ANATOMY OF THE DIGESTIVE SYSTEM

1. The digestive system consists of the digestive tract and accessory digestive organs. The digestive tract is also called the alimentary (relating to nourishment) tract or the gastrointestinal (GI) tract, although the term gastrointestinal technically refers to only the stomach and the intestines.

2. The digestive tract is about 30 feet long and it passes through the body (a tube within a tube). Consequently, materials within the digestive tract are not inside the body.

3. The digestive tract is the site of the mechanical and chemical breakdown of food, the absorption of food, and the elimination of wastes. It consists of the following parts.
   A. Oral cavity
   B. Pharynx
   C. Esophagus
   D. Stomach
   E. Small intestine
      1) Duodenum
      2) Jejunum
      3) Ileum
   F. Large intestine
      1) Cecum and appendix
      2) Ascending, transverse, descending and sigmoid colons
      3) Rectum and anal canal

4. Accessory digestive organs secrete chemicals that function in the breakdown and absorption of food. They also excrete chemicals that are waste products. The accessory digestive organs are:
   A. Salivary glands
   B. Liver
   C. Gallbladder
   D. Pancreas
FUNCTIONS OF THE DIGESTIVE SYSTEM

Ingest food and water

Mechanical and chemical alteration
(complex molecules broken down into simple molecules)

Unused materials out Used materials absorbed
in feces into blood or lymph

Materials enter cells

"Metabolic Mill"

Waste products Synthesis of complex Synthesis of ATP
(eliminated by molecules from simple (energy)
kidneys, etc.) molecules

HISTOLOGY OF THE DIGESTIVE TRACT
The digestive tract consists of four layers or tunics.

FIGURE 24.4

Mucosa
1. The mucosa is the innermost layer of the digestive tract. It is an example of a mucous membrane. Recall that mucous membranes line cavities and passages that open to the outside of the body. Other mucous membranes are found lining the respiratory, excretory, and reproductive passages.

2. The mucosa consists of three parts:
   A. Mucous epithelium.
      1) The oral cavity, esophagus, and anal canal are moist stratified squamous epithelium.
      2) The stomach to the rectum is simple columnar epithelium.

   Explain the locations of the two different types of epithelium lining the digestive tract based on your knowledge of the functions of different types of epithelia.
B. The lamina propria is loose connective tissue containing blood vessels and lymphatic tissue. The mucous epithelium and the lamina propria form the mucous membrane of the digestive tract.

C. The muscularis mucosae is a thin layer of smooth muscle.

Submucosa
The submucosa is dense or loose connective tissue containing blood vessels, lymphatic tissue, glands, and a submucosal nerve plexus.

Muscularis
1. The muscularis usually consists of two layers of muscle.
   A. There is an inner layer of circular muscle and an outer layer of longitudinal muscle. In the stomach there is also an oblique layer.

   B. The upper part of the esophagus is skeletal muscle. The remaining inferior part of the digestive tract is smooth muscle.

   C. The myenteric nerve plexus is between the circular and longitudinal muscle layers.

2. Functions.
   A. The muscularis is responsible for mixing up the contents of the digestive tract and for moving materials through the digestive tract.

   B. In some locations the circular part of the muscularis thickens to form sphincter muscles that regulate the movement of materials through the digestive tract.

3. The enteric nerve plexus is a complex interconnection of nerve cells within the wall of the digestive tract.
   A. The enteric nerve plexus consists of parasympathetic neurons, sympathetic neurons, enteric neurons, and sensory neurons (see chapter 16).

   B. The enteric nerve plexus consists of the submucosal plexus found in the submucosa, and the myenteric plexus found in the muscularis.

   C. The enteric nerve plexus functions to coordinate movement and secretory activities of the digestive tract.
**Serosa or Adventitia**
1. The outer layer of the digestive tract is called the serosa or adventitia.

2. The *serosa* is a serous membrane (visceral peritoneum) that forms the outer layer of most of the digestive tract. It consists of simple squamous epithelium and a thin layer of connective tissue.

3. *Adventitia* is the outermost connective tissue covering of an organ or structure that is derived from adjacent connective tissue. The esophagus and parts of retroperitoneal organs are covered by adventitia.

**REGULATION OF THE DIGESTIVE SYSTEM**

**Nervous Regulation of the Digestive System**
1. The somatic nervous system, which controls skeletal muscles, controls the muscles of mastication, swallowing, and the external anal sphincter.

2. The parasympathetic and sympathetic divisions of the autonomic nervous system (ANS) control the smooth muscle and glands of the digestive tract and the accessory digestive glands.

**FIGURE 16.9**

A. Parasympathetic division.
1) The parasympathetic division is generally stimulatory, and is more important than the sympathetic division in day-to-day regulation of the digestive tract.

