Chapter 24: The Digestive System

The Digestive System: An Overview, p. 863

Objectives

1. Identify the organs of the digestive system and list their major functions.
2. Describe the functional histology of the digestive tract.
3. Explain the processes by which materials move through the digestive tract.
4. Outline the mechanisms that regulate digestion.

• All living organisms must obtain nutrients from their environment to sustain life. These substances are used as raw materials for synthesizing essential compounds (anabolism) or are decomposed to provide energy that cells need to continue functioning (catabolism). The catabolic reactions require two essential ingredients: (1) oxygen and (2) organic molecules (such as carbohydrates, fats, or proteins) that can be broken down by intracellular enzymes.

• In our bodies, the respiratory system works in concert with the cardiovascular system to supply the necessary oxygen. The digestive system, working with the cardiovascular and lymphatic systems, provides the organic molecules.

• The digestive system consists of a muscular tube, the digestive tract, also called the gastrointestinal (GI) tract or alimentary canal, and various accessory organs.

Figure 24-1

• The digestive tract begins at the oral cavity and continues through the pharynx, esophagus, stomach, small intestine, and large intestine, which opens to the exterior at the anus.

Functions of the Digestive System

• We can regard digestive functions as a series of integrated steps:
  o Ingestion occurs when materials enter the digestive tract via the mouth. Ingestion is an active process involving conscious choice and decision making.
  o Mechanical processing is crushing and shearing that makes materials easier to propel along the digestive tract. It also increases their surface area, making them more susceptible to enzymatic attack.
  o Digestion refers to the chemical breakdown of food into small organic fragments suitable for absorption by the digestive epithelium. Simple molecules in food, such as glucose, can be absorbed intact, but epithelial cells have no way to absorb molecules the size and complexity of proteins, polysaccharides, or triglycerides. These molecules must be disassembled by digestive enzymes prior to absorption.
  o Secretion is the release of water, acids, enzymes, buffers, and salts by the epithelium of the digestive tract and by glandular organs.
  o Absorption is the movement of organic substrates, electrolytes (inorganic ions), vitamins, and water across the digestive epithelium and into the interstitial fluid of the digestive tract.
Excretion is the removal of waste products from body fluids. The digestive tract and glandular organs discharge waste products in secretions that enter the lumen of the tract. Most of these waste products, after mixing with the indigestible residue of the digestive process, will leave the body.

- The lining of the digestive tract also plays a protective role by safeguarding surrounding tissues against (1) the corrosive effects of digestive acids and enzymes; (2) mechanical stresses, such as abrasion; and (3) bacteria that either are swallowed with food or reside in the digestive tract.
- The digestive epithelium and its secretions provide a nonspecific defense against these bacteria. When bacteria reach the underlying layer of areolar tissue, the lamina propria, they are attacked by macrophages and other cells of the immune system.

The Digestive Organs and the Peritoneum

- The abdominopelvic cavity contains the peritoneal cavity, which is lined by a serous membrane consisting of a superficial mesothelium covering a layer of areolar tissue.
  - We can divide the serous membrane into the serosa, or visceral peritoneum, which covers organs within the peritoneal cavity, and the parietal peritoneum, which lines the inner surfaces of the body wall.
- The serous membrane lining the peritoneal cavity continuously produces peritoneal fluid, which provides essential lubrication. Because a thin layer of peritoneal fluid separates the parietal and visceral surfaces, sliding movement can occur without friction and resulting irritation.
  - About 7 liters of fluid are secreted and reabsorbed each day, although the volume within the peritoneal cavity at any one time is very small.

Mesenteries

- Portions of the digestive tract are suspended within the peritoneal cavity by sheets of serous membrane that connect the parietal peritoneum with the visceral peritoneum. These mesenteries are double sheets of peritoneal membrane.
  - The areolar tissue between the mesothelial surfaces provides an access route for the passage of blood vessels, nerves, and lymphatic vessels to and from the digestive tract.
  - Mesenteries also stabilize the positions of the attached organs and prevent the intestines from becoming entangled during digestive movements or sudden changes in body position.

Figure 24-2

- During embryonic development, the digestive tract and accessory organs are suspended within the peritoneal cavity by dorsal and ventral mesenteries.
- The ventral mesentery later disappears along most of the digestive tract, persisting in adults in only two places:
  - on the ventral surface of the stomach, between the stomach and the liver (the lesser omentum). The lesser omentum stabilizes the position of the stomach and provides an access route for blood vessels and other structures entering or leaving the liver.
and between the liver and the anterior abdominal wall (the falciform ligament). The falciform ligament helps stabilize the position of the liver relative to the diaphragm and abdominal wall.

- The dorsal mesentery of the stomach becomes greatly enlarged and forms an enormous pouch that extends inferiorly between the body wall and the anterior surface of the small intestine.
  - This pouch, the greater omentum, hangs like an apron from the lateral and inferior borders of the stomach.
  - Adipose tissue in the greater omentum conforms to the shapes of the surrounding organs, providing padding and protection across the anterior and lateral surfaces of the abdomen.
  - The lipids in the adipose tissue are an important energy reserve. The greater omentum also provides insulation that reduces heat loss across the anterior abdominal wall.

- All but the first 25 cm (10 in.) of the small intestine is suspended by the mesentery proper, a thick mesenterial sheet that provides stability, but permits some independent movement.
  - The mesentery associated with the initial portion of the small intestine (the duodenum) and the pancreas fuses with the posterior abdominal wall, locking those structures in position.

- A mesocolon is a mesentery associated with a portion of the large intestine.
  - During normal development, the mesocolon of the ascending colon, the descending colon, and the rectum of the large intestine fuse to the dorsal body wall. These regions become locked in place.
  - The transverse mesocolon, which supports the transverse colon, and the sigmoid mesocolon, which supports the sigmoid colon, are all that remains of the original embryonic mesocolon.

**Histological Organization of the Digestive Tract**

- The major layers of the digestive tract include (1) the mucosa, (2) the submucosa, (3) the muscularis externa, and (4) the serosa.

**Figure 24.3**

**The Mucosa**

- The inner lining, or mucosa, of the digestive tract is a mucous membrane consisting of an epithelium, moistened by glandular secretions, and a lamina propria of areolar tissue.

**The Digestive Epithelium**

- The mucosal epithelium is either simple or stratified, depending on its location and the stresses to which it is most often subjected.
  - ♣ The oral cavity, pharynx, and esophagus (where mechanical stresses are most severe) are lined by a stratified squamous epithelium.
  - ♣ The stomach, the small intestine, and almost the entire length of the large intestine (where absorption occurs) have a simple columnar epithelium that contains goblet cells. Scattered among the columnar cells are enteroendocrine cells, which secrete...
hormones that coordinate the activities of the digestive tract and the accessory glands.

- The lining of the digestive tract is often thrown into longitudinal folds, which disappear as the tract fills, and permanent transverse folds, or plicae.
  - The folding dramatically increases the surface area available for absorption.

The Lamina Propria

- The lamina propria consists of a layer of areolar tissue that also contains blood vessels, sensory nerve endings, lymphatic vessels, smooth muscle cells, and scattered areas of lymphoid tissue.
  - In the oral cavity, pharynx, esophagus, stomach, and duodenum (the proximal portion of the small intestine), the lamina propria also contains the secretory cells of mucous glands.
- In most areas of the digestive tract, the lamina propria contains a narrow band of smooth muscle and elastic fibers. This band is called the muscularis mucosae.
  - The smooth muscle cells in the muscularis mucosae are arranged in two concentric layers.
  - The inner layer encircles the lumen (the circular muscle), and the outer layer contains muscle cells oriented parallel to the long axis of the tract (the longitudinal layer). Contractions in these layers alter the shape of the lumen and move the epithelial pleats and folds.

The Submucosa

- The submucosa is a layer of dense irregular connective tissue that surrounds the muscularis mucosae.
  - The submucosa has large blood vessels and lymphatic vessels, and in some regions it also contains exocrine glands that secrete buffers and enzymes into the lumen of the digestive tract.
  - Along its outer margin, the submucosa contains a network of intrinsic nerve fibers and scattered neurons. This submucosal plexus, or plexus of Meissner, contains sensory neurons, parasympathetic ganglionic neurons, and sympathetic postganglionic fibers that innervate the mucosa and submucosa.

