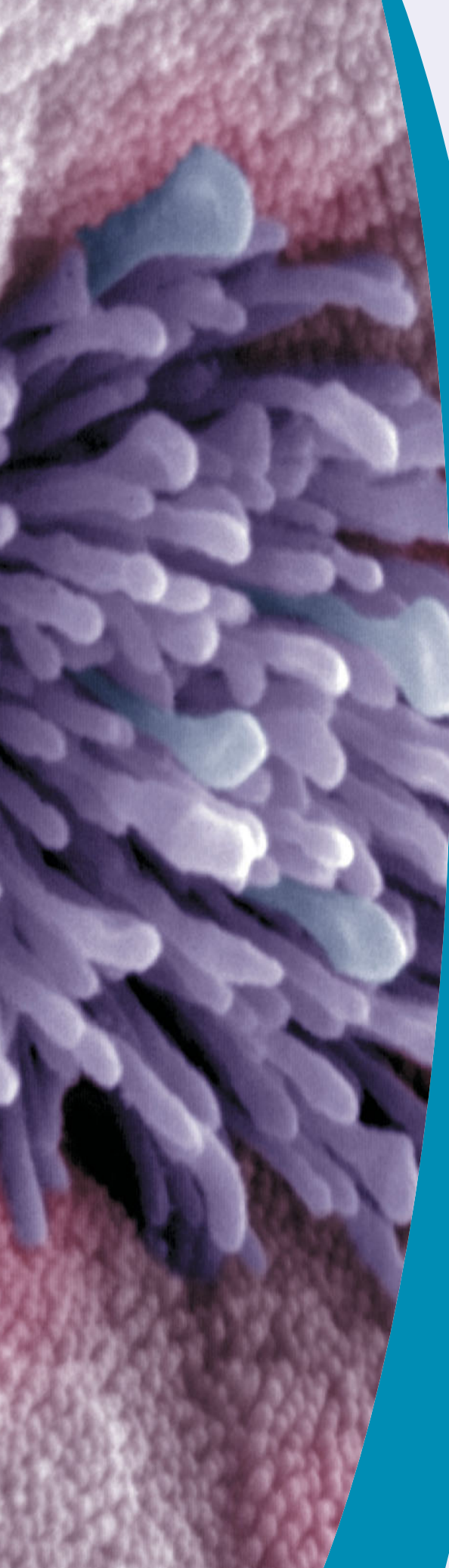


The Digestive System 23

The globet cell surface of the jejunum showing a region of microvilli and the surrounding absorptive cells (SEM). © Kessel & Kardon/Visuals Unlimited.

"You are what you eat": simplistic, but true! The nutrients used to build body structures and to enable body functions come from the food we ingest. Nutrition influences health status, mental and emotional state, and our overall sense of well-being. Proteins, complex carbohydrates, unsaturated fats, vitamins, minerals, and water are essential components of a healthy diet. The body system that converts the food we eat into units our body can absorb and use is the digestive system. This chapter explores structures of the body that take in food, break it into nutrient molecules, absorb these molecules into the circulatory system, and then eliminate the indigestible wastes.

OVERVIEW

- Describe the overall function of the digestive system, and differentiate the alimentary canal from the accessory digestive organs.
- List the major processes that occur during digestion.
- Draw the major subdivisions of the anterior abdominal wall.

The various organs of the digestive system **(Figure 23.1)** can be divided into two main groups: the *alimentary canal* (*aliment* = nourishment) and the *accessory digestive organs.*

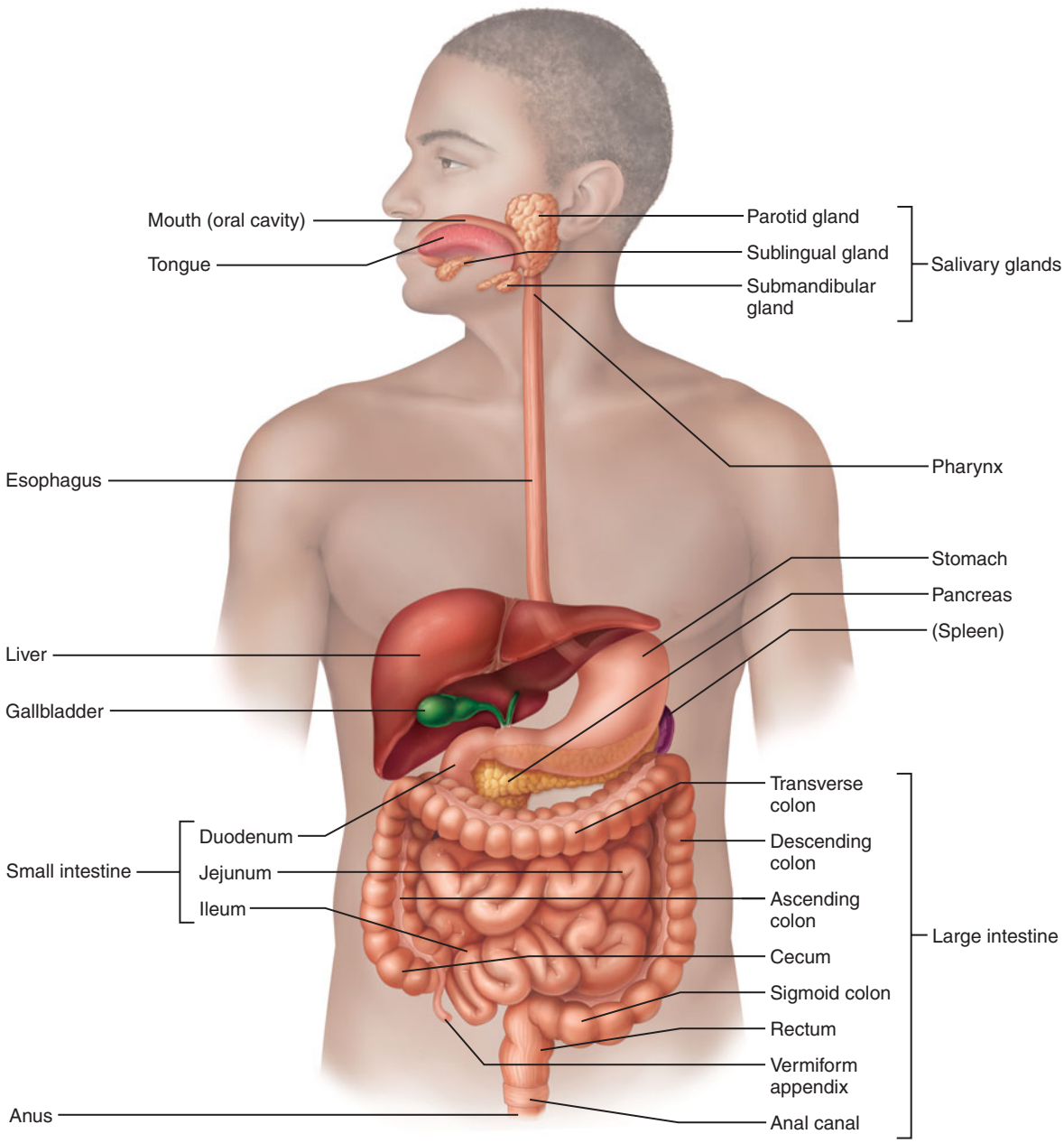


FIGURE 23.1 The alimentary canal and the accessory digestive organs. (See *A Brief Atlas of the Human Body,* Second Edition, Figures 64a and 66.)

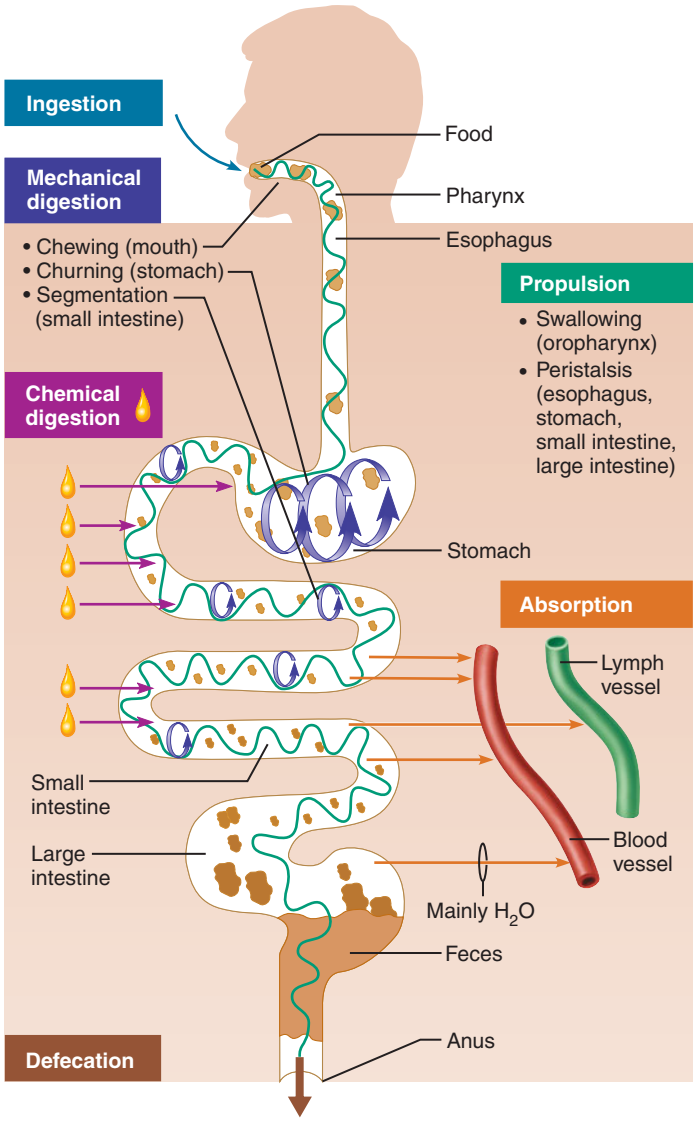
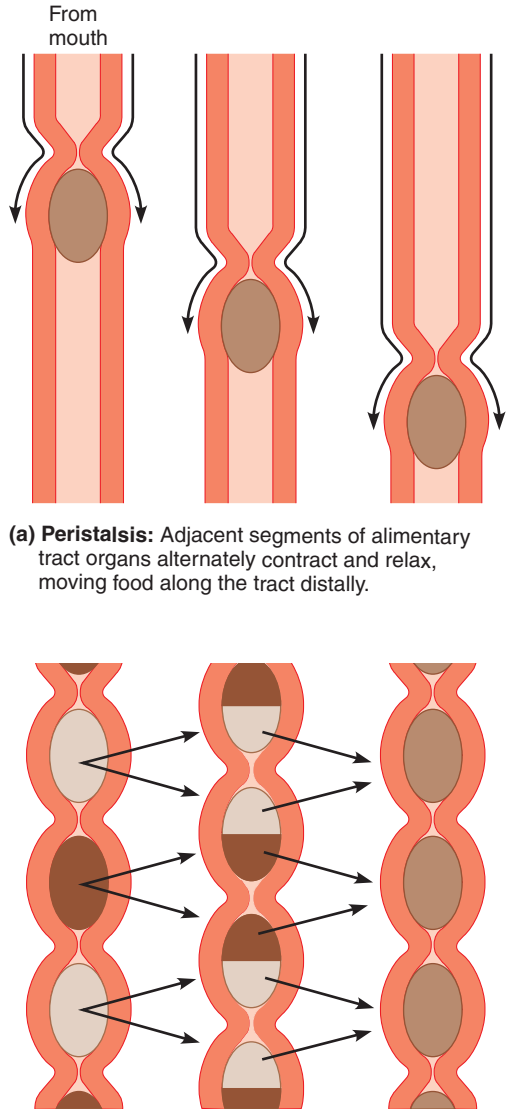


FIGURE 23.2 Activities of the gastrointestinal tract.



(a) Peristalsis: Adjacent segments of alimentary tract organs alternately contract and relax, moving food along the tract distally.

(b) Segmentation: Nonadjacent segments of alimentary tract organs alternately contract and relax, moving the food forward then backward. Food is mixed and slowly propelled.

FIGURE 23.3 Peristalsis and segmentation.

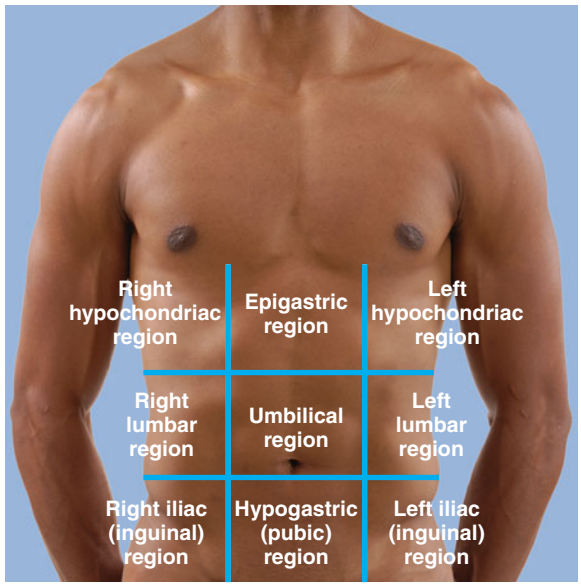
The **alimentary canal,** also called the *gastrointestinal (GI) tract,* is the muscular digestive tube that winds through the body, extending from the mouth to the anus. The organs of the alimentary canal are the *mouth, pharynx, esophagus, stomach, small intestine* (small bowel), and *large intestine* (large bowel), the last of which leads to the terminal opening, or *anus.* In a cadaver, the alimentary canal is about 9 m (30 feet) long, but in a living person it is considerably shorter because of its muscle tone. Food material in the alimentary canal is technically considered to be *outside* the body because the canal is open to the external environment at both ends.

The **accessory digestive organs** are the *teeth* and *tongue,* plus the *gallbladder* and various large digestive glands—the *salivary glands, liver,* and *pancreas*—that lie external to and are connected to the alimentary canal by ducts. The accessory digestive glands secrete saliva, bile, and digestive enzymes, all of which contribute to the breakdown of foodstuffs.

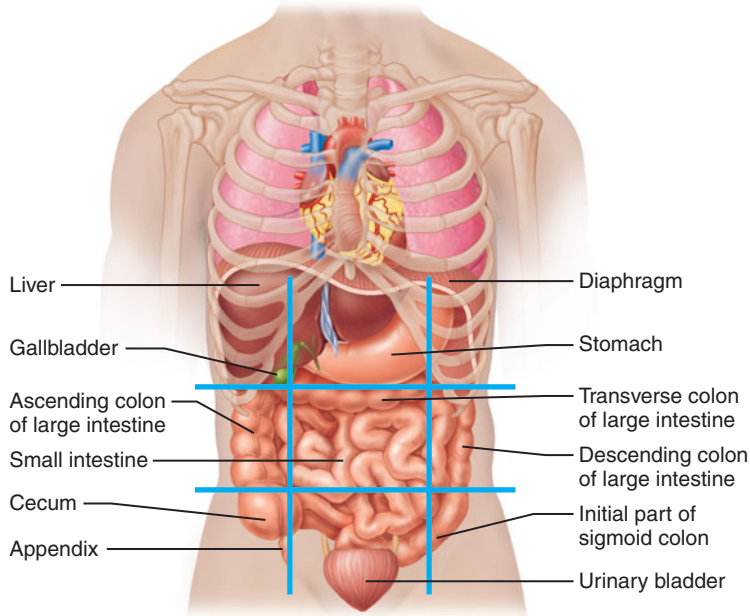
Digestive Processes

The organs of the digestive system perform the following six essential food-processing activities: ingestion, propulsion, mechanical digestion, chemical digestion, absorption, and defecation (Figure 23.2).