2) Components.
   a. Various cranial nerves supply the salivary glands.
   b. The vagus nerves (cranial nerve X) supply the digestive tract from the esophagus to the first half of the large intestine.
   c. The pelvic nerves (S2 - S4) supply the last half of the large intestine, the rectum, and the anal canal.

B. Sympathetic division.
1) The sympathetic division is generally inhibitory and has its main effects during exercise.

2) Components.
   a. Sympathetic nerves to the salivary glands.
   b. Splanchnic nerves (T8 - L2) to the abdominopelvic organs.
C. The activity of medullary regulatory centers can be affected through ANS reflexes and higher brain centers. Remember that reflexes are unconscious, stereotypic responses that function to maintain homeostasis.

3. The enteric nervous system (part of the ANS) consists of neurons located within the digestive tract. The enteric nervous system controls the digestive system through local reflexes. Stimulation of neurons (chemoreceptors, mechanoreceptors) in the digestive tract wall leads to a response through the enteric nerve plexus. Note that the CNS is NOT involved in this reflex.

---

**Chemical Regulation of the Digestive System**

1. **Hormonal regulation.** A stimulus causes the release of a hormone from the digestive tract wall. The hormone can have a local effect (parahormone) or travel through the blood to other target tissues.

2. Other chemicals, such as histamine, released locally within the digestive tract, affect the activity of nearby cells.
1. Swallowing, or **deglutition**, has three phases.

2. The **voluntary phase** moves the bolus of food to the oropharynx with the tongue.

3. The pharyngeal and esophageal phases are involuntary ANS reflexes.
   
   A. **Pharyngeal phase**.
      
      1) Stretch and pressure receptors in the oropharynx detect the bolus of food.

      2) Action potentials go to the swallowing center in the medulla oblongata, which activates the following responses:
         
         a. The soft palate closes off the opening to the nasal cavity, preventing the entry of swallowed materials into the nasal cavity.

         b. The pharynx raises to better accept the bolus.

         c. The pharyngeal constrictor muscles contract and push the bolus into the esophagus.

         d. Entry of swallowed materials into the larynx is prevented as muscles raise the larynx (move it out of the way), the epiglottis (a cartilage flap) covers the opening into the larynx (lower respiratory tract), and the vestibular and vocal folds come together at the midline.

         e. The upper esophageal sphincter relaxes and the bolus enters the esophagus.

   B. **Esophageal phase**.
      
      1) Peristalsis moves the bolus through the esophagus to the stomach. **Peristalsis** is a wave of muscular relaxation followed by a wave of muscular contraction. The wave of relaxation allows the esophagus to expand as the wave of contraction pushes the bolus into the relaxed part of the esophagus.

      2) Peristalsis is regulated by local and ANS reflexes.
3) The lower esophageal (cardiac) sphincter relaxes and the bolus passes into the stomach.
   a. **Achalasia** (failure to relax) is difficulty in swallowing that occurs when the lower esophageal sphincter does not relax properly. It usually results from enteric nerve plexus damage.

   b. **Heartburn** results from the reflux of gastric juices into the esophagus when the lower esophageal sphincter does not properly close.

4) If there is any food left in the esophagus, the resulting distention activates reflexes which cause secondary peristaltic waves in the esophagus.

   When a bolus becomes "stuck" in the esophagus, why does drinking something help to get the bolus "unstuck"?

5) Movement through the esophagus results from peristalsis, not gravity. It is possible to swallow upside down or in zero gravity (astronauts).

6) Swallowing is inhibited by some anesthetics, and vomiting of the stomach contents into the pharynx can lead to choking and death. Because some anesthetics cause nausea and vomiting, it is recommended that patients do not eat prior to anesthesia.

**STOMACH**

**Anatomy of the Stomach**
1. Gastroesophageal (cardiac) opening - passage of materials is regulated by the lower esophageal sphincter.
2. Cardiac region
3. Fundus - general term for the back part of an organ.
4. Body
5. Greater curvature
6. Lesser curvature
7. Pyloric part - joins the small intestine.
8. Pyloric orifice
9. Pyloric sphincter - controls the movement of materials from the stomach into the small intestine through the pyloric opening.
Histology of the Stomach
1. The muscular layer (muscularis) has an additional layer of oblique smooth muscle, which increases the mixing and mashing power of the stomach.

2. **Rugae** are longitudinal folds of the mucosa and submucosa that allow the stomach to expand.

3. The mucosa is lined with simple columnar epithelium. The epithelium has numerous invaginations called **gastric pits**. At the bottom of the gastric pits are **gastric glands**. There are five types of epithelial cells:
   A. **Surface mucous cells** form the surface of the epithelium and line the gastric pits. They produce mucus.
   B. **Mucous neck cells**, located at the entry into the gastric glands, also produce mucus.
   C. **Parietal cells** secrete hydrochloric acid and intrinsic factor.
   D. **Chief cells** secrete pepsinogen.
   E. **Endocrine cells** secrete the hormone gastrin and histamine.