The Muscularis Externa

- The submucosal plexus lies along the inner border of the muscularis externa, a region dominated by smooth muscle cells.
  - Like the smooth muscle cells in the muscularis mucosae, those in the muscularis externa are arranged in an inner circular layer and an outer longitudinal layer. These layers play an essential role in mechanical processing and in the movement of materials along the digestive tract. The movements are coordinated primarily by the sensory neurons, interneurons, and motor neurons of the enteric nervous system (ENS).
  - The ENS is innervated primarily by the parasympathetic division of the ANS.
Sympathetic postganglionic fibers also synapse here, although many continue onward to innervate the mucosa and the myenteric plexus, orplexus of Auerbach.

This network of parasympathetic ganglia, sensory neurons, interneurons, and sympathetic postganglionic fibers lies sandwiched between the circular and longitudinal muscle layers.

The Serosa
- Along most portions of the digestive tract inside the peritoneal cavity, the muscularis externa is covered by a serous membrane known as the serosa.
- There is no serosa covering the muscularis externa of the oral cavity, pharynx, esophagus, and rectum, where a dense network of collagen fibers firmly attaches the digestive tract to adjacent structures.
  - This fibrous sheath is called an adventitia.

The Movement of Digestive Materials
- The muscular layers of the digestive tract consist of visceral smooth muscle tissue.
- The smooth muscle along the digestive tract has rhythmic cycles of activity due to the presence of pacesetter cells. These smooth muscle cells undergo spontaneous depolarization, triggering a wave of contraction that spreads throughout the entire muscular sheet.
  - Pacesetter cells are located in the muscularis mucosae and muscularis externa, the layers of which surround the lumen of the digestive tract.
- The coordinated contractions of the muscularis externa play a vital role in the movement of materials along the tract, through peristalsis, and in mechanical processing, through segmentation.

Figure 24-4
Peristalsis
- The muscularis externa propels materials from one portion of the digestive tract to another by contractions known as peristalsis.
- Peristalsis consists of waves of muscular contractions that move a bolus, or small oval mass of digestive contents, along the length of the digestive tract.
  - During a peristaltic movement, the circular muscles contract behind the bolus while circular muscles ahead of the bolus relax. Longitudinal muscles ahead of the bolus then contract, shortening adjacent segments. A wave of contraction in the circular muscles then forces the bolus forward.

Segmentation
- Most areas of the small intestine and some portions of the large intestine undergo cycles of contraction that churn and fragment the bolus, mixing the contents with intestinal secretions.
  - This activity, called segmentation, does not follow a set pattern, and thus does not push materials along the tract in any one direction.

Control of Digestive Function
- The activities of the digestive system are regulated by neural, hormonal, and local mechanisms

Figure 24-5
Neural Mechanisms
• The movement of materials along your digestive tract, as well as many secretory functions, is controlled primarily by neural mechanisms.
• The motor neurons that control smooth muscle contraction and glandular secretion are located in the myenteric plexus.
  o These neurons are usually considered parasympathetic, because some of them are innervated by parasympathetic preganglionic fibers.
  o The plexus also contains sensory neurons, motor neurons, and interneurons responsible for local reflexes that operate entirely outside the control of the central nervous system.
    ♣ The reflexes controlled by these neurons are called short reflexes.
    ♣ These reflexes are also called myenteric reflexes, and the term enteric nervous system is often used to refer to the neural network that coordinates the myenteric reflexes along the digestive tract.
  o Short reflexes control relatively localized activities that involve small segments of the digestive tract.
  o The enteric nervous system has roughly as many neurons as the spinal cord, and as many neurotransmitters as the brain.
• Sensory information from receptors in the digestive tract is also distributed to the CNS, where it can trigger long reflexes, which involve interneurons and motor neurons in the CNS.
  o Long reflexes provide a higher level of control over digestive and glandular activities, generally controlling largescale peristaltic waves that move materials from one region of the digestive tract to another.
  o Long reflexes may involve parasympathetic motor fibers in the glossopharyngeal, vagus, or pelvic nerves that synapse in the myenteric plexus.

Hormonal Mechanisms
• The sensitivity of the smooth muscle cells to neural commands can be enhanced or inhibited by digestive hormones.
  o The digestive tract produces at least 18 hormones that affect almost every aspect of digestive function, and some of them also affect the activities of other systems.
  o The hormones (gastrin, secretin, and others), which are peptides produced by enteroendocrine cells in the digestive tract, reach their target organs after their distribution in the bloodstream.

Local Mechanisms
• Prostaglandins, histamine, and other chemicals released into interstitial fluid may affect adjacent cells within a small segment of the digestive tract.
  o These local messengers are important in coordinating a response to changing conditions (such as variations in the local pH or certain chemical or physical stimuli) that affect only a portion of the tract.

The Oral Cavity, p. 870

Objectives
1. Describe the anatomy of the oral cavity.
2. Discuss the functions of the major structures and regions of the oral cavity.

**Figure 24-6**

- The mouth opens into the oral cavity, or buccal cavity.
- The functions of the oral cavity include
  - sensory analysis of material before swallowing;
  - mechanical processing through the actions of the teeth, tongue, and palatal surfaces;
  - lubrication by mixing with mucus and salivary gland secretions; and
  - limited digestion of carbohydrates and lipids.
- The oral cavity is lined by the oral mucosa, which has a stratified squamous epithelium. Only the regions exposed to severe abrasion—such as the superior surface of the tongue and the opposing surface of the hard palate (part of the roof of the mouth)—are covered by a layer of keratinized cells.
  - The epithelial lining of the cheeks, lips, and inferior surface of the tongue is relatively thin, nonkeratinized, and delicate.
  - Although nutrients are not absorbed in the oral cavity, the mucosa inferior to the tongue is thin enough and vascular enough to permit the rapid absorption of lipid-soluble drugs.
- The mucosae of the cheeks, or lateral walls of the oral cavity, are supported by pads of fat and the buccinator muscles.
  - Anteriorly, the mucosa of each cheek is continuous with that of the lips, or labia. The vestibule is the space between the cheeks (or lips) and the teeth. The gingivae, or gums, are ridges of oral mucosa that surround the base of each tooth on the alveolar processes of the maxillary bones and mandible.
- The roof of the oral cavity is formed by the hard and soft palates; the tongue dominates its floor.
  - The hard palate is formed by the palatine processes of the maxillary bones and the horizontal plates of the palatine bones. A prominent central ridge, or raphe, extends along the midline of the hard palate. The mucosa lateral and anterior to the raphe is thick, with complex ridges.
  - The soft palate lies posterior to the hard palate. A thinner and more delicate mucosa covers the posterior margin of the hard palate and extends onto the soft palate. The posterior margin of the soft palate supports the uvula, a dangling process that helps prevent food from entering the pharynx prematurely.
  - On either side of the uvula are two pairs of muscular pharyngeal arches.
    - The more anterior palatoglossal arch extends between the soft palate and the base of the tongue. A curving line that connects the palatoglossal arches and uvula forms the boundaries of the fauces, the passageway between the oral cavity and the oropharynx.
    - The more posterior palatopharyngeal arch extends from the soft palate to the pharyngeal wall. A palatine tonsil lies between the palatoglossal and palatopharyngeal arches on either side.

**The Tongue**

*Figure 24-6*
• The tongue manipulates materials inside the mouth and is occasionally used to bring foods into the oral cavity.
  o The primary functions of the tongue are (1) mechanical processing by compression, abrasion, and distortion; (2) manipulation to assist in chewing and to prepare material for swallowing; (3) sensory analysis by touch, temperature, and taste receptors, and (4) secretion of mucins and the enzyme lingual lipase.
• We can divide the tongue into an anterior body, or oral portion, and a posterior root, or pharyngeal portion.
  o The superior surface, or dorsum, of the body contains a forest of fine projections, the lingual papillae.
  o The thickened epithelium covering each papilla assists the tongue in moving materials. A V-shaped line of circumvallate papillae roughly demarcates the boundary between the body and the root of the tongue, which is situated in the oropharynx.
• The epithelium covering the inferior surface of the tongue is thinner and more delicate than that of the dorsum.
  o Along the inferior midline is the lingual frenulum, a thin fold of mucous membrane that connects the body of the tongue to the mucosa covering the floor of the oral cavity.
  o Ducts from two pairs of salivary glands open on either side of the lingual frenulum, which serves to prevent extreme movements of the tongue.
• The tongue’s epithelium is flushed by the secretions of small glands that extend into the underlying lamina propria.
  o These secretions contain water, mucins, and the enzyme lingual lipase, which works over a broad pH range (3.0–6.0), enabling it to start lipid digestion immediately.
• The tongue contains two groups of skeletal muscles. All gross movements of the tongue are performed by the relatively large extrinsic tongue muscles.
• The smaller intrinsic tongue muscles change the shape of the tongue and assist the extrinsic muscles during precise movements, as in speech. Both intrinsic and extrinsic tongue muscles are under the control of the hypoglossal nerve (XII).

