Unit 5

Absorption and Excretion

chapter 15

Digestion and Nutrition

PREVENTING VITAMIN D DEFICIENCY. In recent years, many people have been trying to limit their exposure to the sun because of links between excessive sunning and skin cancers. Too little sun, however, can lead to vitamin D deficiency, because exposure to the ultraviolet wavelengths in sunlight is needed to convert certain precursors in skin cells into vitamin D.

Vitamin D is necessary for intestinal absorption of phosphorus and calcium, minerals that are essential for the health of the skeletal system. A deficiency of the vitamin causes the parathyroid glands to become overactive, taking more calcium from bones and causing osteoporosis. Demineralization, which removes phosphorus from bones, causes the bone-softening condition osteomalacia. In youngsters, lack of vitamin D leads to the bone-weakening condition rickets.

Evidence for vitamin D deficiency related to sun avoidance has a long history. The link between lack of sunlight and development of rickets was noted in 1822, and a century later, researchers realized that sun exposure helps reverse the disease in children. Other evidence comes from diverse sources, such as women who wear veils and naval personnel serving 3-month tours of duty on submarines.

Because older people tend to be outdoors less than younger individuals, the Institute of Medicine suggests that daily vitamin D intake escalate with age (see the following table).

AGE RANGE (YEARS)	INTERNATIONAL UNITS OF VITAMIN D
<50	200
50–70	400
70+	600

In addition, brief exposure to the sun can do wonders for maintaining vitamin D levels, without raising the risk of developing skin cancer—just 5 minutes of sunshine two or three times a week should do the trick.

Photo:
Sunshine is necessary for an adequate supply of vitamin D.

Chapter Objectives

After studying this chapter, you should be able to do the following:

15.1 Introduction

1. Describe the general functions of the digestive system. (p. 393)
2. Name the major organs of the digestive system. (p. 393)

15.2 General Characteristics of the Alimentary Canal

3. Describe the structure of the wall of the alimentary canal. (p. 394)
4. Explain how the contents of the alimentary canal are mixed and moved. (p. 395)

15.3 Mouth

5. Name the structures of the mouth and describe their functions. (p. 396)
6. Describe how different types of teeth are adapted for different functions. (p. 398)
7. List the parts of a tooth. (p. 398)

15.4–15.10 Salivary Glands—Large Intestine

8. List the enzymes the digestive organs and glands secrete, and describe the function of each. (p. 399)
9. Describe how digestive secretions are regulated. (p. 399)
10. Describe the mechanism of swallowing. (p. 400)
11. Explain how the products of digestion are absorbed. (p. 404)
12. Describe the defecation reflex. (p. 419)

15.11 Nutrition and Nutrients

13. List the major sources of carbohydrates, lipids, and proteins. (p. 420)
14. Describe how cells utilize carbohydrates, lipids, and amino acids. (p. 420)
15. List the fat-soluble and water-soluble vitamins, and summarize the general functions of each vitamin. (p. 423)
16. List the major minerals and trace elements, and summarize the general functions of each. (p. 424)
17. Describe an adequate diet. (p. 426)

Aids to Understanding Words

aliment- [food] *aliment*ary canal: Tubelike portion of the digestive system.

chym- [juice] *chym*e: Semifluid paste of food particles and gastric juice formed in the stomach.

decidu- [falling off] *decidu*ous teeth: Teeth that are shed during childhood.

gastr- [stomach] *gastr*ic gland: Portion of the stomach that secretes gastric juice.

hepat- [liver] *hepat*ic duct: Duct that carries bile from the liver to the common bile duct.

lingu- [tongue] *lingu*al tonsil: Mass of lymphatic tissue at the root of the tongue.

nutri- [nourish] *nutri*ent: Substance needed to nourish body cells.

peri- [around] *peri*stalsis: Wavelike ring of contraction that moves material along the alimentary canal.

pyl- [gatekeeper] *pyl*oric sphincter: Muscle that serves as a valve between the stomach and small intestine.

vill- [hairy] *vill*i: Tiny projections of mucous membrane in the small intestine.

Key Terms

alimentary canal (al´´ĭ-men´tar-e kah-nal´)
bile (bīl)
calorie (kal´o-re)
chyme (kīm)
feces (fe´sēz)
gastric juice (gas´trik jo͞os)
intestinal villus (in-tes´tĭ-nal vil´us); plural: **villi** (vil´i)
intrinsic factor (in-trin´sik fak´tor)
malnutrition (mal´´nu-trish´un)
mesentery (mes´en-ter´´e)
mineral (min´er-al)
nutrient (nu´tre-ent)
pancreatic juice (pan´´kre-at´ik jo͞os)
peristalsis (per´´ĭ-stal´sis)
vitamin (vi´tah-min)

15.1 Introduction

Digestion is the mechanical and chemical breakdown of foods and the absorption of the resulting nutrients by cells. The organs of the digestive system carry out these processes. The **digestive system** consists of the alimentary canal, which extends about 9 meters from the mouth to the anus, and several accessory organs, which secrete substances used in the process of digestion into the canal. The **alimentary canal** includes the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anal canal; the accessory organs include the salivary glands, liver, gallbladder, and pancreas (fig. 15.1; reference plates 4, 5, and 6, pp. 25–27). Overall,

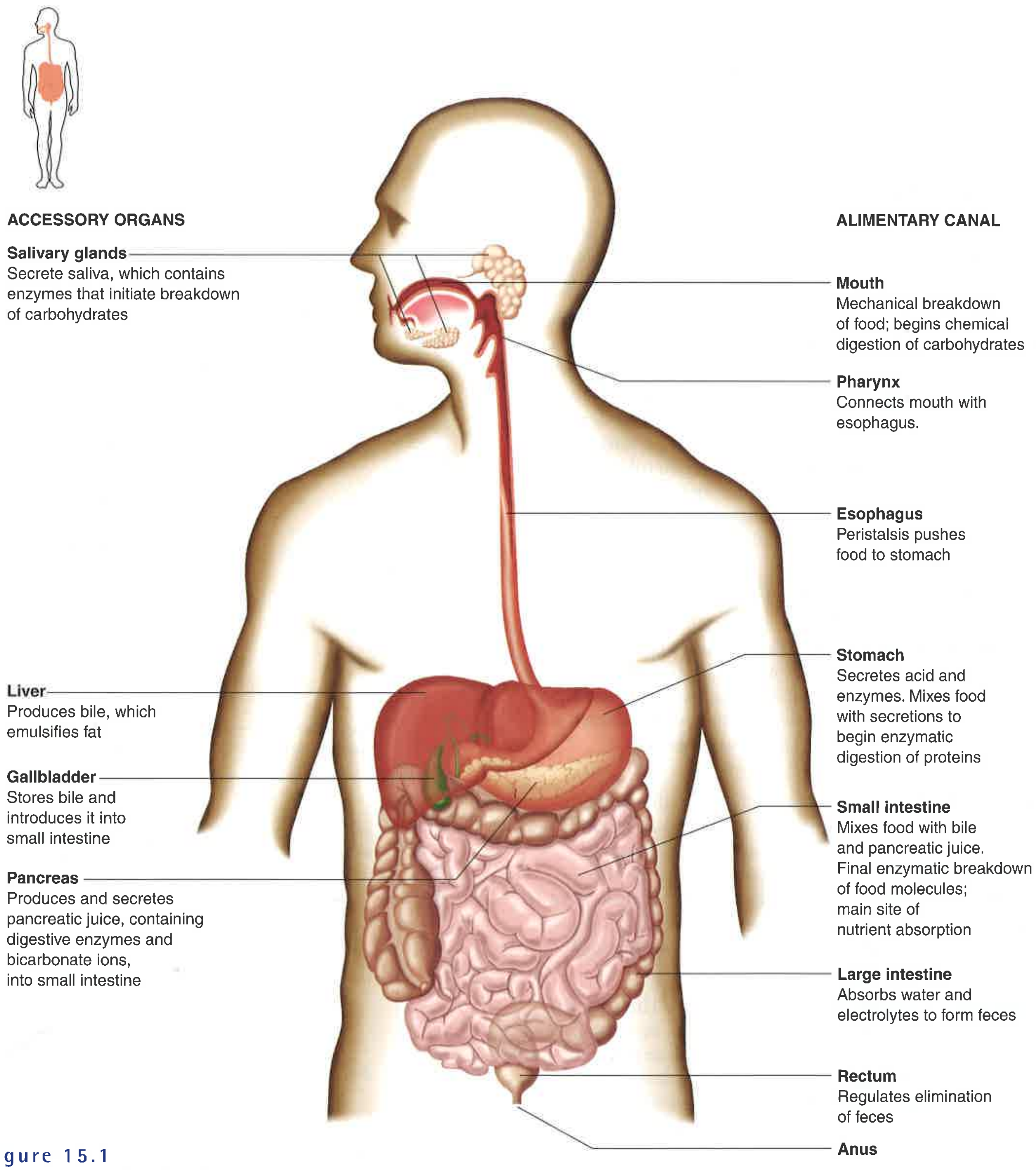


Figure 15.1
Major organs of the digestive system.

the digestive system is a tube, open at both ends, that has a surface area of 186 square meters. It supplies body cells with nutrients.

15.2 General Characteristics of the Alimentary Canal

The alimentary canal is a muscular tube that passes through the body's ventral cavity. It is specialized in certain regions to carry on particular functions, but the structure of its wall, how it moves food, and its innervation are similar throughout its length (fig. 15.2).

Structure of the Wall

The wall of the alimentary canal consists of four distinct layers that are developed to different degrees from region to region. Beginning with the innermost tissues, these layers are (fig. 15.3):

1. **Mucosa,** or **mucous membrane** (mu´kus mem´brān) Surface epithelium, underlying connective tissue, and a small amount of smooth muscle form this layer. In some regions, the mucosa develops folds and tiny projections that extend into the passageway, or **lumen,** of the digestive tube and increase the mucosa's absorptive surface area. The mucosa may also contain glands that are tubular invaginations into which the lining cells secrete mucus and digestive enzymes. The mucosa protects the tissues beneath it and carries on secretion and absorption.
2. **Submucosa** The submucosa contains considerable loose connective tissue as well as glands, blood vessels, lymphatic vessels, and nerves organized into a network called a plexus. Its vessels nourish surrounding tissues and carry away absorbed materials.
3. **Muscular layer** This layer, which produces movements of the tube, consists of two coats of smooth muscle tissue and some nerves organized into a plexus. The fibers of the inner coat encircle the tube. When these *circular fibers* contract, the tube's diameter decreases. The fibers of the outer muscular coat run lengthwise. When these *longitudinal fibers* contract, the tube shortens.
4. **Serosa,** or **serous layer** (se´rus la´er) The *visceral peritoneum* comprises the serous layer, or outer covering, of the tube. The cells of the serosa protect underlying tissues and secrete serous fluid, which moistens and lubricates the tube's outer surface so that organs within the abdominal cavity slide freely against one another.

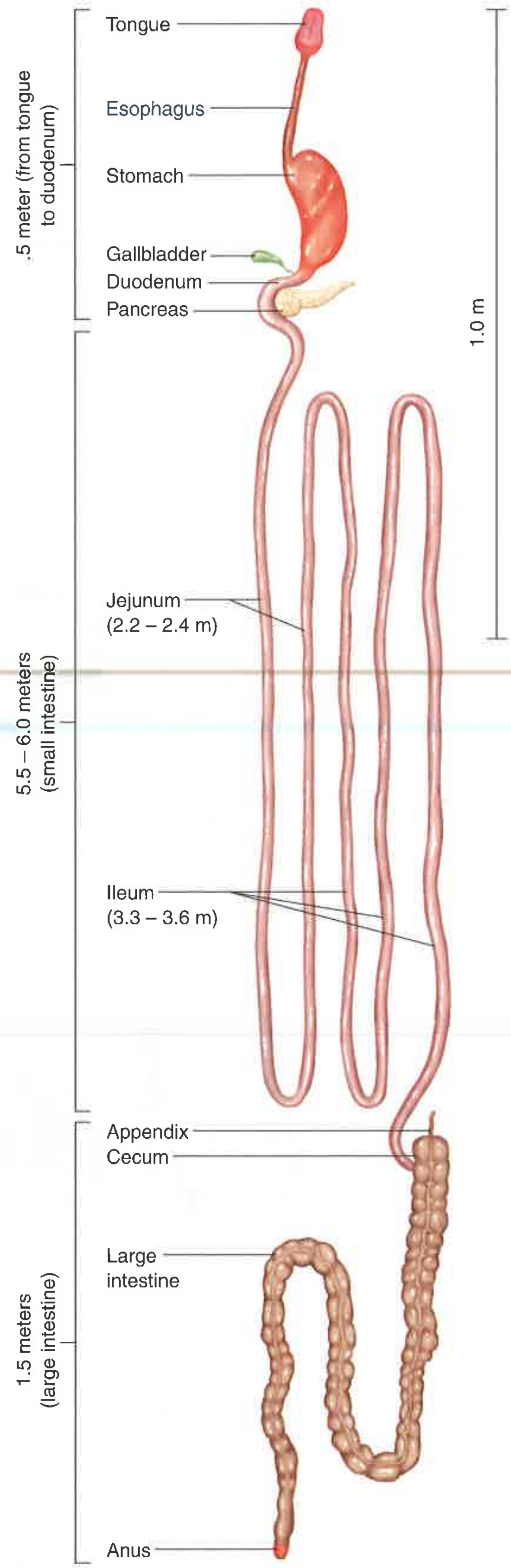


Figure 15.2
The alimentary canal is a muscular tube about 9 meters long.

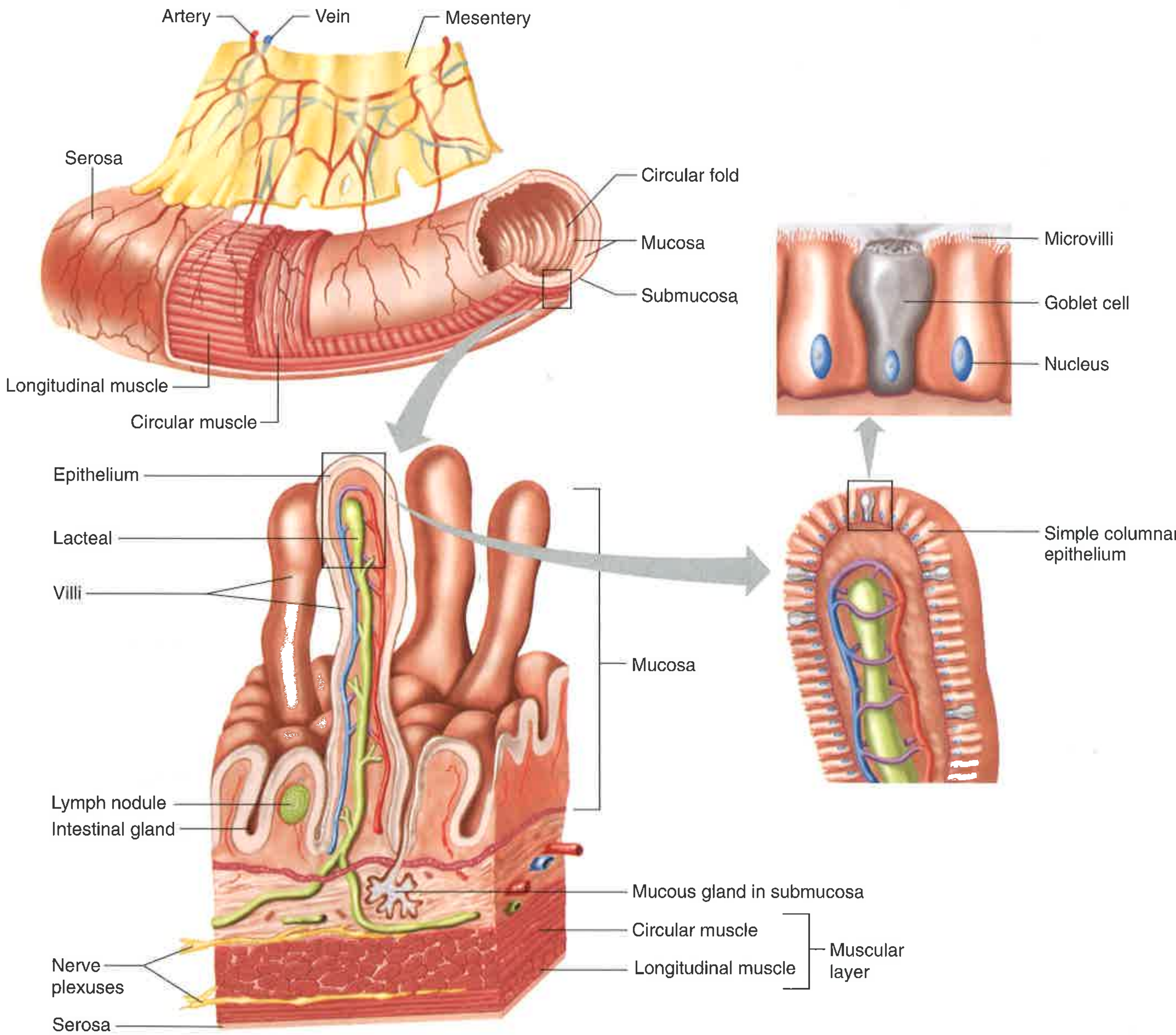


Figure 15.3
The wall of the small intestine, as in other portions of the alimentary canal, includes four layers: an inner mucosa, a submucosa, a muscular layer, and an outer serosa.

Movements of the Tube

The motor functions of the alimentary canal are of two basic types—*mixing movements* and *propelling movements*. Mixing occurs when smooth muscles in small segments of the tube contract rhythmically. For example, when the stomach is full, waves of muscular contractions move along its walls from one end to the other. These waves mix food with digestive juices that the mucosa secretes (fig. 15.4*A*).

Propelling movements include a wavelike motion called **peristalsis** (per″ĭ-stal′sis). When peristalsis occurs, a ring of contraction appears in the wall of the tube. At the same time, the muscular wall just ahead of the ring relaxes. As the peristaltic wave moves along, it pushes the tubular contents ahead of it (fig. 15.4*B*).

CHECK YOUR RECALL

1. Which organs constitute the digestive system?
2. Describe the wall of the alimentary canal.
3. Name the two types of movements that occur in the alimentary canal.

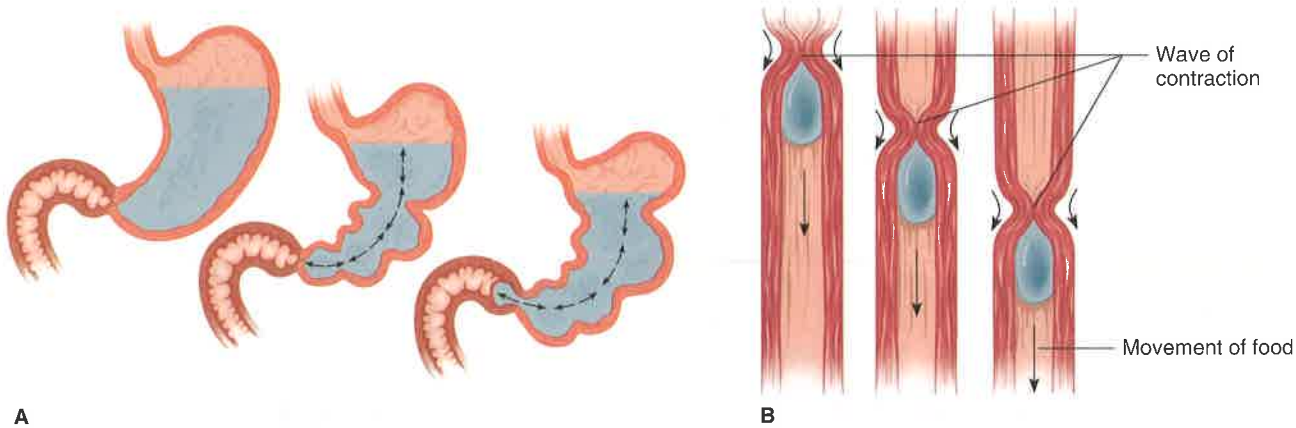


Figure 15.4
Movements through the alimentary canal. (*A*) Mixing movements occur when small segments of the muscular wall of the alimentary canal rhythmically contract. (*B*) Peristaltic waves move the contents along the canal.

15.3 Mouth

The **mouth** receives food and begins digestion by mechanically reducing the size of solid particles and mixing them with saliva. The lips, cheeks, tongue, and palate surround the mouth, which includes a chamber between the palate and tongue called the *oral cavity*, as well as a narrow space between the teeth, cheeks, and lips called the *vestibule* (fig. 15.5).

Cheeks and Lips

The **cheeks** consist of outer layers of skin, pads of subcutaneous fat, muscles associated with expression and chewing, and inner linings of moist, stratified squamous epithelium. The **lips** are highly mobile structures that surround the mouth opening. They contain skeletal muscles and sensory receptors useful in judging the temperature and texture of foods. Their normal reddish color is due to the many blood vessels near their surfaces.

Tongue

The **tongue** nearly fills the oral cavity when the mouth is closed. Mucous membrane covers the tongue, and a membranous fold called the **frenulum** connects the midline of the tongue to the floor of the mouth.

The *body* of the tongue is largely composed of skeletal muscle. These muscles mix food particles with saliva during chewing and move food toward the pharynx during swallowing. The tongue also helps move food underneath the teeth for chewing. Rough projections called **papillae** on the tongue surface provide friction, which helps handle food. These papillae also contain taste buds (see chapter 10, p. 258).

The posterior region, or *root*, of the tongue is anchored to the hyoid bone. It is covered with rounded masses of lymphatic tissue called **lingual tonsils** (fig. 15.6).

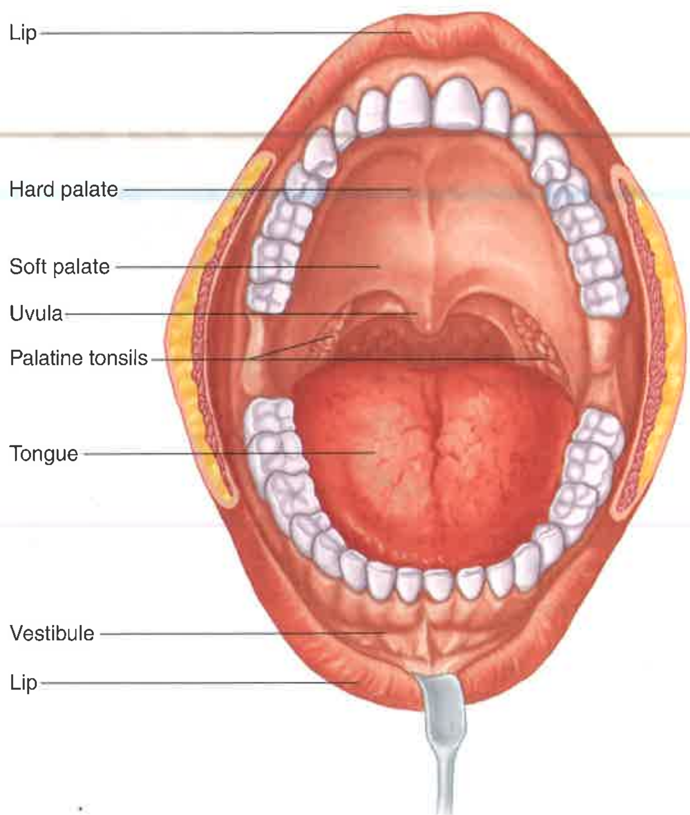


Figure 15.5
The mouth is adapted for ingesting food and preparing it for digestion.