Secretions of the Stomach
1. The stomach functions primarily as a storage chamber in which food is mixed with stomach secretions. The resulting semifluid material, called **chyme**, passes into the small intestine.

2. Protein digestion begins in the stomach, but little absorption of materials occurs in the stomach.

3. Secretions and their functions.
   A. **Mucus** is a viscous, alkaline substance.
      1) Mucus is secreted by surface mucous cells and mucous neck cells.
      2) Mucus covers the epithelial surface, protecting the stomach lining from harmful stomach secretions. It also lubricates the inner surface of the stomach.
   B. **Intrinsic factor** is a glycoprotein.
      1) Intrinsic factor is a glycoprotein secreted by parietal cells.
      2) Intrinsic factor binds with vitamin B12. Without intrinsic factor, not enough vitamin B12 is absorbed in the small intestine. Vitamin B12 is important in DNA synthesis.
   C. **Hydrochloric acid**.
      1) Hydrochloric acid (HCl) is secreted by parietal cells.
      2) Hydrochloric acid provides the acid environment necessary for the function of pepsin.
D. **Pepsinogen** is the inactive form of pepsin.
   1) Pepsinogen is secreted by chief cells.
   2) Pepsinogen is converted to pepsin by hydrochloric acid in the stomach.

\[
\begin{align*}
\text{Parietal cells} & \quad \downarrow HCl \\
& \quad \downarrow \\
\text{Chief cells} & \rightarrow \text{Pepsinogen} \rightarrow \text{Pepsin} \rightarrow \text{Digest proteins}
\end{align*}
\]

3) **Pepsin** begins the process of protein digestion by splitting proteins into smaller polypeptide chains. At pH values greater than 5, pepsin is inactive.

E. **Gastrin** and **histamine** are secreted by endocrine cells. These substances regulate the secretion of HCl from parietal cells. Gastrin also increases pepsinogen secretion by chief cells.

**Regulation of Stomach Secretions**
1. The stomach secretes 2-3 L of gastric secretions per day. Regulation of stomach secretions can be divided into three phases: cephalic, gastric, and intestinal phases.

2. **Cephalic phase.**

   ![FIGURE 24.13a](image)

   A. The cephalic phase is an anticipatory response that prepares the stomach to receive food.

   B. Various stimuli activate the medulla oblongata. The stimuli include the taste or smell of food, the sensations of chewing and swallowing, and the thought of food. These are the same stimuli that promote saliva production.

   C. Action potentials from the medulla oblongata are carried by the vagus nerves to the stomach. Release of acetylcholine (ACh) from parasympathetic postganglionic nerve endings stimulates parietal (hydrochloric acid), chief (pepsinogen), and endocrine cells (gastrin, histamine) to secrete.

   D. The cephalic phase is absent when a person is afraid, depressed, has no desire for food, or when the vagus nerve is cut.
3. **Gastric phase.**

A. The greatest volume of secretions is produced during the gastric phase.

B. Distention of the stomach activates **local reflexes** and **parasympathetic reflexes** (through the vagus nerves). Release of acetylcholine (ACh) from nerve endings stimulates parietal (hydrochloric acid), chief (pepsinogen), and endocrine cells (gastrin, histamine) to secrete.

酒精和咖啡因刺激胃泌素的释放。为什么适量的酒精有益于消化？过多的酒精会引发胃部不适或反酸吗？

蛋白质（例如，氨基酸和肽）刺激盐酸的释放。为什么这是合理的（提示：主管细胞）？
4. **Intestinal phase.**

A. The intestinal phase of stomach secretions is stimulated by the movement of chyme into the small intestine.

B. Intestinal mechanisms that inhibit gastric secretions.
   1) When the pH of chyme is 2 or below it stimulates the release of secretin from the **duodenum** (the first part of the small intestine). The secretin travels to the stomach and inhibits gastric secretions.

   2) *Fats* stimulate the release of **gastric inhibitory polypeptide** and **cholecystokinin** from the **duodenum**. These hormones travel to the stomach and inhibit gastric secretions.

   3) Distention of the duodenal wall, reduced pH, and other stimuli activate the **enterogastric reflex** (parasympathetic and local reflexes), which inhibits gastric secretions.