Salivary Glands

Figure 24-7

• Three pairs of salivary glands secrete into the oral cavity.
• Each pair has a distinctive cellular organization and produces saliva, a mixture of glandular secretions, with slightly different properties:
  o The large parotid salivary glands lie inferior to the zygomatic arch deep to the skin covering the lateral and posterior surface of the mandible.
    ♣ The parotid salivary glands produce a serous secretion containing large amounts of salivary amylase, an enzyme that breaks down starches (complex carbohydrates).
    ♣ The secretions of each parotid gland are drained by a parotid duct (Stensen’s duct), which empties into the vestibule at the level of the second upper molar.
The sublingual salivary glands are covered by the mucous membrane of the floor of the mouth. These glands produce a mucous secretion that acts as a buffer and lubricant. Numerous sublingual ducts (Rivinus’ ducts) open along either side of the lingual frenulum.

The submandibular salivary glands are in the floor of the mouth along the inner surfaces of the mandible within a depression called the mandibular groove. Cells of the submandibular glands secrete a mixture of buffers, glycoproteins called mucins, and salivary amylase. The submandibular ducts (Wharton’s ducts) open into the mouth on either side of the lingual frenulum immediately posterior to the teeth.

Saliva

- The salivary glands produce 1.0–1.5 liters of saliva each day.
  - Saliva is 99.4 percent water; the remaining 0.6 percent includes an assortment of electrolytes (principally and Na⁺, Cl⁻, and HCO₃⁻), buffers, glycoproteins, antibodies, enzymes, and waste products.
  - The glycoproteins, called mucins, are primarily responsible for the lubricating action of saliva.
  - About 70 percent of saliva originates in the submandibular salivary glands, 25 percent in the parotids, and the remaining 5 percent in the sublingual salivary glands.
- The saliva produced when you eat has a variety of functions, including the following:
  - Lubricating the mouth.
  - Moistening and lubricating materials in the mouth.
  - Dissolving chemicals that can stimulate the taste buds and provide sensory information about the material.
  - Initiating the digestion of complex carbohydrates before the material is swallowed.
    - The enzyme involved is salivary amylase, also known as ptyalin or alpha-amylase. Although the digestive process begins in the oral cavity, it is not completed there, and no absorption of nutrients occurs across the lining of the cavity.
    - Saliva also contains a small amount of lingual lipase that is secreted by the glands of the tongue.

Control of Salivary Secretions

- Salivary secretions are normally controlled by the autonomic nervous system. Each salivary gland receives parasympathetic and sympathetic innervation.
  - The parasympathetic outflow originates in the salivatory nuclei of the medulla oblongata and synapses in the submandibular and otic ganglia.
  - Parasympathetic stimulation accelerates secretion by all the salivary glands, resulting in the production of large amounts of saliva.
- The salivatory nuclei are also influenced by other brain stem nuclei, as well as by the activities of higher centers.
The Teeth

Figure 24-8

- Movements of the tongue are important in passing food across the opposing surfaces, or occlusal surfaces, of the teeth. These surfaces perform chewing, or mastication, of food.
- The bulk of each tooth consists of a mineralized matrix similar to that of bone. This material, called dentin, differs from bone in that it does not contain cells.
  - The pulp cavity receives blood vessels and nerves through the root canal, a narrow tunnel located at the root, or base, of the tooth. Blood vessels and nerves enter the root canal through an opening called the apical foramen to supply the pulp cavity.
- The root of each tooth sits in a bony socket called an alveolus.
  - A layer of cementum covers the dentin of the root, providing protection and firmly anchoring the periodontal ligament.
- The neck of the tooth marks the boundary between the root and the crown, the exposed portion of the tooth that projects beyond the soft tissue of the gingiva. A shallow groove called the gingival sulcus surrounds the neck of each tooth.
- The dentin of the crown is covered by a layer of enamel.

Types of Teeth

- The alveolar processes of the maxillary bones and the mandible form the upper and lower dental arches, respectively. These arches contain four types of teeth, each with specific functions:
  - Incisors are blade-shaped teeth located at the front of the mouth. Incisors are useful for clipping or cutting. These teeth have a single root.
  - The cuspids, or canines, are conical, with a sharp ridgeline and a pointed tip. They are used for tearing or slashing. Cuspids have a single root.
  - Bicuspids, or premolars, have flattened crowns with prominent ridges. They crush, mash, and grind. Bicuspids have one or two roots.
  - Molars have very large, flattened crowns with prominent ridges adapted for crushing and grinding. Molars typically have three or more roots.

Dental Succession

Figure 24-9

- During embryonic development, two sets of teeth begin to form. The first to appear are the deciduous teeth, the temporary teeth of the primary dentition.
  - Deciduous teeth are also called primary teeth, milk teeth, or baby teeth. Most children have 20 deciduous teeth—5 on each side of the upper and lower jaws.
  - On each side of the upper or lower jaw, the primary dentition consists of two incisors, one cuspid, and a pair of deciduous molars.
  - These teeth will later be replaced by the secondary dentition, or permanent dentition.
- Adult jaws are larger and can accommodate more than 20 permanent teeth. Three additional molars appear on each side of the upper and lower jaws as the individual ages, extending the length of the tooth rows posteriorly and bringing the permanent tooth count to 32.

Mastication
• The muscles of mastication close your jaws and slide or rock your lower jaw from side to side. Chewing is not a simple process; it can involve any combination of mandibular elevation/depression, protraction/retraction, and medial/lateral movement.
• During mastication, you force food from the oral cavity to the vestibule and back, crossing and recrossing the occlusal surfaces.

The Pharynx, p. 875

Objective
1. Describe the anatomy and functions of the pharynx.
• The pharynx serves as a common passageway for solid food, liquids, and air. The epithelial lining and regions of the pharynx—the nasopharynx, the oropharynx, and the laryngopharynx.
• Food normally passes through the oropharynx and laryngopharynx on its way to the esophagus.

The Esophagus, p. 875

Objective
1. Describe the anatomy and functions of the esophagus.

Figure 24-10
• The esophagus is a hollow muscular tube with a length of approximately 25 cm (10 in.) and a diameter of about 2 cm (0.80 in.) at its widest point.
• The primary function of the esophagus is to convey solid food and liquids to the stomach.
• The esophagus begins posterior to the cricoid cartilage, at the level of vertebra
• The esophagus is innervated by parasympathetic and sympathetic fibers from the esophageal plexus. Resting muscle tone in the circular muscle layer in the superior 3 cm (1.2 in.) of the esophagus normally prevents air from entering the esophagus.

Histology of the Esophagus
• The wall of the esophagus contains mucosal, submucosal, and muscularis layers.
• Distinctive features of the esophageal wall include the following:
  o The mucosa of the esophagus contains a nonkeratinized, stratified squamous epithelium similar to that of the pharynx and oral cavity.
  o The mucosa and submucosa are thrown into large folds that extend the length of the esophagus.
  o The muscularis mucosae consists of an irregular layer of smooth muscle.
  o The submucosa contains scattered esophageal glands, which produce a mucous secretion that reduces friction between the bolus and the esophageal lining.
  o The muscularis externa has the usual inner circular and outer longitudinal layers.

Swallowing
Figure 24-11
• Swallowing, or deglutition, is a complex process that can be initiated voluntarily but proceeds automatically once it begins.
• We can divide swallowing into buccal, pharyngeal, and esophageal phases:
  o The **buccal phase** begins with the compression of the bolus against the hard palate. Subsequent retraction of the tongue then forces the bolus into the oropharynx and assists in the elevation of the soft palate, thereby sealing off the nasopharynx.
  o The **pharyngeal phase** begins as the bolus comes into contact with the palatoglossal and palatopharyngeal arches and the posterior pharyngeal wall.
    ♣ The swallowing reflex begins when tactile receptors on the palatal arches and uvula are stimulated by the passage of the bolus.
  o The **esophageal phase** of swallowing begins as the contraction of pharyngeal muscles forces the bolus through the entrance to the esophagus.
• **Primary peristaltic waves** are peristaltic movements coordinated by afferent and efferent fibers in the glosso-pharyngeal and vagus nerves.

**The Stomach, p. 877**

**Objective**

1. Describe the anatomy of the stomach, its histological features, and its roles in digestion and absorption.

• The stomach performs four major functions: (1) storage of ingested food, (2) mechanical breakdown of ingested food, (3) disruption of chemical bonds in food material through the action of acids and enzymes, and (4) production of **intrinsic factor**, a glycoprotein whose presence in the digestive tract is required for the absorption of vitamin B₁₂ in the small intestine.