Palate

The **palate** forms the roof of the oral cavity and consists of a hard anterior part (*hard palate*) and a soft posterior part (*soft palate*). The soft palate forms a muscular arch, which extends posteriorly and downward as a cone-shaped projection called the **uvula.**

During swallowing, muscles draw the soft palate and the uvula upward. This action closes the opening

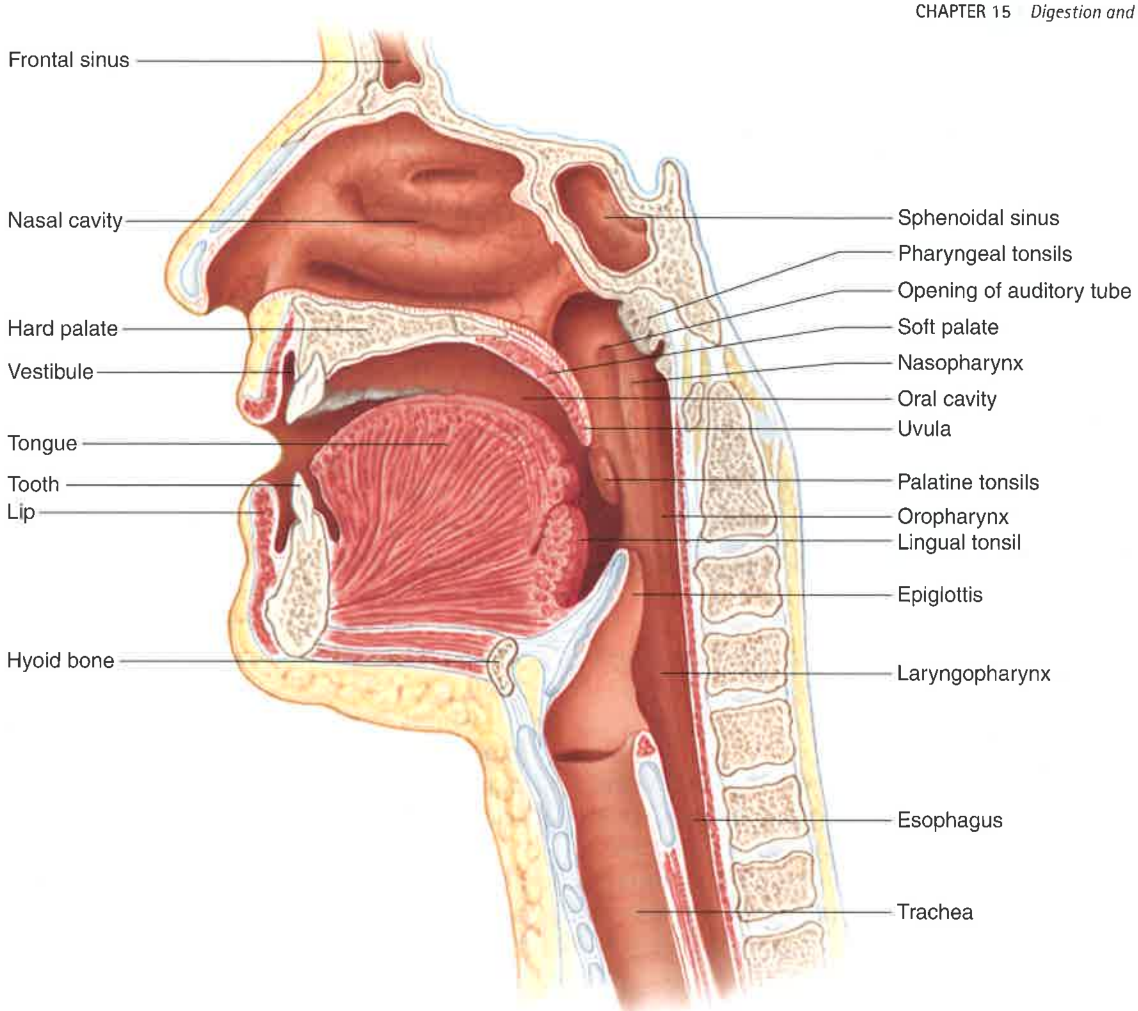


Figure 15.6
Sagittal section of the mouth, nasal cavity, and pharynx.

between the nasal cavity and the pharynx, preventing food from entering the nasal cavity.

In the back of the mouth, on either side of the tongue and closely associated with the palate, are masses of lymphatic tissue called **palatine tonsils** (see figs. 15.5 and 15.6). These structures lie beneath the epithelial lining of the mouth and, like other lymphatic tissues, help protect the body against infection.

The palatine tonsils are common sites of infection, and when inflamed, produce *tonsillitis.* Infected tonsils may swell so greatly that they block the passageways of the pharynx and interfere with breathing and swallowing. Because the mucous membranes of the pharynx, auditory tubes, and middle ears are continuous, such an infection can travel from the throat into the middle ears (*otitis media*).

When tonsillitis occurs repeatedly and does not respond to antibiotic treatment, the tonsils are sometimes surgically removed (*tonsillectomy*). However, tonsillectomies are done less often today than they were a generation ago because the tonsils' role in immunity is now recognized.

Other masses of lymphatic tissue, called **pharyngeal tonsils,** or *adenoids,* are on the posterior wall of the pharynx, above the border of the soft palate (fig. 15.6). If the adenoids enlarge and block the passage between the pharynx and the nasal cavity, they also may be surgically removed.

CHECK YOUR RECALL

1. How does the tongue function as part of the digestive system?
2. What is the role of the soft palate in swallowing?
3. Where are the palatine tonsils located?

Teeth

Two different sets of **teeth** form during development. The members of the first set, the *primary teeth* (deciduous teeth), usually erupt through the gums at regular intervals between the ages of six months and two to four years (fig. 15.7). There are twenty deciduous teeth—ten in each jaw.

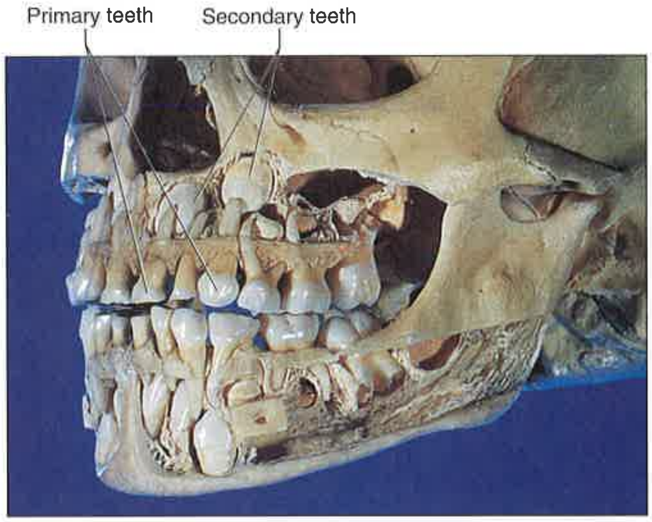


Figure 15.7
This partially dissected child's skull reveals primary and developing secondary teeth in the maxilla and mandible.

The primary teeth are usually shed in the same order they appeared. Before this happens, though, their roots are resorbed. Pressure from the developing *secondary teeth* (permanent teeth) then pushes the primary teeth out of their sockets. This secondary set consists of thirty-two teeth—sixteen in each jaw (fig. 15.8). The secondary teeth usually begin to appear at six years, but the set may not be complete until the third molars appear between seventeen and twenty-five years.

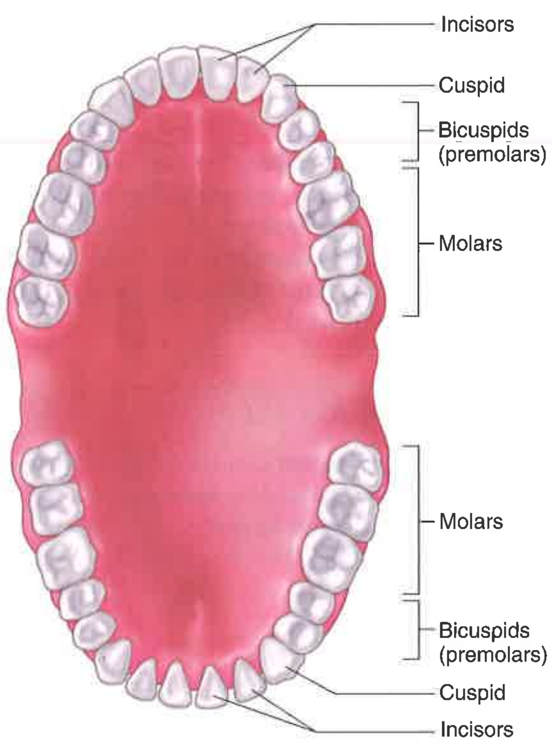


Figure 15.8
The secondary teeth of the upper and lower jaws.

Teeth break pieces of food into smaller pieces. This action increases the surface area of food particles, allowing digestive enzymes to react more effectively with the food molecules.

Different teeth are adapted to handle food in different ways. The *incisors* are chisel-shaped, and their sharp edges bite off large pieces of food. The *cuspids* are cone-shaped, and they grasp and tear food. The *bicuspids* and *molars* have somewhat flattened surfaces and are specialized for grinding food particles (fig. 15.8). Table 15.1 summarizes the number and kinds of teeth that appear during development.

Each tooth consists of two main portions—the *crown,* which projects beyond the gum, and the *root,* which is anchored to the alveolar process of the jaw. Where these portions meet is called the *neck* of the tooth.

Glossy, white *enamel* covers the crown. Enamel mainly consists of calcium salts and is the hardest substance in the body. Unfortunately, if damaged by abrasive action or injury, enamel is not replaced.

The bulk of a tooth beneath the enamel is composed of *dentin,* a substance much like bone, but somewhat harder. Dentin surrounds the tooth's central cavity (pulp cavity), which contains a combination of blood vessels, nerves, and connective tissue called *pulp.* Blood vessels and nerves reach this cavity through tubular *root canals* extending into the root.

A thin layer of bonelike material called *cementum* encloses the root. A *periodontal ligament* surrounds the cementum. This ligament contains bundles of thick collagenous fibers, which pass between the cementum and the bone of the alveolar process, firmly attaching the tooth to the jaw. It also contains blood vessels and nerves (fig. 15.9).

TABLE 15.1 PRIMARY AND SECONDARY TEETH

PRIMARY TEETH (DECIDUOUS)		SECONDARY TEETH (PERMANENT)	
Type	Number	Type	Number
Incisor		Incisor	
Central	4	Central	4
Lateral	4	Lateral	4
Cuspid	4	Cuspid	4
		Bicuspid	
		First	4
		Second	4
Molar		Molar	
First	4	First	4
Second	4	Second	4
		Third	4
Total	20	Total	32

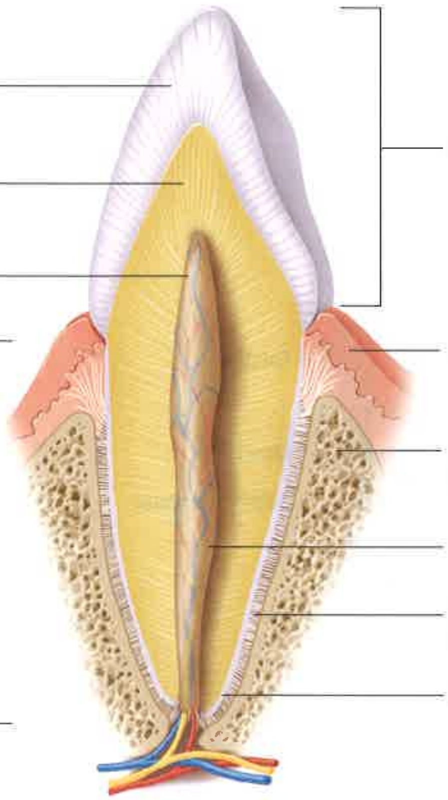


Figure 15.9
A section of a cuspid tooth.

CHECK YOUR RECALL

1. How do primary teeth differ from secondary teeth?
2. Describe the structure of a tooth.
3. Explain how a tooth is attached to the bone of the jaw.

15.4 Salivary Glands

The **salivary glands** secrete saliva. This fluid moistens food particles, helps bind them, and begins the chemical digestion of carbohydrates. Saliva is also a solvent, dissolving foods so that they can be tasted, and it helps cleanse the mouth and teeth.

Salivary Secretions

Within a salivary gland are two types of secretory cells—*serous cells* and *mucous cells*. These cells are present in varying proportions within different glands. Serous cells produce a watery fluid that contains the digestive enzyme **amylase.** This enzyme splits starch and glycogen molecules into disaccharides—the first step in the chemical digestion of carbohydrates. Mucous cells secrete a thick liquid called **mucus,** which binds food particles and lubricates during swallowing.

When a person sees, smells, tastes, or even thinks about pleasant food, parasympathetic nerve impulses elicit the secretion of a large volume of watery saliva. Conversely, food that looks, smells, or tastes unpleasant inhibits parasympathetic activity so that less saliva is produced, and swallowing may become difficult.

Major Salivary Glands

Three pairs of major salivary glands—the parotid, submandibular, and sublingual glands—and many minor ones are associated with the mucous membranes of the tongue, palate, and cheeks (fig. 15.10). The **parotid glands** are the largest of the major salivary glands. Each gland lies anterior and somewhat inferior to each ear, between the skin of the cheek and the masseter muscle. The parotid glands secrete a clear, watery fluid that is rich in amylase.

Topic of Interest — DENTAL CARIES

Sticky foods, such as caramel, lodge between the teeth and in the crevices of molars, feeding bacteria such as *Actinomyces, Streptococcus mutans,* and *Lactobacillus.* These microbes metabolize carbohydrates in the food, producing acid by-products that destroy tooth enamel and dentin. The bacteria also produce sticky substances that hold them in place.

If a person eats a candy bar, for example, but does not brush the teeth soon afterward, the actions of the acid-forming bacteria may produce decay in the tooth enamel, called *dental caries.* Unless a dentist cleans and fills the resulting cavity that forms where enamel is destroyed, the damage will spread to the underlying dentin. The tooth becomes very sensitive.

Dental caries can be prevented in several ways:

1. Brush and floss teeth regularly.
2. Have regular dental exams and cleanings.
3. Drink fluoridated water or receive a fluoride treatment. Fluoride is actually incorporated into the enamel's chemical structure, strengthening it.
4. Have the dentist apply a sealant to children's and adolescents' teeth where crevices might hold onto decay-causing bacteria. The sealant is a coating that keeps acids from eating away at tooth enamel.

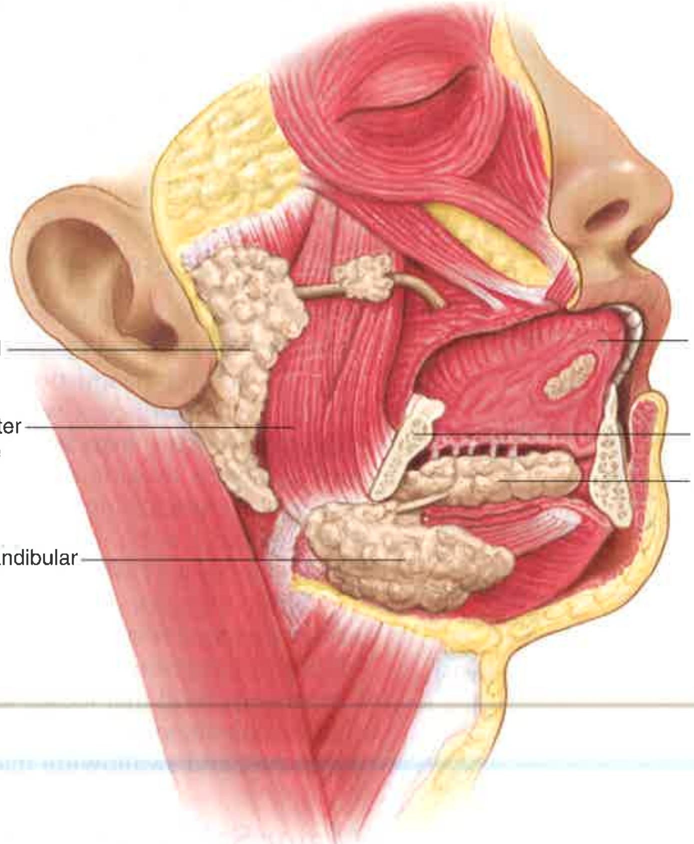


Figure 15.10
Locations of the major salivary glands.

The **submandibular glands** are located in the floor of the mouth on the inside surface of the lower jaw. The secretory cells of these glands are predominantly serous, with a few mucous cells. Consequently, the submandibular glands secrete a more viscous fluid than the parotid glands.

The **sublingual glands,** the smallest of the major salivary glands, are on the floor of the mouth inferior to the tongue. Their secretory cells are primarily the mucous type, making their secretions thick and stringy.

CHECK YOUR RECALL

1. What is the function of saliva?
2. What stimulates salivary glands to secrete saliva?
3. Where are the major salivary glands located?

15.5 Pharynx and Esophagus

The pharynx is a cavity posterior to the mouth from which the tubular esophagus leads to the stomach (see fig. 15.1). The pharynx and the esophagus do not digest food, but both are important passageways whose muscular walls function in swallowing.

Structure of the Pharynx

The **pharynx** (far´inks) connects the nasal and oral cavities with the larynx and esophagus. It has three parts (see fig. 15.6):

1. The **nasopharynx** communicates with the nasal cavity and provides a passageway for air during breathing.
2. The **oropharynx** is posterior to the soft palate and inferior to the nasopharynx. It is a passageway for food moving downward from the mouth and for air moving to and from the nasal cavity.
3. The **laryngopharynx,** just inferior to the oropharynx, is a passageway to the esophagus.

Swallowing Mechanism

Swallowing has three stages. In the first stage, which is voluntary, food is chewed and mixed with saliva. Then the tongue rolls this mixture into a mass (bolus) and forces it into the pharynx.

Computer simulation experiments show that each food requires an optimum range of number of chews to form a bolus. Eating raw carrots, for example, requires 20 to 25 chews.

The second stage begins as food stimulates sensory receptors around the pharyngeal opening. This triggers the swallowing reflex, which includes the following actions:

1. The soft palate raises, preventing food from entering the nasal cavity.
2. The hyoid bone and the larynx are elevated. A flaplike structure attached to the larynx, called the *epiglottis,* closes off the top of the trachea so that food is less likely to enter.
3. The tongue is pressed against the soft palate, sealing off the oral cavity from the pharynx.
4. The longitudinal muscles in the pharyngeal wall contract, pulling the pharynx upward toward the food.
5. Muscles in the lower portion of the pharynx relax, opening the esophagus.
6. A peristaltic wave begins in the pharyngeal muscles and forces food into the esophagus.

The swallowing reflex momentarily inhibits breathing. Then, during the third stage of swallowing, peristalsis transports the food in the esophagus to the stomach.

Esophagus

The **esophagus** (ĕ-sof´ah-gus), a straight, collapsible tube about 25 centimeters long, is a food passageway from the pharynx to the stomach (see figs. 15.1 and 15.6). The esophagus begins at the base of the pharynx and descends posterior to the trachea, passing through the mediastinum. It penetrates the diaphragm through an opening, the *esophageal hiatus,* and is continuous with the stomach on the abdominal side of the diaphragm.

Mucous glands are scattered throughout the submucosa of the esophagus. Their secretions moisten and lubricate the tube's inner lining.

Just above where the esophagus joins the stomach, some circular smooth muscle fibers in the esophageal wall thicken, forming the *lower esophageal sphincter* (lo´er ĕ-sof´´ah-je´al sfing´ter), or cardiac sphincter (fig. 15.11). These fibers usually remain contracted, and they close the entrance to the stomach, preventing regurgitation of the stomach contents into the esophagus. When peristaltic waves reach the stomach, the muscle fibers temporarily relax and allow the swallowed food to enter.

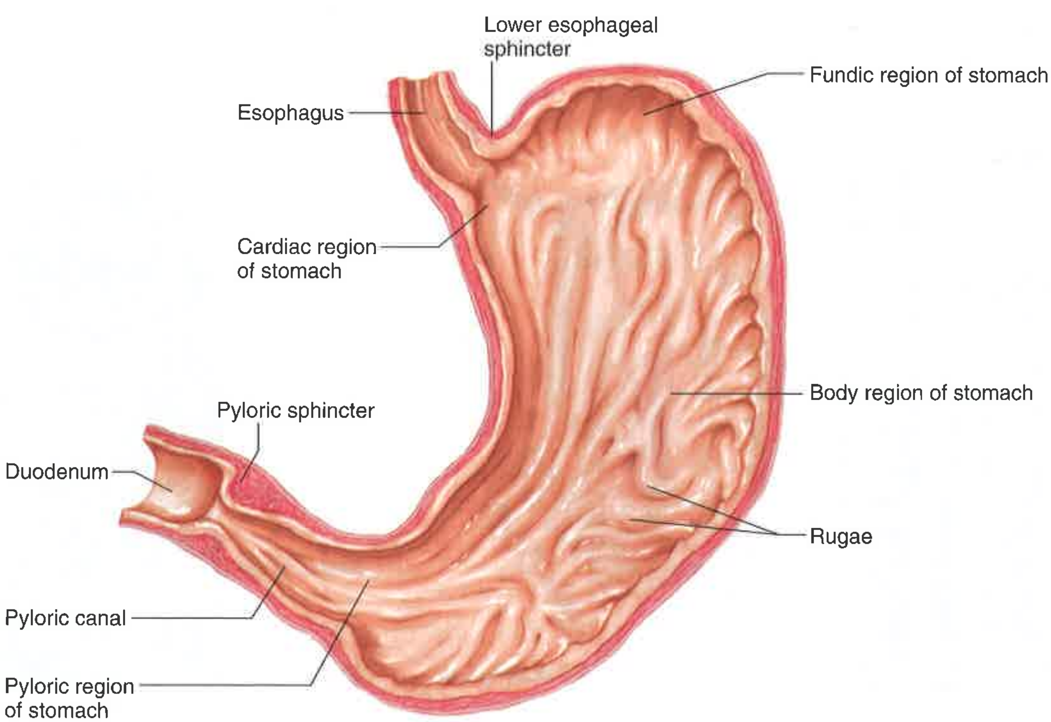


Figure 15.11
Major regions of the stomach.

In a *hiatal hernia,* a portion of the stomach protrudes through a weakened area of the diaphragm, through the esophageal hiatus, and into the thorax. As a result of a hiatal hernia, regurgitation (reflux) of gastric juice into the esophagus may inflame the esophageal mucosa, causing heartburn, difficulty in swallowing, or ulceration and blood loss. In response to the destructive action of gastric juice, columnar epithelium may replace the squamous epithelium that normally lines the esophagus. This condition, called *Barrett's esophagus,* increases the risk of developing esophageal cancer.