Why does it make sense that the intestinal phase inhibits gastric secretions (Hint: the optimal pH for enzyme activity in the duodenum is higher than that in the stomach)?
# Review of Stomach Secretions

| Gastrin is released by | Oral cavity  
|                        | Esophagus  
<table>
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<th>Stomach</th>
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</table>
| Gastrin secretion is mediated through | Local reflexes  
|                        | Parasympathetic reflexes  
|                        | Substances in food  |
| Gastrin secretion is increased during the | Cephalic phase  
|                        | Gastric phase  |
| Gastrin secretion is increased by | Taste or smell of food  
|                        | Thoughts of food  
|                        | Tactile sensation of food in the mouth  |
| Gastrin secretion is increased by | Distention of the stomach  
|                        | Alcohol  
|                        | Caffeine  
|                        | pH < 2 in the duodenum  |
| Gastrin secretion is decreased by | Secretin  
|                        | Gastric inhibitory polypeptide  
|                        | Cholecystokinin  
|                        | Enterogastric reflex  |
| Hydrochloric acid secretion is increased by | Gastrin  
|                        | Proteins in the stomach  
|                        | Fats in the stomach  
|                        | Local reflexes  
|                        | Parasympathetic reflexes  |
| Pepsinogen is converted to pepsin by | Gastrin  
|                        | Hydrochloric acid  
|                        | Intrinsic factor  |
| Pepsin digests | Carbohydrates  
|                        | Fats  
|                        | Proteins  |
| Secretin secretion is increased by | pH < 2 in the duodenum  
|                        | Proteins in the duodenum  
|                        | Fats in the duodenum  |
| Gastric inhibitory polypeptide and cholecystokinin secretion are increased by | pH < 2 in the duodenum  
|                        | Proteins in the duodenum  
|                        | Fats in the duodenum  |
| Secretions of the stomach are inhibited by | Secretin  
|                        | Gastric inhibitory polypeptide  
|                        | Cholecystokinin  |
Knowledge is Power – How to Treat Overproduction of Stomach Acid

1. Antacids.
   A. Antacids, such as Tums and Rolaids, are bases that are ingested.
   B. Antacids are fast acting because they quickly mix with stomach contents and neutralize stomach acid.

2. Histamine blockers.
   A. The secretion of hydrochloric acid is regulated by histamine, gastrin, and ACh.
      1) Endocrine cells in the stomach are sometimes called enterochromaffin cells (entero = intestine, chromaffin = a staining reaction used to prepare cells for microscopic viewing). Enterochromaffin-like (ECL) cells, which secrete histamine, are found in the pyloric part of the stomach.
      2) Histamine has the greatest effect on acid secretion, followed by gastrin. ACh has the smallest effect. Without histamine, the effects of ACh and gastrin are greatly reduced.

   ![Parasympathetic or Local Reflex Diagram]

   3) There are separate receptors on parietal cells for histamine, gastrin, and ACh. Drugs such as Pepcid and Tagamet block the histamine receptor.

   4) There are two types of histamine receptors. The H₁ receptor activates allergic reactions and the H₂ receptor stimulates hydrochloric acid secretion. Drugs that block allergic reactions, e.g., antihistamines, do not affect stomach acid secretion. Drugs that block stomach acid secretion do not block allergic reactions.

3. Proton pump inhibitors.
   A. Carbon dioxide (CO₂) diffuses into parietal cells and combines with water to form carbonic acid (H₂CO₃).
   B. Carbonic acid dissociates to form hydrogen ions (H⁺) and bicarbonate ions (HCO₃⁻).
   C. Hydrogen ions are pumped out of the parietal cells into the stomach by active transport. The greater the number of functioning pumps, the greater the number of H⁺ pumped into the stomach, and the lower the pH of stomach juices.
Peptic Ulcers

1. A **peptic ulcer** is an ulcer in the lining of the digestive tract, usually in the duodenum or stomach.

2. Damage to the mucosa by stomach acids contributes to the development of peptic ulcers. Therefore overproduction of stomach acid (e.g. stress) is associated with peptic ulcers, and neutralizing stomach acid or reducing stomach acid secretions are used as treatment.

3. It is now known that a bacterium, *Helicobacter pylori*, is responsible for most cases of peptic ulcers. Treatment with antibiotics has proven to be very effective.

Movements of the Stomach

1. Types of movements.
   - **Mixing waves** combine ingested materials with secretions from the stomach.
   - **Peristaltic waves** cause food to move from the stomach into the small intestine. Food remains in the stomach for 3 to 6 hours.

2. Description of movements.
   - **Pacemaker cells**, which are specialized smooth muscle cells in the greater curvature of the stomach, generate action potentials about every 20 seconds.
   - A wave of contraction passes from the pacemaker cells toward the pyloric part of the stomach. Visceral smooth-muscle cells can be joined by gap junctions that allow the smooth-muscle cells to function as a single unit.
   - Weak waves of contraction (about 80% of the waves) push chyme toward the pyloric part and solid materials toward the fundus. These are mixing waves.
   - Stronger waves of contraction (about 20% of the waves) push the chyme through the pyloric orifice. These are peristaltic waves, and the movement of the chyme is called the **pyloric pump**.
3. Regulation of stomach movements.
   A. Regulation of stomach movements keeps food in the stomach the right amount of time to ensure proper processing of the food.
   