**Anatomy of the Stomach**

**Figure 24-12**

• The stomach has the shape of an expanded J.
  o A short lesser curvature forms the medial surface of the organ, and a long greater curvature forms the lateral surface.
  o The anterior and posterior surfaces are smoothly rounded.
  o The shape and size of the stomach are extremely variable from individual to individual and even from one meal to the next.
  o In an “average” stomach, the lesser curvature has a length of approximately 10 cm (4 in.), and the greater curvature measures about 40 cm (16 in.).
    o The stomach typically extends between the levels of vertebrae T₇ and L₃.
• We can divide the stomach into four regions:
  o The **Cardia**.
  o The **Fundus**.
  o The **Body**.
  o The **Pylorus**.
The muscularis mucosae and muscularis externa of the stomach contain extra layers of smooth muscle cells in addition to the usual circular and longitudinal layers.

**Histology of the Stomach**

**Figure 24-13**
- A simple columnar epithelium lines all portions of the stomach. The epithelium is a secretory sheet, which produces a carpet of mucus that covers the interior surfaces of the stomach.
- Shallow depressions called gastric pits open onto the gastric surface. The mucous cells at the base, or neck, of each gastric pit actively divide, replacing superficial cells that are shed into the chyme.

**Gastric Glands**
- In the fundus and body of the stomach, each gastric pit communicates with several gastric glands, which extend deep into the underlying lamina propria. Gastric glands are dominated by two types of secretory cells:
  - parietal cells
  - chief cells.

**Gastrin**
- Parietal cells also secrete hydrochloric acid (HCl).
- Chief cells are most abundant near the base of a gastric gland. These cells secrete pepsinogen, an inactive proenzyme. Pepsinogen is converted by the acid in the gastric lumen to pepsin, an active proteolytic enzyme.

**Pyloric Glands**
- Glands in the pylorus produce primarily a mucous secretion, rather than enzymes or acid. In addition, several types of enteroendocrine cells are scattered among the mucus-secreting cells.
  - Gastrin is produced by G cells, which are most abundant in the gastric pits of the pyloric antrum.
  - The pyloric glands also contain D cells, which release somatostatin, a hormone that inhibits the release of gastrin.

**Regulation of Gastric Activity**

**Figure 24-15 and Table 24-1**
- The production of acid and enzymes by the gastric mucosa can be (1) controlled by the CNS, (2) regulated by short reflexes of the enteric nervous system, coordinated in the wall of the stomach, and (3) regulated by hormones of the digestive tract.

**The Cephalic Phase**
- The cephalic phase of gastric secretion begins when you see, smell, taste, or think of food. This stage, which is directed by the CNS, prepares the stomach to receive food.

**The Gastric Phase**
- The gastric phase begins with the arrival of food in the stomach and builds on the stimulation provided during the cephalic phase.

**The Intestinal Phase**
- The intestinal phase of gastric secretion begins when chime first enters the small intestine. The intestinal phase generally starts after several hours of mixing.
contractions, when waves of contraction begin sweeping down the length of the stomach.

**Digestion and Adsorption in the Stomach**
- The stomach performs preliminary digestion of proteins by pepsin and, for a variable period, permits the digestion of carbohydrates and lipids by salivary amylase and lingual lipase.
- As the stomach contents become more fluid and the pH approaches 2.0, pepsin activity increases and protein disassembly begins. Although digestion occurs in the stomach, nutrients are not absorbed there, for several reasons.

**Key**
- The stomach is a storage site that provides time for the physical breakdown of food that must precede chemical digestion.
- Protein digestion begins in the acid environment of the stomach through the action of pepsin.
- Carbohydrate digestion, which began with the release of salivary amylase by the salivary glands before swallowing, continues for a variable period after food arrives in the stomach.

**The Small Intestine and Associated Glandular Organs, p. 884**

**Objectives**
1. Describe the anatomical and histological characteristics of the small intestine.
2. Explain the functions of the intestinal secretions and discuss the regulation of secretory activities.
3. Describe the structure, functions, and regulation of the accessory digestive organs.

- The stomach is a holding tank in which food is saturated with gastric juices and exposed to stomach acids and the digestive effects of pepsin.
- The mucosa of the small intestine produces only a few of the enzymes involved. The pancreas provides digestive enzymes, as well as buffers that help neutralize chyme. The liver secretes bile, a solution stored in the gallbladder for subsequent discharge into the small intestine. Bile contains buffers and bile salts, compounds that facilitate the digestion and absorption of lipids.

**The Small Intestine**

**Figure 24-16**
- The small intestine plays the key role in the digestion and absorption of nutrients. Ninety percent of nutrient absorption occurs in the small intestine; most of the rest occurs in the large intestine.
- The **duodenum**, 25 cm (10 in.) in length, is the segment closest to the stomach. This portion of the small intestine is a “mixing bowl” that receives chyme from the stomach and digestive secretions from the pancreas and liver.
- The **jejunum** is about 2.5 meters (8.2 ft) long. The bulk of chemical digestion and nutrient absorption occurs in the jejunum.
- The **ileum**, the final segment of the small intestine, is also the longest, averaging 3.5 meters (11.48 ft) in length.
Hisotology of the Small Intestine

• The intestinal lining bears a series of transverse folds called plicae, or plicae circulares. Unlike the rugae in the stomach, the plicae are permanent features that do not disappear when the small intestine fills.

Figure 24-17

• Intestinal Villi The mucosa of the small intestine is thrown into a series of fingerlike projections, the intestinal villi. These structures are covered by a simple columnar epithelium that is carpeted with microvilli.
  o Intestinal Glands Goblet cells between the columnar epithelial cells eject mucins onto the intestinal surfaces. At the bases of the villi are the entrances to the intestinal glands, or crypts of Lieberkühn.
  o Several important brush border enzymes enter the intestinal lumen in this way. Brush border enzymes are integral membrane proteins located on the surfaces of intestinal microvilli. These enzymes perform the important digestive function of breaking down materials that come in contact with the brush border.
    o Enterokinase, one brush border enzyme that enters the lumen in this way, does not directly participate in digestion, but it activates a key pancreatic proenzyme, trypsinogen.
    o Intestinal glands also contain enteroendocrine cells responsible for the production of several intestinal hormones, including gastrin, cholecystokinin, and secretin.

• The duodenum has numerous mucous glands, both in the epithelium and deep to it. In addition to intestinal glands, its submucosa contains duodenal glands, also called submucosal glands or Brunner’s glands, which produce copious quantities of mucus when chyme arrives from the stomach.

• Regional Specializations The duodenum has few plicae, and their villi are small. The primary function of the duodenum is to receive chyme from the stomach and neutralize its acids before they can damage the absorptive surfaces of the small intestine.

• Intestinal Secretions. Roughly 1.8 liters of watery intestinal juice enters the intestinal lumen each day. Intestinal juice moistens chyme, assists in buffering acids, and keeps both the digestive enzymes and the products of digestion in solution.

Intestinal Movements

• After chyme has arrived in the duodenum, weak peristaltic contractions move it slowly toward the jejunum. The contractions are myenteric reflexes that are not under CNS control.
• The stimulation of the parasympathetic system increases the sensitivity of the weak myenteric reflexes and accelerates both local peristalsis and segmentation. More elaborate reflexes coordinate activities along the entire length of the small intestine.
  o The gastroenteric reflex stimulates motility and secretion along the entire small intestine; the gastroileal reflex triggers the relaxation of the ileocecal valve. The net result is that materials pass from the small intestine into the large intestine.

Key
• The small intestine receives and raises the pH of materials from the stomach.
• It then absorbs water, ions, vitamins, and the chemical products released by the action of digestive enzymes produced by intestinal glands and the exocrine glands of the pancreas.

**The Pancreas**

**Figure 24-18**

• The pancreas lies posterior to the stomach, extending laterally from the duodenum toward the spleen. The pancreas is an elongate, pinkish-gray organ about 15 cm (6 in.) long and weighing about 80 g (3 oz).
  o The broad **head** of the pancreas lies within the loop formed by the duodenum as it leaves the pylorus.
  o The slender **body** of the pancreas extends toward the spleen, and the **tail** is short and bluntly rounded.
  o The pancreas is retroperitoneal and is firmly bound to the posterior wall of the abdominal cavity. The surface of the pancreas has a lumpy, lobular texture. A thin, transparent capsule of connective tissue wraps the entire organ.
• The pancreas is primarily an exocrine organ, producing digestive enzymes and buffers. The large pancreatic duct (**duct of Wirsung**) delivers these secretions to the duodenum.
  o The pancreatic duct extends within the attached mesentery to reach the duodenum, where it meets the **common bile duct** from the liver and gallbladder.
  o The two ducts then empty into the **duodenal ampulla**, a chamber located roughly halfway along the length of the duodenum.