CHECK YOUR RECALL

1. Describe the regions of the pharynx.
2. List the major events that occur during swallowing.
3. What is the function of the esophagus?

15.6 Stomach

The **stomach** is a J-shaped, pouchlike organ that hangs inferior to the diaphragm in the upper left portion of the abdominal cavity and has a capacity of about 1 liter or more (figs. 15.1 and 15.11; reference plates 4 and 5, pp. 25–26). Thick folds (rugae) of mucosal and submucosal layers mark the stomach's inner lining and disappear when the stomach wall is distended. The stomach receives food from the esophagus, mixes the food with gastric juice, initiates protein digestion, carries on limited absorption, and moves food into the small intestine.

Parts of the Stomach

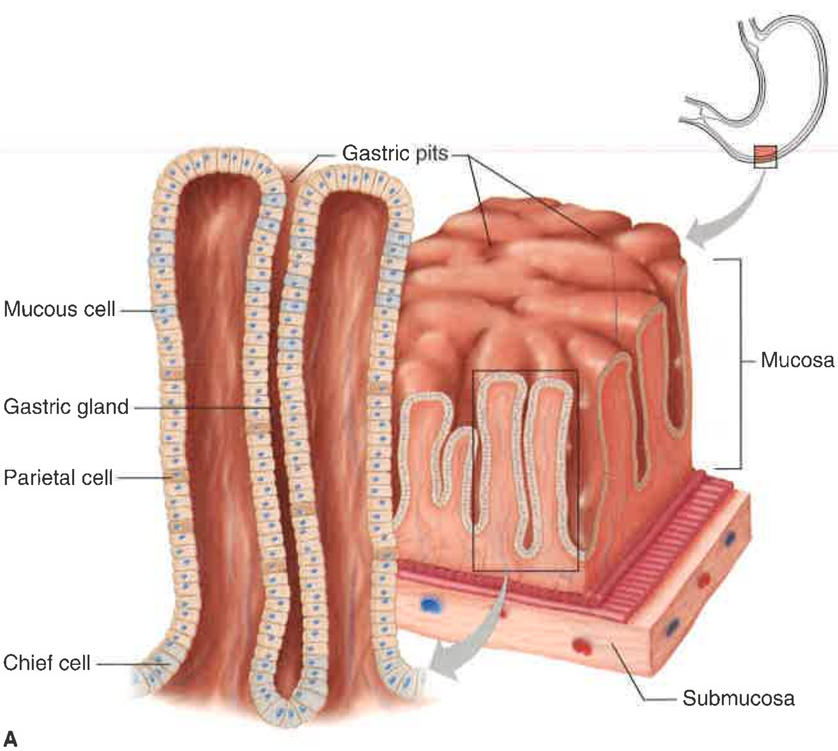
The stomach is divided into the cardiac, fundic, body, and pyloric regions (fig. 15.11). The *cardiac region* is a small area near the esophageal opening. The *fundic region,* which balloons superior to the cardiac portion, is a temporary storage area. The dilated *body region,* which is the main part of the stomach, lies between the fundic and pyloric portions. The *pyloric region* narrows and becomes the *pyloric canal* as it approaches the small intestine.

At the end of the pyloric canal, the muscular wall thickens, forming a powerful circular muscle, the **pyloric sphincter** (pylorus). This muscle is a valve that controls gastric emptying.

Gastric Secretions

The mucous membrane that forms the inner lining of the stomach is thick, its surface studded with many small openings called *gastric pits.* Gastric pits are at the ends of tubular **gastric glands** (fig. 15.12).

Gastric glands generally contain three types of secretory cells. *Mucous cells* (goblet cells) occur in the



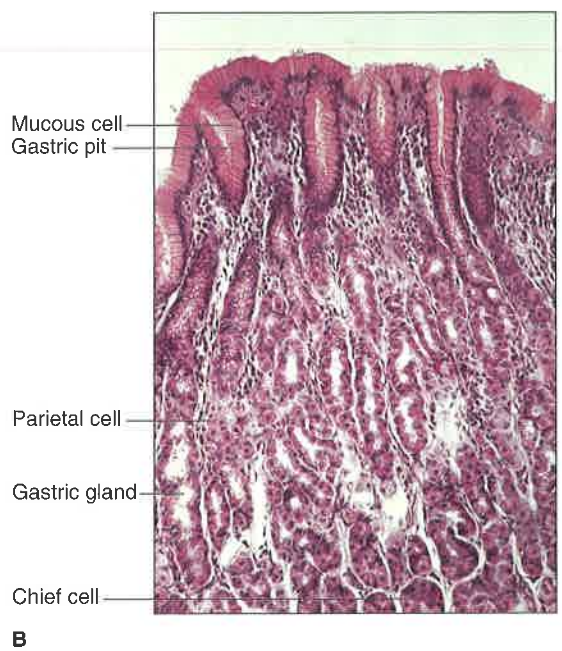


Figure 15.12
Lining of the stomach. (*A*) Gastric glands include mucous cells, parietal cells, and chief cells. (*B*) The mucosa of the stomach is studded with gastric pits that are the openings of the gastric glands.

necks of the glands, near the openings of the gastric pits. *Chief cells* and *parietal cells* are found in the deeper parts of the glands. The chief cells secrete digestive enzymes, and the parietal cells release hydrochloric acid. The products of the mucous cells, chief cells, and parietal cells together form **gastric juice** (gas´trik jo͞os).

Of the several digestive enzymes in gastric juice, **pepsin** is by far the most important. The chief cells secrete it as the inactive enzyme precursor **pepsinogen.** However, when pepsinogen contacts the hydrochloric acid from the parietal cells, it is cut down rapidly, forming pepsin. Pepsin begins the digestion of nearly all types of dietary protein into polypeptide strands. This enzyme is most active in an acidic environment, provided by the hydrochloric acid in gastric juice.

The mucous cells of the gastric glands secrete large quantities of thin mucus. In addition, the cells of the mucous membrane associated with the stomach's inner lining and between the gastric glands release a more viscous and alkaline secretion, which coats the inside of the stomach wall. This coating normally prevents the stomach from digesting itself.

Another component of gastric juice is **intrinsic factor** (in-trin´sik fak´tor), which the parietal cells secrete. Intrinsic factor helps the small intestine absorb vitamin B_{12}. Table 15.2 summarizes the components of gastric juice.

CHECK YOUR RECALL

1. What are the secretions of the chief cells and parietal cells?
2. Which is the most important digestive enzyme in gastric juice?
3. Why doesn't the stomach digest itself?

The 40 million cells that line the stomach's interior can secrete 2 to 3 quarts (about 2 to 3 liters) of gastric juice per day.

Regulation of Gastric Secretions

Gastric juice is produced continuously, but the rate varies considerably and is controlled both neurally and hormonally. When a person tastes, smells, or even sees appetizing food, or when food enters the stomach, parasympathetic impulses on the vagus nerves stimulate acetylcholine (Ach) release from nerve endings. This Ach stimulates gastric glands to secrete large amounts of gastric juice, which is rich in hydrochloric acid and pepsinogen. These parasympathetic impulses also stimulate certain stomach cells to release the peptide hormone **gastrin,** which increases the secretory activity of gastric glands (fig. 15.13).

As food moves into the upper part of the small intestine, acid triggers sympathetic nerve impulses that inhibit gastric juice secretion. At the same time, proteins and fats in this region of the intestine cause the intestinal wall to release the peptide hormone **cholecystokinin** (ko´´le-sis´´to-ki´nin). This hormonal action decreases gastric motility as the small intestine fills with food.

Gastrin stimulates cell growth in the mucosa of the stomach and intestines, except where gastrin is produced. This cell growth helps repair mucosal cells damaged by normal stomach function, disease, or medical treatments.

TABLE 15.2 MAJOR COMPONENTS OF GASTRIC JUICE

COMPONENT	SOURCE	FUNCTION
Pepsinogen	Chief cells of the gastric glands	Inactive form of pepsin
Pepsin	Formed from pepsinogen in the presence of hydrochloric acid	A protein-splitting enzyme that digests nearly all types of dietary protein
Hydrochloric acid	Parietal cells of the gastric glands	Provides the acid environment needed for the conversion of pepsinogen into pepsin and for the action of pepsin
Mucus	Goblet cells and mucous glands	Provides a viscous, alkaline protective layer on the inside stomach wall
Intrinsic factor	Parietal cells of the gastric glands	Aids in vitamin B_{12} absorption

An *ulcer* is an open sore in the mucous membrane resulting from localized tissue breakdown. Gastric ulcers occur in the stomach and duodenal ulcers occur in the region of the small intestine nearest the stomach.

For many years, both types of ulcers were attributed to stress and treated with medications to decrease stomach acid secretion. In 1982, two Australian researchers boldly suggested that stomach infection by the bacterium *Helicobacter pylori* causes gastric ulcers. When the medical community did not believe them, one of the researchers swallowed the bacteria to demonstrate their effect—and soon developed stomach pain. Still, it was twelve years before U.S. government physicians advised colleagues to treat gastric ulcers as an infection in people with evidence of *Helicobacter pylori.* Today, a short course of antibiotics, often combined with acid-lowering drugs, can cure a gastric ulcer.

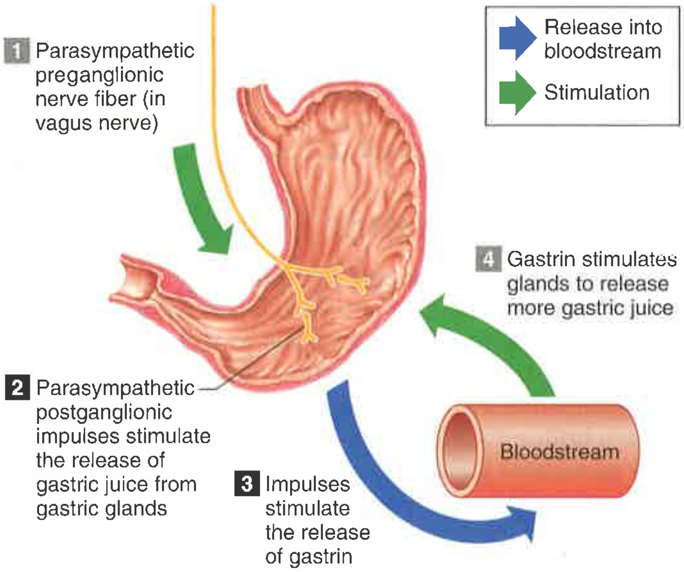


Figure 15.13
The secretion of gastric juice is regulated in part by parasympathetic nerve impulses that stimulate the release of gastric juice and gastrin.

Gastric Absorption

Gastric enzymes begin breaking down proteins, but the stomach wall is not well adapted to absorbing digestive products. The stomach absorbs only small quantities of water and certain salts as well as alcohol and some lipid-soluble drugs.

CHECK YOUR RECALL

1. What controls gastric juice secretion?
2. What is the function of cholecystokinin?
3. What substances can the stomach absorb?

Mixing and Emptying Actions

Following a meal, the mixing movements of the stomach wall aid in producing a semifluid paste of food particles and gastric juice called **chyme** (kīm). Peristaltic waves push the chyme toward the pyloric region of the stomach, and as chyme accumulates near the pyloric sphincter, this muscle begins to relax. Stomach contractions push chyme a little at a time into the small intestine.

The rate at which the stomach empties depends on the fluidity of the chyme and the type of food present. For example, liquids usually pass through the stomach quite rapidly, but solids remain until they are well mixed with gastric juice. Fatty foods may remain in the stomach 3–6 hours; foods high in proteins move through more quickly; and carbohydrates usually pass through faster than either fats or proteins.

As chyme enters the **duodenum** (the first portion of the small intestine), accessory organs—the pancreas, liver, and gallbladder—add their secretions.

Vomiting results from a complex reflex that empties the stomach through the esophagus, pharynx, and mouth. Irritation or distension in the stomach or intestines can trigger vomiting. Sensory impulses travel from the site of stimulation to the *vomiting center* in the medulla oblongata, and several motor responses follow. These include taking a deep breath, raising the soft palate and thus closing the nasal cavity, closing the opening to the trachea (glottis), relaxing the circular muscle fibers at the base of the esophagus, contracting the diaphragm so it presses downward over the stomach, and contracting the abdominal wall muscles to increase pressure inside the abdominal cavity. As a result, the stomach is squeezed from all sides, forcing its contents upward and out.

CHECK YOUR RECALL

1. How is chyme produced?
2. What factors influence how quickly chyme leaves the stomach?

15.7 Pancreas

The **pancreas,** discussed as an endocrine gland in chapter 11 (p. 296), also has an exocrine function—secretion of a digestive juice called **pancreatic juice** (pan″kre-at′ik jo͞os).

Structure of the Pancreas

The pancreas is closely associated with the small intestine. It extends horizontally across the posterior abdominal wall in the C-shaped curve of the duodenum (figs. 15.1 and 15.14).

The cells that produce pancreatic juice, called *pancreatic acinar cells,* make up the bulk of the pancreas. These cells cluster around tiny tubes, into which they release their secretions. The smaller tubes unite to form larger ones, which in turn give rise to a *pancreatic duct* extending the length of the pancreas. The pancreatic duct usually connects with the duodenum at the same place where the bile duct from the liver and gallbladder joins the duodenum, although other connections may be present (fig. 15.14). A hepatopancreatic sphincter controls the movement of pancreatic juices into the duodenum.

Pancreatic Juice

Pancreatic juice contains enzymes that digest carbohydrates, fats, nucleic acids, and proteins. The carbohydrate-digesting enzyme **pancreatic amylase** splits

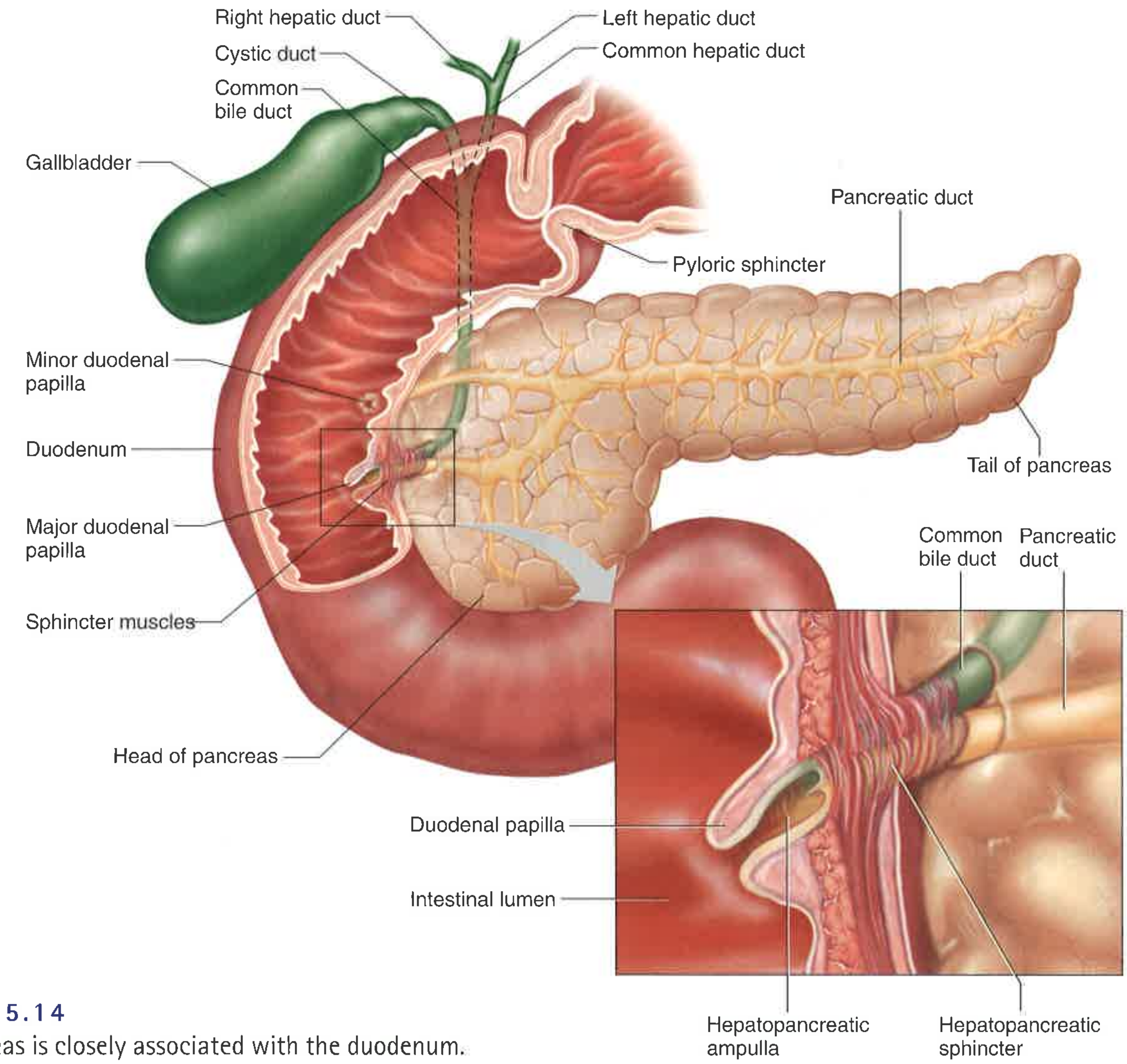


Figure 15.14
The pancreas is closely associated with the duodenum.

molecules of starch or glycogen into double sugars (disaccharides). The fat-digesting enzyme **pancreatic lipase** breaks triglyceride molecules into fatty acids and glycerol. Pancreatic juice also contains two **nucleases,** which are enzymes that break down nucleic acid molecules into nucleotides.

The protein-splitting (proteolytic) enzymes are **trypsin, chymotrypsin,** and **carboxypeptidase.** These enzymes split the bonds between particular combinations of amino acids in proteins. Because no single enzyme can split all the possible amino acid combinations, complete digestion of protein molecules requires several types of enzymes.

The proteolytic enzymes are stored within tiny structures in cells called *zymogen granules.* These enzymes, like gastric pepsin, are secreted in inactive forms. After they reach the small intestine, other enzymes activate them. For example, the pancreatic cells release inactive *trypsinogen,* which is activated to trypsin when it contacts the enzyme **enterokinase** secreted by the mucosa of the small intestine.

A painful condition called *acute pancreatitis* results from a blockage in the release of pancreatic juice. Trypsinogen, activated as pancreatic juice builds up, digests parts of the pancreas. Alcoholism, gallstones, certain infections, traumatic injuries, or the side effects of some drugs can cause pancreatitis.

Regulation of Pancreatic Secretion

As with gastric and small intestinal secretions, the nervous and endocrine systems regulate release of pancreatic juice. For example, when parasympathetic impulses stimulate gastric juice secretion, other parasympathetic impulses stimulate the pancreas to release digestive enzymes. Also, as acidic chyme enters the duodenum, the duodenal mucous membrane releases the peptide hormone **secretin** into the bloodstream (fig. 15.15). This hormone stimulates secretion of pancreatic juice that has a high concentration of bicarbonate ions. These ions neutralize the acid of chyme and provide a favorable environment for digestive enzymes in the intestine.

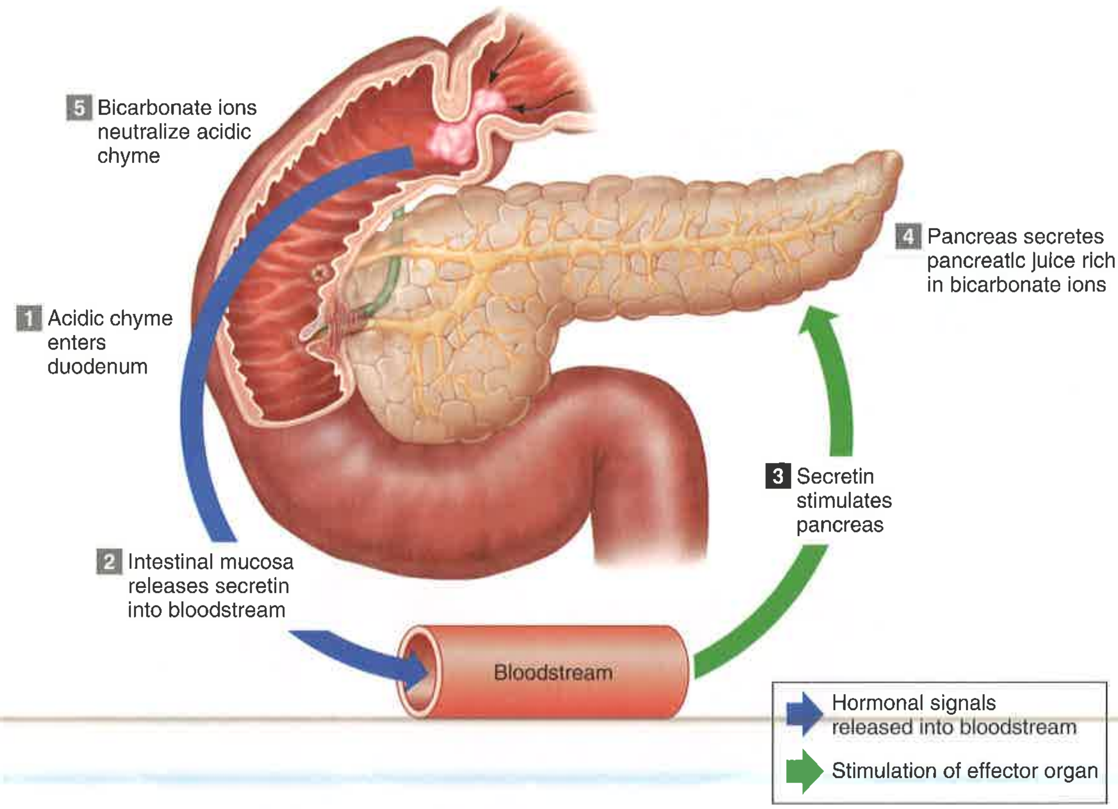


Figure 15.15
Acidic chyme entering the duodenum from the stomach stimulates the release of secretin, which in turn stimulates the release of pancreatic juice.

Proteins and fats in chyme within the duodenum also stimulate the intestinal wall to release the hormone **cholecystokinin.** Like secretin, cholecystokinin travels via the bloodstream to the pancreas. Pancreatic juice secreted in response to cholecystokinin has a high concentration of digestive enzymes.

In cystic fibrosis, abnormal chloride channels in cells in various tissues cause water to be drawn into the cells from interstitial spaces. This dries out secretions in the lungs and pancreas, leaving a very sticky mucus that impairs the functioning of these organs. When the pancreas is plugged with mucus, its secretions, containing digestive enzymes, cannot reach the duodenum. Individuals with cystic fibrosis must take digestive enzyme supplements—usually as a powder mixed with a soft food such as applesauce—to prevent malnutrition.

CHECK YOUR RECALL

1. List the enzymes in pancreatic juice.
2. What are the functions of the enzymes in pancreatic juice?
3. What regulates secretion of pancreatic juice?