1. **Ingestion** is the taking of food into the mouth.
2. **Propulsion** is the movement of food through the alimentary canal. It includes swallowing, which is initiated voluntarily, and peristalsis, an involuntary process. **Peristalsis** (per″ĭ-stal′sis; "around contraction"), the major means of propulsion throughout the alimentary canal, involves alternate waves of contraction and relaxation of musculature in the organ walls (Figure 23.3a). Its net effect is to squeeze food from one organ to the next, but some mixing occurs as well.



(a) Nine regions delineated by four planes



(b) Anterior view of the nine regions showing the superficial organs

FIGURE 23.4 Divisions of the anterior abdominal wall. The parasagittal planes are the midclavicular lines; the transverse planes are the subcostal plane superiorly and the transtubercle plane inferiorly.

3. **Mechanical digestion** physically prepares food for chemical digestion by enzymes by breaking it into smaller pieces. Mechanical processes include chewing, the churning of food in the stomach, and **segmentation,** the rhythmic local constrictions of the intestine (Figure 23.3b). Segmentation mixes food with digestive juices and increases the efficiency of nutrient absorption by repeatedly moving different parts of the food mass over the intestinal wall.
4. **Chemical digestion** is a series of steps in which complex food molecules (carbohydrates, proteins, and lipids) are broken down to their chemical building blocks (simple sugars, amino acids, and fatty acids and glycerol). Glands in the gastrointestinal tract and in the accessory organs produce enzymes and other substances and secrete them into the lumen of the alimentary canal, where they carry out chemical digestion.
5. **Absorption** is the transport of digested end products from the lumen of the alimentary canal into the blood and lymphatic capillaries located in the wall of the canal.
6. **Defecation** is the elimination of indigestible substances from the body as feces.

Abdominal Regions

Most digestive organs are contained in the abdominopelvic cavity, the largest division of the ventral body cavity. As an aid to locating the positions of these abdominopelvic organs, clinicians typically divide the anterior abdominal wall into a number of regions.

In one scheme, four planes forming a pattern similar to a tic-tac-toe grid divide the abdominal wall into nine regions (Figure 23.4a and b). The two parasagittal planes are the *midclavicular lines*, which extend inferiorly from the midpoint of each clavicle. The superior transverse plane is in the *subcostal* ("below the ribs") *plane* and connects the inferior points of the costal margins, whereas the inferior transverse plane is in the *transtubercular plane* and connects the tubercles (widest points) of the iliac crests. (All of these bony landmarks can be felt on the body's surface.) The superior three of the nine regions are the **right** and **left hypochondriac regions** (hī″po-kon′dre-ak; "deep to the cartilage") and the central **epigastric region** (ep′ĭ-gas′trik; "superior to the belly"). The middle three regions are the **right** and **left lumbar regions** (or *lateral regions*) and the central **umbilical region.** The inferior three regions are the **right** and **left iliac regions,** or **inguinal regions,** and the central **hypogastric region** ("inferior to the belly") (also called the **pubic region**). Because many abdominal organs move, their positions within the abdominal grid are only approximate.

In a simpler scheme, a vertical and a horizontal line intersecting at the navel define four regions: the **right** and **left upper** and **lower quadrants** (see Figure 1.8c, p. 13).

BOWEL SOUNDS To acquire the valuable information conveyed by **bowel sounds,** clinicians place a stethoscope in each of the four quadrants of the anterior abdominal wall. Normal bowel sounds, which result from the movement of gas and intestinal contents by peristalsis, are high-pitched gurgles that occur every 5–15 seconds. Less frequent bowel sounds can indicate a halt in intestinal activity, whereas loud sounds may indicate increased activity associated with inflammation, diarrhea, or other bowel disorders.

The Peritoneal Cavity and Peritoneum

- Explain the location and function of the peritoneum and peritoneal cavity. Define mesentery.
- Differentiate between intraperitoneal and secondarily retroperitoneal digestive organs. Name the mesenteries associated with the intraperitoneal digestive organs.

The digestive organs in the abdominopelvic cavity all develop surrounded by *peritoneum* and the *peritoneal cavity* (Figure 23.5a). Recall from Chapter 1 (p. 12) that all divisions of the ventral body cavity contain slippery *serous membranes,* the most extensive of which is the **peritoneum** (per″ĭ-to-ne′um) of the abdominopelvic cavity. The **visceral peritoneum** covers the external surfaces of most digestive organs. The visceral peritoneum is continuous with the **parietal peritoneum,** which lines the body wall. Between the visceral and parietal peritonea is the **peritoneal cavity,** a slitlike potential space between the digestive organs and the abdominal body wall (Figure 23.5b). The peritoneal cavity contains a lubricating serous fluid that is secreted by the peritoneum and allows the digestive organs to glide easily along one another and along the body wall as they move during digestion. These structures are homologous to the parietal and visceral pleurae, and the pleural cavity surrounding the lungs.

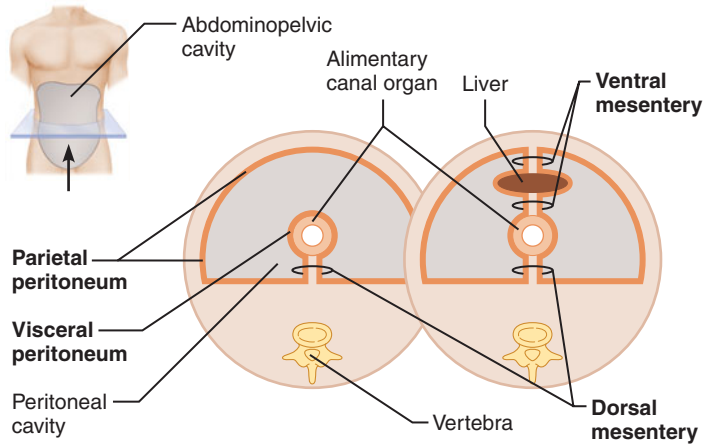
Mesenteries

A **mesentery** (mes′en-ter″e) is a double layer of peritoneum—a sheet of two serous membranes fused back to back—that extends to the digestive organs from the body wall (Figure 23.5a and Figure 23.6). Mesenteries hold the organs in place, are sites of fat storage, and provide a route by which circulatory vessels and nerves reach the organs in the peritoneal cavity.

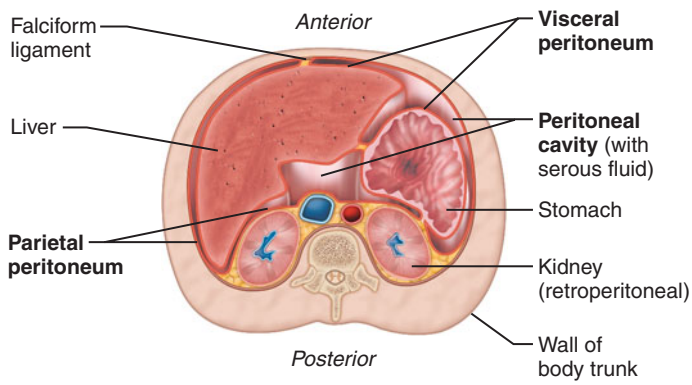
Most mesenteries are *dorsal* mesenteries, extending dorsally from the alimentary canal to the posterior abdominal wall. In the superior abdomen, however, a *ventral* mesentery extends ventrally from the stomach and liver to the anterior abdominal wall. As you read about the different parts of the dorsal and ventral mesenteries, note that some mesenteries are called "ligaments," even though these peritoneal sheets are not the same as the fibrous ligaments that interconnect bones.

The two ventral mesenteries are the falciform ligament and the lesser omentum. The **falciform ligament** (fal′sĭ-form; "sickle-shaped") binds the anterior aspect of the liver to the anterior abdominal wall and diaphragm (Figure 23.6a). The **lesser omentum** (o-men′tum; "fatty skin") runs from the liver to the lesser curvature of the stomach and the beginning of the duodenum (Figure 23.6b).

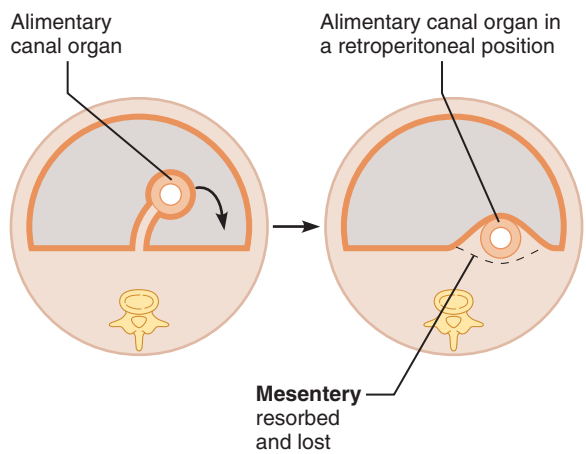
All remaining mesenteries are dorsal mesenteries. The **greater omentum** (Figure 23.6a and d) connects the greater curvature of the stomach to the posterior abdominal wall, but in a very roundabout way: Anteriorly, it is tremendously elongated and extends inferiorly to cover the transverse colon and coils of the small intestine like a butterfly net. The left border of the greater omentum wraps around the spleen as the *gastrosplenic ligament* and continues dorsally as the *splenorenal ligament*



(a) Schematic cross sections of abdominal cavity illustrating the peritonea and mesenteries

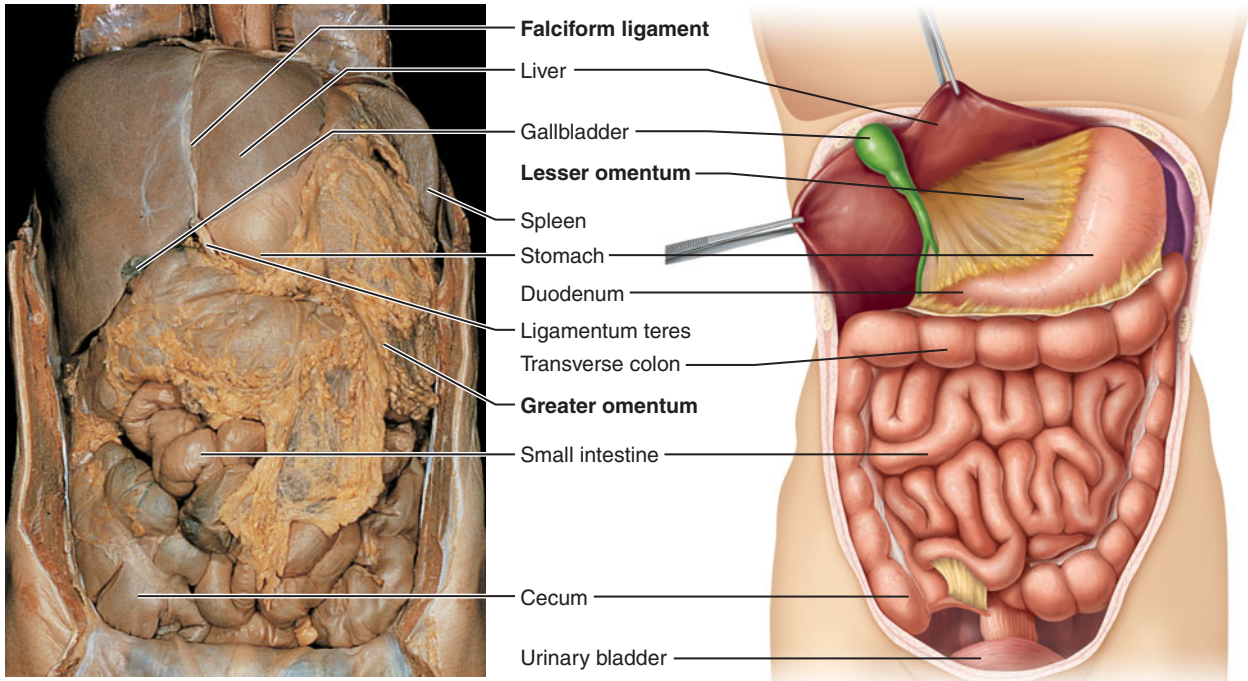


(b) Illustration of the peritonea in a cross section through the superior abdomen, inferior view



(c) Some organs lose their mesentery and become retroperitoneal during development.

FIGURE 23.5 The peritoneum and peritoneal cavity. Note that the peritoneal cavity is merely a slit between the organs and the body wall. (See also *A Brief Atlas of the Human Body,* Second Edition, Figure 64b.)



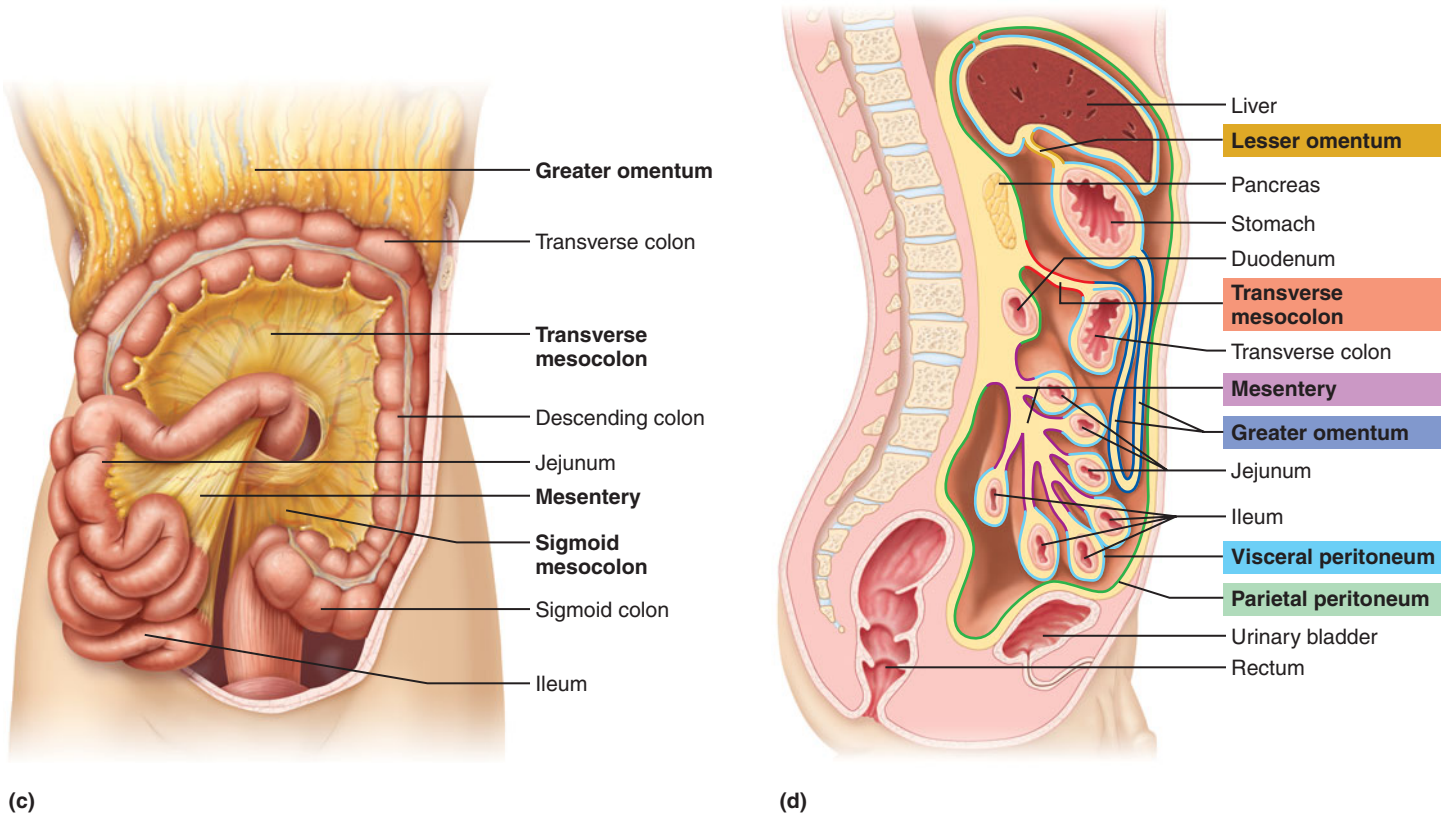


FIGURE 23.6 The mesenteries. (a) The greater omentum, a dorsal mesentery, is in its normal position covering the abdominal viscera. **(b)** The lesser omentum attaches the lesser curvature of the stomach to the liver (the liver is lifted out of the way). The greater omentum has been removed, exposing the small and large intestines. **(c)** The greater omentum and transverse colon have been reflected superiorly to reveal the mesentery to the small intestine, the transverse mesocolon, and the sigmoid mesocolon. **(d)** Sagittal section of the abdominopelvic cavity, of a male. (See *A Brief Atlas of the Human Body,* Second Edition, Figures 64, 66, and 67.)