**Histological Organization**

• Partitions of connective tissue divide the interior of the pancreas into distinct lobules. The blood vessels and tributaries of the pancreatic ducts are situated within these connective-tissue septa.
• The pancreas is an example of a compound tubuloalveolar gland.
  o In each lobule, the ducts branch repeatedly before ending in blind pockets called **pancreatic acini**. Each pancreatic acinus is lined with a simple cuboidal epithelium.
  o **Pancreatic islets**, the endocrine tissues of the pancreas, are scattered among the acini. The islets account for only about 1 percent of the cell population of the pancreas.
• The pancreas has two distinct functions, one endocrine and the other exocrine. The endocrine cells of the pancreatic islets secrete insulin and glucagon into the bloodstream. The exocrine cells include the acinar cells and the epithelial cells that line the duct system.

**Physiology of the Pancreas**

• Each day, the pancreas secretes about 1000 ml (1 qt) of pancreatic juice. The secretory activities are controlled primarily by hormones from the duodenum.
• The specific pancreatic enzymes involved include the following:
Pancreatic alpha-amylase, a carbohydrate—an enzyme that breaks down certain starches. Pancreatic alpha-amylase is almost identical to salivary amylase.

Pancreatic lipase, which breaks down certain complex lipids, releasing products (such as fatty acids) that can be easily absorbed.

Nucleases, which break down nucleic acids.

Proteolytic enzymes, which break certain proteins apart. The proteolytic enzymes of the pancreas include proteases, which break apart large protein complexes, and peptidases, which break small peptide chains into individual amino acids.

- Proteolytic enzymes account for about 70 percent of total pancreatic enzyme production. The enzymes are secreted as inactive proenzymes and are activated only after they reach the small intestine.
- Once inside the duodenum, enterokinase located in the brush border and in the lumen triggers the conversion of trypsinogen to trypsin, an active protease.

**Key**

- The exocrine pancreas produces a mixture of buffers and enzymes essential for normal digestion.
- Pancreatic secretion occurs in response to the release of regulatory hormones (CCK and secretin) by the duodenum.

**The Liver**

- The liver, the largest visceral organ, is one of the most versatile organs in the body. Most of its mass lies in the right hypochondriac and epigastric regions, but it may extend into the left hypochondriac and umbilical regions as well.
  - The liver weighs about 1.5 kg (3.3 lb). This large, firm, reddish-brown organ performs essential metabolic and synthetic functions.

**Anatomy of the Liver**

**Figure 24-19**

- The liver is wrapped in a tough fibrous capsule and is covered by a layer of visceral peritoneum.
  - On the anterior surface, the falciform ligament marks the division between the organ’s left lobe and the right lobe.
  - A thickening in the posterior margin of the falciform ligament is the round ligament, or ligamentum teres, a fibrous band that marks the path of the fetal umbilical vein.
- On the posterior surface of the liver, the impression left by the inferior vena cava marks the division between the right lobe and the small caudate lobe.
  - Inferior to the caudate lobe lies the quadrate lobe, sandwiched between the left lobe and the gallbladder.
  - Afferent blood vessels and other structures reach the liver by traveling within the connective tissue of the lesser omentum. They converge at a region called the porta hepatis (“doorway to the liver”).
- Roughly one-third of the blood supply to the liver is arterial blood from the hepatic artery proper. The rest is venous blood from the hepatic portal vein, which begins in the capillaries of the esophagus, stomach, small intestine, and most of the large intestine.
Liver cells, called hepatocytes, adjust circulating levels of nutrients through selective absorption and secretion. Blood leaving the liver returns to the systemic circuit via the hepatic veins, which open into the inferior vena cava.

**Histological Organization of the Liver**

**Figure 24-20**

- Each lobe of the liver is divided by connective tissue into approximately 100,000 liver lobules, the basic functional units of the liver.
- Each lobule is roughly 1 mm in diameter. Adjacent lobules are separated from each other by an interlobular septum. The hepatocytes in a liver lobule form a series of irregular plates arranged like the spokes of a wheel.
- In addition to containing typical endothelial cells, the sinusoidal lining includes a large number of Kupffer cells, also known as stellate reticuloendothelial cells.
- Blood enters the liver sinusoids from small branches of the hepatic portal vein and hepatic artery proper. A typical liver lobule has a hexagonal shape in cross section.
  - There are six portal areas, or hepatic triads, one at each corner of the lobule. A portal area contains three structures: (1) a branch of the hepatic portal vein, (2) a branch of the hepatic artery proper, and (3) a small branch of the bile duct.
- Branches from the arteries and veins deliver blood to the sinusoids of adjacent liver lobules. As blood flows through the sinusoids, hepatocytes absorb solutes from the plasma and secrete materials such as plasma proteins. Pressures in the hepatic portal system are usually low, averaging 10 mm Hg or less. This pressure can increase markedly, however, if blood flow through the liver becomes restricted as a result of a blood clot or damage to the organ. Such a rise in portal pressure is called portal hypertension.

**The Bile Duct System**

- The liver secretes a fluid called bile into a network of narrow channels between the opposing membranes of adjacent liver cells. These passageways, called bile canaliculi, extend outward, away from the central vein.
  - Eventually, they connect with fine bile ductules, which carry bile to bile ducts in the nearest portal area.
  - The right and left hepatic ducts collect bile from all the bile ducts of the liver lobes. These ducts unite to form the common hepatic duct, which leaves the liver.
  - The bile in the common hepatic duct either flows into the common bile duct, which empties into the duodenal ampulla, or enters the cystic duct, which leads to the gallbladder.
- The common bile duct is formed by the union of the cystic duct and the common hepatic duct. The common bile duct passes within the lesser omentum toward the stomach, turns, and penetrates the wall of the duodenum to meet the pancreatic duct at the duodenal ampulla.

**The Physiology of the Liver**

- The liver is responsible for three general categories of functions: (1) metabolic regulation, (2) hematological regulation, and (3) bile production.
• Metabolic Regulation The liver is the primary organ involved in regulating the composition of circulating blood.
  
  o All blood leaving the absorptive surfaces of the digestive tract enters the hepatic portal system and flows into the liver. Liver cells extract nutrients or toxins from the blood before it reaches the systemic circulation through the hepatic veins.
  
  o The liver remove s and stores excess nutrients, and it corrects nutrient deficiencies by mobilizing stored reserves or performing synthetic activities. The liver's regulatory activities affect the following:
    ♣ Carbohydrate Metabolism. The liver stabilizes blood glucose levels at about 90 mg dl. If blood glucose levels drop, hepatocytes break down glycogen reserves and release glucose into the bloodstream.
    ♣ Lipid Metabolism. The liver regulates circulating levels of triglycerides, fatty acids, and cholesterol. When those levels decline, the liver breaks down its lipid reserves and releases the breakdown products into the bloodstream.
    ♣ Amino Acid Metabolism. The liver removes excess amino acids from the bloodstream. These amino acids can be used to synthesize proteins or can be converted to lipids or glucose for storage.
    ♣ Waste Product Removal. When converting amino acids to lipids or carbohydrates, or when breaking down amino acids to get energy, the liver strips off the amino groups, a process called deamination.
    ♣ Vitamin Storage. Fat-soluble vitamins (A, D, E, and K) and vitamin are absorbed from the blood and stored in the liver. These reserves are called on when your diet contains inadequate amounts of those vitamins.
    ♣ Mineral Storage. The liver converts iron reserves to ferritin and stores this protein–iron complex.
    ♣ Drug Inactivation. The liver removes and breaks down circulating drugs, thereby limiting the duration of their effects.
  
• Hematological Regulation The liver, the largest blood reservoir in your body, receives about 25 percent of cardiac output. As blood passes through it, the liver performs the following functions:
  
  o Phagocytosis and Antigen Presentation. Kupffer cells in the liver sinusoids engulf old or damaged red blood cells, cellular debris, and pathogens, removing them from the bloodstream. Kupffer cells are antigen-presenting cells that can stimulate an immune response.
  
  o Synthesis of Plasma Proteins. Hepatocytes synthesize and release most of the plasma proteins, including the albumins (which contribute to the osmotic concentration of the blood), the various types of transport proteins, clotting proteins, and complement proteins.
  
  o Removal of Circulating Hormones. The liver is the primary site for the absorption and recycling of epinephrine, norepinephrine, insulin, thyroid hormones, and steroid hormones, such as the sex hormones (estrogens and androgens) and corticosteroids. The liver also absorbs cholecalciferol from the blood. Liver cells then convert the cholecalciferol, which may be
synthesized in the skin or absorbed in the diet, into an intermediary product, 25-hydroxy- that is released back into the bloodstream.