15.8 Liver

The **liver** is located in the upper right quadrant of the abdominal cavity, just inferior to the diaphragm. It is partially surrounded by the ribs, and extends from the level of the fifth intercostal space to the lower margin of the ribs. The reddish-brown liver is well supplied with blood vessels (see fig. 15.1 and reference plates 4 and 5, pp. 25–26).

The average adult liver is the heaviest organ in the body at around 3 pounds.

Liver Structure

A fibrous capsule encloses the liver, and connective tissue divides the organ into a large *right lobe* and a smaller *left lobe* (fig. 15.16). Each lobe is separated into many tiny **hepatic lobules,** which are the liver's functional units (figs. 15.17 and 15.18). A lobule consists of many hepatic cells radiating outward from a *central vein*. Vascular channels called **hepatic sinusoids** separate platelike groups of these cells from each other.

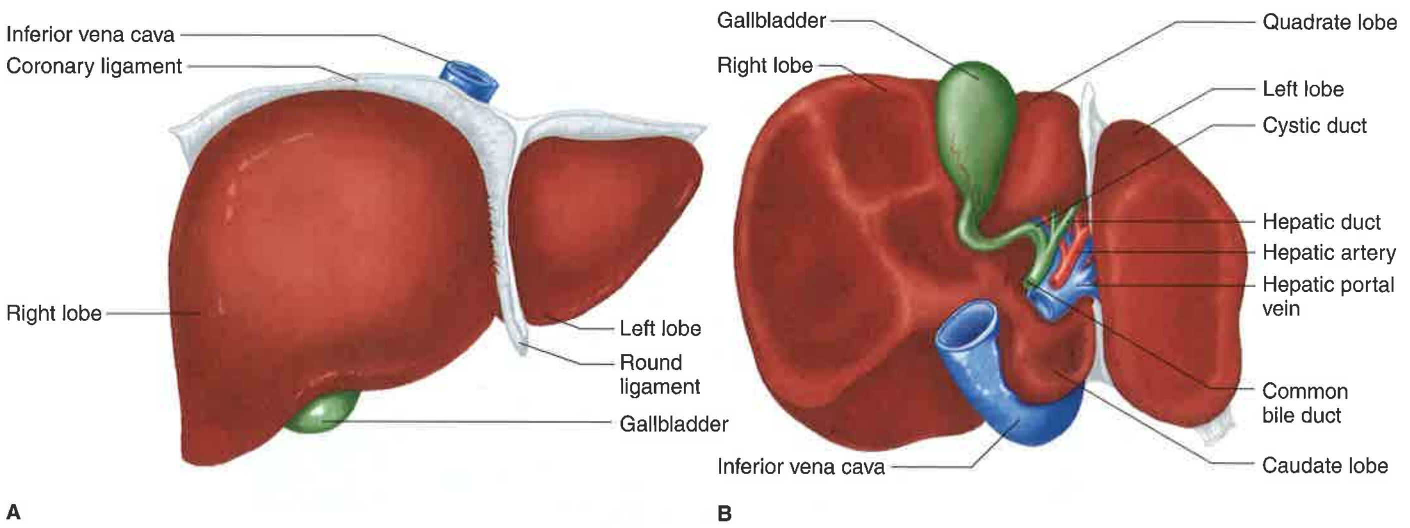


Figure 15.16
Lobes of the liver, viewed (*A*) anteriorly and (*B*) inferiorly.

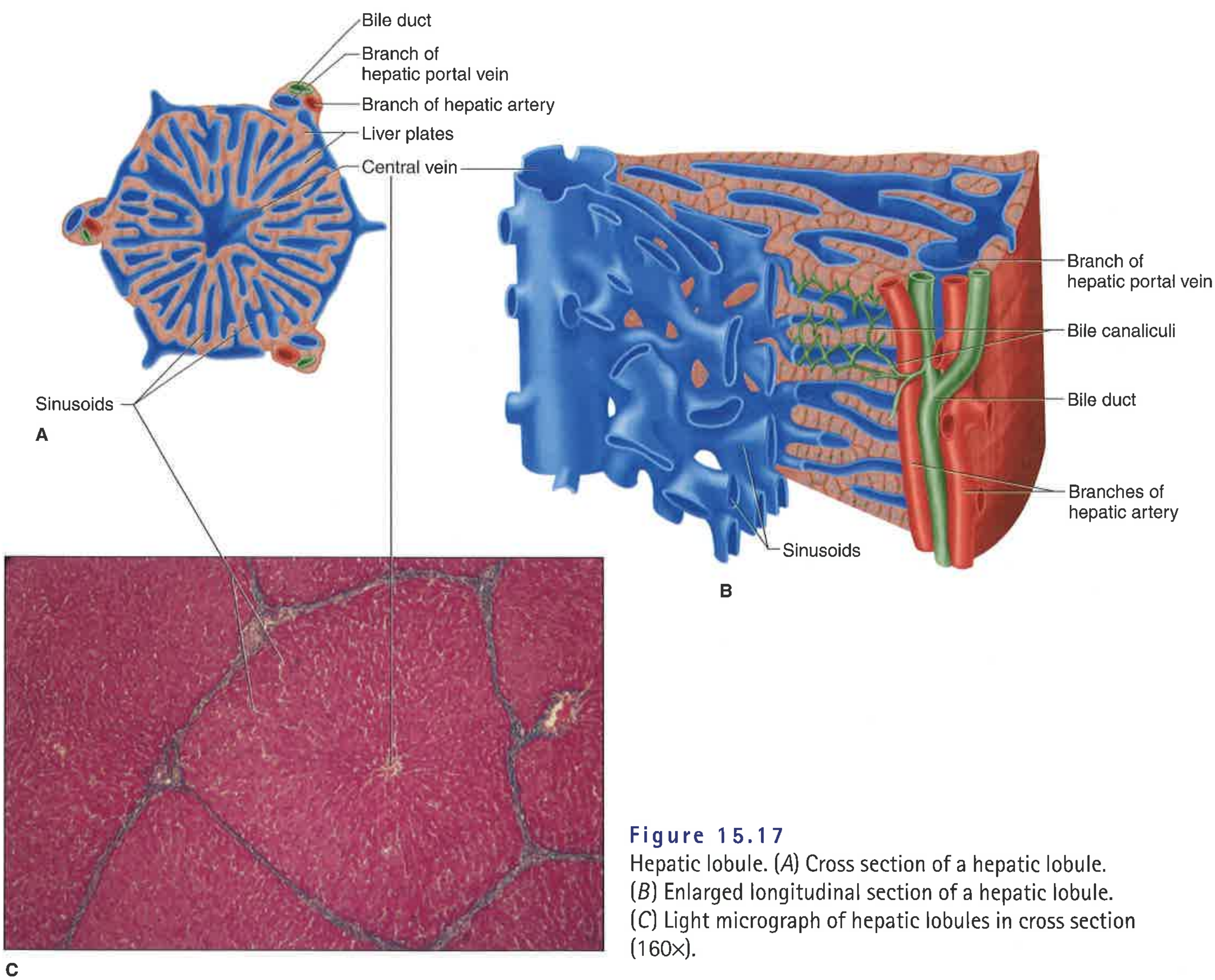


Figure 15.17
Hepatic lobule. (*A*) Cross section of a hepatic lobule. (*B*) Enlarged longitudinal section of a hepatic lobule. (*C*) Light micrograph of hepatic lobules in cross section (160×).

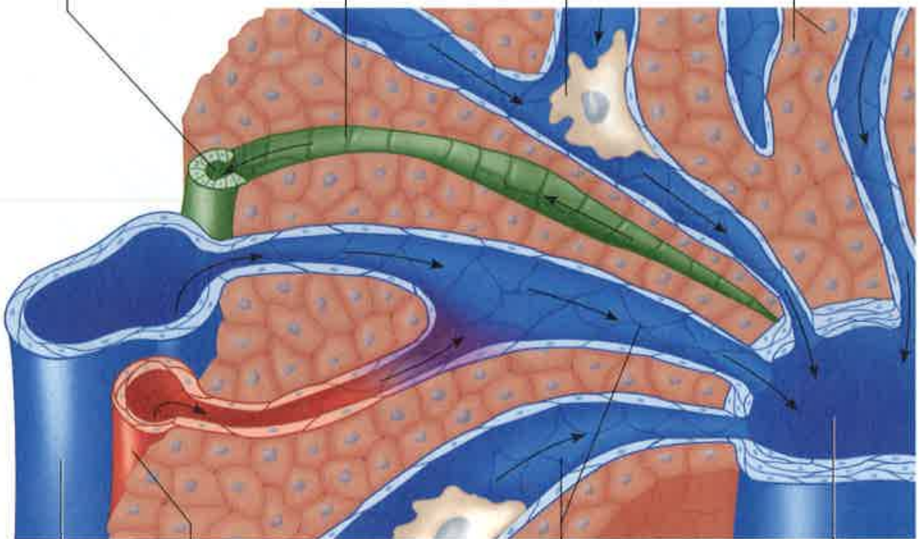


Figure 15.18
The paths of blood and bile within a hepatic lobule.

Blood from the digestive tract, which is carried in the *hepatic portal vein* (see chapter 13, p. 358), brings newly absorbed nutrients into the sinusoids and nourishes the hepatic cells.

Large phagocytic macrophages called *Kupffer cells* are fixed to the inner linings of the hepatic sinusoids. They remove bacteria or other foreign particles that enter the blood in the portal vein through the intestinal wall. Blood passes from these sinusoids into the central veins of the hepatic lobules and exits the liver.

Within the hepatic lobules are many fine *bile canals,* which receive secretions from hepatic cells. The canals of neighboring lobules unite to form larger ducts and then converge to become the **hepatic ducts.** These ducts merge, in turn, to form the **common hepatic duct.**

Liver Functions

The liver has many important metabolic activities. Recall from chapter 11 (p. 296) that the liver plays a key role in carbohydrate metabolism by helping maintain the normal concentration of blood glucose. Liver cells responding to hormones such as insulin and glucagon lower the blood glucose level by polymerizing glucose to glycogen, and raise the blood glucose level by breaking down glycogen to glucose or by converting noncarbohydrates into glucose.

The liver's effects on lipid metabolism include oxidizing fatty acids at an especially high rate (p. 421); synthesizing lipoproteins, phospholipids, and cholesterol; and converting portions of carbohydrate and protein molecules into fat molecules. The blood transports fats synthesized in the liver to adipose tissue for storage.

The most vital liver functions concern protein metabolism. They include deaminating amino acids; forming urea (p. 422); synthesizing plasma proteins, such as clotting factors (see chapter 12, p. 316); and converting certain amino acids to other amino acids.

The liver also stores many substances, including glycogen, iron, and vitamins A, D, and B_{12}. In addition, macrophages in the liver help destroy damaged red blood cells and phagocytize foreign antigens. The liver also removes toxic substances such as alcohol from blood (detoxification) and secretes bile.

Many of these liver functions are not directly related to the digestive system and are discussed in other chapters. Bile secretion, however, is important to digestion and is explained next in this chapter. Table 15.3 summarizes the major functions of the liver.

CHECK YOUR RECALL

1. Describe the location of the liver.
2. Describe a hepatic lobule.
3. Review liver functions.

Topic of Interest HEPATITIS

Hepatitis is an inflammation of the liver. It has several causes, but the various types have similar symptoms.

For the first few days, hepatitis may resemble the flu, producing mild headache, low fever, fatigue, lack of appetite, nausea and vomiting, and sometimes stiff joints. By the end of the first week, more distinctive symptoms arise: a rash, pain in the upper right quadrant of the abdomen, dark and foamy urine, and pale feces. The skin and sclera of the eyes begin to turn yellow from accumulating bile pigments (jaundice). Great fatigue may continue for two or three weeks, and then gradually the person begins to feel better.

This is hepatitis in its most common, least dangerous acute guise. About half a million people develop hepatitis in the United States each year, and 6,000 die. In a rare form called *fulminant hepatitis,* symptoms occur suddenly and severely, along with altered behavior and personality. Medical attention is necessary to prevent kidney or liver failure or coma. Hepatitis that persists for more than six months is termed chronic. As many as 300 million people worldwide are hepatitis carriers. They do not have symptoms but can infect others. Five percent of carriers develop liver cancer.

Only rarely does hepatitis result from alcoholism, autoimmunity, or the use of certain drugs. Usually, one of several types of viruses can cause hepatitis. Viral types are distinguished by the route of infection and by biochemical differences, such as gene sequences and surface proteins. The viral types are classified as follows:

Hepatitis A spreads by contact with food or objects contaminated with virus-containing feces. In day-care centers, it spreads through diaper changing. An outbreak affecting children in several states was traced to contaminated strawberries in school lunches. The course of hepatitis A is short and mild.

Hepatitis B spreads by contact with virus-containing body fluids, such as blood, saliva, or semen. It may be transmitted by blood transfusions, hypodermic needles, or sexual activity.

Hepatitis C is believed to be responsible for about half of all cases of hepatitis. This virus is primarily transmitted in blood—by sharing razors or needles, from pregnant woman to fetus, or in blood transfusions or use of blood products. As many as 60% of individuals infected with the hepatitis C virus suffer chronic symptoms.

Hepatitis D occurs in people already infected with the hepatitis B virus. It is blood-borne and associated with blood transfusions and intravenous drug use. About 20% of individuals infected with this virus die.

Hepatitis E virus is usually transmitted in water contaminated with feces in developing nations—not to residents, who are immune, but most often to visitors.

Hepatitis F passes from feces and can infect other primates.

Hepatitis G accounts for many cases of fulminant hepatitis.

Because a virus usually causes hepatitis, antibiotic drugs, which are effective against bacteria, are not helpful. Usually, the person must just wait out the symptoms. Hepatitis C, however, sometimes responds to a form of interferon, an immune system biochemical given as a drug.

TABLE 15.3 MAJOR FUNCTIONS OF THE LIVER

GENERAL FUNCTION	SPECIFIC FUNCTION
Carbohydrate metabolism	Polymerizes glucose to glycogen; breaks down glycogen to glucose; converts noncarbohydrates to glucose
Lipid metabolism	Oxidizes fatty acids; synthesizes lipoproteins, phospholipids, and cholesterol; converts portions of carbohydrate and protein molecules into fats
Protein metabolism	Deaminates amino acids; forms urea; synthesizes plasma proteins; converts certain amino acids to other amino acids
Storage	Stores glycogen, iron, and vitamins A, D, and B_{12}
Blood filtering	Removes damaged red blood cells and foreign substances by phagocytosis
Detoxification	Removes toxins from blood
Secretion	Secretes bile

Composition of Bile

Bile (bīl) is a yellowish-green liquid that hepatic cells continuously secrete. In addition to water, bile contains *bile salts, bile pigments* (bilirubin and biliverdin), *cholesterol,* and *electrolytes.* Of these, bile salts are the most abundant and are the only bile substances that have a digestive function. Bile pigments are breakdown products of hemoglobin from red blood cells and are normally excreted in the bile (see chapter 12, p. 309).

Jaundice turns the skin and whites of the eyes yellow. The distinctive skin color reflects buildup of bile pigments. The condition can have several causes. In *obstructive jaundice*, bile ducts are blocked. In *hepatocellular jaundice*, the liver is diseased. In *hemolytic jaundice*, red blood cells are destroyed too rapidly.

Gallbladder

The **gallbladder** is a pear-shaped sac located in a depression on the liver's inferior surface. It connects to the **cystic duct,** which in turn joins the common hepatic duct (see figs. 15.1 and 15.20). The gallbladder is lined with epithelial cells and has a strong, muscular layer in its wall. It stores bile between meals, reabsorbs water to concentrate bile, and releases bile into the small intestine.

The common hepatic and cystic ducts join to form the *common bile duct.* It leads to the duodenum (see fig. 15.14), where the *hepatopancreatic sphincter* guards its exit. This sphincter normally remains contracted, so that bile collects in the common bile duct and backs up into the cystic duct. When this happens, bile flows into the gallbladder, where it is stored.

Cholesterol in bile may precipitate and form crystals called *gallstones* under certain conditions (fig. 15.19). Gallstones entering the common bile duct may block bile flow into the small intestine and cause considerable pain. A surgical procedure called *cholecystectomy* removes the gallbladder when gallstones are obstructive. The surgery is often performed with a laser, which shortens recovery time.

Regulation of Bile Release

Normally, bile does not enter the duodenum until cholecystokinin stimulates the gallbladder to contract. The intestinal mucosa releases this hormone in response to proteins and fats in the small intestine. (Recall its action to stimulate pancreatic enzyme secretion.) The hepatopancreatic sphincter usually remains contracted until a peristaltic wave in the duodenal wall approaches it. Then the sphincter relaxes, and bile is squirted into the small intestine (fig. 15.20). Table 15.4 summarizes the hormones that help control digestive functions.

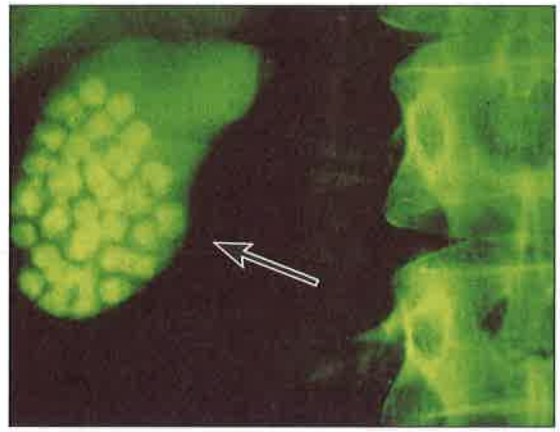


Figure 15.19
Radiograph of a gallbladder that contains gallstones (arrow).

Functions of Bile Salts

Bile salts aid digestive enzymes. Bile salts affect *fat globules* (clumped molecules of fats) much like a soap or detergent would affect them. That is, bile salts break fat globules into smaller droplets, an action called **emulsification** that greatly increases the total surface area of the fatty substance. The tiny fat droplets then mix with water. Fat-splitting enzymes (lipases) can then digest fat molecules more effectively.

Bile salts also enhance absorption of fatty acids, cholesterol, and the fat-soluble vitamins A, D, E, and K. Lack of bile salts results in poor lipid absorption and vitamin deficiencies.

CHECK YOUR RECALL

1. Explain how bile originates.
2. Describe the function of the gallbladder.
3. How is secretion of bile regulated?
4. How do bile salts function in digestion?

TABLE 15.4 HORMONES OF THE DIGESTIVE TRACT

HORMONE	SOURCE	FUNCTION
Gastrin	Gastric cells, in response to food	Causes gastric glands to increase their secretory activity
Cholecystokinin	Intestinal wall cells, in response to proteins and fats in the small intestine	Causes gastric glands to decrease their secretory activity and inhibits gastric motility; stimulates pancreas to secrete fluid with a high digestive enzyme concentration; stimulates gallbladder to contract and release bile
Secretin	Cells in the duodenal wall, in response to acidic chyme entering the small intestine	Stimulates pancreas to secrete fluid with a high bicarbonate ion concentration

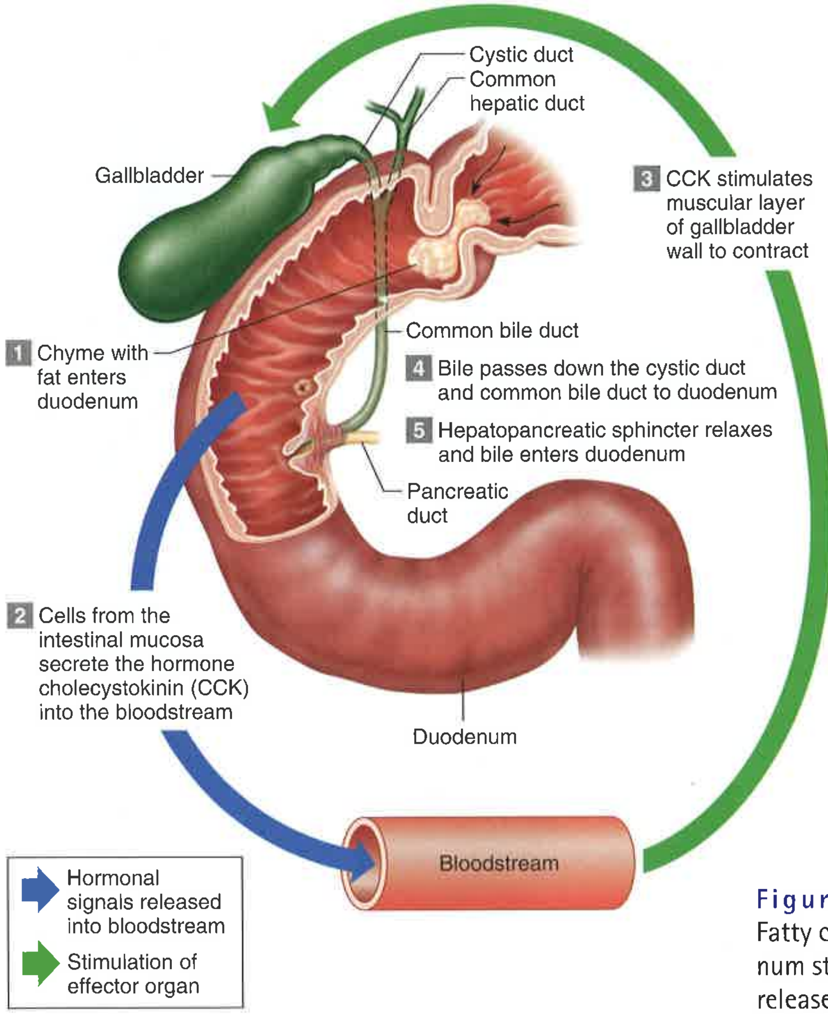


Figure 15.20
Fatty chyme entering the duodenum stimulates the gallbladder to release bile.

15.9 Small Intestine

The **small intestine** is a tubular organ that extends from the pyloric sphincter to the beginning of the large intestine. With its many loops and coils, it fills much of the abdominal cavity (see fig. 15.1 and reference plates 4 and 5, pp. 25–26).

The small intestine receives secretions from the pancreas and liver. It also completes digestion of the nutrients in chyme, absorbs the products of digestion, and transports the residues to the large intestine.

Parts of the Small Intestine

The small intestine consists of three portions: the duodenum, the jejunum, and the ileum (figs. 15.21 and 15.22). The **duodenum,** which is about 25 centimeters long and 5 centimeters in diameter, lies posterior to the parietal peritoneum and is the most fixed portion of the small intestine. It follows a C-shaped path as it passes anterior to the right kidney and the upper three lumbar vertebrae.