   B. The same basic mechanisms that regulate stomach secretions also regulate stomach movements.

   **Review**

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<thead>
<tr>
<th></th>
<th>Increases</th>
<th>Decreases</th>
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<tbody>
<tr>
<td>Distention of the stomach</td>
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<tr>
<td>Gastrin</td>
<td>Increases</td>
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<td>Gastrin</td>
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<td>Secretin</td>
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<tr>
<td>Enterogastric reflex</td>
<td>Increases</td>
<td>Decreases</td>
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4. Vomiting (reverse gastric emptying).
   A. Irritation in the stomach, odors, drugs, emotions, and movement (e.g., sea sickness) can stimulate the vomiting center in the medulla.
   
   B. Steps in vomiting.
      1) Take a deep breath, close the opening to the larynx, close the opening to the nasal cavity (soft palate), and relax the upper esophageal sphincter.
      
     2) Contract the diaphragm and abdominal muscles to place pressure on the stomach contents.
      
     3) Relax the lower esophageal sphincter.
      
     4) Stand back!

**SMALL INTESTINE**

1. The **small intestine** is divided into three parts: the duodenum (25 cm. long), jejunum (2.5 m. long), and ileum (3.5 m. long) for a total length of 6.25 m or 20.5 ft.
2. **Duodenum**
   A. The duodenum is the site where accessory digestive organs empty into the digestive tract.

   1) The *pancreatic duct* and the *common bile duct* (from the liver) join to form the *hepatopancreatic ampulla*.

   2) The hepatopancreatic ampulla empties into the duodenum at the *major duodenal papilla*. The *hepatopancreatic ampullar sphincter* regulates the movement of secretions.

   3) In most people, an *accessory pancreatic duct* empties into the duodenum at the *minor duodenal papilla*.

B. Modifications that increase surface area (and therefore absorption).

   1) **Circular folds**, or *plicae circularis*, are circular shelflike folds of the mucosa and submucosa.

   2) **Villi** are fingerlike extensions of the mucosa.
      a. Villi contain blood capillaries.
      b. Villi contain lymphatic capillaries called *lacteals*.

   3) **Microvilli** are cytoplasmic extensions of the epithelial cells of most of the mucosa.

   4) Analogy: the circular folds are mountains, the villi are pine trees on the mountains, and the microvilli are pine needles on the pine trees.

C. Cell types.
   1) **Absorptive cells** produce *digestive enzymes* and absorb digested food.

   2) **Goblet cells** secrete *mucus*.

   3) **Endocrine cells** produce regulatory hormones.

D. Glands.
   1) **Intestinal glands** are tubular invaginations of the mucosa. They are located at the base of the villi. Analogy: the villi are mountains and the intestinal glands are valleys.
      a. Intestinal glands produce the epithelium of the mucosa.
      b. The absorptive epithelial cells migrate up the villi and are lost from the villi tips.
2) **Duodenal glands** are located at the base of the intestinal glands. Duodenal glands secrete mucus.

3. **Jejunum and ileum.**
   A. Similar in structure to the duodenum.
   B. The ileum has aggregations of lymphoid tissue called **Peyer's patches**.
   C. The **ileocecal valve** and **ileocecal sphincter** control movement of materials from the small intestine into the large intestine.

**Secretions of the Small Intestine**
1. The small intestine produces digestive enzymes that complete the process of digestion. The digested food is then absorbed in the small intestine.

2. The small intestine produces about 2 L of secretions per day.
   A. **Mucus** is secreted by goblet cells and duodenal glands. Mucus lubricates and protects the intestinal wall from acidic chyme.
   B. **Digestive enzymes** are released from the surface of the microvilli of absorptive cells. These enzymes must complete the digestive process before the food molecules can be absorbed. They include disaccharidases (breakdown disaccharides to monosaccharides), peptidases (split the peptide bond between amino acids), and nuclease (breakdown nucleic acids).
   C. Endocrine cells release regulatory hormones, e.g., **secretin**, **gastric inhibitory polypeptide**, and **cholecystokinin**.

**Movement in the Small Intestine**
1. **Segmental contractions** travel a short distance down the intestinal tract. They function primarily to mix food with intestinal secretions.

2. **Peristaltic contractions** travel longer distances down the intestinal tract. In some cases they travel the entire length of the small intestine. Peristaltic contractions function primarily to move the intestinal contents. It takes 3 to 10 hours for chyme to pass through the small intestine.

**Regulation of the Liver and Gallbladder**
1. The entry of chyme into the small intestine activates hormonal and neural mechanisms that increase bile secretions and promote emptying of the gallbladder.
2. Bile neutralizes acid and promotes fat digestion by emulsifying fats.

3. Hormonal regulation.  
   A. Secretin from the small intestine increases the rate of bile secretion.  
   B. Cholecystokinin from the small intestine causes the gallbladder to contract and the hepatopancreatic ampullar sphincter to relax.  

   During what phase (i.e., cephalic, gastric, or intestinal) of stomach secretions would you expect secretin and cholecystokinin secretion to increase? Explain.