TABLE 23.1 Summary of Intraperitoneal and Secondarily Retroperitoneal Digestive Organs in the Abdomen and Pelvis

Intraperitoneal Organs (and Their Mesenteries)	Secondarily Retroperitoneal Organs (Lack Mesenteries)
Liver (falciform ligament and lesser omentum)	Duodenum (almost all of it)
Stomach (greater and lesser omentum)	Ascending colon
Ileum and jejunum (mesentery proper)	Descending colon
Transverse colon (transverse mesocolon)	Rectum
Sigmoid colon (sigmoid mesocolon)	Pancreas

(extending between the spleen and the left kidney) to the posterior body wall. The greater omentum contains a great deal of fat and also has a remarkable ability to limit the spread of infections within the peritoneal cavity; for example, it can wrap around and enclose an inflamed appendix. The long coils of the jejunum and ileum are supported by the **mesentery** (Figure 23.6c and d). This sheet fans inferiorly from the posterior abdominal wall like long, pleated curtains. The transverse colon is held to the posterior abdominal wall by the **transverse mesocolon** (mez″o-ko′lon; "mesentery of the colon"), a nearly horizontal sheet that is fused to the underside of the greater omentum, so that it can be viewed only inferiorly (Figure 23.6c). The **sigmoid mesocolon** (Figure 23.6c) is the mesentery that connects the sigmoid colon to the posterior pelvic wall.

Not all digestive organs have a mesentery or are surrounded by the peritoneal cavity on all sides. During embryonic development, some organs (some parts of the intestine, for example) have a mesentery at first but, because of the complex rotations of the digestive tract during development, they end up against the posterior abdominal wall. These organs fuse to the dorsal abdominal wall (Figure 23.5c), in the process losing their mesentery and lodging behind the peritoneum. Such organs are called **secondarily retroperitoneal** (*retro* = behind) because they are initially formed within the peritoneum but are located behind the peritoneum once they are fully developed. By contrast, the digestive organs that keep their mesentery and remain surrounded by the peritoneal cavity are called **intraperitoneal** or **peritoneal** organs. The stomach is an example of such an organ. In Figure 23.6d you can clearly see the intraperitoneal organs and their mesenteries surrounded by the peritoneal cavity, and the secondarily retroperitoneal organs (the pancreas, duodenum, and rectum) behind the peritoneum. The intraperitoneal organs and their mesenteries and the secondarily retroperitoneal organs are listed in Table 23.1.

PERITONITIS Inflammation and infection of the peritoneum is called **peritonitis.** It can arise from a piercing wound to the abdomen, from a perforating ulcer that leaks stomach juices into the peritoneal cavity, or from poor sterile technique during abdominal surgery. Most commonly, however, it results from a burst appendix that leaks feces into the peritoneal cavity. Peritonitis that is widespread within the peritoneal cavity is a dangerous condition that can lead to death. Treatment involves rinsing the peritoneum with large amounts of sterile saline solution and giving antibiotics intravenously.

check your understanding

1. Where in the alimentary canal does propulsion occur?
2. Differentiate the abdominal cavity from the peritoneal cavity. Which digestive system organs are located in the abdominal cavity but are not intraperitoneal?
3. Identify all the mesenteries that connect to each organ listed: (a) liver, (b) stomach, (c) sigmoid colon. For each, state whether it is a dorsal mesentery or a ventral mesentery.
4. Injury to the spleen or liver can cause extensive internal bleeding. Where would blood collect from such an injury?

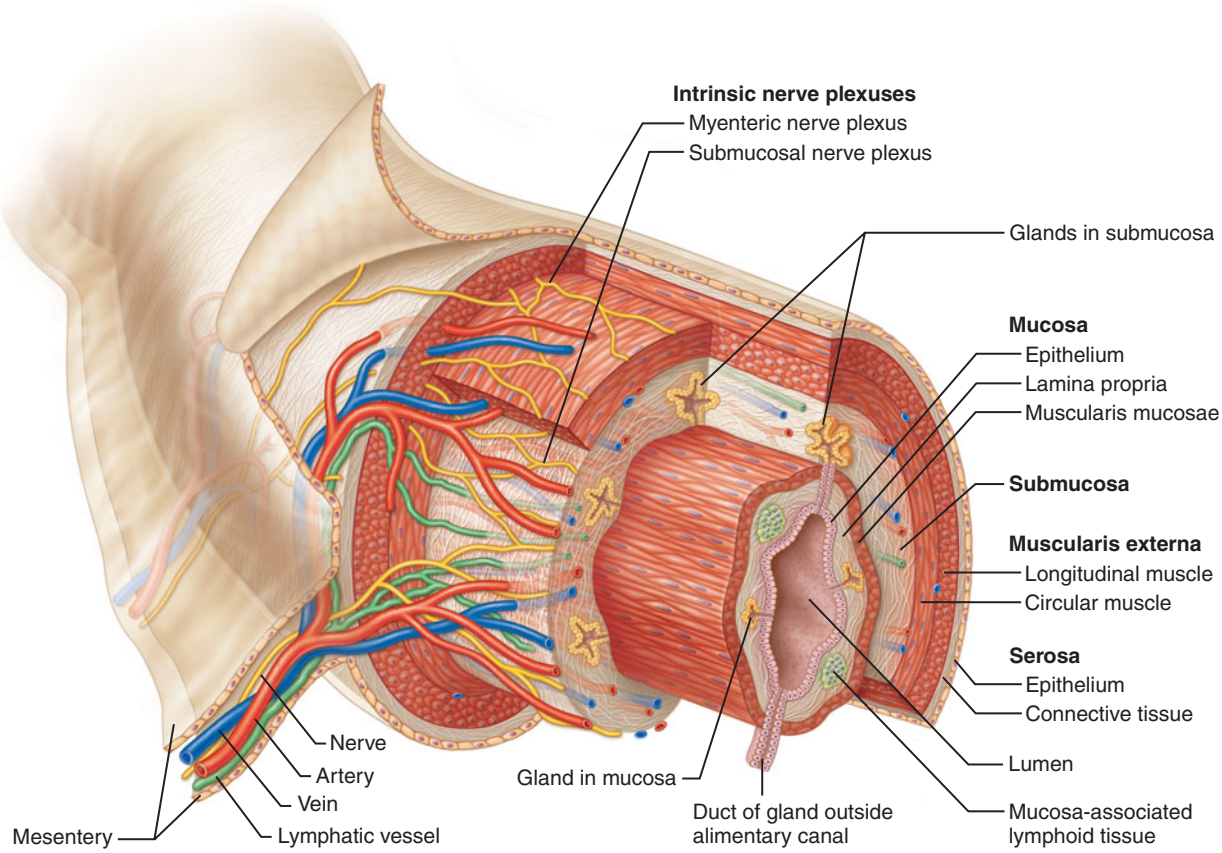
For answers, see Appendix B.

ANATOMY OF THE ALIMENTARY CANAL

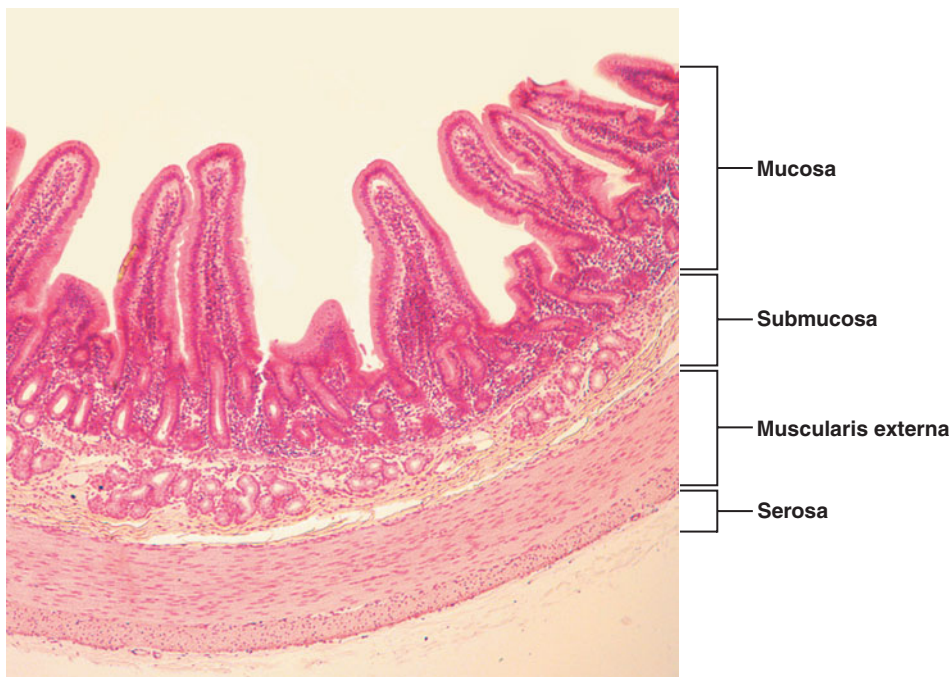
Histology

- Describe the four layers of the wall of the alimentary canal.
- Describe the structure and appearance of smooth muscle fibers, and describe how smooth muscle cells are joined together to form a sheetlike tissue.
- Describe the innervation and activity of smooth muscle tissue, and discuss the different stimuli that can initiate contraction of this muscle tissue.

The walls of the alimentary canal, from the esophagus to the anal canal, have the same four tissue layers (Figure 23.7). In



(a) Longitudinal and cross-sectional views through the small intestine



(b) Light micrograph cross section through the small intestine (30×)

FIGURE 23.7 Histological layers of the alimentary canal. The four basic layers in the wall are the mucosa, submucosa, muscularis externa, and serosa.

fact, most such layers occur in the hollow organs of the respiratory, urinary, and reproductive systems as well. From the lumen outward, these layers are the *mucosa, submucosa, muscularis externa,* and *serosa.*

The Mucosa

The innermost layer is the **mucosa,** or *mucous membrane.* More complex than other mucous membranes in the body, the typical digestive mucosa contains three sublayers: (1) a lining epithelium, (2) a lamina propria, and (3) a muscularis mucosae.

The lining **epithelium** abuts the lumen of the alimentary canal and performs many functions related to digestion, such as absorbing nutrients and secreting mucus. This epithelium is continuous with the ducts and secretory cells of the various digestive glands, most of which lie fully within the wall and are called *intrinsic glands.*

The **lamina propria** is a loose areolar or reticular connective tissue whose capillaries nourish the lining epithelium and absorb digested nutrients. The lamina propria contains most of the mucosa-associated lymphoid tissue (MALT), which defends against invasion by bacteria and other microorganisms in the alimentary canal.

External to the lamina propria is the **muscularis mucosae,** a thin layer of smooth muscle that produces local movements of the mucosa. For example, the twitching of this muscle layer dislodges sharp food particles that become embedded in the mucosa.

The Submucosa

Just external to the mucosa is the **submucosa,** a layer of connective tissue containing major blood and lymphatic vessels and nerve fibers. Its rich vascular network sends branches to all other layers of the wall. Its connective tissue is a type intermediate between loose areolar and dense irregular—a "moderately dense" connective tissue. The many elastic fibers in the submucosa enable the alimentary canal to return to its shape after food material passes through it.

The Muscularis Externa

External to the submucosa is the **muscularis externa,** also simply called the *muscularis.* Throughout most of the alimentary canal, this tunic consists of two layers of smooth muscle, an inner *circular layer* whose fibers orient around the circumference of the canal, and an outer *longitudinal layer* whose fibers orient along the length of the canal. Functionally, the circular layer squeezes the gut tube, and the longitudinal layer shortens it. Together, these layers are responsible for peristalsis and segmentation. In some places, the circular layer thickens to form sphincters that act as valves to prevent the backflow of food from one organ to the next.

The histological structure of smooth muscle, the mechanism of its contraction, and its innervation will be discussed in detail shortly.

The Serosa

The **serosa,** which is the visceral peritoneum, is the outermost layer of the intraperitoneal organs of the alimentary canal. Like all serous membranes (see p. 12), it is formed of a simple squamous epithelium (mesothelium) underlain by a thin layer of areolar connective tissue.

Parts of the alimentary canal that are not associated with the peritoneal cavity lack a serosa and have an *adventitia,* an ordinary fibrous connective tissue, as their outer layer. For example, the esophagus in the thorax has an adventitia that binds it to surrounding structures. Secondarily retroperitoneal organs (discussed on p. 671) have both a serosa and an adventitia—a serosa on the anterior side facing the peritoneal cavity and an adventitia on the posterior side embedded in the posterior abdominal wall.

Smooth Muscle

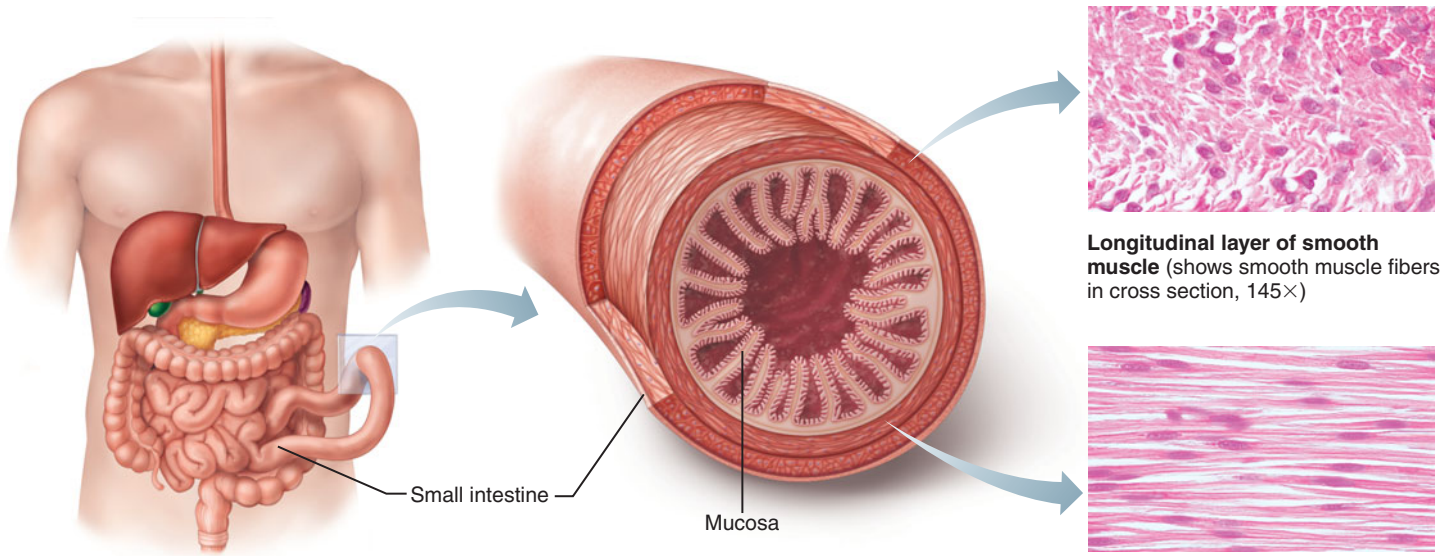
Most smooth muscle of the body is found in the walls of visceral organs such as the urinary bladder, uterus, and intestines **(Figure 23.8a** and **b)**. More specifically, smooth muscle has six major locations: the iris of the eye, and in the walls of the circulatory vessels, respiratory tubes, digestive tubes, urinary organs, and reproductive organs.