The remainder of the small intestine is mobile and lies free in the peritoneal cavity. The proximal two-fifths

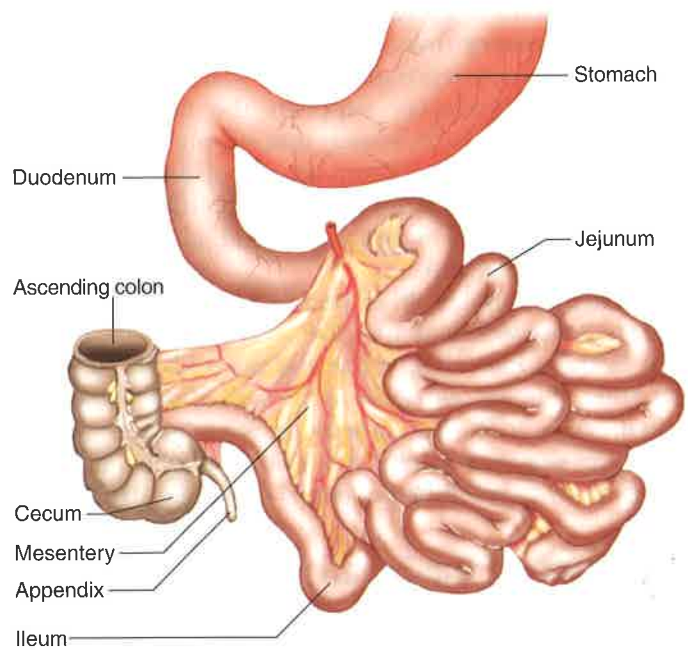


Figure 15.21
The three parts of the small intestine are the duodenum, the jejunum, and the ileum.

Figure 15.22
Radiograph showing a normal small intestine containing a radiopaque substance that the patient ingested.

of this portion is the **jejunum,** and the remainder is the **ileum.** A double-layered fold of peritoneal membrane called **mesentery** (mes´en-ter´´e) suspends these portions from the posterior abdominal wall (figs. 15.21 and 15.23). The mesentery supports the blood vessels, nerves, and lymphatic vessels that supply the intestinal wall. The jejunum and ileum are not distinctly separate parts; however, the diameter of the jejunum is greater and its wall thicker, more vascularized, and more active than that of the ileum.

A filmy, double fold of peritoneal membrane called the *greater omentum* drapes like an apron from the stomach over the transverse colon and the folds of the small intestine. If infections occur in the wall of the alimentary canal, cells from the omentum may adhere to the inflamed region and help wall it off so that the infection is less likely to enter the peritoneal cavity (fig. 15.23).

Structure of the Small Intestine Wall

Throughout its length, the inner wall of the small intestine appears velvety due to many tiny projections of mucous membrane called **intestinal villi** (in-tes´tĭ-nal vil´i) (figs. 15.24 and 15.25; see fig. 15.3). These structures are most numerous in the duodenum and the prox-

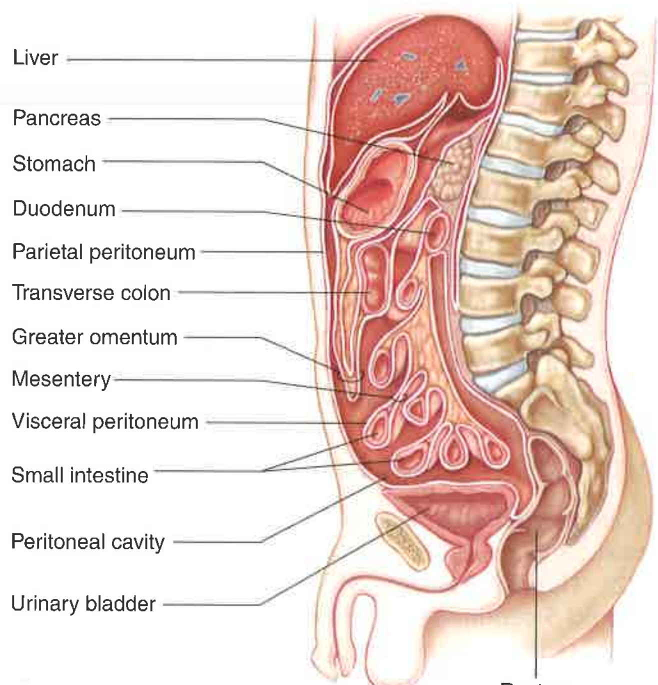


Figure 15.23
Mesentery formed by folds of the peritoneal membrane suspends portions of the small intestine from the posterior abdominal wall.

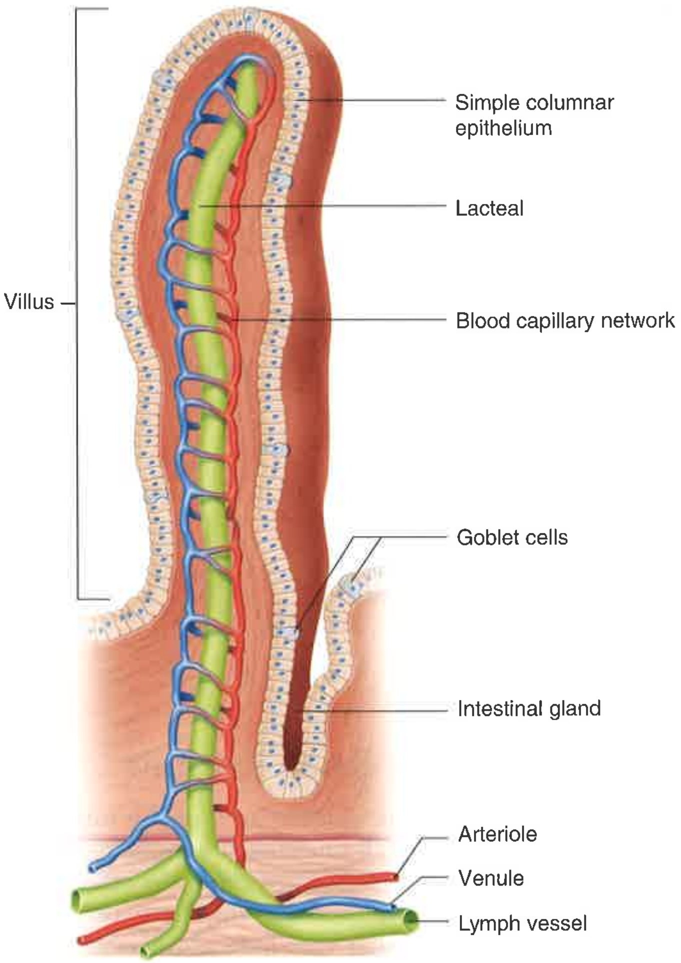


Figure 15.24
Structure of a single intestinal villus.

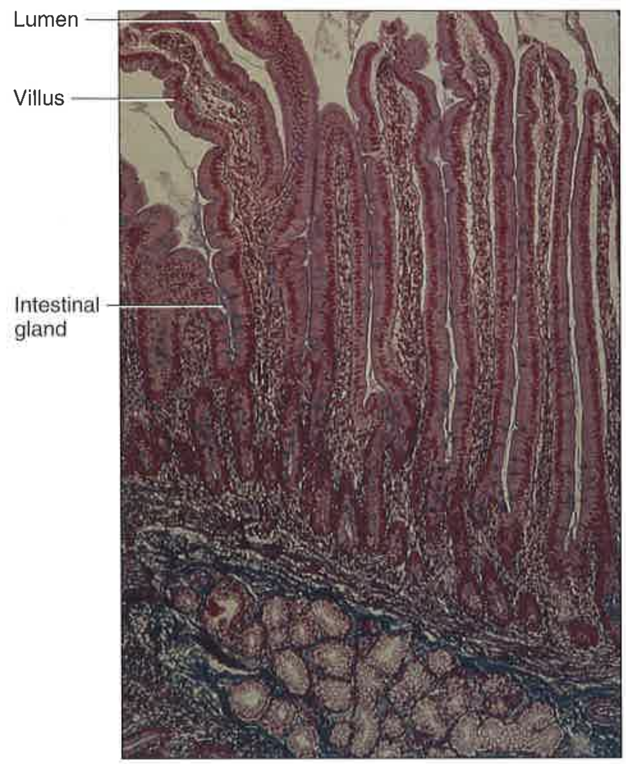


Figure 15.25
Light micrograph of intestinal villi from the wall of the duodenum (50×).

imal portion of the jejunum. They project into the lumen of the alimentary canal, contacting the intestinal contents. Villi greatly increase the surface area of the intestinal lining, aiding the absorption of digestive products.

Each villus consists of a layer of simple columnar epithelium and a core of connective tissue containing blood capillaries, a lymphatic capillary called a **lacteal,** and nerve fibers. Blood capillaries and lacteals carry away absorbed nutrients, and nerve fibers transmit impulses to stimulate or inhibit villus activities. Between the bases of adjacent villi are tubular **intestinal glands** that extend downward into the mucous membrane (figs. 15.24 and 15.25; see fig. 15.3).

The epithelial cells that form the lining of the small intestine are continually replaced. New cells form within the intestinal glands by mitosis and migrate outward onto the villus surface. When the migrating cells reach the tip of the villus, they are shed. This *cellular turnover* renews the small intestine's epithelial lining every three to six days. As a result, nearly one-quarter of the bulk of feces consists of dead epithelial cells from the small intestine.

Secretions of the Small Intestine

Mucus-secreting goblet cells are abundant throughout the mucosa of the small intestine. In addition, many specialized *mucus-secreting glands* in the submucosa within the proximal portion of the duodenum secrete large quantities of thick, alkaline mucus in response to certain stimuli.

The intestinal glands at the bases of the villi secrete large amounts of a watery fluid. The villi rapidly reabsorb this fluid, which carries digestive products into the villi. The fluid the intestinal glands secrete has a nearly neutral pH (6.5–7.5), and it lacks digestive enzymes. However, the epithelial cells of the intestinal mucosa have digestive enzymes embedded in the membranes of their microvilli on their luminal surfaces. These enzymes break down food molecules just before absorption takes place. The enzymes include **peptidases,** which split peptides into their constituent amino acids; **sucrase, maltase,** and **lactase,** which split the double sugars (disaccharides) sucrose, maltose, and lactose into the simple sugars (monosaccharides) glucose, fructose, and galactose; and **intestinal lipase,** which splits fats into fatty acids and glycerol. Table15.5 summarizes the sources and actions of the major digestive enzymes.

TABLE 15.5 SUMMARY OF THE MAJOR DIGESTIVE ENZYMES

ENZYME	SOURCE	DIGESTIVE ACTION
Salivary enzyme		
Amylase	Salivary glands	Begins carbohydrate digestion by breaking down starch and glycogen to disaccharides
Gastric enzyme		
Pepsin	Gastric glands	Begins protein digestion
Pancreatic enzymes		
Amylase	Pancreas	Breaks down starch and glycogen into disaccharides
Pancreatic lipase	Pancreas	Breaks down fats into fatty acids and glycerol
Proteolytic enzymes	Pancreas	Breaks down proteins or partially digested proteins into peptides
(a) Trypsin		
(b) Chymotrypsin		
(c) Carboxypeptidase		
Nucleases	Pancreas	Breaks down nucleic acids into nucleotides
Intestinal enzymes		
Peptidase	Mucosal cells	Breaks down peptides into amino acids
Sucrase, maltase, lactase	Mucosal cells	Breaks down disaccharides into monosaccharides
Intestinal lipase	Mucosal cells	Breaks down fats into fatty acids and glycerol
Enterokinase	Mucosal cells	Converts trypsinogen into trypsin

Many adults do not produce sufficient lactase to adequately digest lactose, or milk sugar. In this condition, called *lactose intolerance*, lactose remains undigested, increasing the osmotic pressure of the intestinal contents and drawing water into the intestines. At the same time, intestinal bacteria metabolize undigested sugar, producing organic acids and gases. The overall result of lactose intolerance is bloating, intestinal cramps, and diarrhea. To avoid these symptoms, people with lactose intolerance can take lactase in pill form before eating dairy products. Infants with lactose intolerance can drink formula based on soybeans rather than milk. Genetic evidence suggests that lactose intolerance may be the "normal" condition, with ability to digest lactose the result of a mutation that occurred recently in our evolutionary past. Because lactose intolerance most often affects adults, and is not seen in other primates, it may not have adversely affected prehistoric humans, who did not live long enough to experience symptoms.

Regulation of Small Intestine Secretions

Goblet cells and intestinal glands secrete their products when chyme provides both chemical and mechanical stimulation. Distension of the intestinal wall activates the nerve plexuses within the wall and stimulates parasympathetic reflexes that also trigger release of small intestine secretions.

CHECK YOUR RECALL

1. Describe the parts of the small intestine.
2. What is the function of an intestinal villus?
3. What is the function of the intestinal glands?
4. List the intestinal digestive enzymes.

Absorption in the Small Intestine

Villi greatly increase the surface area of the intestinal mucosa, making the small intestine the most important absorbing organ of the alimentary canal. So effective is the small intestine in absorbing digestive products, water, and electrolytes that very little absorbable material reaches its distal end.

Carbohydrate digestion begins in the mouth with the activity of salivary amylase, and enzymes from the intestinal mucosa and pancreas complete the process in the small intestine. Villi absorb the resulting monosaccharides, which enter blood capillaries. Simple sugars are absorbed by facilitated diffusion or active transport (see chapter 3, pp. 59 and 62).

Pepsin activity begins protein digestion in the stomach, and enzymes from the intestinal mucosa and the pancreas complete digestion in the small intestine. During this process, large protein molecules are broken down into amino acids, which are then actively transported into the villi and carried away by the blood.

Enzymes from the intestinal mucosa and pancreas digest fat molecules almost entirely. The resulting fatty acids and glycerol molecules diffuse into villi epithelial cells. The endoplasmic reticula of the cells use the fatty acids to resynthesize fat molecules similar to those digested. These fats are encased in protein to form *chylomicrons,* which make their way to the lacteals of the villi. Lymph in the lacteals and other lymphatic vessels carries chylomicrons to the bloodstream (see chapter 14, p. 367) (fig. 15.26). Some fatty acids with relatively short carbon chains may be absorbed directly into the blood capillary of a villus without being changed back into fat.

Chylomicrons transport dietary fats to muscle and adipose cells. Similarly, VLDL (very-low-density lipo-

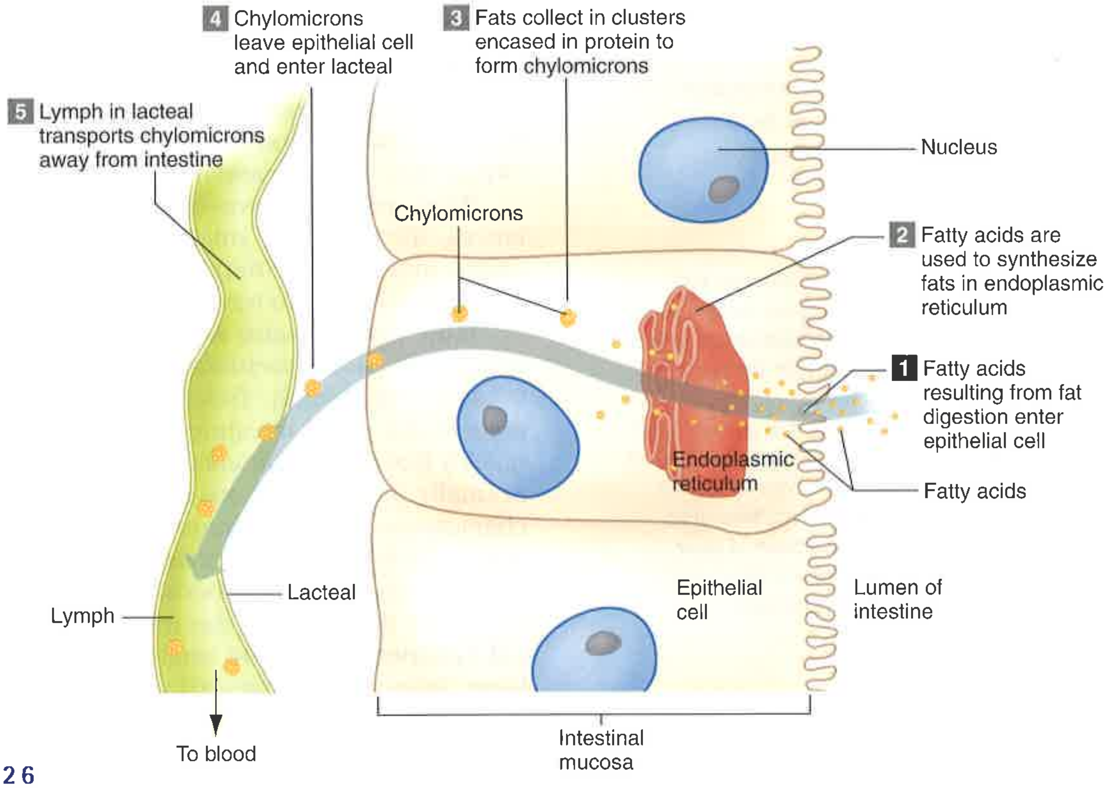


Figure 15.26
Fat absorption has several steps.

protein) molecules, produced in the liver, transport triglycerides synthesized from excess dietary carbohydrates. After VLDL molecules deliver their loads of triglycerides to adipose cells, an enzyme, *lipoprotein lipase,* converts their remnants to LDL (low-density lipoproteins). Because most of the triglycerides have been removed, LDL molecules have a higher cholesterol content than do the original VLDL molecules. Various cells, including liver cells, have surface receptors that combine with apoproteins associated with LDL molecules. These cells slowly remove LDL from plasma by receptor-mediated endocytosis, supplying cells with cholesterol (see chapter 3, p. 63).

After chylomicrons deliver their triglycerides to cells, their remnants are transferred to HDL (high-density lipoproteins) molecules. HDL molecules, which form in the liver and small intestine, transport chylomicron remnants to the liver, where they enter cells rapidly by receptor-mediated endocytosis. The liver disposes of the cholesterol it obtains in this manner by secreting it into bile or by using it to synthesize bile salts.

The intestine reabsorbs much of the cholesterol and bile salts in bile, which are then transported back to the liver, and the secretion-reabsorption cycle repeats. During each cycle, some of the cholesterol and bile salts escape reabsorption, reach the large intestine, and are eliminated with the feces.

The intestinal villi absorb electrolytes by active transport and water by osmosis in addition to the products of carbohydrate, protein, and fat digestion. Table 15.6 summarizes the absorption process.

TABLE 15.6 INTESTINAL ABSORPTION OF NUTRIENTS

NUTRIENT	ABSORPTION MECHANISM	MEANS OF TRANSPORT
Monosaccharides	Facilitated diffusion and active transport	Blood in capillaries
Amino acids	Active transport	Blood in capillaries
Fatty acids and glycerol	Facilitated diffusion of glycerol; diffusion of fatty acids into cells	Lymph in lacteals
	(a) Most fatty acids are resynthesized into fats and incorporated into chylomicrons for transport	
	(b) Some fatty acids with relatively short carbon chains are transported without being changed back into fats	Blood in capillaries
Electrolytes	Diffusion and active transport	Blood in capillaries
Water	Osmosis	Blood in capillaries

CHECK YOUR RECALL

1. Which substances resulting from digestion of carbohydrate, protein, and fat molecules does the small intestine absorb?
2. Describe how fatty acids are absorbed and transported.

In *malabsorption*, the small intestine digests, but does not absorb, some nutrients. Causes of malabsorption include surgical removal of a portion of the small intestine, obstruction of lymphatic vessels due to a tumor, or interference with the production and release of bile as a result of liver disease.

Another cause of malabsorption is a reaction to *gluten*, found in certain grains, especially wheat and rye. This condition is called *celiac disease*. Microvilli are damaged, and in severe cases, villi may be destroyed. Both of these effects reduce the absorptive surface of the small intestine, preventing absorption of some nutrients. Symptoms of malabsorption include diarrhea, weight loss, weakness, vitamin deficiencies, anemia, and bone demineralization.

Movements of the Small Intestine

Like the stomach, the small intestine carries on mixing movements and peristalsis. The mixing movements include small, periodic, ringlike contractions that cut chyme into segments and move it back and forth.

Weak peristaltic waves propel chyme short distances through the small intestine. Consequently, chyme moves slowly through the small intestine, taking from 3 to 10 hours to travel its length.

If the small intestine wall becomes overdistended or irritated, a strong *peristaltic rush* may pass along the organ's entire length. This movement sweeps the contents of the small intestine into the large intestine so quickly that water, nutrients, and electrolytes that would normally be absorbed are not. The result is *diarrhea*, characterized by more frequent defecation and watery stools. Prolonged diarrhea causes imbalances in water and electrolyte concentrations.

At the distal end of the small intestine, the **ileocecal sphincter** joins the small intestine's ileum to the large intestine's cecum (fig. 15.27). Normally, this

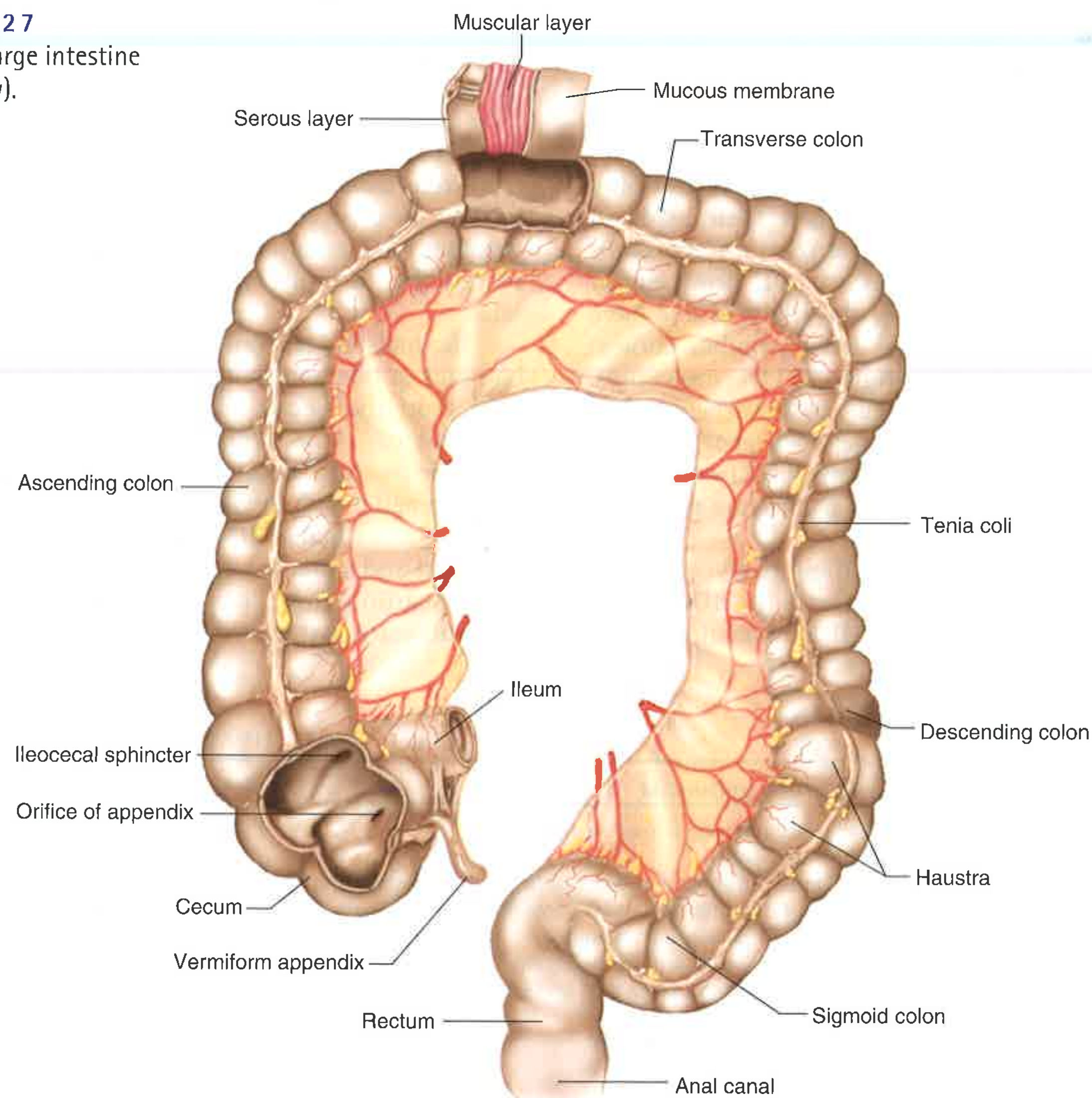


Figure 15.27
Parts of the large intestine (anterior view).

sphincter remains constricted, preventing the contents of the small intestine from entering the large intestine, and the contents of the large intestine from backing up into the ileum. However, after a meal, a gastroileal reflex increases peristalsis in the ileum and relaxes the sphincter, forcing some of the contents of the small intestine into the cecum.