- Removal of Antibodies. The liver absorbs and breaks down antibodies, releasing amino acids for recycling.
- Removal or Storage of Toxins. Lipid-soluble toxins in the diet, such as the insecticide DDT, are absorbed by the liver and stored in lipid deposits, where they do not disrupt cellular functions. Other toxins are removed from the bloodstream and are either broken down or excreted in the bile.
- The Synthesis and Secretion of Bile. Bile is synthesized in the liver and excreted into the lumen of the duodenum. Bile consists mostly of water, with minor amounts of ions, bilirubin (a pigment derived from hemoglobin), cholesterol, and an assortment of lipids collectively known as the bile salts.

**The Functions of Bile**

- Most dietary lipids are not water soluble. Mechanical processing in the stomach creates large drops containing a variety of lipids.
  - Pancreatic lipase is not lipid soluble, so the enzymes can interact with lipids only at the surface of a lipid droplet. The larger the droplet, the more lipids are inside, isolated and protected from these enzymes.
  - Bile salts break the droplets apart in a process called emulsification, which dramatically increases the surface area accessible to enzymatic attack.
- Emulsification creates tiny emulsion droplets with a superficial coating of bile salts. The formation of tiny droplets increases the surface area available for enzymatic attack.

**The Gallbladder**

**Figure 24-21**

- The gallbladder is a hollow, pear-shaped organ that stores and concentrates bile prior to its excretion into the small intestine. This muscular sac is located in a fossa, or recess, in the posterior surface of the liver’s right lobe.
  - The gallbladder is divided into three regions: (1) the fundus, (2) the body, and (3) the neck.
  - The cystic duct extends from the gallbladder to the point where its union with the common hepatic duct forms the common bile duct.
  - At the duodenum, the common bile duct meets the pancreatic duct before emptying into a chamber called the duodenal ampulla, which receives buffers and enzymes from the pancreas and bile from the liver and gallbladder.
  - The duodenal ampulla opens into the duodenum at the duodenal papilla, a small mound. The muscular hepatopancreatic sphincter (sphincter of Oddi) encircles the lumen of the common bile duct and, generally, the pancreatic duct and duodenal ampulla as well.

**Physiology of the Gallbladder**

- A major function of the gallbladder is bile storage. Bile is secreted continuously—roughly 1 liter is produced each day—but it is released into the duodenum only under the stimulation of the intestinal hormone CCK.
o In the absence of CCK, the hepatopancreatic sphincter remains closed, so bile exiting the liver in the common hepatic duct cannot flow through the common bile duct and into the duodenum. Instead, it enters the cystic duct and is stored within the expandable gallbladder.

o Whenever chyme enters the duodenum, CCK is released, relaxing the hepatopancreatic sphincter and stimulating contractions in the walls of the gallbladder that push bile into the small intestine. The amount of CCK secreted increases markedly when the chyme contains large amounts of lipids.

• The gallbladder also functions in bile modification. When full, the gallbladder contains 40–70 ml of bile. The composition of bile gradually changes as it remains in the gallbladder: Much of the water is absorbed, and the bile salts and other components of bile become increasingly concentrated.

• If bile becomes too concentrated, crystals of insoluble minerals and salts begin to form. These deposits are called gallstones. Small gallstones are not a problem so long as they can be flushed down the bile duct and excreted.

**Key**

• The liver is the center for metabolic regulation in the body.

• It also produces bile that is stored in the gallbladder and ejected into the duodenum under the stimulation of CCK.

• Bile is essential for the efficient digestion of lipids; it breaks down large lipid droplets so that individual lipid molecules can be attacked by digestive enzymes.

**The Coordination of Secretion and Absorption**

• A combination of neural and hormonal mechanisms coordinates the activities of the digestive glands. These regulatory mechanisms are centered around the duodenum, where acids must be neutralized and the appropriate enzymes added.

• Neural mechanisms involving the CNS (1) prepare the digestive tract for activity (parasympathetic innervation) or inhibit gastrointestinal activity (sympathetic innervation) and (2) coordinate the movement of materials along the length of the digestive tract (the enterogastric, gastroenteric, and gastroileal reflexes).

• In addition, motor neurons synapsing in the digestive tract release a variety of neurotransmitters.

**Intestinal Hormones**

**Figure 24-22**

• The intestinal tract secretes a variety of peptide hormones with similar chemical structures. Many of these hormones have multiple effects in several regions of the digestive tract, and in the accessory glandular organs as well.

• Duodenal enteroendocrine cells produce the following hormones known to coordinate digestive functions:
  o Secretin is released when chyme arrives in the duodenum. Secretin’s primary effect is an increase in the secretion of bile and buffers by the liver and pancreas.
  o Cholecystokinin (CCK) is secreted when chyme arrives in the duodenum, especially when the chyme contains lipids and partially digested proteins.
    ♣ In the pancreas, CCK accelerates the production and secretion of all types of digestive enzymes.
It also causes a relaxation of the hepatopancreatic sphincter and contraction of the gallbladder, resulting in the ejection of bile and pancreatic juice into the duodenum.

- Gastric inhibitory peptide (GIP) is secreted when fats and carbohydrates—especially glucose—enter the small intestine.
- Vasoactive intestinal peptide (VIP) stimulates the secretion of intestinal glands, dilates regional capillaries, and inhibits acid production in the stomach.
- Gastrin is secreted by G cells in the duodenum when they are exposed to large quantities of incompletely digested proteins. The functions of gastrin include promoting increased stomach motility and stimulating the production of acids and enzymes.
- Enterocrinin, a hormone released when chyme enters the small intestine, stimulates mucin production by the submucosal glands of the duodenum.

**Intestinal Absorption**

- On average, it takes about five hours for materials to pass from the duodenum to the end of the ileum, so the first of the materials to enter the duodenum after you eat breakfast may leave the small intestine at lunchtime.
  - Along the way, the organ’s absorptive effectiveness is enhanced by the fact that so much of the mucosa is movable.
  - The microvilli can be moved by their supporting microfilaments, the individual villi by smooth muscle cells, groups of villi by the muscularis mucosae, and the plicae by the muscularis mucosae and the muscularis externa.
  - These movements stir and mix the intestinal contents, changing the environment around each epithelial cell from moment to moment.

**The Large Intestine, p. 896**

**Objectives**

1. Describe the gross and histological structure of the large intestine.
2. List the regional specializations of the large intestine.
3. Explain the significance of the large intestine in the absorption of nutrients.

**Figure 24-23**

- The horseshoe-shaped large intestine begins at the end of the ileum and ends at the anus. The large intestine lies inferior to the stomach and liver and almost completely frames the small intestine.
- The major functions of the large intestine include (1) the reabsorption of water and the compaction of the intestinal contents into feces, (2) the absorption of important vitamins liberated by bacterial action, and (3) the storage of fecal material prior to defecation.
- The large intestine, also known as the large bowel, has an average length of about 1.5 meters (4.9 ft) and a width of 7.5 cm (3 in.). We can divide it into three parts: (1) the pouchlike cecum, the first portion of the large intestine; (2) the colon, the largest portion; and (3) the rectum, the last 15 cm (6 in.) of the large intestine and the end of the digestive tract.

**The Cecum**
Material arriving from the ileum first enters an expanded pouch called the cecum. The ileum attaches to the medial surface of the cecum and opens into the cecum at the ileocecal valve.

The cecum collects and stores materials from the ileum and begins the process of compaction.

The slender, hollow appendix, or vermiform appendix, is attached to the posteromedial surface of the cecum.

- The appendix is generally about 9 cm (3.6 in.) long, but its size and shape are quite variable.
- A small mesentery called the mesoappendix connects the appendix to the ileum and cecum.
- The mucosa and submucosa of the appendix are dominated by lymphoid nodules, and the primary function of the appendix is as an organ of the lymphatic system.

**The Colon**

The colon has a larger diameter and a thinner wall than the small intestine.

Distinctive features of the colon include the following:

- The wall of the colon forms a series of pouches, or haustra. Haustra permit the expansion and elongation of the colon, rather like the bellows that allow an accordion to lengthen.
- Three separate longitudinal bands of smooth muscle—called the taeniae coli—run along the outer surfaces of the colon just deep to the serosa. These bands correspond to the outer layer of the muscularis externa in other portions of the digestive tract. Muscle tone within the taeniae coli is what creates the haustra.