Smooth muscle cells are called fibers because of their elongated shape. Each fiber tapers at its ends and has one centrally located nucleus (Figure 23.8b). Typically, these fibers have a diameter of 3–8 μm and a length ranging from 15 to 200 μm. They are separated from one another by a delicate connective tissue, the endomysium. In the walls of hollow viscera, the fibers are grouped into *sheets* of smooth muscle tissue. Most often two sheets are present, with their fibers oriented at right angles to each other. In the more externally located **longitudinal layer,** the muscle fibers run parallel to the long axis of the organ; in the deeper **circular layer,** the fibers run around the circumference of the organ. The circular layer constricts the hollow organ, and the longitudinal layer shortens the organ's length and enlarges its lumen. These muscle layers generate the alternate waves of contraction and relaxation that propel substances through the organ by peristalsis.

Smooth muscle fibers have no striations when viewed by light microscopy, and electron microscopy confirms that there are no sarcomeres. Interdigitating thick and thin filaments, however, are present. These contractile myofilaments lie nearly parallel to the long axis of the fiber, but at a slightly oblique angle, and fill much of the cell volume.

Myofilaments in smooth muscle operate by interacting with elements of the cytoskeleton **(Figure 23.9a)**. Tension-resisting *intermediate filaments* extend through the cell in a lattice-like arrangement. Along these intermediate filaments lie **dense bodies** at regular intervals that anchor the thin filaments. These dense bodies correspond to the Z discs of skeletal muscle. Through this anchoring attachment, the sliding myofilaments shorten the muscle cell by pulling on the cytoskeleton (Figure 23.9b). The dense bodies attached to the sarcolemma also bind the muscle cell to the endomysium outside the cell and to adjacent cells, transmitting the contractile force to the surrounding connective tissue. This contributes to the synchronous contraction of most smooth muscle.

As in skeletal and cardiac muscle, the entry of Ca^{2+} into the sarcoplasm stimulates the smooth muscle fiber to contract. Some of these calcium ions enter from the extracellular



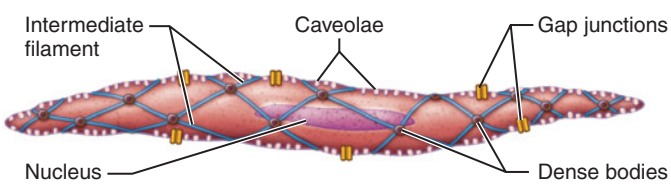
(a) Location and plane of section shown in (b)

(b) Cross section of the intestine showing the smooth muscle layers (one circular and the other longitudinal) running at right angles to each other

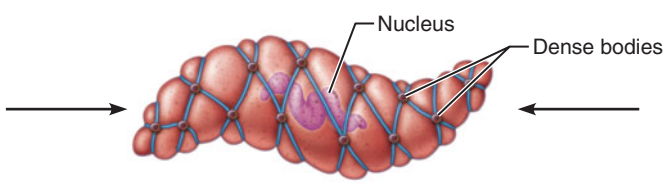
FIGURE 23.8 Arrangement of smooth muscle in the walls of hollow organs.

fluid through tiny spherical infoldings of the sarcolemma, called *caveolae* (Figure 23.9a). These invaginations enclose bits of extracellular fluid, allowing high concentrations of Ca^{2+} to be sequestered close to the surface membrane. Ca^{2+} ions are also stored and released by an intracellular sarcoplasmic reticulum (not illustrated).

The contraction of smooth muscle is slow, sustained, and resistant to fatigue. Whereas smooth muscle takes 30 times longer to contract and relax than does skeletal muscle, it can maintain its contractile force for a long time without tiring. This is a valuable feature because the smooth muscle in the walls of the small arteries and visceral organs must sustain a moderate degree of contraction day in and day out without fatiguing. Because smooth muscle's energy requirements are low, mitochondria are not abundant in its fibers.



(a) Relaxed smooth muscle fiber (note that adjacent fibers are connected by gap junctions)



(b) Contracted smooth muscle fiber

FIGURE 23.9 Cytoskeletal elements involved in the contraction of smooth muscle.

Innervation of Smooth Muscle and Glands

We do not have direct voluntary control over the contraction of our smooth muscle, because it is innervated by the autonomic nervous system. In general, *only a few smooth muscle fibers in each muscle sheet are innervated, and the impulse spreads through gap junctions between adjacent fibers.* Through such intercellular communication, the whole sheet contracts as a single unit. This arrangement is called *single-unit innervation*. There are exceptions: In the iris of the eye and the arrector pili muscles of the skin, every smooth muscle fiber is innervated individually, an arrangement called *multiunit innervation*. In addition, contraction of smooth muscle does not always require a nervous signal; contraction can be stimulated by stretching the muscle fibers or by hormones. The contraction of the muscular wall of the uterus during labor and delivery is an excellent example of both stretching and hormonal stimuli causing the contraction of smooth muscle.

The contacts between visceral motor neurons and the visceral effectors (smooth muscle, cardiac muscle, and glands) are much simpler than the elaborate neuromuscular junctions present in skeletal muscle. Near the smooth muscle or gland cells it innervates, a visceral motor axon swells into a row of knobs (varicosities) resembling beads on a necklace **(Figure 23.10)**. These varicosities are the presynaptic terminals, which contain synaptic vesicles filled with neurotransmitter. Some of these axon terminals form shallow indentations on the membrane of the effector cell, but many remain a considerable distance from any cell. Because it takes time for neurotransmitters to diffuse across these wide synaptic clefts,

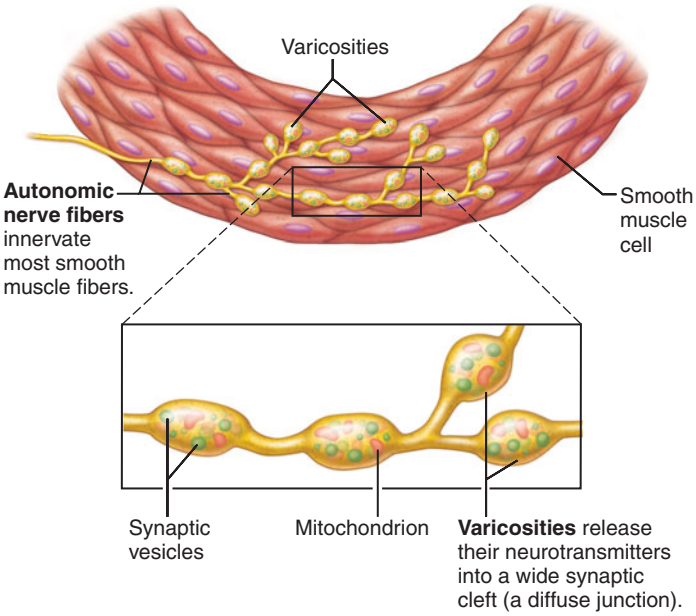


FIGURE 23.10 Innervation of smooth muscle.

visceral motor responses tend to be slower than somatic motor reflexes. Refer to Table 10.2 on pp. 254–255 for a comparison of skeletal, cardiac, and smooth muscle tissue.

Nerve Plexuses Visceral nerve plexuses also occur within the wall of the alimentary canal (see Figure 23.7). The **myenteric nerve plexus** (mi-en-ter′ik; "intestinal muscle") is in the muscularis externa between the circular and longitudinal layers, where it innervates the muscularis externa to control peristalsis and segmentation. The **submucosal nerve plexus** lies within the submucosa, extends inward, and signals the glands in the mucosa to secrete and the muscularis mucosae to contract. Both plexuses contain parasympathetic and sympathetic motor components and visceral sensory fibers, all of which link the alimentary canal to the brain and bring digestion under the influence of the central nervous system.

Despite this external influence from the brain, digestive activity is largely automatic, controlled by an internal nervous system of *enteric neurons* (*enteric* = gut) in both the myenteric and submucosal plexuses. Within the wall of the alimentary canal, enteric neurons form independent reflex arcs of sensory, intrinsic, and motor neurons that control the normal movements of peristalsis and segmentation, as well as glandular secretion by the mucosa. The classical autonomic nervous system (parasympathetic and sympathetic) merely speeds or slows this inherent activity and allows the central nervous system to influence it. Even though few people seem to know that the gut has its own **enteric nervous system,** this system is not trivial: It consists of 100 million neurons, as many as in the entire spinal cord!

The sympathetic and parasympathetic inputs to the digestive organs are postganglionic sympathetic fibers, preganglionic parasympathetic fibers, and postganglionic parasympathetic neurons (see Chapter 15). Recall that parasympathetic input stimulates digestive functions, whereas sympathetic input inhibits digestion.

check your understanding

5. Name the three sublayers of the mucosa. Which sublayer forms the instrinsic glands that produce digestive secretions?
6. Name the tissue layer of the alimentary canal that is responsible for peristalsis and segmentation.
7. Contrast smooth muscle to skeletal muscle, noting differences in cell shape, number and location of nuclei in each cell, the presence or absence of striations, innervation, the stimuli for contraction, and fatigue resistance.

For answers, see Appendix B.

The Mouth and Associated Organs

➤ Describe the gross and microscopic anatomy and the basic functions of the mouth, teeth, salivary glands, and pharynx.

The Mouth

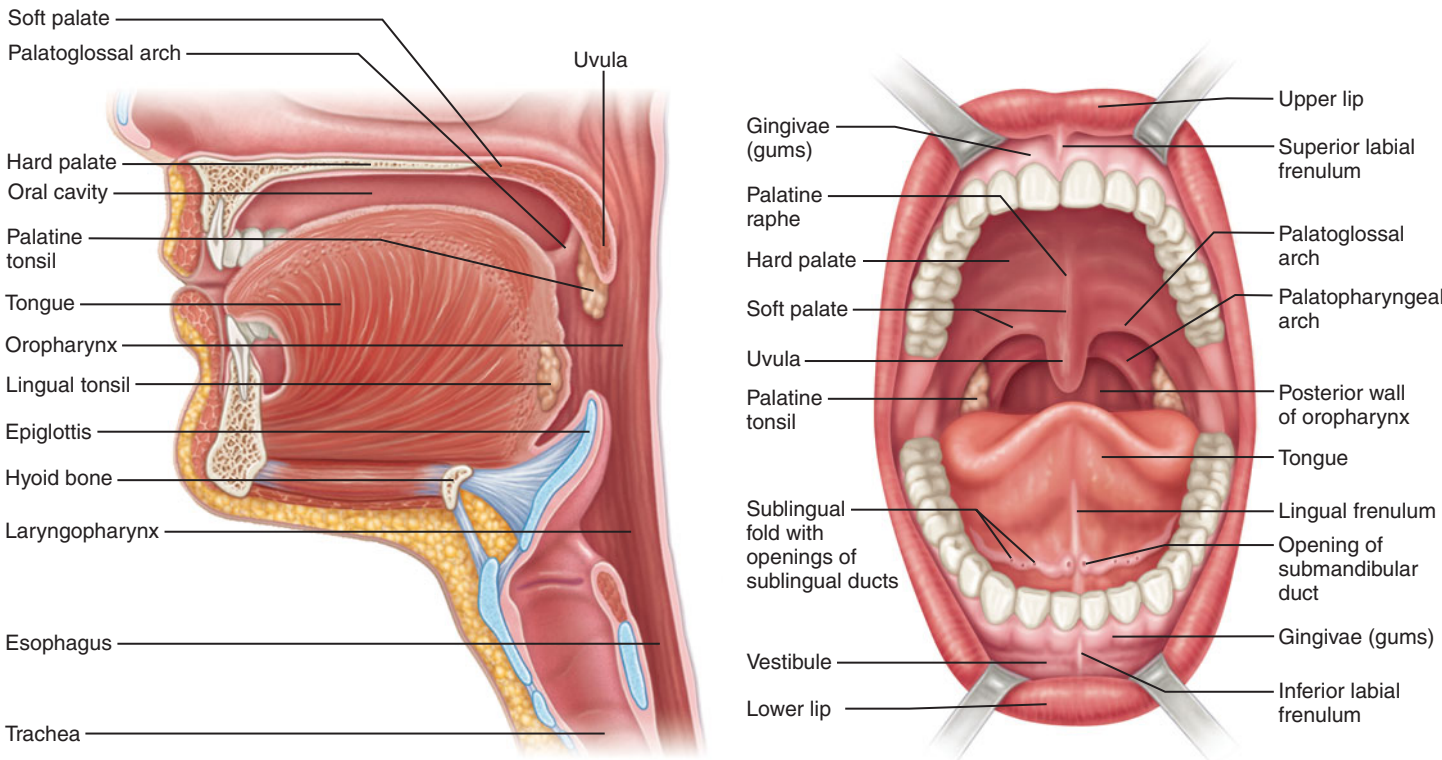
Food enters the alimentary canal through the mouth, where it is chewed, manipulated by the tongue, and moistened with saliva. The **mouth,** or **oral cavity** (Figure 23.11), is a mucosa-lined cavity whose boundaries are the lips anteriorly, the cheeks laterally, the palate superiorly, and the tongue inferiorly. Its anterior opening is the **oral orifice.** Posteriorly, the mouth borders the fauces of the oropharynx (see p. 641).

The mouth is divided into the vestibule and the oral cavity proper. The **vestibule** (ves′tĭ-būl; "porch") is the slit between the teeth and the cheeks (or lips). When you brush the outer surface of your teeth, your toothbrush is in the vestibule. The **oral cavity proper** is the region of the mouth that lies internal to the teeth.

Histology of the Mouth The walls of the oral cavity consist of just a few layers of tissue: an internal mucosa made of an epithelium and lamina propria only, a thin submucosa in some areas, and an external layer of muscle or bone. The lining of the mouth, a thick stratified squamous epithelium, protects it from abrasion by sharp pieces of food during chewing. On the tongue, palate, lips, and gums this epithelium may show slight keratinization, which provides extra protection against abrasion.

The Lips and Cheeks The **lips** (or **labia**) and the **cheeks,** which help keep food inside the mouth during chewing, are composed of a core of skeletal muscle covered by skin. Whereas the cheeks are formed largely by the buccinator muscles, the orbicularis oris muscle (p. 279) forms the bulk of the lips.

The lips are thick flaps extending from the inferior boundary of the nose to the superior boundary of the chin. The region of the lip where one applies lipstick or lands a kiss is called the *transition part,* a zone where the highly keratinized skin meets the oral mucosa. This region is poorly keratinized and translucent, so it derives its reddish color from blood in the underlying capillaries. Because the transition part lacks sweat and sebaceous glands, it must be moistened



(a) Sagittal section of the oral cavity and pharynx

(b) Anterior view

FIGURE 23.11 Anatomy of the mouth.

with saliva periodically to prevent drying and cracking. The **labial frenulum** (fren′u-lum; "little bridle of the lip") is a median fold that connects the internal aspect of each lip to the gum (Figure 23.11b).

The Palate The **palate,** which forms the roof of the mouth, has two distinct parts: the *hard palate* anteriorly and the *soft palate* posteriorly (Figure 23.11). The bony hard palate forms a rigid surface against which the tongue forces food during chewing. The muscular soft palate is a mobile flap that rises to close off the nasopharynx during swallowing. (To demonstrate this action, try to breathe and swallow at the same time.) The separation of the nasal and oral cavities by the palate is characteristic of all mammals and is essential for producing the suction necessary for suckling in infants (see discussion of cleft palate in Chapter 7, p. 176). Dipping inferiorly from the free edge of the soft palate is the fingerlike uvula. Laterally, the soft palate is anchored to the tongue by the **palatoglossal arches** and to the wall of the oropharynx by the **palatopharyngeal arches** (Figure 23.11b). These two folds form the boundaries of the fauces, the arched area of the oropharynx that contains the palatine tonsils.