CHECK YOUR RECALL

1. Describe the movements of the small intestine.
2. What stimulus relaxes the ileocecal sphincter?

15.10 Large Intestine

The **large intestine** is so named because its diameter is greater than that of the small intestine. This portion of the alimentary canal is about 1.5 meters long, and it begins in the lower right side of the abdominal cavity, where the ileum joins the cecum. From there, the large intestine ascends on the right side, crosses obliquely to the left, and descends into the pelvis. At its distal end, it opens to the outside of the body as the anus (see fig. 15.1).

The large intestine absorbs water and electrolytes from chyme remaining in the alimentary canal. It also forms and stores feces.

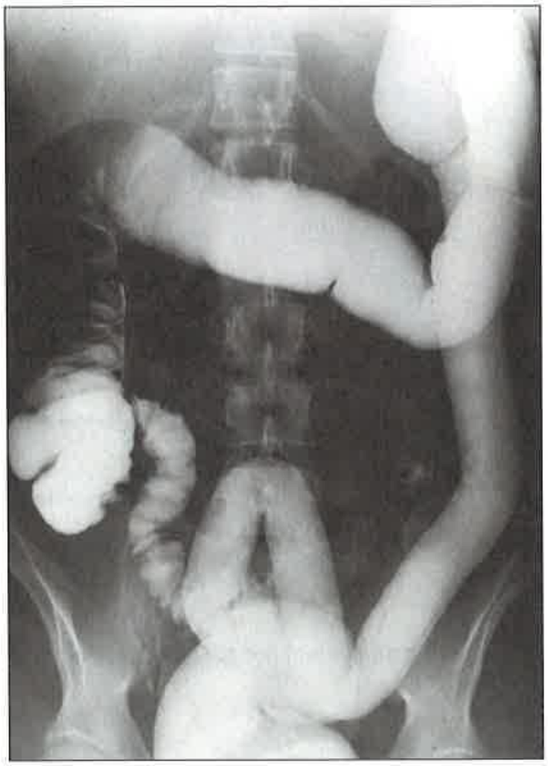


Figure 15.28
Radiograph of the large intestine containing a radiopaque substance that the patient ingested.

Parts of the Large Intestine

The large intestine consists of the cecum, colon, rectum, and anal canal (figs. 15.27 and 15.28; reference plates 4 and 5, pp. 25–26). The **cecum,** at the beginning of the large intestine, is a dilated, pouchlike structure that hangs slightly below the ileocecal opening. Projecting downward from it is a narrow tube with a closed end called the **vermiform appendix.** The human appendix has no known digestive function. However, it contains lymphatic tissue.

In *appendicitis,* the appendix becomes inflamed and infected. Surgery is required to prevent the appendix from rupturing. If it does break open, the contents of the large intestine may enter the abdominal cavity and cause a serious infection of the peritoneum called *peritonitis.*

The **colon** is divided into four portions—the ascending, transverse, descending, and sigmoid colons. The **ascending colon** begins at the cecum and travels upward against the posterior abdominal wall to a point just inferior to the liver. There, it turns sharply to the left and becomes the **transverse colon.** The transverse colon is the longest and most movable part of the large intestine. It is suspended by a fold of peritoneum and sags in the middle below the stomach. As the transverse colon approaches the spleen, it turns abruptly downward and becomes the **descending colon.** At the brim of the pelvis, the descending colon makes an S-shaped curve called the **sigmoid colon** and then becomes the rectum.

The **rectum** lies next to the sacrum and generally follows its curvature. The peritoneum firmly attaches the rectum to the sacrum, and the rectum ends about 5 centimeters below the tip of the coccyx, where it becomes the anal canal (see fig. 15.27).

The last 2.5–4.0 centimeters of the large intestine form the **anal canal** (fig. 15.29). The mucous membrane in the canal is folded into a series of six to eight longitudinal *anal columns.* At its distal end, the canal opens to the outside as the **anus.** Two sphincter muscles guard the anus—an *internal anal sphincter muscle* composed of smooth muscle under involuntary control and an *external anal sphincter muscle* composed of skeletal muscle under voluntary control.

CHECK YOUR RECALL

1. What is the general function of the large intestine?
2. Describe the parts of the large intestine.

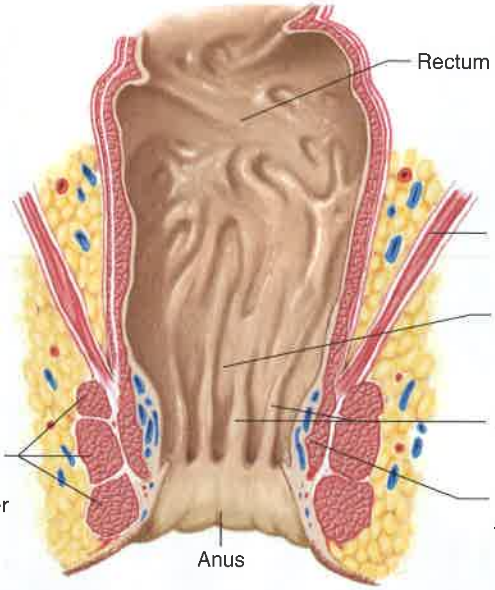


Figure 15.29
The rectum and the anal canal are at the distal end of the alimentary canal.

Figure 15.30
Light micrograph of the large intestinal mucosa (560×).

Hemorrhoids are, literally, a pain in the rear. Enlarged and inflamed branches of the rectal vein in the anal columns cause intense itching, sharp pain, and sometimes bright red bleeding. The hemorrhoids may be internal or bulge out of the anus. Causes of hemorrhoids include anything that puts prolonged pressure on the delicate rectal tissue, including obesity, pregnancy, constipation, diarrhea, and liver disease.

Eating more fiber-rich foods and drinking lots of water can usually prevent or cure hemorrhoids. Warm soaks in the tub, cold packs, and careful wiping of painful areas also help, as do external creams and ointments. Surgery—with a scalpel or a laser—can remove severe hemorrhoids.

Structure of the Large Intestine Wall

The wall of the large intestine is composed of the same types of tissues as other parts of the alimentary canal but has some unique features. The large intestine wall, for example, lacks the villi characteristic of the small intestine. Also, the layer of longitudinal muscle fibers does not uniformly cover the large intestine wall. Instead, the fibers form three distinct bands (teniae coli) that extend the entire length of the colon (see fig. 15.27). These bands exert tension lengthwise on the wall, creating a series of pouches (haustra).

Functions of the Large Intestine

Unlike the small intestine, which secretes digestive enzymes and absorbs digestive products, the large intestine has little or no digestive function. However, the mucous membrane that forms the large intestine's inner lining contains many tubular glands. Structurally, these glands are similar to those of the small intestine, but they are composed almost entirely of goblet cells (fig. 15.30). Consequently, mucus is the large intestine's only significant secretion.

Mucus secreted into the large intestine protects the intestinal wall against the abrasive action of the materials passing through it. Mucus also binds particles of fecal matter, and its alkalinity helps control the pH of the large intestine contents.

Chyme entering the large intestine contains materials that the small intestine did not digest or absorb. It also contains water, electrolytes, mucus, and bacteria. The large intestine normally absorbs water and electrolytes in the proximal half of the tube. Substances that remain in the tube become feces and are stored for a time in the distal portion of the large intestine.

The many bacteria that normally inhabit the large intestine, called *intestinal flora,* break down some of the molecules that escape the actions of human digestive enzymes. For instance, cellulose, a complex carbohydrate in food of plant origin, passes through the alimentary canal almost unchanged, but colon bacteria can break down cellulose and use it as an energy source. These bacteria, in turn, synthesize certain vitamins, such as K, B_{12}, thiamine, and riboflavin, which the intestinal mucosa absorbs. Bacterial actions in the large intestine may produce intestinal gas (flatus).

The colon is home to 100 trillion bacteria.

CHECK YOUR RECALL

1. How does the structure of the large intestine differ from that of the small intestine?
2. What substances does the large intestine absorb?

Topic of Interest — A BRIEF HISTORY OF CONSTIPATION

The idea that the normal contents of the large intestine can poison a person is not new. An Egyptian papyrus from the sixteenth century B.C. traces the origins of many diseases to various decomposing foods in the lower digestive tract. The discovery in the late eighteenth century that bacteria are normal residents of a human's intestines added to the concept of "intestinal autointoxication," a belief that bacteria mixed with leftovers from digestion could poison us from within. From then until the present time, many societies have attributed a variety of ills to constipation, which was thought to be a consequence of an increasingly urban lifestyle accompanied by less exercise and an unhealthy diet.

In the 1920s and 1930s, people widely feared that constipation would cause "sewer-like blood." Parents forced children to defecate daily, preferably in the morning so they wouldn't need to fret over a missed movement all day long. People discovered that eating bran helped them meet this daily requirement, and brands of bran flourished, one even called DinaMite. Gizmos and gadgets galore, various foods from yeast to yogurt, and many types of laxatives became staples in grocery stores. Some people even had parts of their large intestines removed to lessen the likelihood that the foul contents would kill them (fig. 15A).

In the second half of the twentieth century, after antibiotics had helped control many infectious diseases, attention turned to cancer. The dietary connection to constipation extended to cancer, and the idea that certain foods can either cause or prevent cancers of the large intestine or rectum (colorectal cancer) arose, based largely on studies of populations. People whose diets were low in meat and fat and high in fruits and vegetables tended to have a lower incidence of colorectal cancer than populations whose diets were fatty. In the 1970s, the "fiber hypothesis" gained favor, echoing the earlier popularity of bran cereal. However, two studies published in 2000 showed that, in more than 3,500 individuals, low-fat, high-fiber diets had no effect on the recurrence of intestinal polyps, which are growths that often precede development of cancer. These results were confusing, because epidemiological studies continue to show associations between high-fiber diets and lower incidence of colorectal cancer. Further studies are needed. It is possible that some other aspect of these cultures—such as exercise habits or the way meat is prepared—prevents colorectal cancer. Meanwhile, bran, fruits, and vegetables remain healthful foods that can prevent constipation.

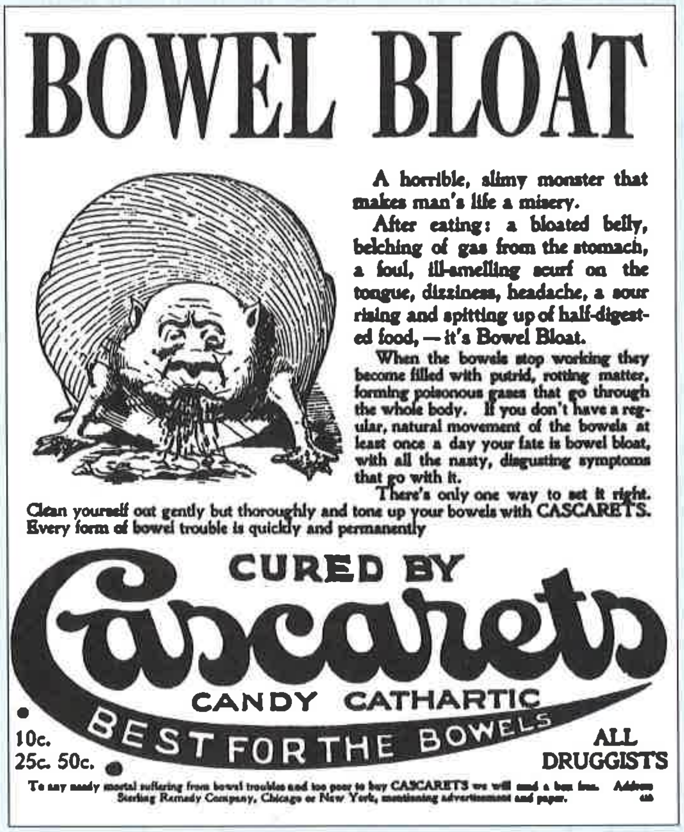


Figure 15A

In the first half of the twentieth century, an industry revolved around the perceived necessity of a daily bowel movement.

Movements of the Large Intestine

The movements of the large intestine—mixing and peristalsis—are similar to those of the small intestine, although usually slower. Also, peristaltic waves of the large intestine happen only two or three times each day. These waves produce *mass movements* in which a large section of the intestinal wall constricts vigorously, forcing the intestinal contents toward the rectum. Typically, mass movements follow a meal as a result of the gastrocolic reflex initiated in the small intestine. Irritations of the intestinal mucosa also can trigger such movements. For instance, a person with an inflamed colon (colitis) may experience frequent mass movements.

A person usually can initiate a *defecation reflex* by holding a deep breath and contracting the abdominal wall muscles. This action increases internal abdominal pressure and forces feces into the rectum. As the rectum fills, its wall distends, triggering the defecation reflex. This stimulates peristaltic waves in the descending colon, and the internal anal sphincter relaxes. At the same time, other reflexes involving the sacral region of the spinal cord strengthen the peristaltic waves, lower the diaphragm, close the glottis, and contract the abdominal wall muscles. These actions further increase internal abdominal pressure and squeeze the rectum. The external anal sphincter is signaled to relax, and the feces are forced to the outside. Contracting the external anal sphincter allows voluntary inhibition of defecation.

Feces

Feces (fe´sēz), include materials that were not digested or absorbed, plus water, electrolytes, mucus, shed intestinal cells, and bacteria. Usually, feces are about 75% water, and their color derives from bile pigments altered by bacterial action. Feces' pungent odor results from a variety of compounds that bacteria produce.

CHECK YOUR RECALL

1. How does peristalsis in the large intestine differ from peristalsis in the small intestine?
2. List the major events that occur during defecation.
3. Describe the composition of feces.

15.11 Nutrition and Nutrients

Nutrition is the study of nutrients and how the body utilizes them. **Nutrients** (nu´tre-enz) include carbohydrates, lipids, proteins, vitamins, minerals, and water (see chapter 2, p. 39, and chapter 4, p. 77). Foods provide these nutrients, and digestion breaks them down to sizes that can be absorbed and transported in the bloodstream. Nutrients that human cells cannot synthesize, such as certain amino acids, are called **essential nutrients.**

Carbohydrates

Carbohydrates are organic compounds used primarily to supply energy for cellular processes.

Carbohydrate Sources

Carbohydrates are ingested in a variety of forms, including starch from grains and vegetables; glycogen from meats; disaccharides from cane sugar, beet sugar, and molasses; and monosaccharides from honey and fruits. Digestion breaks down complex carbohydrates into monosaccharides, which are small enough to be absorbed.

Cellulose is a complex carbohydrate that is abundant in food—it gives celery its crunch and lettuce its crispness. Humans cannot digest cellulose, so the portion of it that is not broken down by intestinal flora passes through the alimentary canal largely unchanged. Thus, cellulose provides bulk (also called fiber or roughage) against which the muscular wall of the digestive system can push, facilitating the movement of food.

Carbohydrate Utilization

The monosaccharides absorbed from the digestive tract include *fructose, galactose,* and *glucose*. Liver enzymes convert fructose and galactose into glucose, which is the carbohydrate form most commonly oxidized for cellular fuel.

Some excess glucose is polymerized to form *glycogen* and stored in the liver and muscles. When required to supply energy, glucose can be mobilized rapidly from glycogen. However, only a certain amount of glycogen can be stored, and excess glucose is usually converted into fat and stored in adipose tissue.

Cells use carbohydrates as starting materials for the synthesis of such vital biochemicals as the five-carbon sugars *ribose* and *deoxyribose,* required for production of the nucleic acids RNA and DNA. Carbohydrates are also required to synthesize the disaccharide *lactose* (milk sugar) when the breasts are actively secreting milk.

Many cells obtain energy by oxidizing fatty acids. Some cells, however, such as neurons, normally require a continuous supply of glucose for survival. Even a temporary decrease in the glucose supply may seriously impair nervous system function. Consequently, the body requires a minimum amount of carbohydrates. If foods do not provide an adequate carbohydrate supply, the liver may convert some noncarbohydrates, such as amino acids from proteins, into glucose. Thus, the requirement for glucose has physiological priority over the requirement to synthesize proteins from available amino acids.

Carbohydrate Requirements

Because carbohydrates provide the primary fuel source for cellular processes, the requirement for carbohydrates varies with individual energy expenditure. Physically active individuals require more fuel than sedentary ones. The minimum carbohydrate requirement in the human diet is unknown, but a daily carbohydrate intake of at least 125–175 grams is necessary to spare protein (that is, to avoid protein breakdown) and to avoid metabolic disorders resulting from excess fat utilization. A rule of thumb suggests that carbohydrates should supply about 60% of a person's diet.

CHECK YOUR RECALL

1. List several common sources of carbohydrates.
2. Explain the importance of cellulose in the diet.
3. Explain why the requirement for glucose has priority over protein synthesis.

Lipids

Lipids are organic compounds that include fats, oils, and fatlike substances (see chapter 2, p. 39). They supply energy for cellular processes and for building structures such as cell membranes. Lipids include fats, phospholipids, and cholesterol. The most common dietary lipids are the fats called *triglycerides* (tri-glis´er-īdz).

Lipid Sources

Triglycerides are found in plant- and animal-based foods. Saturated fats (which should comprise no more than 10% of the diet) are found mainly in foods of animal origin, such as meats, eggs, milk, and lard, as well as in palm and coconut oils. Unsaturated fats are in seeds, nuts, and plant oils, such as those from corn, peanuts, and olives.

Cholesterol is abundant in liver and egg yolk and, to a lesser extent, in whole milk, butter, cheese, and meats. It is generally not present in foods of plant origin.

Lipid Utilization

Many foods contain lipids in the form of phospholipids, cholesterol, or the most common dietary lipids, triglycerides. Recall from chapter 2 (p. 40) that a triglyceride molecule consists of a glycerol and three fatty acids.

Lipids serve a variety of physiological functions, but the main one is to supply energy. Gram for gram, fats contain more than twice as much chemical energy as carbohydrates or proteins.

Before a triglyceride molecule can release energy, it must undergo hydrolysis. Digestion breaks triglycerides down into fatty acids and glycerol. After being absorbed, these products are transported in lymph and blood to tissues. Figure 15.31 shows that, upon hydrolysis, some of the resulting fatty acid portions can react to form molecules of acetyl coenzyme A by a series of reactions called **beta oxidation.** Excess acetyl coenzyme A can be converted into compounds called *ketone bodies,* such as acetone, which later may be changed back to acetyl coenzyme A. In either case, the resulting acetyl coenzyme A can be oxidized in the citric acid cycle. The glycerol portions of the triglyceride molecules can also enter metabolic pathways leading to the citric acid cycle, or they can be used to synthesize glucose. Fatty acid molecules released from fat hydrolysis can also combine to form fat molecules by anabolic processes and be stored in fat tissue.

The liver can convert fatty acids from one form to another, but it cannot synthesize certain fatty acids, called **essential fatty acids.** *Linoleic acid,* for example, is required for phospholipid synthesis, which in turn is necessary for cell membrane formation and the transport of circulating lipids. Good sources of linoleic acid include corn, cottonseed, and soy oils. Other essential fatty acids are linolenic acid and arachidonic acid.

The liver uses free fatty acids to synthesize triglycerides, phospholipids, and lipoproteins that may then be released into the blood. Thus, the liver regulates circulating lipids. It also controls the total amount of cholesterol in the body by synthesizing cholesterol and releasing it into the bloodstream, or by removing cholesterol from the bloodstream and excreting it into bile. The liver also uses cholesterol to produce bile salts.

Cholesterol is not an energy source. It provides structural material for cell and organelle membranes and is a starting material for the synthesis of certain sex hormones and adrenal hormones.

Adipose tissue stores excess triglycerides. If the blood lipid concentration drops (in response to fasting, for example), some of these triglycerides are hydrolyzed into free fatty acids and glycerol, and then released into the bloodstream.

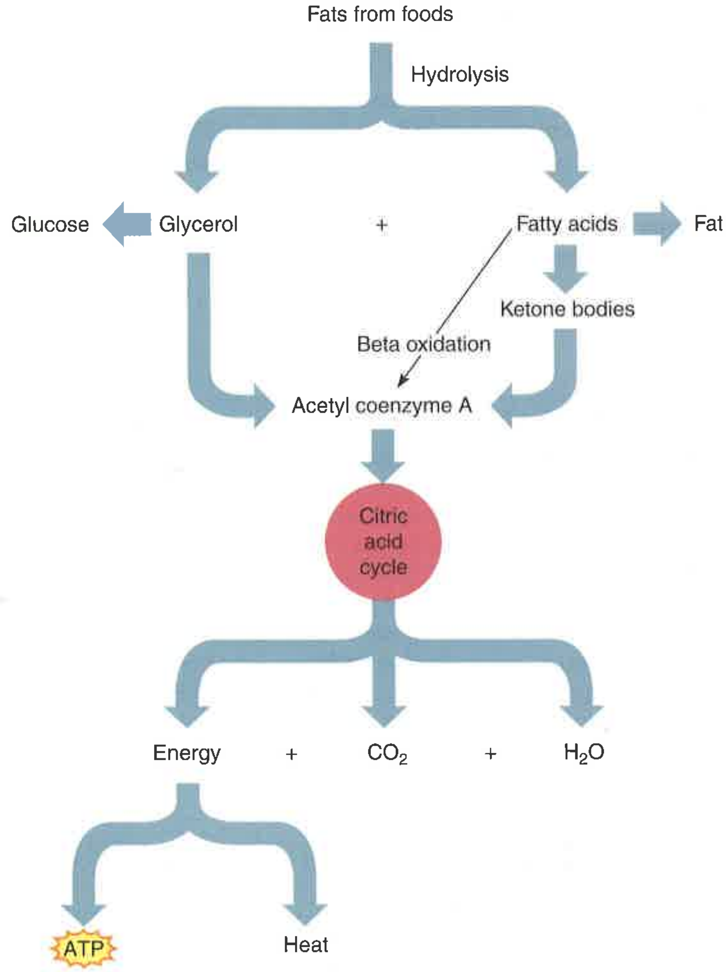


Figure 15.31
The body digests fats from foods into glycerol and fatty acids, which may enter catabolic pathways and be used as energy sources.

