 m², roughly the size of a tennis court.
• The enormous surface of the small intestine is an adaptation that greatly increases the rate of nutrient absorption.

• Large circular folds in the lining bear fingerlike projections called villi, and each epithelial cell of a villus has many microscopic appendages called microvilli that are exposed to the intestinal lumen.
• Penetrating the core of each villus is a net of microscopic blood vessels (capillaries) and a single vessel of the lymphatic system called a lacteal.

• Nutrients are absorbed across the intestinal epithelium and then across the unicellular epithelium of capillaries or lacteals.

• Only these two single layers of epithelial cells separate nutrients in the lumen of the intestine from the bloodstream.
• In some cases, such as fructose, transport of nutrients across the epithelial cells is passive, as molecules move down their concentration gradients from the lumen of the intestine into the epithelial cells, and then into capillaries.

• Other nutrients, including amino acids, small peptides, vitamins, and glucose, are pumped against concentration gradients by epithelial membranes.

• This active transport allows the intestine to absorb a much higher proportion of the nutrients in the intestine than would be possible with passive diffusion.
• In some cases, transport of nutrients across the epithelial cells is passive.
  • Compounds like fructose move down their concentration gradients from the lumen of the intestine into the epithelial cells, and then into capillaries.
  • Most are transported by exocytosis out of epithelial cells and into lacteals.
  • The lacteals converge into the larger vessels of the lymphatic system, eventually draining into large veins that return blood to the heart.
• In contrast, glycerol and fatty acids absorbed by epithelial cells are recombined into fats.

• The fats are mixed with cholesterol and coated with special proteins to form small globules called **chylomicrons**.
  
  • The capillaries and veins that drain nutrients away from the villi converge into the **hepatic portal vessel**, which leads directly to the liver.
• Therefore, the liver - which has the metabolic versatility to interconvert various organic molecules - has first access to amino acids and sugars absorbed after a meal is digested.

• The liver modifies and regulates this varied mix before releasing materials back into the bloodstream.

  • For example, the liver helps regulate the levels of glucose in the blood, ensuring that blood exiting the liver usually has a glucose concentration very close to 0.1%, regardless of carbohydrate content of the meal.
• The digestive and absorptive processes is very effective in obtaining energy and nutrients.
  • People eating the typical diets consumed in developed countries usually absorb 80 to 90 percent of the organic material in their food.
  • Much of the undigestible material is cellulose from plant cell walls.
• The active mechanisms of digestion, including peristalsis, enzyme secretion, and active transport, may require that an animal expend an amount of energy equal to between 3% and 30% of the chemical energy contained in the meal.
4. Hormones help regulate digestion

- Hormones released by the wall of the stomach and duodenum help ensure that digestive secretions are present only when needed.
  - When we see, smell, or taste food, impulses from the brain initiate the secretion of gastric juice.
  - Certain substances in food stimulate the stomach wall to release the hormone gastrin into the circulatory system.
    - As it recirculates, gastrin stimulates further secretion of gastric juice.
    - If the pH of the stomach contents becomes too low, the acid will inhibit the release of gastrin.
• Other hormones, collectively called **enterogastrones**, are secreted by the walls of the duodenum.

• The acidic pH of the chyme entering the duodenum stimulates epidermal cells to release the hormone **secretin** which signals the pancreas to release bicarbonate to neutralize the chyme.

• **Cholecystokinin (CCK)**, secreted in response to the presence of amino acids or fatty acids, causes the gallbladder to contract and release bile into the small intestine and triggers the release of pancreatic enzymes.

• The chyme, particularly if rich in fats, causes the duodenum to release other enterogastrones that inhibit peristalsis by the stomach, slowing entry of food.
5. Reclaiming water is a major function of the large intestine

- The **large intestine**, or **colon**, is connected to the small intestine at a T-shaped junction where a sphincter controls the movement of materials.
  - One arm of the T is a pouch called the **cecum**.
    - The relatively small cecum of humans has a fingerlike extension, the **appendix**, that makes a minor contribution to body defense.
  - The main branch of the human colon is shaped like an upside-down U about 1.5 m long.
• A major function of the colon is to recover water that has entered the alimentary canal as the solvent to various digestive juices.

• About 7 L of fluid are secreted into the lumen of the digestive tract of a person each day.

• Over 90% of the water is reabsorbed, most in the the small intestine, the rest in the colon.

• Digestive wastes, the **feces**, become more solid as they are moved along the colon by peristalsis.

• Movement in the colon is sluggish, requiring 12 to 24 hours for material to travel the length of the organ.

• Diarrhea results if insufficient water is absorbed and constipation if too much water is absorbed.
Living in the large intestine is a rich flora of mostly harmless bacteria.

- One of the most common inhabitants of the human colon is *Escherichia coli*, a favorite research organism.
- As a byproduct of their metabolism, many colon bacteria generate gases, including methane and hydrogen sulfide.
- Some bacteria produce vitamins, including biotin, folic acid, vitamin K, and several B vitamins, which supplement our dietary intake of vitamins.
• Feces contain masses of bacteria and undigested materials including cellulose.
  
  • Although cellulose fibers have no caloric value to humans, their presence in the diet helps move food along the digestive tract.
  
  • The feces may also contain excess salts that are excreted into the lumen of the colon.
• The terminal portion of the colon is called the **rectum**, where feces are stored until they can be eliminated.
  
  • Between the rectum and the anus are two sphincters, one involuntary and one voluntary.
  
  • Once or more each day, strong contractions of the colon create an urge to defecate.