3. Neural regulation. Parasympathetic stimulation through the vagus nerve causes weak contraction of the gallbladder.

4. Enterohepatic circulation.  
   A. The ileum reabsorbs 94% of the bile salts in bile.  
   B. The bile salts are carried by the blood to the liver. The bile salts stimulate the secretion of additional bile. The process also recycles the bile salts, reducing the amount of bile salts lost in the feces.  

   Is the enterohepatic circulation an example of positive or negative feedback?
1. The **pancreas** consists of a head, body, and tail.

2. The endocrine portion, the **pancreatic islets (islets of Langerhans)** secrete **insulin** and **glucagon** into the blood.

3. The exocrine portion consists of **acini** (saclike glands that empty into ducts). The acini secrete digestive enzymes that empty through a duct system into the duodenum.

**Pancreatic Secretions**

1. The endocrine portion (pancreatic islets) secretes insulin and glucagon. The exocrine portion secretes about 1.2 L of pancreatic juices per day through the pancreatic duct.

2. The **aqueous component** of pancreatic juice.
   A. The aqueous component is produced primarily by the epithelium of the smaller pancreatic ducts.
   
   B. The aqueous component contains bicarbonate ions that act to neutralize the acidic chyme as it enters the small intestine. This is an important function, because the digestive enzymes in the small intestine don't function in an acidic environment.

3. The **enzymatic component** of pancreatic juice.
   A. The enzymatic component is produced in the acini.
   
   B. The enzymatic component contains digestive enzymes.
      1) **Protein enzymes** digest proteins. They include trypsin (derived from trypsinogen) and chymotrypsin (derived from chymotrypsinogen).
      
      2) **Amylase** digests polysaccharides.
      
      3) **Lipase** digests lipids.
Regulation of Pancreatic Secretion

1. The entry of chyme into the small intestine activates hormonal and neural mechanisms that increase pancreatic juice secretion.

2. Hormonal regulation.
   A. Secretin stimulates the release of the **aqueous component** of pancreatic juices, which has a high concentration of bicarbonate ions.
   B. Cholecystokinin stimulates the release of the **enzymatic component** of pancreatic juices, which contains digestive enzymes.

   What is the main stimulus for the secretion of secretin? For cholecystokinin? Why does this make sense?

3. Neural regulation. Parasympathetic stimulation during the cephalic and gastric phases of stomach secretion causes increased secretion of the enzymatic component.

   **Review of Liver, Gallbladder, and Pancreas Regulation**

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<th>Bile production increases in response to</th>
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LARGE INTESTINE
1. The large intestine consists of the cecum (with appendix), colon, rectum, and anal canal.

2. Chyme from the small intestine is converted into feces in the large intestine and is eliminated by the process of defecation.

3. The first half of the large intestine functions to reabsorb water and some salts. The second half of the large intestine stores feces until it is eliminated.

Anatomy of the Large Intestine

Cecum
1. The cecum is a blind pouch near the point where the ileum joins the large intestine.

2. The vermiform (wormlike) appendix is a narrow blind tube off of the cecum. It can become infected and inflamed in appendicitis.

Colon
1. The colon has four parts: the ascending colon, transverse colon, descending colon, and sigmoid colon.

2. Colon modifications.

Rectum
1. The rectum is a 7 to 8 inch long muscular tube.

2. The rectum connects the sigmoid colon to the anal canal.
**Anal Canal**

1. The anal canal is the last inch of the digestive tract. The anal canal opens to the exterior through the **anus**.

2. The anal canal is surrounded by an **internal anal sphincter** of smooth muscle and an **external anal sphincter** of skeletal muscle. The sphincters regulate the movement of feces out of the digestive tract.

3. Within the anal canal the mucosa is folded into longitudinal folds called **anal columns**. Each column contains an artery and vein.
   - **Internal hemorrhoids** (piles) are enlarged rectal veins in the anal columns. Chronic constipation with prolonged straining can result in internal hemorrhoids. They are not usually painful.
   - **External hemorrhoids** are enlarged rectal veins under the skin around the anus. They can be painful.

**Secretions of the Large Intestine**

1. The large intestine produces about 60 ml of secretions per day.

2. The major secretion is mucus, produced by goblet cells within the intestinal crypts. The mucus functions as a lubricant and helps to bind fecal matter together.


4. The large intestine supports a large number of bacteria. About 30% of the dry weight of feces results from bacteria.
   - Some bacteria can synthesize vitamin K that is absorbed by the large intestine.
   - Some bacteria produce gas that can be released as flatus.

**Movement in the Large Intestine**

1. Description of movements.
   - A little **segmental mixing** movements occurs.
   - **Mass movements** are powerful peristaltic waves that push the colon contents toward the rectum. They move 1/2 to 3/4 the length of the colon, and they occur three to four times a day. Normally it takes 18 to 24 hours for materials to pass through the large intestine.
   - **Defecation**, or bowel movement, is the elimination of feces from the rectum.
2. Regulation of movements.