The serosa of the colon contains numerous teardrop-shaped sacs of fat called fatty appendices, or epiploic appendages. We can subdivide the colon into four regions: the ascending colon, transverse colon, descending colon, and sigmoid colon.

- The ascending colon begins at the superior border of the cecum and ascends along the right lateral and posterior wall of the peritoneal cavity to the inferior surface of the liver. There, the colon bends sharply to the left at the right colic flexure, or hepatic flexure, which marks the end of the ascending colon and the beginning of the transverse colon.
- The transverse colon curves anteriorly from the right colic flexure and crosses the abdomen from right to left. The transverse colon is supported by the transverse mesocolon and is separated from the anterior abdominal wall by the layers of the greater omentum. As the transverse colon reaches the left side of the body, it passes inferior to the greater curvature of the stomach. Near the spleen, the colon makes a 90° turn at the left colic flexure, or splenic flexure, and becomes the descending colon.
- The descending colon proceeds inferiorly along the person’s left side until reaching the iliac fossa formed by the inner surface of the left ilium. The descending colon is retroperitoneal and firmly attached to the abdominal wall. At the iliac fossa, the descending colon curves at the sigmoid flexure and becomes the sigmoid colon.
The sigmoid flexure is the start of the sigmoid colon, an S-shaped segment that is only about 15 cm (6 in.) long. The sigmoid colon lies posterior to the urinary bladder, suspended from the sigmoid mesocolon. The sigmoid colon empties into the rectum.

• The large intestine receives blood from tributaries of the superior mesenteric and inferior mesenteric arteries. Venous blood is collected from the large intestine by the superior mesenteric and inferior mesenteric veins.

The Rectum
• The rectum, which forms the last 15 cm (6 in.) of the digestive tract, is an expandable organ for the temporary storage of feces. The movement of fecal material into the rectum triggers the urge to defecate.
• The last portion of the rectum, the anal canal, contains small longitudinal folds called anal columns.
• The anus, or anal orifice, is the exit of the anal canal. There, the epidermis becomes keratinized and identical to the surface of the skin.
  • The circular muscle layer of the muscularis externa in this region forms the internal anal sphincter, the smooth muscle cells of which are not under voluntary control. The external anal sphincter, which guards the anus, consists of a ring of skeletal muscle fibers that encircles the distal portion of the anal canal.
  • This sphincter consists of skeletal muscle and is under voluntary control.

Histology of the Large Intestine

Figure 24-24

• Although the diameter of the colon is roughly three times that of the small intestine, its wall is much thinner. The major characteristics of the colon are the lack of villi, the abundance of goblet cells, and the presence of distinctive intestinal glands.
  • The glands in the large intestine are deeper than those of the small intestine and are dominated by goblet cells.
  • The mucosa of the large intestine does not produce enzymes; any digestion that occurs results from enzymes introduced in the small intestine or from bacterial action.
  • The mucus provides lubrication as the fecal material becomes drier and more compact.
  • Large lymphoid nodules are scattered throughout the lamina propria and submucosa.
  • The muscularis externa of the large intestine is unusual, because the longitudinal layer has been reduced to the muscular bands of the taeniae coli.

Physiology of the Large Intestine
• Less than 10 percent of the nutrient absorption under way in the digestive tract occurs in the large intestine.
• The large intestine also prepares fecal material for ejection from the body.

Absorption on the Large Intestine
• The reabsorption of water is an important function of the large intestine. Although roughly 1500 ml of material enters the colon each day, only about 200 ml of feces is ejected.
• In addition to reabsorbing water, the large intestine absorbs a number of other substances that remain in the feces or were secreted into the digestive tract along its length.
• Most of the bile salts entering the large intestine are promptly reabsorbed in the cecum and transported in blood to the liver for secretion into bile.
• Vitamins are organic molecules that are important as cofactors or coenzymes in many metabolic pathways. The normal bacterial residents of the colon generate three vitamins that supplement our dietary supply:
  o Vitamin K, a fat-soluble vitamin the liver requires for synthesizing four clotting factors, including prothrombin. Intestinal bacteria produce roughly half of your daily vitamin K requirements.
  o Biotin, a water-soluble vitamin important in various reactions, notably those of glucose metabolism.
  o Pantothenic acid, a water-soluble vitamin required in the manufacture of steroid hormones and some neurotransmitters.
• Organic Wastes In the large intestine, bacteria convert bilirubin to urobilinogens and stercobilinogens. Some urobilinogens are absorbed into the bloodstream and then excreted in urine. The urobilinogens and stercobilinogens remaining within the colon are converted to urobilins and stercobilins by exposure to oxygen.
  o Bacterial action breaks down peptides that remain in the feces and generates (1) ammonia, in the form of soluble ammonium ions (2) indole and skatole, two nitrogen-containing compounds that are primarily responsible for the odor of feces; and (3) hydrogen sulfide a gas that produces a “rotten egg” odor.
  o Indigestible carbohydrates are not altered by intestinal Enzymes, so they arrive in the colon virtually intact. These complex polysaccharides provide a reliable nutrient source for colonic bacteria, whose metabolic activities are responsible for the small quantities of flatus, or intestinal gas, in the large intestine.

Movements of the Large Intestine

Figure 24-25
• The gastroileal and gastroenteric reflexes move materials into the cecum while you eat. Movement from the cecum to the transverse colon is very slow, allowing hours for water absorption to convert the already thick material into a sludgy paste.
• Peristaltic waves move material along the length of the colon, and segmentation movements, called haustral churning, mix the contents of adjacent haustra.
• Movement from the transverse colon through the rest of the large intestine results from powerful peristaltic contractions called mass movements, which occur a few times each day. The stimulus is distension of the stomach and duodenum; the commands are relayed over the intestinal nerve plexuses.
Distension of the rectal wall then triggers the defecation reflex, which involves two positive feedback loops. Both loops are triggered by the stimulation of stretch receptors in the walls of the rectum.
  - The first loop is a short reflex that triggers a series of peristaltic contractions in the rectum that move feces toward the anus.
  - The second loop is a long reflex coordinated by the sacral parasympathetic system. This reflex stimulates mass movements that push feces toward the rectum from the descending colon and sigmoid colon.
  - Rectal stretch receptors also trigger two reflexes important to the voluntary control of defecation.
    - One is a long reflex mediated by parasympathetic innervation within the pelvic nerves. This reflex causes the relaxation of the internal anal sphincter, the smooth muscle sphincter that controls the movement of feces into the anal canal.
    - The second is a somatic reflex that stimulates the immediate contraction of the external anal sphincter, a skeletal muscle. The motor commands are carried by the pudendal nerves.
    - The elimination of feces requires that both the internal and external anal sphincters be relaxed, but the two reflexes just mentioned open the internal sphincter and close the external sphincter. The actual release of feces requires a conscious effort to open the external sphincter. In addition to opening the external sphincter, consciously directed activities such as tensing the abdominal muscles or making expiratory movements while closing the glottis elevate intra-abdominal pressures and help force fecal material out of the rectum.

Digestion and Absorption, p. 902

Objectives
1. Specify the nutrients required by the body.
2. Describe the chemical events responsible for the digestion of organic nutrients.
3. Describe the mechanisms involved in the absorption of organic and inorganic nutrients.
- A typical meal contains carbohydrates, proteins, lipids, water, electrolytes, and vitamins. The digestive system handles each component differently. Large organic molecules must be broken down by digestion before absorption can occur. Water, electrolytes, and vitamins can be absorbed without preliminary processing, but special transport mechanisms may be involved.

The Processing and Absorption of Nutrients

Figure 24-26
- Food contains large organic molecules, many of them insoluble. The digestive system first breaks down the physical structure of the ingested material and then proceeds to disassemble the component molecules into smaller fragments.
The molecules released into the bloodstream are absorbed by cells and either (1) broken down to provide energy for the synthesis of ATP or (2) used to synthesize carbohydrates, proteins, and lipids. Digestive enzymes break the bonds between the component molecules of carbohydrates, proteins, lipids, and nucleic acids in a process called hydrolysis. The classes of digestive enzymes differ with respect to their targets. Carbohydrases break the bonds between simple sugars, proteases split the linkages between amino acids, and lipases separate fatty acids from glycerides. Digestive enzymes secreted by the salivary glands, tongue, stomach, and pancreas are mixed into the ingested material as it passes along the digestive tract. These enzymes break down large carbohydrates, proteins, lipids, and nucleic acids into smaller fragments, which in turn must typically be broken down further before absorption can occur. The final enzymatic steps involve brush border enzymes, which are attached to the exposed surfaces of microvilli. Nucleic acids are broken down into their component nucleotides. Brush border enzymes digest these nucleotides into sugars, phosphates, and nitrogenous bases that are absorbed by active transport.