The Tongue

The **tongue,** which occupies the floor of the mouth (Figure 23.11), is predominantly a muscle constructed of interlacing fascicles of skeletal muscle fibers. During chewing, the tongue grips food and constantly repositions it between the teeth. Tongue movements also mix the food with saliva and form it into a compact mass called a *bolus* (bo′lus; "lump"); then, during swallowing, the tongue moves posteriorly to push the bolus into the pharynx. In speech, the tongue helps to form some consonants (*k, d, t,* and *l,* for example). Finally, it houses most of the taste buds.

The tongue has both intrinsic and extrinsic muscle fibers. The *intrinsic muscles,* which are confined within the tongue and are not attached to bone, have fibers that run in several different planes. These intrinsic muscles change the shape of the tongue, for example rolling the tongue, but do not change its position. The *extrinsic muscles* extend to the tongue from bones of the skull and the hyoid bone (see pp. 280–281). These extrinsic muscles alter the position of the tongue: They protrude it, retract it, and move it laterally. The tongue is divided by a median septum of connective tissue, and both halves contain identical groups of muscles.

A fold of mucosa on the undersurface of the tongue, the **lingual frenulum** (see Figure 23.11), secures the tongue to the floor of the mouth and limits its posterior movements. Individuals in which the lingual frenulum is abnormally short or extends exceptionally far anteriorly are said to be "tongue-tied," and their speech is distorted because movement of the tongue is restricted. This congenital condition, called **ankyloglossia** (ang″kĭ-lo-glos′e-ah; "fused tongue"), is corrected surgically by snipping the frenulum.

The dorsal surface of the tongue is covered with three major types of peglike projections of the mucosa: the filiform, fungiform, and vallate *papillae.* The terms *papillae* and *taste buds* are not synonymous; the fungiform and vallate papillae *contain* the taste buds.

The conical, pointed, and keratinized **filiform papillae** (fil′ĭ-form; "thread-shaped") roughen the tongue, enabling it

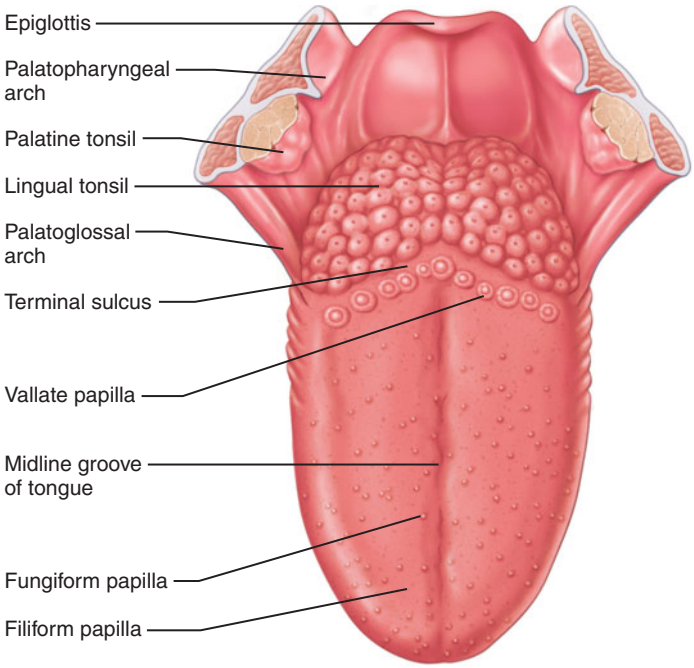


FIGURE 23.12 The dorsal surface of the tongue. (See *A Brief Atlas of the Human Body*, Second Edition, Figure 62.)

to grasp and manipulate food during chewing. These smallest and most numerous papillae line up in parallel rows. They give the tongue's surface its whitish appearance.

The **fungiform papillae** (fun′jĭ-form; "mushroom-shaped"), which resemble tiny mushrooms, have a vascular core that gives them a red color. Although less abundant than filiform papillae, they are scattered widely over the tongue surface. Taste buds occur in the epithelium on the *tops* of these papillae.

Ten to twelve large **vallate papillae** (val′āt; "wall") line up in a V-shaped row bordering the posterior third of the tongue and directly anterior to a groove called the **terminal sulcus,** which marks the border between the mouth and pharynx. Each vallate papilla is surrounded by a circular ridge, from which it is separated by a deep furrow. Taste buds occupy the epithelium on the *sides* of these papillae (see Figure 16.1, p. 483).

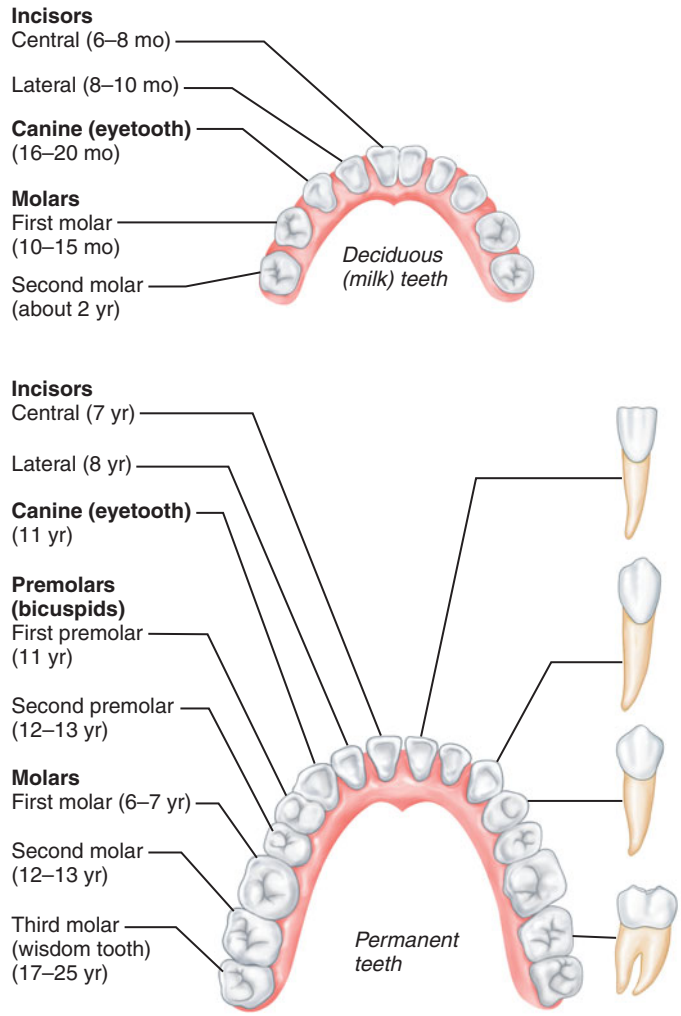
The posterior third of the tongue, which lies in the oropharynx, not in the mouth, is covered not with papillae but with the bumpy *lingual tonsil* **(Figure 23.12)**.

The Teeth

The **teeth** lie in sockets (alveoli) in the gum-covered margins of the mandible and maxilla. We masticate, or chew, by raising and lowering the mandible and by moving it from side to side while using the tongue to position food between the teeth. In the process, the teeth tear and grind the food, breaking it into smaller fragments.

Dentition and the Dental Formula

During their lifetime, humans have two sets of teeth, or *dentitions.* By age 21, the primary dentition, called the **deciduous teeth** (de-sid′-ū-us; "falling off"), has been replaced by the permanent dentition **(Figure 23.13)**.



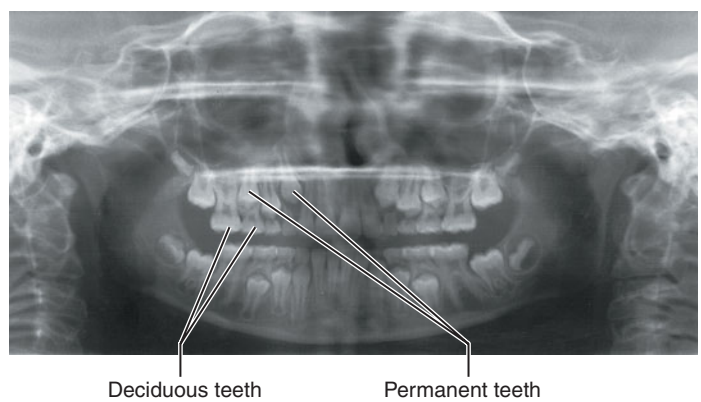


FIGURE 23.13 Human dentition. (a) Deciduous and permanent teeth of the lower jaw. Approximate ages at which the teeth erupt are shown in parentheses. Shapes of the individual teeth are shown at right. **(b)** X-ray image of the mouth of a 7-year-old child.

At about 6 months after birth, the lower central incisors become the first of the deciduous teeth to appear. Additional pairs of teeth erupt at varying intervals until all 20 deciduous teeth have emerged, by about 2 years of age. As the deep-lying **permanent teeth** enlarge and develop, the roots of the deciduous teeth are resorbed until these teeth loosen and fall out, typically between the ages of 6 and 12 years (Figure 23.13b). Generally, by the end of adolescence, all permanent teeth have erupted except for the third molars (also called *wisdom teeth*), which emerge between the ages of 17 and 25 years. There are 32 permanent teeth in a full set, but in some people the wisdom teeth are either completely absent or fail to erupt.

IMPACTED TOOTH Instead of emerging normally, a tooth may remain embedded deep in the jawbone and push on the roots of the other teeth. The **impacted tooth** causes pressure and pain and must be removed by a dentist or oral surgeon. Wisdom teeth are the most commonly impacted teeth.

Teeth are classified according to their shape and function as incisors, canines, premolars, or molars (Figure 23.13). The chisel-shaped **incisors** are adapted for nipping off pieces of food, and the cone-shaped **canines** (cuspids, eyeteeth) tear and pierce. The **premolars** (bicuspids) and **molars** have broad crowns with rounded *cusps* (surface bumps) for grinding food. The molars (literally, "millstones") have four or five cusps and are the best grinders. During chewing, the upper and lower molars lock repeatedly together, the cusps of the uppers fitting into the valleys in the lowers, and vice versa. This action generates tremendous crushing forces.

The *dental formula* is a shorthand way of indicating the numbers and relative positions of the different classes of teeth in the mouth. This formula is written as a ratio of uppers over lowers, for just half of the mouth (because right and left halves are the same). The total number of teeth is calculated by multiplying the dental formula by 2. The formula for the permanent dentition (two incisors, one canine, two premolars, and three molars) is written as follows:

$$\frac{2\text{I, } 1\text{C, } 2\text{P, } 3\text{M}}{2\text{I, } 1\text{C, } 2\text{P, } 3\text{M}} \times 2 \text{ (equals 32 teeth)}$$

The dental formula for the deciduous teeth is as follows:

$$\frac{2\text{I, } 1\text{C, } 2\text{M}}{2\text{I, } 1\text{C, } 2\text{M}} \times 2 \text{ (equals 20 teeth)}$$

The upper teeth are innervated by the superior alveolar nerves, branches of the maxillary division of the trigeminal nerve (cranial nerve V). The lower teeth are innervated by the inferior alveolar nerves, branches of the mandibular division of the trigeminal nerve. The arterial supply for the teeth comes via the superior and inferior alveolar arteries, which are branches of the maxillary artery from the external carotid.

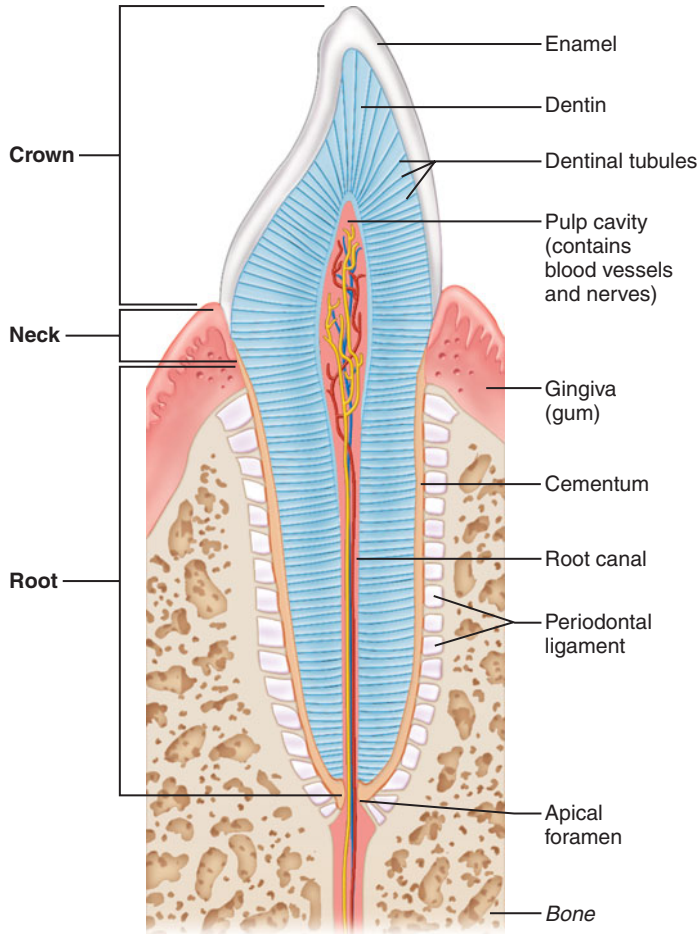


FIGURE 23.14 Longitudinal section of a canine tooth within its bony alveolus (socket).

Tooth Structure Each tooth has two main regions, the exposed **crown** and the **root(s)** in the socket. These regions meet at the **neck** near the gum line (Figure 23.14). The surface of the crown, which bears the forces of chewing, is covered by a layer of **enamel,** the hardest substance in the body, that is 0.96–1.6 mm thick. Enamel lacks cells and vessels, and 99% of its mass consists of densely packed hydroxyapatite crystals (the same calcium salts found in bone) arranged in force-resisting rods or prisms oriented perpendicular to the tooth's surface.

Dentin, or **dentine,** underlies the enamel cap and forms the bulk of the tooth. This is a bonelike tissue with mineral and collagen components, but it is harder than bone and lacks internal blood vessels. Dentin contains unique radial striations called **dentinal tubules.**

The **pulp cavity,** in the center of the tooth, is filled with dental **pulp,** a loose connective tissue containing the tooth's vessels and nerves. Pulp supplies nutrients for the tooth's hard tissues and provides for tooth sensation. The part of the pulp cavity in the root is the **root canal.** The opening into the root canal at the tip of each root is the **apical foramen.** When a tooth is damaged by a blow or by a deep cavity, the pulp may die and become infected. In such cases, **root canal therapy** must be performed. In this procedure, all of the pulp is

drilled out, and the pulp cavity is sterilized and filled with an artificial, inert material before the tooth is capped.

The external surface of the tooth root is covered by a calcified connective tissue called **cementum.** Essentially a bone layer, cementum attaches the tooth to the **periodontal ligament** (per″e-o-don′tal; "around the tooth"), or **periodontium.** This ligament anchors the tooth in the bony socket of the jaw. The periodontal ligament is continuous with the gum, or **gingiva** (jin-jī′vah), at the neck of the tooth.

Dental **cavities,** or **caries** (kar′ēz; "rottenness"), result from a gradual demineralization of the enamel and dentin by bacterial action. The decay process begins with the accumulation of **dental plaque,** a film of sugar, bacteria, and other debris that adheres to the teeth. Metabolism of the trapped sugars by the bacteria produces acids, which dissolve the calcium salts from the teeth. Once the salts have leached out, the remaining organic matrix is broken down by protein-digesting bacterial enzymes. Frequent brushing helps prevent tooth decay by removing plaque.