A. Regulation of mass movement.
   1) Local reflexes initiated by distention of the large intestine or by irritation of the large intestine cause mass movements.

   2) Local reflexes initiated in other parts of the digestive tract.
      a. The gastrocolic reflex is activated by distention of the stomach.
      b. The duodenocolic reflex is activated by distention of the duodenum.

   What “message” does the gastrocolic and duodenocolic reflex send to the large intestine?

B. Regulation of defecation.
   1) Normally the rectum is empty. The internal anal sphincter (smooth muscle) and external anal sphincter (skeletal muscle) are tonically constricted, which prevents the movement of feces.

   2) Mass movement of feces into the rectum causes distention of the rectum, which activates the defecation reflex.
      a. Local reflexes cause weak contraction of the descending colon, sigmoid colon, and rectum and relaxation of the internal anal sphincter.
      b. Parasympathetic reflexes (through pelvic nerves S2 - S4) cause strong contraction of the colon and rectum and also relaxation of the internal anal sphincter. The parasympathetic reflexes are responsible for most of the contractive force that moves the feces.

   3) Distension of the rectum results in action potentials ascending to the brain, which can regulate the activity of the reflex centers in the spinal cord and the external anal sphincter.
      a. The brainstem and hypothalmus are involved in unconscious regulation.
      b. In the cerebrum, conscious awareness of the need to defecate occurs. The cerebrum can also voluntarily control the external anal sphincter.
3) The role of skeletal muscles.
   a. Increased abdominal pressure on colon contents moves feces into the rectum. The
      increased pressure is caused by taking a deep breath, closing the opening to the
      larynx, and contracting the abdominal muscles.
   b. Voluntarily relaxation of the external anal sphincter allows feces to pass through
      the anal canal.

Explain how spinal cord injury can result in the loss of voluntary control of
defecation.

If the spinal cord injury occurs above level S2, an enema can initiate a bowel
movement. Explain how an enema can cause a bowel movement. The enema is
usually most effective in the morning after breakfast. Why is this so?

If damage to the spinal cord occurs below S2, defecation is still possible, but now
requires large enemas and cathartics to effect a bowel movement. Cathartics
function by increasing fecal volume, softening feces, or increasing motor activity.
How is it possible for defecation to occur when the spinal cord centers regulating
defecation are destroyed?
3. Some last thoughts on defecation.
   A. **Diarrhea** is a watery feces. In severe cases diarrhea can lead to extreme dehydration and death.
      1) Emotions (through parasympathetic stimulation) increase motility and there is inadequate time to absorb the normal amount of water from the feces.
      2) Increased colon secretions can increase fluid volume, causing distention that stimulates motility. For example, infections (e.g., infant diarrhea, cholera, traveler's diarrhea) can increase colon permeability, resulting in movement of fluid from the blood into the colon.

   B. **Constipation** is difficulty in defecation. It can produce a dry hard feces that is painful to eliminate. Constipation can be caused by old age, by emotions, and by not heeding nature's call. Following a mass movement, if defecation is voluntarily prevented, the fecal matter can remain in the rectum until the next mass movement. This may lead to insensitivity of the rectum to distention. Eventually a "normal" amount of feces no longer will stimulate a defecation reflex. Overuse of enemas can produce the same effect.

Why does fiber in the diet help to prevent constipation?
Ode to the Anal Sphincter

They say that man has succeeded where the animals fail because of the clever use of his hands, yet when compared to the hands, the anal sphincter is far superior. If you place into your cupped hands a mixture of fluids, solid, and gas and then through an opening at the bottom, try to let only the gas escape, you will fail. Yet the anal sphincter can do it. The sphincter apparently can differentiate between solid, fluid, and gas. It apparently can tell whether its owner is alone or with someone, whether its owner has his pants on or off. No other muscle in the body is such a protector of the dignity of man, yet so ready to come to his relief. A muscle like this is worth protecting.

DIGESTION, ABSORPTION, AND TRANSPORT

1. Digestion is the chemical breakdown of organic molecules into their component parts.
   A. Carbohydrates - building blocks are monosaccharides.
   B. Most lipids - building blocks are glycerol and fatty acids.
   C. Proteins - building blocks are amino acids.

2. Absorption is the movement of molecules from the stomach or intestine into the blood capillaries or lacteals.
   A. Water and water soluble substances (e.g., glucose, amino acids) enter blood capillaries and are carried through the hepatic portal system to the liver.
   B. Lipids and the breakdown products of lipids enter lacteals in the villi of the small intestine. Lacteals are small lymphatic vessels that eventually empty into blood vessels.

Carbohydrates

1. Carbohydrate digestion begins in the oral cavity with the breakdown of starch by salivary amylase. Starch is an energy storage molecule in plants. It is a polysaccharide consisting of many glucose molecules bonded together. Salivary amylase clips off two glucose molecules at a time to form the disaccharides maltose and isomaltose. Bread taste sweet because of the disaccharides formed in the mouth.