**Carbohydrate Digestion and Absorption**

- The digestion of complex carbohydrates (simple polysaccharides and starches) proceeds in two steps. One step involves carbohydrases produced by the salivary glands and pancreas; the other, brush border enzymes.

**The Actions of Salivary and Pancreatic Enzymes**

- The digestion of complex carbohydrates involves two enzymes—salivary amylase and pancreatic alpha-amylase—that function effectively at a pH of 6.7–7.5. Carbohydrate digestion begins in the mouth during mastication, through the action of salivary amylase from the parotid and submandibular salivary glands.
- Salivary amylase breaks down starches (complex carbohydrates), producing a mixture composed primarily of disaccharides (two simple sugars) and trisaccharides (three simple sugars). Salivary amylase continues to digest the starches and glycogen in the food for 1–2 hours before stomach acids render the enzyme inactive.

**Action of Brush Border Enzymes**

- Prior to absorption, disaccharides and trisaccharides are fragmented into monosaccharides (simple sugars) by brush border enzymes of the intestinal microvilli. The enzyme maltase splits bonds between the two glucose molecules of the disaccharide maltose.
- Sucrase breaks the disaccharide sucrose into glucose and fructose, another six-carbon sugar.
- Lactase hydrolyzes the disaccharide lactose into a molecule of glucose and one of galactose.

**Absorption of Monosaccharides**

- The intestinal epithelium then absorbs the monosaccharides by facilitated diffusion and cotransport mechanisms. Both methods involve a carrier protein. Facilitated diffusion and cotransport differ in three major ways:
  - Facilitated Diffusion Moves Only One Molecule or Ion through the Cell Membrane, Whereas Cotransport Moves More Than One Molecule or Ion
through the Membrane at the Same Time. In cotransport, the transported materials move in the same direction: down the concentration gradient for at least one of the transported substances.

- Facilitated Diffusion Does Not Require ATP. Although cotransport by itself does not consume ATP, the cell must often expend ATP to preserve homeostasis.
- Facilitated Diffusion Will Not Occur if There Is an Opposing Concentration Gradient for the Particular Molecule or Ion. By contrast, cotransport can occur despite an opposing concentration gradient for one of the transported substances.
- The cotransport system responsible for the uptake of glucose also brings sodium ions into the cell. This passive process resembles facilitated diffusion, except that both a sodium ion and a glucose molecule must bind to the carrier protein before they can move into the cell.
- Comparable cotransport mechanisms exist for other simple sugars and for some amino acids. Although these mechanisms deliver valuable nutrients to the cytoplasm, they also bring in sodium ions that must be ejected by the sodium–potassium exchange pump.
- The simple sugars that are transported into the cell at its apical surface diffuse through the cytoplasm and reach the interstitial fluid by facilitated diffusion across the basolateral surfaces. These monosaccharides then diffuse into the capillaries of the villus for eventual transport to the liver in the hepatic portal vein.

**Lipid Digestion and Absorption**

- Lipid digestion involves lingual lipase from glands of the tongue, and pancreatic lipase from the pancreas. The most important and abundant dietary lipids are triglycerides, which consist of three fatty acids attached to a single molecule of glycerol.
- The lingual and pancreatic lipases break off two of the fatty acids, leaving monoglycerides. Lipases are water-soluble enzymes, and lipids tend to form large drops that exclude water molecules. As a result, lipases can attack only the exposed surfaces of the lipid drops. Lingual lipase begins breaking down triglycerides in the mouth and continues for a variable time within the stomach, but the lipid drops are so large, and the available time so short, that only about 20 percent of the lipids have been digested by the time the chyme enters the duodenum.
- Bile salts improve chemical digestion by emulsifying the lipid drops into tiny emulsion droplets, thereby providing better access for pancreatic lipase. The emulsification occurs only after the chyme has been mixed with bile in the duodenum. Pancreatic lipase then breaks apart the triglycerides to form a mixture of fatty acids and monoglycerides.
- The intestinal cells synthesize new triglycerides from the monoglycerides and fatty acids. These triglycerides, in company with absorbed steroids, phospholipids, and fatsoluble vitamins, are then coated with proteins, creating complexes known as chylomicrons. The intestinal cells then secrete the chylomicrons into interstitial fluid by exocytosis.
Protein Digestion and Absorption

- Proteins have very complex structures, so protein digestion is both complex and time-consuming. The first task is to disrupt the three-dimensional organization of the food so that proteolytic enzymes can attack individual proteins. This step involves mechanical processing in the oral cavity, through mastication, and chemical processing in the stomach, through the action of hydrochloric acid.
- **Pepsin**, which works effectively at a pH of 1.5–2.0, breaks the peptide bonds within a polypeptide chain. When chyme enters the duodenum, enterokinase produced in the small intestine triggers the conversion of trypsinogen to trypsin, and the pH is adjusted to 7–8. Pancreatic proteases can now begin working.

Absorption of Amino Acids

- The epithelial surfaces of the small intestine contain several peptidases, notably dipeptidases—enzymes that break short peptide chains into individual amino acids.
- These amino acids, as well as those produced by the pancreatic enzymes, are absorbed through both facilitated diffusion and cotransport mechanisms. After diffusing to the basal surface of the cell, the amino acids are released into interstitial fluid by facilitated diffusion and cotransport.

Water Absorption

**Figure 24-27**

- Cells cannot actively absorb or secrete water. All movement of water across the lining of the digestive tract, as well as the production of glandular secretions, involves passive water flow down osmotic gradients.

Ion Absorption

**Table 24-4**

- Osmosis does not distinguish among solutes; all that matters is the total concentration of solutes. To maintain homeostasis, however, the concentrations of specific ions must be closely regulated.
- The rate of sodium ion absorption by the digestive tract is increased by aldosterone, a steroid hormone from the adrenal cortex. Calcium ion absorption involves active transport at the epithelial surface. The rate of transport is accelerated by parathyroid hormone (PTH) and calcitriol.
- As other solutes move out of the lumen, the concentration of potassium ions increases. These ions can diffuse into the epithelial cells along the concentration gradient.
- The absorption of magnesium, iron and other cations involves specific carrier proteins; the cell must use ATP to obtain and transport these ions to interstitial fluid.
- The anions chloride iodide bicarbonate and nitrate are absorbed by diffusion or carrier-mediated transport. Phosphate and sulfate ions enter epithelial cells only by active transport.

Vitamin Absorption

- Vitamins are organic compounds required in very small quantities. There are two major groups of vitamins: fatsoluble vitamins and water-soluble vitamins. Vitamins A, D, E, and K are fat-soluble vitamins; their structure allows them to
dissolve in lipids. The nine water-soluble vitamins include the B vitamins, common in milk and meats, and vitamin C, found in citrus fruits.

- All but one of the water-soluble vitamins are easily absorbed by diffusion across the digestive epithelium. Vitamin cannot be absorbed by the intestinal mucosa in normal amounts, unless this vitamin has been bound to intrinsic factor, a glycoprotein secreted by the parietal cells of the stomach.

**Aging and the Digestive System, p. 907**

**Objective**

1. Summarize the effects of the aging process on the digestive system.

- Essentially normal digestion and absorption occur in elderly individuals. However, many changes in the digestive system parallel age-related changes we have already discussed in connection with other systems:
  - The Division Rate of Epithelial Stem Cells Declines. The digestive epithelium becomes more susceptible to damage by abrasion, acids, or enzymes.
  - Smooth Muscle Tone Decreases. General motility decreases, and peristaltic contractions are weaker as a result of a decrease in smooth muscle tone.
  - The Effects of Cumulative Damage Become Apparent. A familiar example is the gradual loss of teeth due to dental caries (cavities) or gingivitis. Cumulative damage can involve internal organs as well. Toxins such as alcohol and other injurious chemicals that are absorbed by the digestive tract are transported to the liver for processing.
  - Cancer Rates Increase. Cancers are most common in organs in which stem cells divide to maintain epithelial cell populations. Rates of colon cancer and stomach cancer rise with age; oral and pharyngeal cancers are particularly common among elderly smokers.
  - Changes in Other Systems Have Direct or Indirect Effects on the Digestive System. The decline in olfactory and gustatory sensitivities with age can lead to dietary changes that affect the entire body.