GUM DISEASE Even more serious than tooth decay is the effect of plaque on the *gums.* As plaque accumulates around the necks of the teeth, the contained bacteria release toxins that irritate the gums and cause them to pull away from the teeth. The plaque calcifies into a layer called **calculus** (kal′ku-lus; "stone"), on which more plaque accumulates, further inflaming the gums. This condition, **gingivitis** (jin″jī-vi′tis), can be reversed if the calculus is removed, but if it is neglected the bacteria invade the periodontal tissues, forming pockets of infection that destroy the periodontal ligament and dissolve away the bone around the tooth. Called **periodontitis,** this condition begins around age 35 and eventually affects 75% of people. (Periodontitis often results in the loss of teeth and is the reason many people wear dentures.) Still, tooth loss is not inevitable. Even advanced cases of periodontitis can be treated by cleaning the infected pockets around the roots, then cutting and stitching the gums to shrink the pockets. Newly available gels, which are injected into the pockets, contain either antibiotics or substances that stimulate regeneration of the gum, cementum, and periodontal ligament.

Dentists recommend that people floss between their teeth every day, beginning at a young age, because flossing removes plaque, thereby minimizing one's chances of developing periodontitis and losing one's teeth later in life.

The Salivary Glands

The salivary glands produce *saliva,* a complex mixture of water, ions, mucus, and enzymes that performs many functions: It moistens the mouth, dissolves food chemicals so that they can be tasted, wets food, and binds the food together into a bolus, and its enzymes begin the digestion of carbohydrates. Saliva contains a bicarbonate buffer that neutralizes the acids that are produced by oral bacteria and that initiate tooth decay. Additionally, it contains bactericidal enzymes, antiviral substances, antibodies, and a cyanide compound, all of which kill harmful oral microorganisms. Saliva also contains proteins that stimulate the growth of beneficial bacteria to outcompete harmful bacteria in the mouth.

All **salivary glands** are compound tubuloalveolar glands. Small *intrinsic salivary glands* are scattered within the mucosa of the tongue, palate, lips, and cheeks. Saliva from these glands keeps the mouth moist at all times. By contrast, large *extrinsic salivary glands,* which lie external to the mouth but connect to it through their ducts **(Figure 23.15)**, secrete saliva only during eating or anticipation of a meal, causing the mouth to water. These paired extrinsic glands are the *parotid, submandibular,* and *sublingual glands.*

The largest extrinsic gland is the **parotid** (pah-rot′id) **gland.** True to its name (*par* = near; *otid* = the ear), it lies anterior to the ear, between the masseter muscle and the skin (Figure 23.15a). Its **parotid duct** runs parallel to the zygomatic arch, penetrates the muscle of the cheek, and opens into the mouth lateral to the second upper molar. Because the branches of the facial nerve run through the parotid gland on their way to the muscles of facial expression, surgery on this gland can lead to facial paralysis.

MUMPS A virus that spreads from one person to another in the saliva causes **mumps**. Its dominant symptom is inflammation and swelling of the parotid gland. When a person with mumps opens the mouth or chews, movements of the mandible pull on the irritated parotid glands and the bulging masseter muscles compress these glands, causing pain.

The **submandibular gland,** which is about the size of a walnut, lies along the medial surface of the mandibular body, just anterior to the angle of the mandible. Its duct raises the mucosa of the floor of the mouth and opens directly lateral to the tongue's lingual frenulum (see Figure 23.11b).

The **sublingual gland** lies in the floor of the oral cavity, inferior to the tongue. Its 10 to 12 ducts open into the mouth, directly superior to the gland (Figure 23.15a).

The secretory cells of the salivary glands are *serous cells,* which produce a watery secretion containing the enzymes and ions of saliva, and *mucous cells,* which produce mucus (Figure 23.15b). (Note, however, that because the serous cells in human salivary glands are now known to secrete a small amount of mucus as well, some scientists refer to these cells as *seromucous cells.*) The parotid glands contain only serous cells; the submandibular and intrinsic glands are mixed glands containing serous and mucous cells; and the sublingual glands, while also are mixed glands, contain mostly mucous cells. The smallest ducts of all salivary glands are formed by a simple cuboidal epithelium.

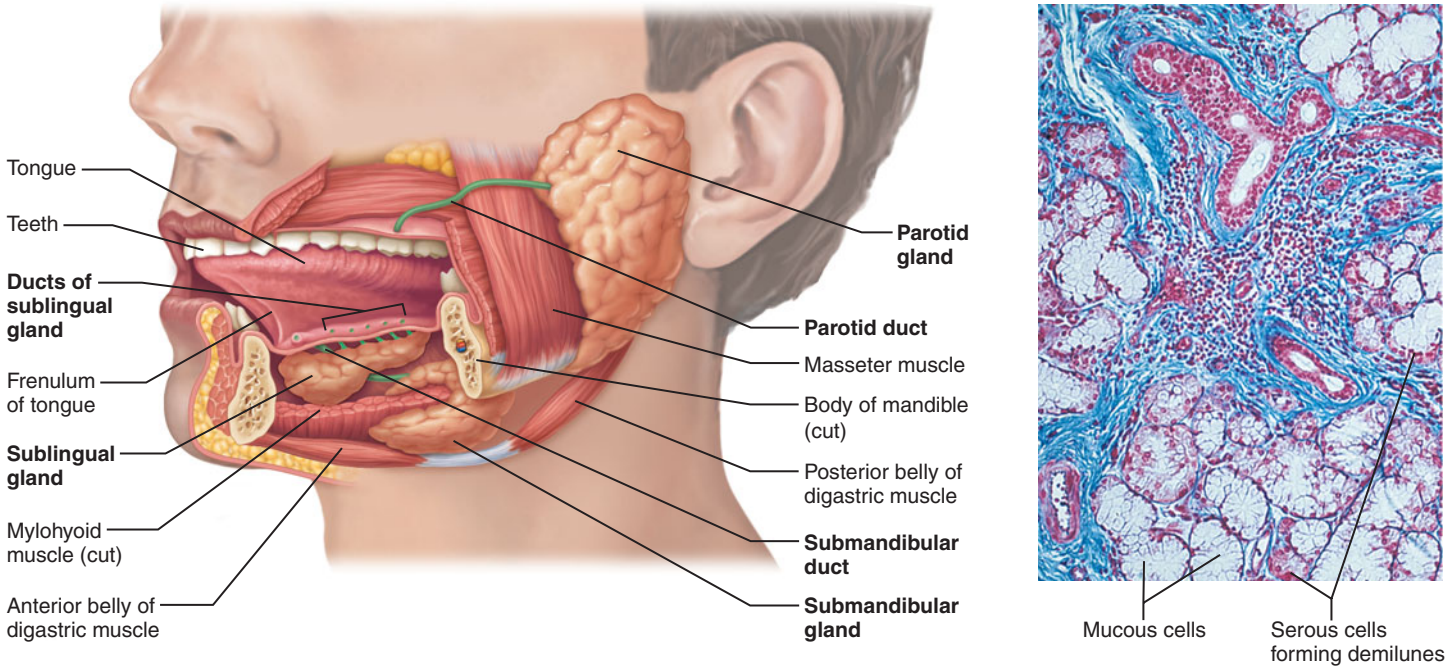


FIGURE 23.15 The extrinsic salivary glands. (a) The parotid, submandibular, and sublingual glands and their ducts. **(b)** Photomicrograph of the sublingual gland (85×), a mixed gland containing mostly mucous cells (white) with a few serous cells (purple). The serous cells may form demilunes (caps) around the bases of the mucous cells.

The Pharynx

From the mouth, swallowed food passes posteriorly into the **oropharynx** and then the **laryngopharynx** (Figure 23.11a), both of which are passageways for food, fluids, and inhaled air.

The histology of the pharyngeal wall resembles that of the mouth: The oropharynx and laryngopharynx are lined by a stratified squamous epithelium, which protects them against abrasion. (Swallowed food often contains rough particles, even after mastication.) The external muscle layer consists primarily of three (superior, middle, and inferior) *pharyngeal constrictor* muscles (shown in Figure 11.11c, p. 284), muscles of swallowing that encircle the pharynx and partially overlap one another. Like three stacked, clutching fists, they contract in sequence, from superior to inferior, to squeeze the bolus into the esophagus. The pharyngeal constrictors are *skeletal* muscles, as swallowing is a voluntary action, innervated by the vagus nerve (cranial nerve X).

check your understanding

8. What type of epithelium forms the mucosa lining the oral cavity and pharynx?
9. Name the three extrinsic salivary glands. What nutrient macromolecule do the enzymes in saliva act on?
10. What cranial nerve innervates the teeth? Which division of this nerve innervates the teeth in the upper jaw? Which innervates the teeth in the lower jaw?

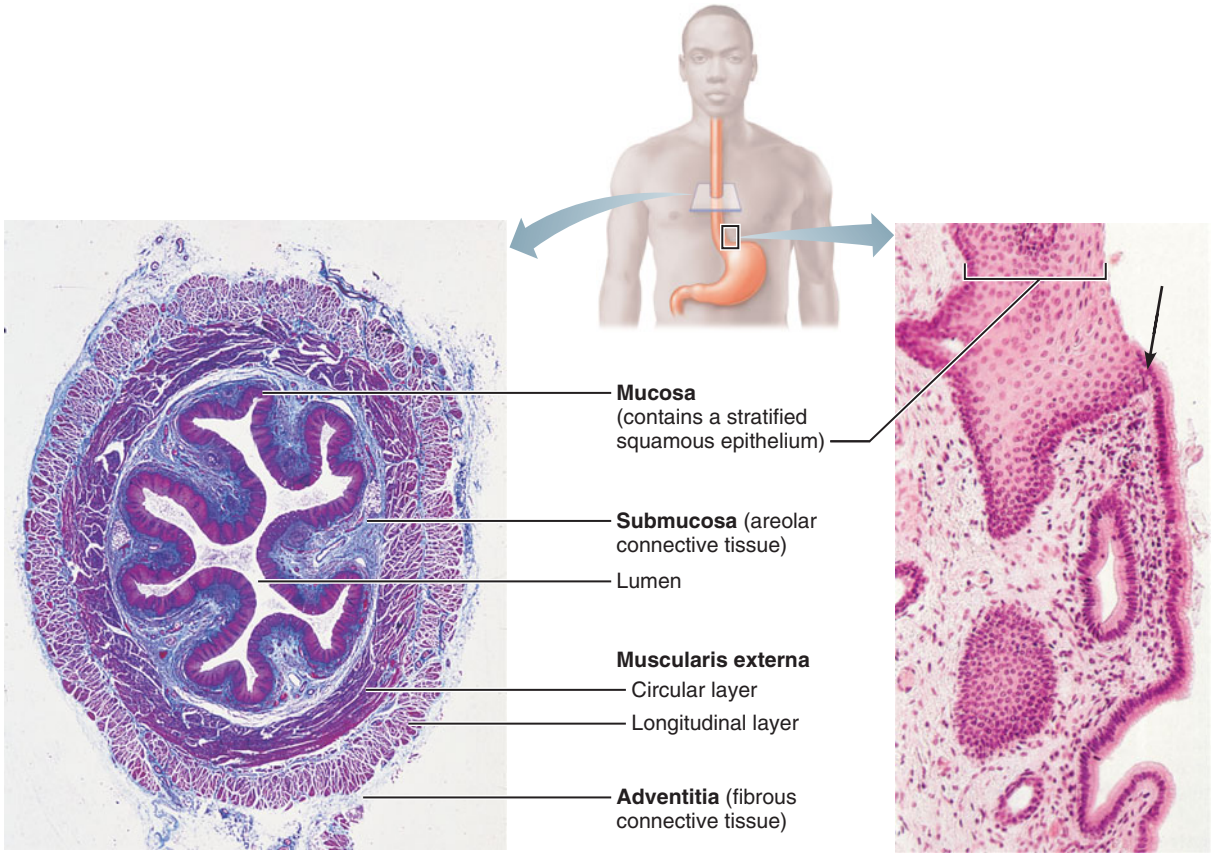
For answers, see Appendix B.

The Esophagus

- Describe the gross and microscopic anatomy of the esophagus and stomach.
- Relate the structure of the mucosal layer of the esophagus and the stomach to the digestive activities that occur in each region.

Gross Anatomy

The **esophagus** is a muscular tube that propels swallowed food to the stomach. Its lumen is collapsed when it is empty. The esophagus begins as a continuation of the pharynx in the midneck, descends through the thorax on the anterior surface of the vertebral column (see Figure 23.1), and passes through the *esophageal hiatus* (hi-a′tus; opening) in the diaphragm to enter the abdomen (see Figure 11.13b, p. 290). Its abdominal part, which is only about 2 cm long, joins the stomach at the **cardiac orifice,** where a **cardiac sphincter** acts to close off the lumen and prevent regurgitation of acidic stomach juices into the esophagus. The only anatomical evidence of this sphincter is a minimal thickening of the smooth muscle in the wall. The edges of the esophageal hiatus also help prevent regurgitation.



(a) Cross section through esophagus (5×)

(b) Gastroesophageal junction, longitudinal section (85×)

FIGURE 23.16 Microscopic structure of the esophagus. The arrow in (b) marks the abrupt change between the stratified squamous epithelium lining the esophagus and the simple columnar epithelium lining the stomach (85×). (See *A Brief Atlas of the Human Body,* Second Edition, Plate 42.)

HIATAL HERNIA AND GASTROESOPHAGEAL REFLUX DISEASE In a **hiatal hernia,** the superior part of the stomach pushes through an enlarged esophageal hiatus into the thorax following a weakening of the diaphragmatic muscle fibers around the hiatus. Because the diaphragm no longer reinforces the action of the cardiac sphincter, the acidic stomach juices are persistently regurgitated, eroding the wall of the esophagus and causing a burning pain.

The regurgitation associated with hiatal hernia is just one form of **gastroesophageal reflux disease (GERD),** a condition that affects at least 4% of Americans. Most cases of GERD are due to abnormal relaxation or weakness of the cardiac sphincter (and probably of the sphincter mechanism of the esophageal hiatus as well). Symptoms include heartburn behind the sternum, regurgitation of stomach contents, and belching. The patient may aspirate the acids that are burped up, leading to hoarseness, coughing, and bronchial asthma. After persistent exposure to the acidic stomach contents, the lower esophagus develops ulcers, and the epithelium there becomes abnormal and precancerous, a condition called **Barrett's esophagus.** Treatment, which is usually successful, involves administering antacids and drugs that decrease the secretion of stomach acids. In severe cases, surgery is used to reconstruct a valve in the lower esophagus.

Microscopic Anatomy

Unlike the mouth and pharynx, the esophagus wall **(Figure 23.16a)** contains all four layers of the alimentary canal described on pp. 671–673. The following histological features are of interest:

1. The lining epithelium is a nonkeratinized stratified squamous epithelium. At the junction of the esophagus and stomach, this thick, abrasion-resistant layer changes abruptly to the thin simple columnar epithelium of the stomach, which is specialized for secretion (Figure 23.16b).