   Salivary Amylase
   Starch → Maltose + Isomaltose

2. Salivary amylase is inactivated by stomach acid. Gastric amylase can digest a small amount of starch.

3. In the small intestine, pancreatic amylase completes the breakdown of starch.
4. In the small intestine, disaccharides are broken down into monosaccharides by enzymes on the microvilli of the absorptive cells.

\[ \text{Maltase} \]
\[ \text{Maltose} \rightarrow \text{Glucose + Glucose} \]
\[ \text{(malt sugar) (blood sugar)} \]

\[ \text{Isomaltase} \]
\[ \text{Isomaltose} \rightarrow \text{Glucose + Glucose} \]
\[ \text{(malt sugar) (blood sugar)} \]

\[ \text{Sucrase} \]
\[ \text{Sucrose} \rightarrow \text{Glucose + Fructose} \]
\[ \text{(table sugar) (fruit sugar)} \]

\[ \text{Lactase} \]
\[ \text{Lactose} \rightarrow \text{Glucose + Galactose} \]
\[ \text{(milk sugar)} \]

5. The monosaccharides are taken up by the absorptive cells of the microvilli. From the absorptive cells, the monosaccharides enter blood capillaries within the villi.

\[ \text{FIGURE 24.16} \]

\[ \text{FIGURE 24.28} \]

**Lipids**

1. A small amount of lipid digestion takes place in the oral cavity (lingual lipase) and in the stomach (gastric lipase).

2. Most digestion of lipids takes place in the small intestine.
   A. Bile salts emulsify lipids (i.e., break large droplets into small droplets). This increases surface area for enzyme activity.

\[ \text{Pancreatic lipase} \]
\[ \text{Triglyceride} \rightarrow \text{Fatty acids + Monoglyceride} \]

B. Bile salts aggregate around digested lipids, cholesterol, and phospholipids to form **micelles**. The micelles transport the digested lipids into intestinal absorptive cells.
C. Within the absorptive cells, the fatty acids and monoglycerides combine to form triglycerides. The triglycerides, cholesterol, phospholipids, and proteins form chylomicrons, which are released to the inside of villi where they pass into lacteals. The lacteals are part of a system of lymphatic vessels that eventually empty into the blood.

**Proteins**

1. Protein digestion begins in the stomach. Proteins are large polypeptides, that is many amino acids connected to each other to form a very long chain of amino acids. Gastric pepsin breaks down proteins into small peptides, which are smaller chains of amino acids. Pepsin accounts for no more than 15% of the digestion of proteins, and protein digestion can be accomplished without pepsin.

   ![Pepsin Diagram]

   Protein $\xrightarrow{\text{Pepsin}}$ Small Peptides

2. In the small intestine, pancreatic enzymes such as trypsin, break down proteins into small peptides.

   ![Trypsin Diagram]

   Protein $\xrightarrow{\text{Trypsin}}$ Small Peptides

3. The microvilli of the small intestine have enzymes within their plasma membranes called peptidases. The peptidases break down the small peptides into tripeptides (three amino acids), dipeptides (two amino acids), and a small number of individual amino acids.

   ![Peptidases Diagram]

   Small Peptides $\xrightarrow{\text{Peptidases}}$ Tripeptides + Dipeptides + Amino Acids

4. The tripeptides, dipeptides, and amino acids are taken into the absorptive cells. The tripeptides and dipeptides are broken down into amino acids. The individual amino acids are transported into the interior of the villi, where they enter blood capillaries.

   ![FIGURE 24.32]

**Water**

1. About 9 L of water enter the digestive tract each day. About 2 L is ingested as fluid or as part of solid food. The other 7 L are secretions.

2. Most of the 9 L is absorbed back into the blood, but about 1% is lost in the feces.
<table>
<thead>
<tr>
<th>Part of the Digestive Tract</th>
<th>Absorption Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral Cavity</td>
<td>Little is absorbed in the oral cavity. However, drugs, such as nitroglycerin, are absorbed by blood vessels under the tongue.</td>
</tr>
<tr>
<td>Stomach</td>
<td>Little is absorbed in the stomach. Exceptions are aspirin and alcohol.</td>
</tr>
</tbody>
</table>
| Small Intestine            | Major site of water reabsorption (92%)  
Bile salts reabsorbed (94%)  
Fat soluble vitamins (A, D, E, and K) in micelles  
Water soluble vitamins (e.g., B complex and C)  
Active transport of sodium, potassium, calcium, magnesium, and phosphate ions.  
Diffusion of chloride (negatively charged chloride ions follow the positively charged ions) in the duodenum and jejunum; active transport of chloride in the ileum |
| Large Intestine            | The small amount of water absorbed determines the consistency of feces  
A few ions  
Vitamins produced by bacteria (e.g., K and B12) |