Lipid Requirements

The amounts and types of fats required for health are unknown. Because linoleic acid is an essential fatty acid, nutritionists recommend that formula-fed infants receive 3% of their energy intake in the form of linoleic acid to prevent deficiency conditions. With lipids supplying not more than 30% of daily food intake, a typical adult diet that includes a variety of foods usually provides adequate fats. Fat intake must also supply required amounts of fat-soluble vitamins.

Before 1993, "lite" and similar markings on prepared food packages could, and did, mean almost anything: A bottle of vegetable oil labeled "lite" referred to the product's color; a "lite" cheesecake referred to its texture! Now, "lite," or any similar spelling, has a distinct meaning: The product must have a third fewer calories than the "real thing" or half the fat calories.

Be wary of claims that a food product is "99% fat-free." This usually refers to percentage by weight—not calories, which is what counts. A creamy concoction that is 99% fat-free may be largely air and water, and in that form, fat comprises very little of it. But when the air is compressed and the water absorbed, as happens in the stomach, the fat percentage may skyrocket.

CHECK YOUR RECALL

1. Which fatty acid is an essential nutrient?
2. What is the liver's role in the utilization of lipids?
3. What are the functions of cholesterol?

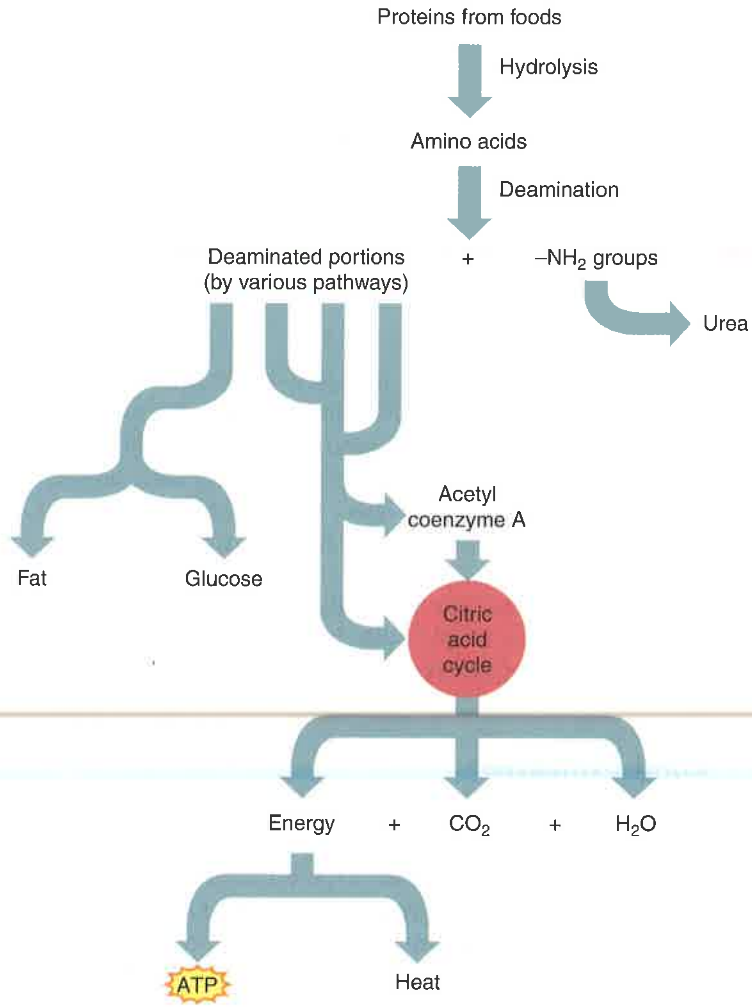


Figure 15.32
The body digests proteins from foods into amino acids but must deaminate these smaller molecules before they can be used as energy sources.

Proteins

Proteins are polymers of amino acids with a wide variety of functions. Proteins include enzymes that control metabolic rates, clotting factors, the keratin of skin and hair, elastin and collagen of connective tissue, plasma proteins that regulate water balance, the muscle components actin and myosin, certain hormones, and the antibodies that protect against infection. Proteins may also supply energy.

When protein molecules are used as energy sources, they are broken down into amino acids. Then the amino acids undergo **deamination,** a process that occurs in the liver and removes their nitrogen-containing portions ($—NH_2$ groups) (see fig. 2.15, p. 42). These $—NH_2$ groups then react to form the waste *urea,* which is excreted in urine.

Depending upon the particular amino acids involved, the remaining deaminated portions are decomposed in one of several pathways (fig. 15.32). Some of these pathways lead to formation of acetyl coenzyme A, and others lead more directly to the steps of the citric acid cycle. As energy is released from the cycle, some of it is captured in ATP molecules. If energy is not required immediately, the deaminated portions of the amino acids may react to form glucose or fat molecules in other metabolic pathways.

Protein Sources

Foods rich in proteins include meats, fish, poultry, cheese, nuts, milk, eggs, and cereals. Legumes, including beans and peas, contain lesser amounts. Digestion breaks down proteins into their component amino acids—smaller molecules that intestinal tissues absorb and blood transports.

The cells of an adult can synthesize all but eight required amino acids, and the cells of a child can produce all but ten. Amino acids that the body can synthe-

TABLE 15.7 AMINO ACIDS IN FOODS

Alanine	Leucine (e)
Arginine (ch)	Lysine (e)
Asparagine	Methionine (e)
Aspartic acid	Phenylalanine (e)
Cysteine	Proline
Glutamic acid	Serine
Glutamine	Threonine (e)
Glycine	Tryptophan (e)
Histidine (ch)	Tyrosine
Isoleucine (e)	Valine (e)

Eight essential amino acids (e) cannot be synthesized by human cells and must be provided in the diet. Two additional amino acids (ch) are essential in growing children.

size are termed nonessential; those that it cannot synthesize are **essential amino acids.** This term refers only to dietary intake since all amino acids are needed for normal protein synthesis.

All of the amino acids must be present in the body at the same time for growth and tissue repair to occur. In other words, if one essential amino acid is missing from the diet, normal protein synthesis cannot take place. This is because many proteins include all twenty types of amino acids. Table 15.7 lists the amino acids in foods and indicates those that are essential.

Proteins are classified as complete or incomplete on the basis of the amino acid types they provide. **Complete proteins,** which include those available in milk, meats, and eggs, contain adequate amounts of the essential amino acids. **Incomplete proteins,** such as *zein* in corn, which has too little of the essential amino acids tryptophan and lysine, are unable by themselves to maintain human tissues or to support normal growth and development. A protein called *gliadin* in wheat is an example of a **partially complete protein.** It does not contain enough lysine to promote growth, but it contains enough to maintain life.

Plant proteins typically contain too little of one or more essential amino acids to provide adequate nutrition for a person. Combining appropriate plant foods can provide a diversity of dietary amino acids. For example, beans are low in methionine but have enough lysine. Rice lacks lysine but has enough methionine. Thus, a meal of beans and rice provides enough of both types of amino acids.

CHECK YOUR RECALL

1. Which foods are rich sources of proteins?
2. Why are some amino acids called essential?
3. Distinguish between complete and incomplete proteins.

Protein Requirements

Proteins supply essential amino acids. They also provide nitrogen and other elements for the synthesis of nonessential amino acids and certain nonprotein nitrogenous substances. Consequently, the amount of protein individuals require varies according to body size, metabolic rate, and nitrogen requirements.

For an average adult, nutritionists recommend a daily protein intake of about 0.8 grams per kilogram of body weight, or 10% of a person's diet. For a pregnant woman, the recommendation increases an additional 30 grams of protein per day. Similarly, a nursing mother requires an extra 20 grams of protein per day to maintain a high level of milk production.

A food's potential energy can be expressed in calories, which are units of heat. A calorie (kal´o-re) is defined as the amount of heat required to raise the temperature of a gram of water by 1° Celsius. The calorie used to measure food energy, however, is 1,000 times greater. This larger calorie (Cal) is technically a kilocalorie, but nutritional studies commonly refer to it simply as a calorie. As a result of cellular oxidation, 1 gram of carbohydrate or 1 gram of protein yields about 4.1 calories, but 1 gram of fat yields 9.5 calories.

CHECK YOUR RECALL

1. What are the physiological functions of proteins?
2. How much protein is recommended for an adult diet?

Vitamins

Vitamins (vi´tah-minz) are organic compounds (other than carbohydrates, lipids, and proteins) that are required in small amounts for normal metabolic processes, but that body cells cannot synthesize in adequate amounts. Thus, they are essential nutrients that must come from foods.

Vitamins can be classified on the basis of solubility because some are soluble in fats (or fat solvents) and others are soluble in water. *Fat-soluble vitamins* include vitamins A, D, E, and K; *water-soluble vitamins* include the B vitamins and vitamin C.

Fat-Soluble Vitamins

Because fat-soluble vitamins dissolve in fats, they associate with lipids and are influenced by the same factors that affect lipid absorption. For example, bile salts in

TABLE 15.8 FAT-SOLUBLE VITAMINS

VITAMIN	CHARACTERISTICS	FUNCTIONS	SOURCES AND RDA* FOR ADULTS
Vitamin A	Occurs in several forms; synthesized from carotenes; stored in liver; stable in heat, acids, and alkalis; unstable in light	Necessary for synthesis of visual pigments, mucoproteins, and mucopolysaccharides; for normal development of bones and teeth; and for maintenance of epithelial cells	Liver, fish, whole milk, butter, eggs, leafy green vegetables, yellow and orange vegetables and fruits; RDA = 4,000–5,000 IU†
Vitamin D	A group of steroids; resistant to heat, oxidation, acids, and alkalis; stored in liver, skin, brain, spleen, and bones	Promotes absorption of calcium and phosphorus; promotes development of teeth and bones	Produced in skin exposed to ultraviolet light; in milk, egg yolk, fish liver oils, fortified foods; RDA = 400 IU
Vitamin E	A group of compounds; resistant to heat and visible light; unstable in presence of oxygen and ultraviolet light; stored in muscles and adipose tissue	An antioxidant; prevents oxidation of vitamin A and polyunsaturated fatty acids; may help maintain stability of cell membranes	Oils from cereal seeds, salad oils, margarine, shortenings, fruits, nuts, and vegetables; RDA = 30 IU
Vitamin K	Occurs in several forms; resistant to heat, but destroyed by acids, alkalis, and light; stored in liver	Needed for synthesis of prothrombin, which functions in blood clotting	Leafy green vegetables, egg yolk, pork liver, soy oil, tomatoes, cauliflower; RDA = 55–70 µg

*RDA = recommended dietary allowance.
†IU = international unit.

the intestine promote absorption of these vitamins. As a group, fat-soluble vitamins are stored in moderate quantities within various tissues. They resist the effects of heat; therefore, cooking and food processing usually do not destroy them. Table 15.8 lists the fat-soluble vitamins and their characteristics, functions, sources, and recommended dietary allowances (RDA) for adults.

CHECK YOUR RECALL

1. What are vitamins?
2. How do bile salts affect absorption of fat-soluble vitamins?

Water-Soluble Vitamins

The water-soluble vitamins include the B vitamins and vitamin C. The **B vitamins** are several compounds that are essential for normal cellular metabolism. They help oxidize carbohydrates, lipids, and proteins. Since the B vitamins often occur together in foods, they are usually referred to as the *vitamin B complex*. Members of this group differ chemically and functionally. Cooking and food processing destroy some of them.

Vitamin C (ascorbic acid) is one of the least stable vitamins and is fairly widespread in plant foods. It is necessary for collagen production, the conversion of folacin to folinic acid, and the metabolism of certain amino acids. Vitamin C also promotes iron absorption and synthesis of certain hormones from cholesterol. Table 15.9 lists the water-soluble vitamins and their characteristics, functions, sources, and RDAs for adults.

English ships carried limes to protect the sailors from scurvy. American ships carried cranberries.

CHECK YOUR RECALL

1. Name the water-soluble vitamins.
2. What is the vitamin B complex?
3. Distinguish between fat-soluble and water-soluble vitamins.

Minerals

Dietary **minerals** (min´er-alz) are elements other than carbon that are essential in human metabolism. Plants usually extract minerals from soil, and humans obtain minerals from plant foods or from animals that have eaten plants.

Characteristics of Minerals

Minerals are responsible for about 4% of body weight and are most concentrated in the bones and teeth. Minerals are usually incorporated into organic molecules. For example, phosphorus is found in phospholipids, iron in hemoglobin, and iodine in thyroxine. Some minerals are part of inorganic compounds, such as the calcium phosphate of bone. Other minerals are free ions, such as sodium, chloride, and calcium ions in blood.

Minerals compose parts of the structural materials in all body cells. They also constitute portions of enzyme

TABLE 15.9 WATER-SOLUBLE VITAMINS

VITAMIN	CHARACTERISTICS	FUNCTIONS	SOURCES AND RDA* FOR ADULTS
Thiamine (vitamin B_1)	Destroyed by heat and oxygen, especially in alkaline environment	Part of coenzyme required to oxidize carbohydrates; coenzyme required for ribose synthesis	Lean meats, liver, eggs, whole-grain cereals, leafy green vegetables, legumes; RDA =1.5 mg
Riboflavin (vitamin B_2)	Stable to heat, acids, and oxidation; destroyed by bases and ultraviolet light	Part of enzymes and coenzymes required to oxidize glucose and fatty acids and for cellular growth	Meats, dairy products, leafy green vegetables, whole-grain cereals; RDA = 1.7 mg
Niacin (nicotinic acid)	Stable to heat, acids, and alkalis; converted to niacinamide by cells; synthesized from tryptophan	Part of coenzymes required to oxidize glucose and to synthesize proteins, fats, and nucleic acids	Liver, lean meats, peanuts, legumes; RDA = 20 mg
Vitamin B_6	Group of three compounds; stable to heat and acids; destroyed by oxidation, bases, and ultraviolet light	Coenzyme required to synthesize proteins and certain amino acids, to convert tryptophan to niacin, to produce antibodies, and to synthesize nucleic acids	Liver, meats, bananas, avocados, beans, peanuts, whole-grain cereals, egg yolk; RDA = 2 mg
Pantothenic acid	Destroyed by heat, acids, and bases	Part of coenzyme A required to oxidize carbohydrates and fats	Meats, whole-grain cereals, legumes, milk, fruits, vegetables; RDA = 10 mg
Cyanocobalamin (vitamin B_{12})	Complex, cobalt-containing compound; stable to heat; inactivated by light, strong acids, and strong bases; absorption regulated by intrinsic factor from gastric glands; stored in liver	Part of coenzyme required to synthesize nucleic acids and to metabolize carbohydrates; plays role in myelin synthesis; needed for normal red blood cell production	Liver, meats, milk, cheese, eggs; RDA = 3–6 µg
Folacin (folic acid)	Occurs in several forms; destroyed by oxidation in acid environment or by heat in alkaline environment; stored in liver, where it is converted into folinic acid	Coenzyme required for metabolism of certain amino acids and for DNA synthesis; promotes red blood cell production	Liver, leafy green vegetables, whole-grain cereals, legumes; RDA = 0.4 mg
Biotin	Stable to heat, acids, and light; destroyed by oxidation and bases	Coenzyme required to metabolize amino acids and fatty acids, and to synthesize nucleic acids	Liver, egg yolk, nuts, legumes, mushrooms; RDA = 0.3 mg
Ascorbic acid (vitamin C)	Closely related to monosaccharides; stable in acids but destroyed by oxidation, heat, light, and bases	Required to produce collagen, to convert folacin to folinic acid, and to metabolize certain amino acids; promotes absorption of iron and synthesis of hormones from cholesterol	Citrus fruits, tomatoes, potatoes, leafy green vegetables; RDA = 60 mg

*RDA = recommended dietary allowance.

molecules, contribute to the osmotic pressure of body fluids, and play vital roles in nerve impulse conduction, muscle fiber contraction, blood coagulation, and maintaining the pH of body fluids.

Major Minerals

The minerals *calcium* and *phosphorus* account for nearly 75% by weight of the mineral elements in the body; thus, they are **major minerals.** Other major minerals, each of which accounts for 0.05% or more of the body weight, include potassium, sulfur, sodium, chlorine, and magnesium. Table 15.10 lists the distribution, functions, sources, and adult RDAs of major minerals.

There is enough phosphorus in the human body to make two thousand match tips.

CHECK YOUR RECALL

1. How are minerals obtained?
2. What are the major functions of minerals?

Trace Elements

Trace elements are essential minerals found in minute amounts, each making up less than 0.005% of adult body weight. They include iron, manganese, copper, iodine, cobalt, zinc, fluorine, selenium, and chromium. Table 15.11 lists the distribution, functions, sources, and adult RDAs of the trace elements.

The iron in a human being could make a small nail.

TABLE 15.10 MAJOR MINERALS

MINERAL	DISTRIBUTION	FUNCTIONS	SOURCES AND RDA* FOR ADULTS
Calcium (Ca)	Mostly in the inorganic salts of bones and teeth	Structure of bones and teeth; essential for nerve impulse conduction, muscle fiber contraction, and blood coagulation; increases permeability of cell membranes; activates certain enzymes	Milk, milk products, leafy green vegetables; RDA = 800 mg
Phosphorus (P)	Mostly in the inorganic salts of bones and teeth	Structure of bones and teeth; component in nearly all metabolic reactions; constituent of nucleic acids, many proteins, some enzymes, and some vitamins; occurs in cell membrane, ATP, and phosphates of body fluids	Meats, cheese, nuts, whole-grain cereals, milk, legumes; RDA = 800 mg
Potassium (K)	Widely distributed; tends to be concentrated inside cells	Helps maintain intracellular osmotic pressure and regulate pH; promotes metabolism; needed for nerve impulse conduction and muscle fiber contraction	Avocados, dried apricots, meats, nuts, potatoes, bananas; RDA = 2,500 mg
Sulfur (S)	Widely distributed; abundant in skin, hair, and nails	Essential part of various amino acids, thiamine, insulin, biotin, and mucopolysaccharides	Meats, milk, eggs, legumes; no RDA established
Sodium (Na)	Widely distributed; large proportion occurs in extracellular fluids and bound to inorganic salts of bone	Helps maintain osmotic pressure of extracellular fluids and regulate water movement; needed for conduction of nerve impulses and contraction of muscle fibers; aids in regulation of pH and in transport of substances across cell membranes	Table salt, cured ham, sauerkraut, cheese, graham crackers; RDA = 2,500 mg
Chlorine (Cl)	Closely associated with sodium (as chloride); most highly concentrated in cerebrospinal fluid and gastric juice	Helps maintain osmotic pressure of extracellular fluids, regulate pH, and maintain electrolyte balance; essential in formation of hydrochloric acid; aids transport of carbon dioxide by red blood cells	Same as for sodium; no RDA established
Magnesium (Mg)	Abundant in bones	Needed in metabolic reactions that occur in mitochondria and are associated with ATP production; plays role in the breakdown of ATP to ADP	Milk, dairy products, legumes, nuts, leafy green vegetables; RDA = 300–350 mg

*RDA = recommended dietary allowance.

CHECK YOUR RECALL

1. Distinguish between a major mineral and a trace element.
2. Name the major minerals and trace elements.

Adequate Diets

An adequate diet provides sufficient energy, essential fatty acids, essential amino acids, vitamins, and minerals to support optimal growth and to maintain and repair body tissues. Because individual requirements for nutrients vary greatly with age, sex, growth rate, amount of physical activity, and level of stress, as well as with genetic and environmental factors, designing a diet that is adequate for everyone is impossible. However, nutrients are so widely distributed in foods, that satisfactory amounts and combinations can usually be obtained in spite of individual food preferences. Figure 15.33 depicts the **food pyramid** system for a healthy diet.

If the diet lacks essential nutrients or a person fails to use available foods to best advantage, **malnutrition** (mal′′nu-trish′un) results. This condition may be due to either *undernutrition,* producing the symptoms of deficiency diseases, or to *overnutrition,* arising from excess nutrient intake.

The factors leading to malnutrition vary. For example, a deficiency condition may stem from lack of food or poor-quality food. On the other hand, malnutrition may result from overeating or taking too many vitamin supplements.

TABLE 15.11 TRACE ELEMENTS

TRACE ELEMENT	DISTRIBUTION	FUNCTIONS	SOURCES AND RDA* FOR ADULTS
Iron (Fe)	Primarily in blood; stored in liver, spleen, and bone marrow	Part of hemoglobin molecule; catalyzes vitamin A formation; incorporated into a number of enzymes	Liver, lean meats, dried apricots, raisins, enriched whole-grain cereals, legumes, molasses; RDA = 10–18 mg
Manganese (Mn)	Most concentrated in liver, kidneys, and pancreas	Occurs in enzymes needed for fatty acid and cholesterol synthesis, urea formation, and normal functioning of the nervous system	Nuts, legumes, whole-grain cereals, leafy green vegetables, fruits; RDA = 2.5–5 mg
Copper (Cu)	Most highly concentrated in liver, heart, and brain	Essential for hemoglobin synthesis, bone development, melanin production, and myelin formation	Liver, oysters, crabmeat, nuts, whole-grain cereals, legumes; RDA = 2–3 mg
Iodine (I)	Concentrated in thyroid gland	Essential component for synthesis of thyroid hormones	Food content varies with soil content in different geographic regions; iodized table salt; RDA = 0.15 mg
Cobalt (Co)	Widely distributed	Component of cyanocobalamin; needed for synthesis of several enzymes	Liver, lean meats, milk; no RDA established
Zinc (Zn)	Most concentrated in liver, kidneys, and brain	Constituent of several enzymes involved in digestion, respiration, bone metabolism, liver metabolism; necessary for normal wound healing and maintaining skin integrity	Meats, cereals, legumes, nuts, vegetables; RDA = 15 mg
Fluorine (F)	Primarily in bones and teeth	Component of tooth structure	Fluoridated water; RDA = 1.5–4.0 mg
Selenium (Se)	Concentrated in liver and kidneys	Occurs in enzymes	Lean meats, fish, cereals; RDA = 0.05–2.00 mg
Chromium (Cr)	Widely distributed	Essential for use of carbohydrates	Liver, lean meats, wine; RDA = 0.05–2.00 mg

*RDA = recommended dietary allowance.