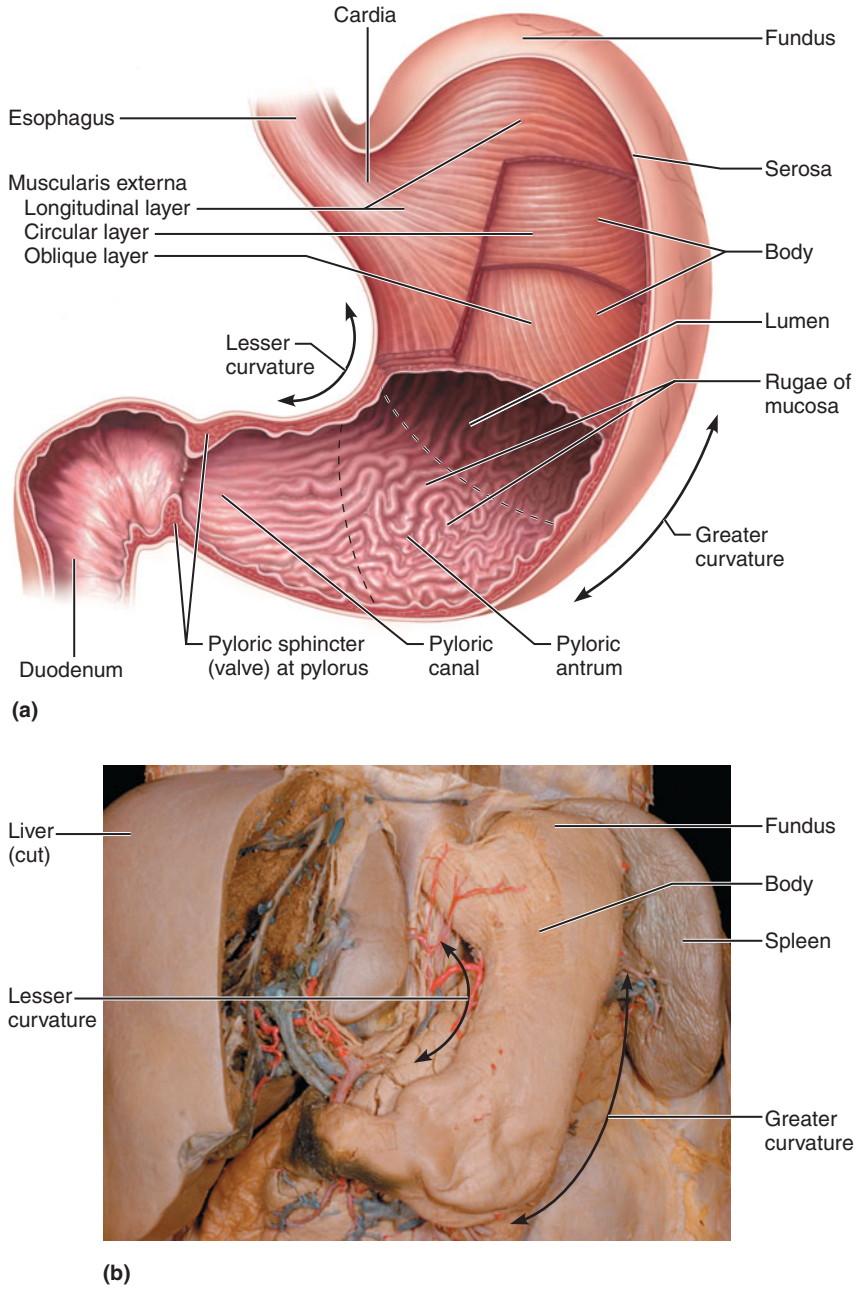


FIGURE 23.17 Gross anatomy of the stomach. (a) Basic regions of the stomach and gross internal anatomy. (See *A Brief Atlas of the Human Body,* Second Edition, Figure 69a.) **(b)** Photograph of external aspect of stomach.

2. When the esophagus is empty, its mucosa and submucosa are thrown into longitudinal folds, but during passage of a bolus, these folds flatten out.
3. The wall of the esophagus contains mucous glands, primarily compound tubuloalveolar glands that extend from the submucosa to the lumen. As a bolus passes, it compresses these glands, causing them to secrete a lubricating mucus. This mucus aids the further passage of the bolus through the esophagus.
4. The muscularis externa consists of skeletal muscle in the superior third of the esophagus, a mixture of skeletal and smooth muscle in the middle third, and smooth muscle in the inferior third. This arrangement is easy to remember if the esophagus is viewed as the zone where the skeletal muscle of the mouth and pharynx gives way to the smooth muscle of the stomach and intestines.
5. The most external esophageal layer is an adventitial, not a serosal, layer, because the thoracic segment of the esophagus is not suspended in the peritoneal cavity.

The Stomach

The J-shaped **stomach** (Figure 23.17), the widest part of the alimentary canal, is a temporary storage tank in which food is

churned and turned into a paste called **chyme** (kīm; "juice"). The stomach also starts the breakdown of food proteins by secreting **pepsin,** a protein-digesting enzyme that can function only under acidic conditions, and hydrochloric acid, a strong acid that destroys many harmful bacteria in the food. Although most nutrients are absorbed in the small intestine, some substances are absorbed through the stomach, including water, electrolytes, and some drugs (aspirin and alcohol). Food remains in the stomach for roughly 4 hours.

Gross Anatomy

The stomach extends from the esophagus to the small intestine. The stomach lies in the superior left part of the peritoneal cavity, in the left hypochondriac, epigastric, and umbilical regions of the abdomen (see Figure 23.4). It is directly inferior to the diaphragm and anterior to the spleen and pancreas. Its upper part is hidden behind the left side of the liver. Although the stomach is anchored at both ends by esophageal and intestinal attachments, it is quite mobile in between. It tends to lie high and run horizontally in short, stout people (steerhorn stomach) and is elongated vertically in many tall, thin people (J-shaped stomach). When full, a J-shaped stomach may extend low enough to reach the pelvis!

The main regions of the stomach are shown in Figure 23.17a. The **cardiac region,** or **cardia** ("near the heart"), is a ring-shaped zone encircling the cardiac orifice at the junction with the esophagus. The **fundus,** the stomach's dome, is tucked under the diaphragm. The large midportion of the stomach, the **body,** ends at the funnel-shaped **pyloric region,** composed of the wider **pyloric antrum** ("cave") and the narrower **pyloric canal.** The pyloric region ends at the terminus of the stomach, the **pylorus** ("gatekeeper") containing the **pyloric sphincter,** which controls the entry of chyme into the intestine. The convex left surface of the stomach is its **greater curvature,** and the concave right margin is the **lesser curvature.** The greater and lesser omenta, mesenteries that connect to the stomach (p. 669), are named for their attachment to these curvatures.

The stomach's structure accounts for its great distensibility—it easily holds 1.5 liters of food and has a maximum capacity of about 4 liters (1 gallon). The internal surface of the empty stomach contains numerous longitudinal folds of mucosa called **rugae** (roo′ge; "wrinkles") (Figure 23.17), which flatten as the stomach fills; the resulting expansion in volume accommodates the increasing quantity of food within the stomach.

Vessels and Nerves The stomach is innervated by sympathetic fibers that derive from the thoracic splanchnic nerves by way of the celiac plexus, and by parasympathetic fibers that derive from the vagus. The stomach contains no submucosal nerve plexus, so the myenteric plexus innervates its mucosa as well as its muscularis externa. The arteries to the stomach arise from the celiac trunk and include the right and left gastric, short gastric, and right and left gastroepiploic arteries; the corresponding veins drain into the portal, splenic, and superior mesenteric veins.

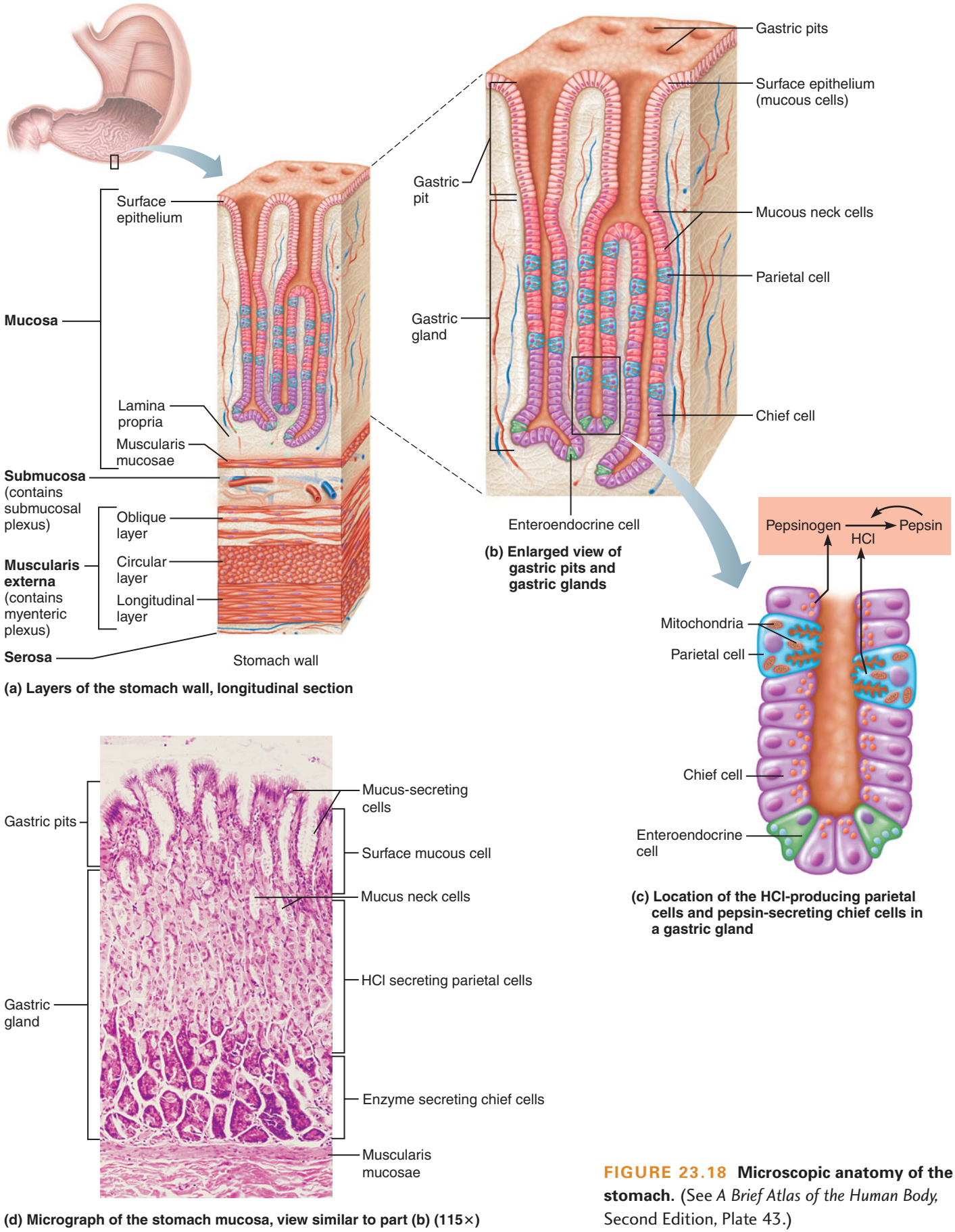
Microscopic Anatomy

The wall of the stomach has the typical layers of the alimentary canal, but its muscularis externa shows special features. Along with circular and longitudinal layers of smooth muscle, the muscularis externa also has another, innermost layer that runs *obliquely* (Figure 23.17a). The circular and longitudinal layers churn and pummel food into smaller fragments, whereas the oblique layer jackknifes the stomach into a V shape to move the chyme into the small intestine. The pyloric sphincter is a thickening of the circular layer.

The histology of the stomach is illustrated in **Figure 23.18**. The lining epithelium ("surface epithelium" in the figure) is simple columnar epithelium and consists entirely of cells that secrete a coat of bicarbonate-buffered mucus. This mucus protects the stomach wall from the destructive effects of acid and pepsin in the lumen. This mucous secretion is necessary because the stomach mucosa is exposed to some of the harshest conditions in the entire alimentary canal. The oversecretion of stomach acid can result in peptic ulcers; see "Disorders of the Digestive System" on p. 699.

The surface of the stomach mucosa is dotted with millions of cup-shaped **gastric pits,** which open into tubular **gastric glands** (Figure 23.18b). Surface mucous cells invariably line the gastric pits, but the cells lining the gastric glands vary among the different regions of the stomach. In the pyloric and cardiac regions (not illustrated), the cells of the glands are primarily mucous cells. In the fundus and body, by contrast, the gastric glands contain three types of secretory cells: mucous neck cells, parietal (oxyntic) cells, and chief (zymogenic) cells (see Figure 23.18b–d).

1. **Mucous neck cells,** which occur in the upper ends, or necks, of the gastric glands, secrete a different type of mucus from that secreted by the surface cells. The specific function of this mucus is not known.
2. **Parietal (oxyntic) cells,** which occur mainly in the middle regions of the glands, produce the stomach's hydrochloric acid (HCl) by pumping hydrogen and chloride ions into the lumen of the gland. Although parietal cells appear spherical when viewed by light microscopy, they actually have three thick prongs like those of a pitchfork. Many long microvilli cover each prong, providing a large surface area to enable rapid movement of H^+ and Cl^- out of the cells. The cytoplasm contains many mitochondria that supply the large amount of energy expended in pumping these ions. Parietal cells also secrete **gastric intrinsic factor,** a protein necessary for the absorption of vitamin B_{12} by the small intestine. The body uses this vitamin in the manufacture of red blood cells.
3. **Chief (zymogenic) cells** occur mainly in the basal parts of the glands. Chief cells make and secrete the enzymatic protein **pepsinogen** (pep-sin′o-jen), which is activated to pepsin when it encounters acid in the apical region of the gland (Figure 23.18c). Chief cells have features typical of protein-secreting cells: a well-developed rough endoplasmic reticulum (rough ER) and Golgi apparatus, plus secretory granules in the apical cytoplasm.



(a) Layers of the stomach wall, longitudinal section

(b) Enlarged view of gastric pits and gastric glands

(c) Location of the HCl-producing parietal cells and pepsin-secreting chief cells in a gastric gland

(d) Micrograph of the stomach mucosa, view similar to part (b) (115×)

FIGURE 23.18 Microscopic anatomy of the stomach. (See *A Brief Atlas of the Human Body*, Second Edition, Plate 43.)

At least two other epithelial cell types occur in the gastric glands but also extend beyond these glands:

1. **Enteroendocrine cells** (en″ter-o-en′do-krin; "gut endocrine") are hormone-secreting cells scattered throughout the lining epithelium and glands of the alimentary canal. These cells (Figure 23.18d) release their hormones into the capillaries of the underlying lamina propria. One of these hormones, *gastrin,* signals parietal cells to secrete HCl when food enters the stomach. Most enteroendocrine cells that produce gastrin are in the stomach's pyloric region.
2. **Undifferentiated stem cells** (not illustrated) are located throughout the stomach, at the junction of the gastric glands and gastric pits. These cells divide continuously, replacing the entire lining epithelium of mucus-secreting cells every 3–7 days. Such rapid replacement is vital because these cells can survive for only a few days in the harsh environment of the stomach.

check your understanding

11. How does the epithelial lining change from the esophagus to the stomach? What is unique about the muscularis externa in the stomach?
12. Describe the location of the stomach in reference to the abdominal regions defined in Figure 23.4.
13. What do chief cells produce? What do parietal cells produce? What do the surface cells that line the stomach produce?

For answers, see Appendix B.

The Small Intestine

- Describe the gross and microscopic anatomy of the small and large intestine.
- Relate the histological modifications in the wall of the intestines to the digestive activities of these regions.

The **small intestine** is the longest part of the alimentary canal (see Figure 23.1) and the site of most enzymatic digestion and virtually all absorption of nutrients. Most digestive enzymes that operate within the small intestine are secreted not by the intestine, but by the pancreas. During digestion, the small intestine undergoes active segmentation movements, shuffling the chyme back and forth and thereby maximizing its contact with the nutrient-absorbing mucosa. Peristalsis propels chyme through the small intestine in about 3–6 hours.

Gross Anatomy

The small intestine is a convoluted tube that runs from the pyloric sphincter, in the epigastric region of the abdomen, to the first part of the large intestine, in the lower right quadrant. It is shorter in living people (2.7–5 meters) than in preserved cadavers (6–7 meters), where loss of muscle tone and the effects of preservatives have caused it to lengthen.