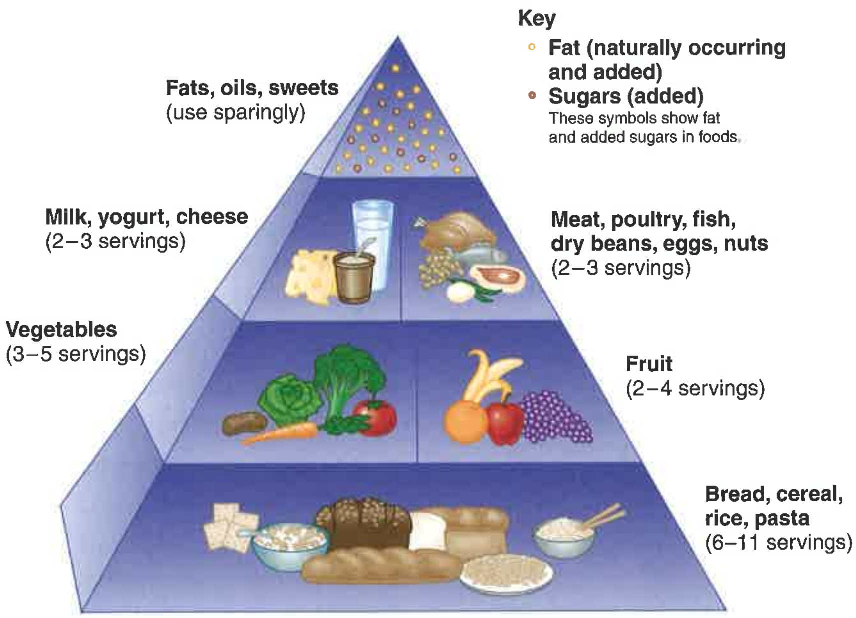


Figure 15.33
The U.S. Department of Agriculture introduced the food pyramid in 1992 as a guideline to healthy eating. In contrast to former food group plans, the pyramid gives an instant idea of which foods should make up the bulk of the diet—whole grains, fruits, and vegetables.

CHECK YOUR RECALL

1. What is an adequate diet?
2. What factors influence individual requirements for nutrients?
3. What causes malnutrition?

Clinical Terms Related to the Digestive System and Nutrition

achalasia (ak´´ah-la´ze-ah) Failure of the smooth muscle to relax at some junction in the digestive tube, such as between the esophagus and stomach.
achlorhydria (ah´´klor-hi´dre-ah) Lack of hydrochloric acid in gastric secretions.
anorexia nervosa (ă-nah-rek´se-ah ner vo´sah) Self-starvation.
aphagia (ah-fa´je-ah) Inability to swallow.
cachexia (kah-kek´se-ah) State of chronic malnutrition and physical wasting.
celiac disease (se´le-ak dĭ-zēz´) Inability to digest or use fats and carbohydrates.
cholecystitis (ko´´le-sis-ti´tis) Inflammation of the gallbladder.
cholelithiasis (ko´´le-lĭ-thi´ah-sis) Stones in the gallbladder.
cholestasis (ko´´le-sta´sis) Blockage in bile flow from the gallbladder.
cirrhosis (sĭ-ro´sis) Liver condition in which the hepatic cells degenerate and the surrounding connective tissues thicken.
diverticulitis (di´´ver-tik´´u-li´tis) Inflammation of small pouches (diverticula) that form in the lining and wall of the colon.
dumping syndrome (dum´ping sin´drōm) Symptoms, including diarrhea, that often occur following a gastrectomy.
dysentery (dis´en-ter´´e) Intestinal infection by viruses, bacteria, or protozoans that causes diarrhea and cramps.
dyspepsia (dis-pep´se-ah) Indigestion; difficulty in digesting a meal.
dysphagia (dis-fa´je-ah) Difficulty in swallowing.
enteritis (en´´tĕ-ri´tis) Inflammation of the intestine.
esophagitis (e-sof´´ah-ji´tis) Inflammation of the esophagus.
gastrectomy (gas-trek´to-me) Partial or complete removal of the stomach.
gastrostomy (gas-tros´to-me) Creation of an opening in the stomach wall through which food and liquids can be administered when swallowing is not possible.
glossitis (glŏs-si´tis) Inflammation of the tongue.
hyperalimentation (hi´´-per-al´´-ĭ-men-ta´shun) Long-term intravenous nutrition.
ileitis (il´´e-i´tis) Inflammation of the ileum.
pharyngitis (far´´in-ji´tis) Inflammation of the pharynx.
polyphagia (pol´´e-fa´je-ah) Overeating.
pyloric stenosis (pi-lor´ik stĕ-no´sis) Congenital obstruction at the pyloric sphincter due to an enlarged pyloric muscle.
pylorospasm (pi-lor´o-spazm) Spasm of the pyloric portion of the stomach or of the pyloric sphincter.
pyorrhea (pi´´o-re´ah) Inflammation of the dental periosteum with pus formation.
stomatitis (sto´´mah-ti´tis) Inflammation of the lining of the mouth.

Clinical Connection

Saliva is vital for tasting and processing food, so that it can be swallowed and digested. It also keeps teeth healthy by washing away bacteria and plaque. In a condition called xerostomia, or "dry mouth," saliva production is insufficient. As a result, chewed food does not soften enough and is difficult to swallow. Even licking an envelope can be impossible for a person with this condition.

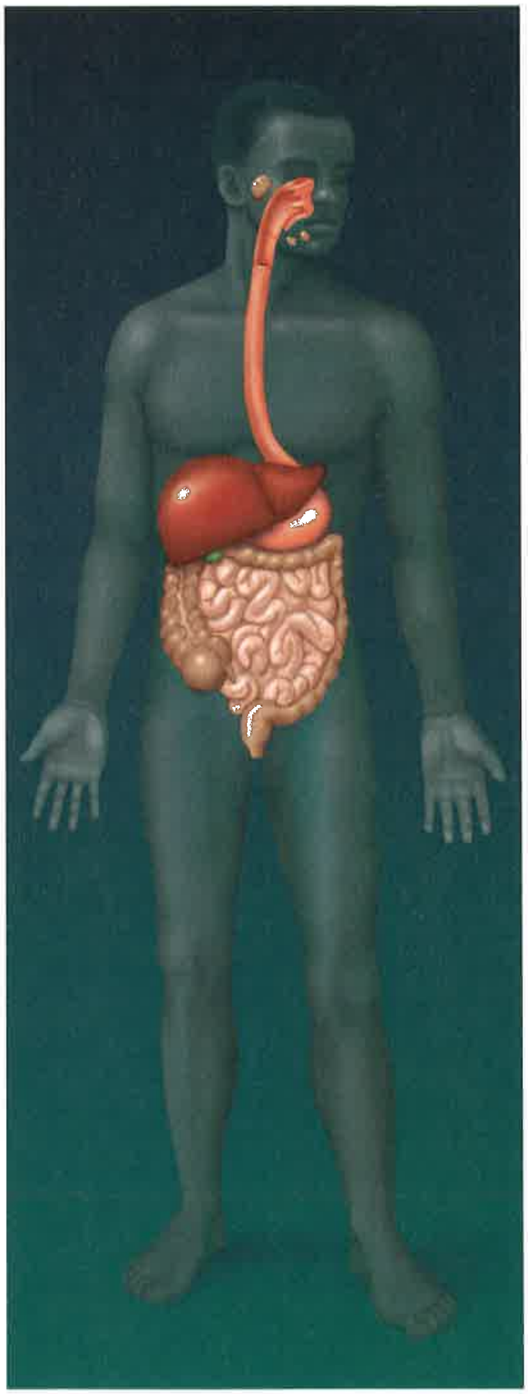
Physicians today no longer accept xerostomia as a normal consequence of aging, but instead ask a patient which drugs he or she is taking. Often, dry mouth is a side effect of a medication. Hundreds of medications can cause xerostomia, including drugs that treat depression, hypertension, cancer, and allergies. Radiation to the head or neck to treat cancer can cause xerostomia. Infection of the salivary glands or Sjogren's syndrome can also cause dry mouth.

Sometimes identifying and avoiding a causative medication can relieve dry mouth. If this isn't possible, the Mayo Clinic Health Letter suggests the following strategies:

- Regularly sip water.
- Avoid mouth breathing.
- Suck on sugar-free hard candy or gum.
- Use room vaporizers to add moisture to the environment.

If these measures fail, saliva substitute sprays are available over-the-counter, or a physician can prescribe a medication that increases production of saliva, such as pilocarpine.

Organization



Digestive System

The digestive system ingests, digests, and absorbs nutrients for use by all body cells.

Integumentary System

Vitamin D activated in the skin plays a role in absorption of calcium from the digestive tract.

Skeletal System

Bones are important in mastication. Calcium absorption is necessary to maintain bone matrix.

Muscular System

Muscles are important in mastication, swallowing, and the mixing and moving of digestion products through the gastrointestinal tract.

Nervous System

The nervous system can influence digestive system activity.

Endocrine System

Hormones can influence digestive system activity.

Cardiovascular System

The bloodstream carries absorbed nutrients to all body cells.

Lymphatic System

The lymphatic system plays a major role in the absorption of fats.

Respiratory System

The digestive system and the respiratory system share common anatomical structures.

Urinary System

The kidneys and liver work together to activate vitamin D.

Reproductive System

In a woman, nutrition is essential for conception and normal development of an embryo and fetus.

SUMMARY OUTLINE

15.1 Introduction (p. 393)

Digestion is the process of mechanically and chemically breaking down foods and absorbing the breakdown products. The digestive system consists of an alimentary canal and several accessory organs.

15.2 General Characteristics of the Alimentary Canal (p. 394)

Regions of the alimentary canal perform specific functions.

1. Structure of the wall
   The wall consists of four layers—the mucosa, submucosa, muscular layer, and serosa.
2. Movements of the tube
   Motor functions include mixing and propelling movements.

15.3 Mouth (p. 396)

The mouth receives food and begins digestion.

1. Cheeks and lips
   a. Cheeks consist of outer layers of skin, pads of fat, muscles associated with expression and chewing, and inner linings of epithelium.
   b. Lips are highly mobile and contain sensory receptors.
2. Tongue
   a. The tongue's rough surface handles food and contains taste buds.
   b. Lingual tonsils are on the root of the tongue.
3. Palate
   a. The palate includes hard and soft portions.
   b. The soft palate closes the opening to the nasal cavity during swallowing.
   c. Palatine tonsils are located on either side of the tongue in the back of the mouth.
4. Teeth
   a. There are twenty primary and thirty-two secondary teeth.
   b. Teeth mechanically break food into smaller pieces, increasing the surface area exposed to digestive actions.
   c. Each tooth consists of a crown and root, and is composed of enamel, dentin, pulp, nerves, and blood vessels.
   d. A periodontal ligament attaches a tooth to the alveolar process.

15.4 Salivary Glands (p. 399)

Salivary glands secrete saliva, which moistens food, helps bind food particles, begins chemical digestion of carbohydrates, makes taste possible, and helps cleanse the mouth.

1. Salivary secretions
   Salivary glands include serous cells that secrete digestive enzymes and mucous cells that secrete mucus.
2. Major salivary glands
   a. The parotid glands secrete saliva rich in amylase.
   b. The submandibular glands produce viscous saliva.
   c. The sublingual glands primarily secrete mucus.

15.5 Pharynx and Esophagus (p. 400)

The pharynx and esophagus are important passageways.

1. Structure of the pharynx
   The pharynx is divided into a nasopharynx, oropharynx, and laryngopharynx.
2. Swallowing mechanism
   Swallowing occurs in three stages:
   a. Food is mixed with saliva and forced into the pharynx.
   b. Involuntary reflex actions move the food into the esophagus.
   c. Peristalsis transports food to the stomach.
3. Esophagus
   a. The esophagus passes through the diaphragm and joins the stomach.
   b. Circular muscle fibers at the distal end of the esophagus help prevent regurgitation of food from the stomach.

15.6 Stomach (p. 402)

The stomach receives food, mixes it with gastric juice, carries on a limited amount of absorption, and moves food into the small intestine.

1. Parts of the stomach
   a. The stomach is divided into cardiac, fundic, body, and pyloric regions.
   b. The pyloric sphincter is a valve between the stomach and small intestine.
2. Gastric secretions
   a. Gastric glands secrete gastric juice.
   b. Gastric juice contains pepsin, hydrochloric acid, and intrinsic factor.
3. Regulation of gastric secretions
   a. Parasympathetic impulses and the hormone gastrin enhance gastric secretion.
   b. Food in the small intestine reflexly inhibits gastric secretions.
4. Gastric absorption
   The stomach wall may absorb a few substances, such as water and other small molecules.
5. Mixing and emptying actions
   a. Mixing movements help produce chyme. Peristaltic waves move chyme into the pyloric region.
   b. The muscular wall of the pyloric region regulates chyme movement into the small intestine.
   c. The rate of emptying depends on the fluidity of chyme and the type of food present.

15.7 Pancreas (p. 404)

1. Structure of the pancreas
   a. The pancreas produces pancreatic juice that is secreted into a pancreatic duct.
   b. The pancreatic duct leads to the duodenum.
2. Pancreatic juice
   a. Pancreatic juice contains enzymes that can split carbohydrates, fats, nucleic acids, and proteins.
   b. Pancreatic juice has a high bicarbonate ion concentration that helps neutralize chyme and causes intestinal contents to be alkaline.
3. Hormones regulate pancreatic secretion
   a. Secretin stimulates the release of pancreatic juice with a high bicarbonate ion concentration.
   b. Cholecystokinin stimulates the release of pancreatic juice with a high concentration of digestive enzymes.

15.8 Liver (p. 406)

1. Liver structure
   a. The right and left lobes of the liver consist of hepatic lobules, the functional units of the gland.
   b. Bile canals carry bile from hepatic lobules to hepatic ducts.
2. Liver functions
   a. The liver metabolizes carbohydrates, lipids, and proteins; stores some substances; filters blood; destroys toxins; and secretes bile.
   b. Bile is the only liver secretion that directly affects digestion.
3. Composition of bile
   a. Bile contains bile salts, bile pigments, cholesterol, and electrolytes.
   b. Only the bile salts have digestive functions.
4. Gallbladder
   a. The gallbladder stores bile between meals.
   b. A sphincter muscle controls release of bile from the common bile duct.

5. Regulation of bile release
   a. Cholecystokinin from the small intestine stimulates bile release.
   b. The sphincter muscle at the base of the common bile duct relaxes as a peristaltic wave in the duodenal wall approaches.
6. Functions of bile salts
   Bile salts emulsify fats and aid in the absorption of fatty acids, cholesterol, and certain vitamins.

15.9 Small Intestine (p. 411)

The small intestine receives secretions from the pancreas and liver, completes nutrient digestion, absorbs the products of digestion, and transports the residues to the large intestine.

1. Parts of the small intestine
   The small intestine consists of the duodenum, jejunum, and ileum.
2. Structure of the small intestine wall
   a. The wall is lined with villi that greatly increase the surface area and aid in mixing and absorption.
   b. Intestinal glands are located between the villi.
3. Secretions of the small intestine
   a. Secretions include mucus and digestive enzymes.
   b. Digestive enzymes split molecules of sugars, proteins, and fats into simpler forms.
4. Regulation of small intestine secretions
   Gastric juice, chyme, and reflexes stimulated by distension of the small intestine wall stimulate small intestine secretions.
5. Absorption in the small intestine
   a. Enzymes on microvilli perform the final steps in digestion.
   b. Villi absorb monosaccharides, amino acids, fatty acids, and glycerol.
   c. Fat molecules with longer chains of carbon atoms enter the lacteals of the villi.
   d. Fatty acids with relatively short carbon chains enter blood capillaries of the villi.
6. Movements of the small intestine
   a. Movements include mixing and peristalsis.
   b. The ileocecal sphincter controls movement of the intestinal contents from the small intestine into the large intestine.

15.10 Large Intestine (p. 417)

The large intestine reabsorbs water and electrolytes, and forms and stores feces.

1. Parts of the large intestine
   a. The large intestine consists of the cecum, colon, rectum, and anal canal.
   b. The colon is divided into ascending, transverse, descending, and sigmoid portions.
2. Structure of the large intestine wall
   a. The large intestine wall resembles the wall in other parts of the alimentary canal.
   b. The large intestine wall has a unique layer of longitudinal muscle fibers arranged in distinct bands.
3. Functions of the large intestine
   a. The large intestine has little or no digestive function.
   b. It secretes mucus.
   c. The large intestine absorbs water and electrolytes.
   d. The large intestine forms and stores feces.
4. Movements of the large intestine
   a. Movements are similar to those in the small intestine.
   b. Mass movements occur two to three times each day.
   c. A defecation reflex stimulates defecation.
5. Feces
   a. Feces consist largely of water, undigested material, electrolytes, mucus, and bacteria.
   b. The color of feces is due to bile pigments that have been altered by bacterial actions.

15.11 Nutrition and Nutrients (p. 420)

Nutrition is the study of nutrients and how the body utilizes them.

1. Carbohydrates
   a. Carbohydrate sources
      (1) Starch, glycogen, disaccharides, and monosaccharides are carbohydrates.
      (2) Cellulose is a polysaccharide that human enzymes cannot digest.
   b. Carbohydrate utilization
      (1) Oxidation releases energy from glucose.
      (2) Excess glucose is stored as glycogen or converted to fat.
      (3) Most carbohydrates supply energy.
   c. Carbohydrate requirements
      (1) Humans survive with a wide range of carbohydrate intakes.
      (2) A rule of thumb suggests carbohydrates make up 60% of a person's diet.
2. Lipids
   a. Lipid sources
      (1) Foods of plant and animal origin provide triglycerides.
      (2) Foods of animal origin provide most cholesterol.
   b. Lipid utilization
      (1) The liver and adipose tissue control triglyceride metabolism.
      (2) Linoleic acid, linolenic acid, and arachidonic acid are essential fatty acids.
      (3) Lipids supply energy and are used to build cell structures.
   c. Lipid requirements
      (1) The amounts and types of fats required for health are unknown.
      (2) Fat intake should not exceed 30% of a person's diet and must be sufficient to carry fat-soluble vitamins.
3. Proteins
   a. Protein sources
      (1) Meats, dairy products, cereals, and legumes provide most proteins.
      (2) Complete proteins contain adequate amounts of all the essential amino acids.
      (3) Incomplete proteins lack adequate amounts of one or more essential amino acids.
   b. Protein utilization
      Proteins serve as structural materials, function as enzymes, and provide energy.
   c. Protein requirements
      Proteins and amino acids must supply essential amino acids and nitrogen for the synthesis of nitrogen-containing molecules. Proteins should make up 10% of a person's diet.
4. Vitamins
   a. Fat-soluble vitamins
      (1) These include vitamins A, D, E, and K.
      (2) They are carried in lipids and are influenced by the same factors that affect lipid absorption.
      (3) They resist the effects of heat; thus, cooking or food processing does not destroy them.
   b. Water-soluble vitamins
      (1) This group includes the B vitamins and vitamin C.
      (2) B vitamins make up a group (the vitamin B complex) and oxidize carbohydrates, lipids, and proteins.
      (3) Cooking or processing food destroys some water-soluble vitamins.

5. Minerals
   a. Characteristics of minerals
      (1) Most minerals are in the bones and teeth.
      (2) Minerals are usually incorporated into organic molecules; some occur in inorganic compounds or as free ions.
      (3) They serve as structural materials, function in enzymes, and play vital roles in metabolic processes.
   b. Major minerals include calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium.
   c. Trace elements include iron, manganese, copper, iodine, cobalt, zinc, fluorine, selenium, and chromium.
6. Adequate diets
   a. An adequate diet provides sufficient energy and essential nutrients to support optimal growth, maintenance, and repair of tissues.
   b. Individual requirements vary so greatly that designing a diet that is adequate for everyone is not possible.
   c. Malnutrition is poor nutrition due to lack of food or failure to make the best use of available food.

REVIEW EXERCISES

1. List and describe the locations of the major parts of the alimentary canal. (p. 393)
2. List and describe the locations of the accessory organs of the digestive system. (p. 393)
3. Name the four layers of the wall of the alimentary canal. (p. 394)
4. Distinguish between mixing movements and propelling movements. (p. 395)
5. Define *peristalsis.* (p. 395)
6. Discuss the functions of the mouth and its parts. (p. 396)
7. Distinguish among the lingual, palatine, and pharyngeal tonsils. (p. 396)
8. Compare the primary and secondary teeth. (p. 397)
9. Describe the structure of a tooth. (p. 398)
10. Explain how a tooth is anchored in its socket. (p. 398)
11. List and describe the locations of the major salivary glands. (p. 399)
12. Explain how the secretions of the salivary glands differ. (p. 399)
13. Discuss the digestive functions of saliva. (p. 399)
14. Explain the function of the esophagus. (p. 401)
15. Describe the structure of the stomach. (p. 402)
16. List the enzymes in gastric juice, and explain the function of each enzyme. (p. 403)
17. Explain how gastric secretions are regulated. (p. 403)
18. Define *cholecystokinin.* (p. 403)
19. Describe the location of the pancreas and the pancreatic duct. (p. 404)
20. List and explain the function of each enzyme found in pancreatic juice. (p. 404)
21. Explain how pancreatic secretions are regulated. (p. 405)
22. Describe the structure of the liver. (p. 406)
23. List the major functions of the liver. (p. 408)
24. Describe the composition of bile. (p. 409)
25. Explain the functions of bile salts. (p. 410)
26. List and describe the locations of the parts of the small intestine. (p. 411)
27. Describe the functions of intestinal villi. (p. 413)
28. Name and explain the function of each enzyme of the intestinal mucosa. (p. 413)
29. Explain how the secretions of the small intestine are regulated. (p. 414)
30. Summarize how each major type of digestive product is absorbed. (p. 414)
31. List and describe the locations of the parts of the large intestine. (p. 417)
32. Explain the general functions of the large intestine. (p. 418)
33. Describe the defecation reflex. (p. 419)
34. List some common sources of carbohydrates. (p. 420)
35. Summarize the importance of cellulose in the diet. (p. 420)
36. Explain why a temporary drop in the blood glucose concentration may impair nervous system functioning. (p. 420)
37. List some common sources of lipids. (p. 421)
38. Describe the liver's role in fat metabolism. (p. 421)
39. List some common sources of protein. (p. 422)
40. Distinguish between essential and nonessential amino acids. (p. 423)
41. Distinguish between complete and incomplete proteins. (p. 423)
42. Discuss the general characteristics of fat-soluble vitamins. (p. 423)
43. List the fat-soluble vitamins, and describe the major functions of each. (p. 424)
44. List the water-soluble vitamins, and describe the major functions of each. (p. 425)
45. Discuss the general characteristics of the mineral nutrients. (p. 424)
46. List the major minerals, and describe the major functions of each. (p. 426)
47. List the trace elements, and describe the major functions of each. (p. 427)
48. Define *adequate diet.* (p. 426)
49. Define *malnutrition.* (p. 426)

CRITICAL THINKING

1. How does mechanical digestion enhance chemical digestion?
2. How can too little fat in the diet lead to a vitamin deficiency, even if a person takes vitamin supplements?
3. Why are vitamins required only in small amounts?
4. How can people consume vastly different diets, yet all obtain adequate nourishment?
5. How would removal of 95% of the stomach (subtotal gastrectomy) to treat severe ulcers or cancer affect the digestion and absorption of foods? How would the patient's eating habits have to be altered? Why?
6. Why may a person with an inflammation of the gallbladder (cholecystitis) also develop an inflammation of the pancreas (pancreatitis)?
7. Why does the blood sugar concentration of a person whose diet is relatively low in carbohydrates remain stable?
8. Examine the label information on the packages of a variety of dry breakfast cereals. Which types of cereals provide adequate sources of vitamins and minerals? Which major nutrients are lacking in these cereals?

WEB CONNECTIONS

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