The small intestine has three subdivisions (see Figure 23.1): the **duodenum** (du″o-de′num; "twelve fingerwidths long"), the **jejunum** (je-joo′num; "empty"), and the **ileum** (il′e-um; "twisted intestine"), which contribute 5%, almost 40%, and almost 60% of the length of the small intestine, respectively. Whereas most of the C-shaped duodenum lies secondarily retroperitoneal, the jejunum and ileum form sausagelike coils that hang from the posterior abdomen by the mesentery and are framed by the large intestine. The jejunum makes up the superior left part of this coiled intestinal mass, whereas the ileum makes up the inferior right part.

Even though the *duodenum* is the shortest subdivision of the small intestine, it has the most features of interest **(Figure 23.19)**. It receives digestive enzymes from the pancreas via the *main pancreatic duct* and bile from the liver and gallbladder via the *bile duct*. These ducts enter the wall of the duodenum where they form a bulb called the **hepatopancreatic ampulla** (hep″ah-to-pan″kre-ah′tik am-pul′ah; "flask from the liver and pancreas"). This ampulla opens into the duodenum via a mound called the **major duodenal papilla.** Entry of bile and pancreatic juice into the duodenum is controlled by sphincters of smooth muscle that surround the hepatopancreatic ampulla and the ends of the pancreatic and bile ducts.

Vessels and Nerves The small intestine is innervated by parasympathetic fibers from the vagus and by sympathetic fibers from the thoracic splanchnic nerves, both relayed through the superior mesenteric (and celiac) plexus. Its arterial supply comes primarily via the superior mesenteric artery. The veins run parallel to the arteries and typically drain into the superior mesenteric vein; from there, the nutrient-rich venous blood drains into the hepatic portal vein, which carries it to the liver.

Microscopic Anatomy

As previously noted, nearly all nutrient absorption occurs in the small intestine, which is highly adapted for this function. In addition to the huge surface area for absorption provided by the small intestine's great length, several other structural features provide even more absorptive surface area, and serve other functions related to digestion as well.

Modifications for Absorption The wall of the small intestine has three structural modifications that amplify its absorptive surface enormously: *circular folds, villi,* and extensive *microvilli* **(Figure 23.20)**. Because most absorption occurs in the proximal region of the small intestine, these specializations decrease in number toward the distal end.

The **circular folds,** or *plicae circulares* (pli′ke), are permanent, transverse ridges of the mucosa and submucosa (Figure 23.20a). They are nearly 1 cm tall. Besides increasing the absorptive surface area, these folds force the chyme to spiral through the intestinal lumen, slowing its movement and allowing time for complete absorption of nutrients.

Villi are fingerlike projections of the mucosa that give it a velvety texture, much like the soft nap of a towel. Over 1 mm high, and thus large enough to be seen with the unaided eye, villi are covered by a simple columnar epithelium made up primarily of **absorptive cells** specialized for absorbing digested nutrients (Figure 23.20b and c). Within the core of lamina propria in each villus is a network of blood capillaries and

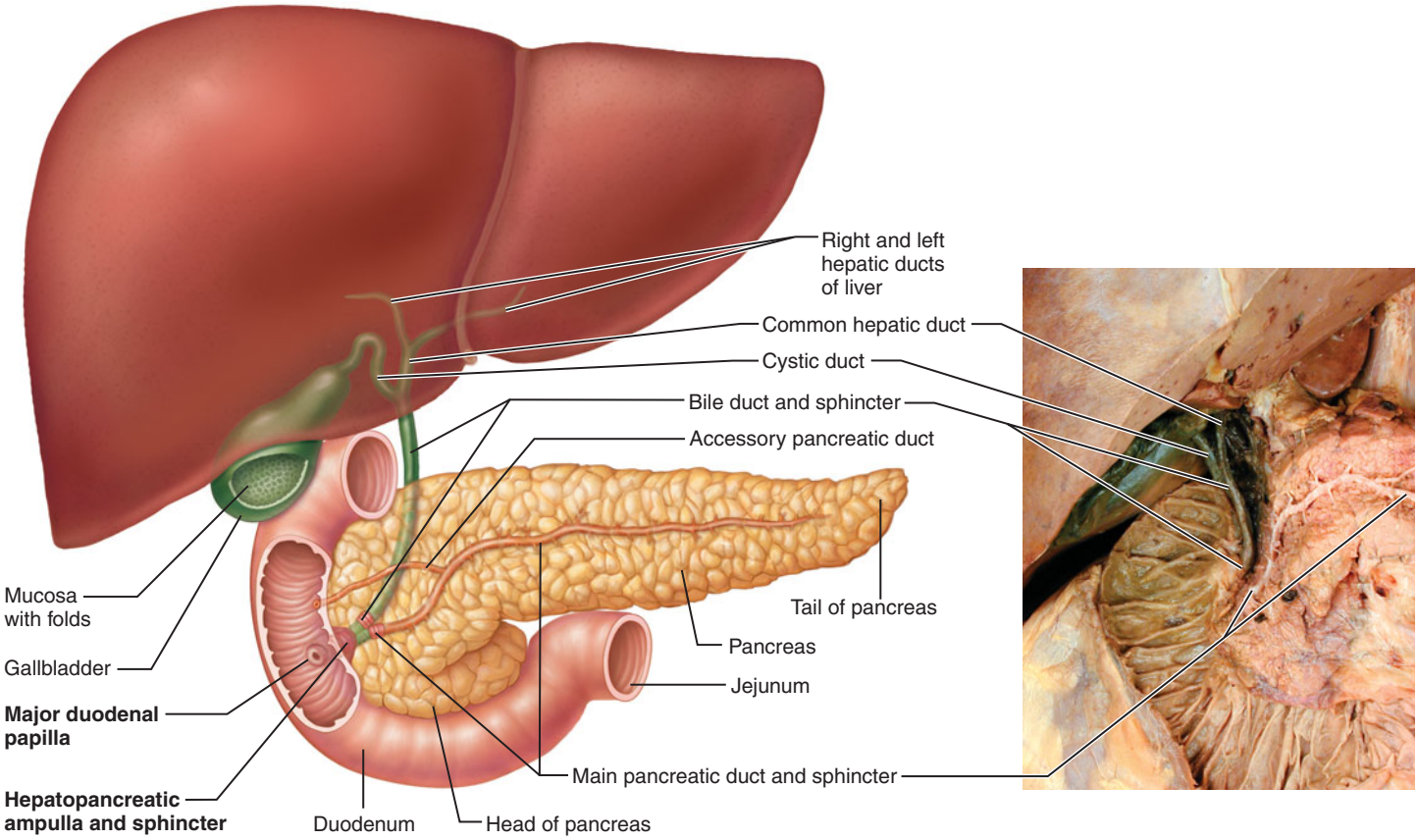


FIGURE 23.19 The duodenum of the small intestine, and related organs.
The cadaver dissection on the right and the illustration on the left show the ducts that open into the duodenum from the pancreas, gallbladder, and liver.

a wide lymphatic capillary called a **lacteal** (see p. 619). The end products of the digestion of carbohydrates and proteins enter the blood capillaries; absorbed fats enter the lacteals. The implications of this distinction are significant. Recall that the blood vessels that drain the small intestine carry absorbed nutrients to the liver via the hepatic portal system (Chapter 20, p. 605). Absorbed fats, however, do not go directly to the liver, but rather travel through the lymphatic vessels and empty into the venous system near the brachiocephalic vein (see Chapter 21, pp. 621–622). Thus, ingested and absorbed fat-soluble toxins, such as pesticides or herbicides, can circulate throughout the body before reaching the liver for detoxification.

Within the core of each villus is a slip of smooth muscle from the muscularis mucosae that allows the villus to move during digestion. These movements enhance absorption efficiency by increasing the amount of contact between the villi and the nutrients in the intestinal lumen, and they also squeeze lymph through the lacteals.

The apical surfaces of the absorptive cells have many **microvilli** (Figure 23.20b). Whereas such projections occur on most epithelial surfaces in the body, those in the small intestine are exceptionally long and densely packed. Besides amplifying the absorptive surface, the plasma membrane of these microvilli contains enzymes that complete the final stages of the breakdown of nutrient molecules.

The amount of absorptive surface in the small intestine is remarkable. Together, the circular folds, villi, and microvilli increase the intestinal surface area to about 200 square meters, equivalent to the floor area of an average two-story house!

Histology of the Wall All typical layers of the alimentary canal occur in the small intestine. The lining epithelium, which occurs not only on the villi but also on the intestinal surface between villi, contains the previously mentioned absorptive cells plus some scattered goblet cells and enteroendocrine cells:

1. **Absorptive cells** (Figure 23.20b and c). These cells contain many mitochondria because the uptake of digested nutrients is an energy-demanding process. They also contain an abundant endoplasmic reticulum, which assembles the newly absorbed lipid molecules into lipid-protein complexes called *chylomicrons* (ki″lo-mi′-kronz). Once made, the chylomicrons enter the lacteal capillaries, so it is in this form that absorbed fat enters the circulation.
2. **Goblet cells** (Figure 23.20b and c). These cells secrete onto the internal surface of the intestine a coat of mucus that lubricates the chyme and forms a protective barrier that prevents enzymatic digestion of the intestinal wall.

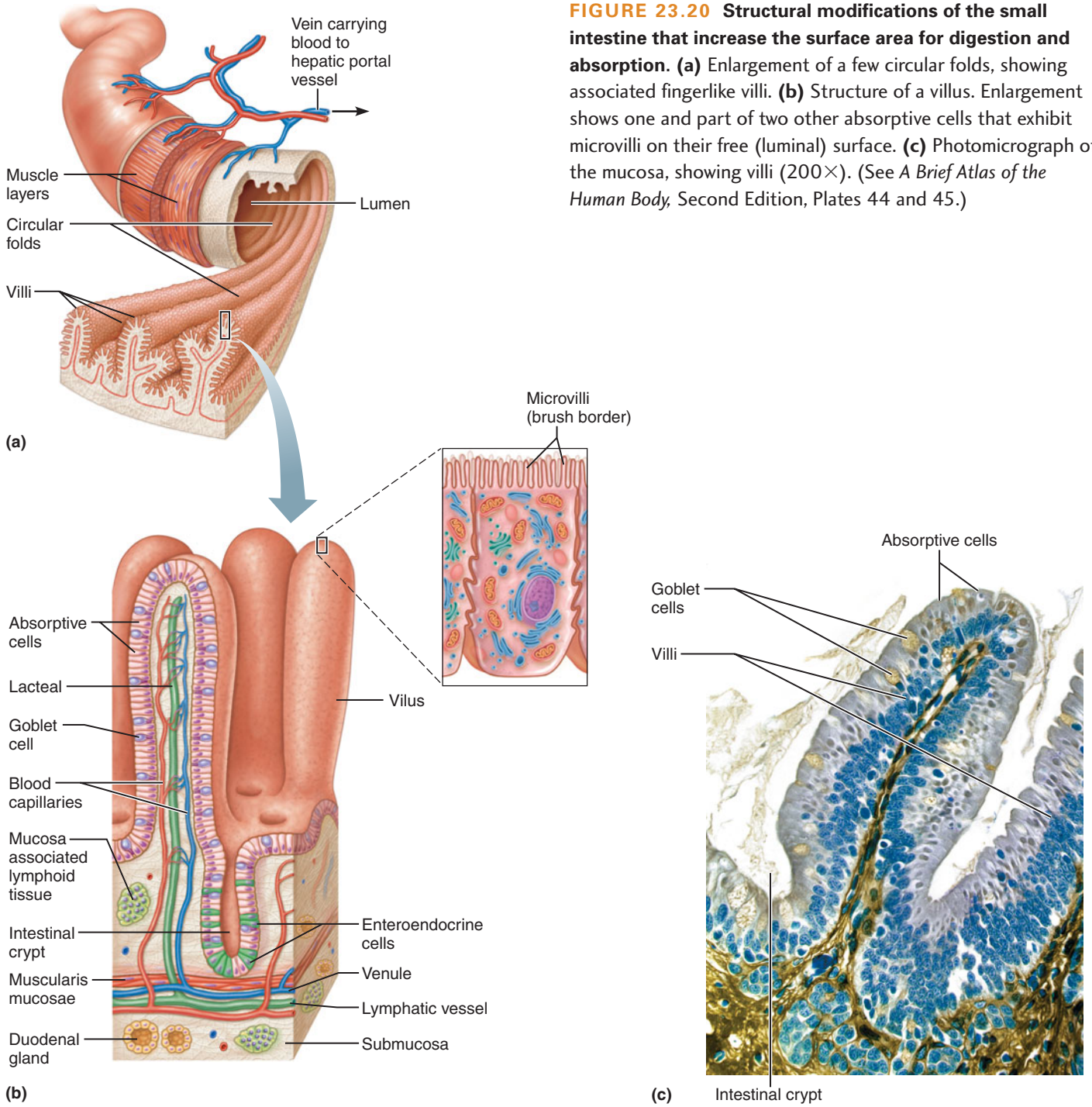


FIGURE 23.20 Structural modifications of the small intestine that increase the surface area for digestion and absorption. (a) Enlargement of a few circular folds, showing associated fingerlike villi. **(b)** Structure of a villus. Enlargement shows one and part of two other absorptive cells that exhibit microvilli on their free (luminal) surface. **(c)** Photomicrograph of the mucosa, showing villi (200×). (See *A Brief Atlas of the Human Body,* Second Edition, Plates 44 and 45.)

3. **Enteroendocrine cells** (Figure 23.20b) The enteroendocrine cells of the duodenum secrete several hormones, which signal the gallbladder to release stored bile and the pancreas to secrete digestive enzymes and a bicarbonate-rich juice to neutralize the acidic chyme entering the duodenum.

Between the villi, the mucosa contains invaginations called **intestinal crypts,** or *crypts of Lieberkühn* (lēb′er-kun) (Figure 23.20b). The epithelial cells that line these crypts secrete *intestinal juice,* a watery liquid that mixes with chyme in the intestinal lumen. Undifferentiated epithelial cells lining the intestinal crypts renew the mucosal epithelium by dividing rapidly and moving continuously onto the villi. These are among the most quickly dividing cells of the body, completely renewing the inner epithelium of the small intestine every 3–6 days. Such rapid replacement is necessary because individual epithelial cells cannot withstand the destructive effects of the digestive enzymes in the intestinal lumen for long.

Intestinal crypts also contain mature *Paneth cells* (not illustrated). These epithelial cells secrete enzymes that destroy

certain bacteria and may help determine which kinds of bacteria live in the intestinal lumen. The permanent bacterial residents of the intestinal lumen, called the *intestinal flora,* manufacture some essential vitamins, which the intestines absorb. Vitamin K is one substance produced by the intestinal bacteria.

The small intestine contains many areas of lymphoid tissue. Mucosa-associated lymphoid tissue (MALT) is found in the mucosal layer throughout the intestine, and *aggregated lymphoid nodules* (*Peyer's patches*) are located in the submucosa of the ileum (see p. 630).

The submucosa of the small intestine is a typical connective tissue. In the duodenum only, it contains a set of compound tubular **duodenal glands** (also called *Brunner's glands*), whose ducts open into the intestinal glands (see Figure 23.20b). These glands secrete an alkaline, bicarbonate-rich mucus that helps neutralize the acidity of the chyme from the stomach and contributes to the protective layer of mucus on the inner surface of the small intestine.

The outer layers of the small intestine (muscularis externa and serosa) have no unusual features.

The Large Intestine

The **large intestine** is the last major organ in the alimentary canal **(Figure 23.21)**. The material that reaches it is a largely digested residue that contains few nutrients. During the 12–24 hours that this residue remains in the large intestine, little additional breakdown of food occurs, except for the small amount of digestion performed by the many bacteria living there. Even though the large intestine absorbs these few remaining nutrients, its main function is to absorb water and electrolytes from the digested mass, resulting in semisolid feces. Propulsion through the large intestine is sluggish and weak, except for **mass peristaltic movements,** which pass over the colon a few times a day to force the feces powerfully toward the rectum.

Gross Anatomy

The large intestine frames the small intestine on 3½ sides, forming an open rectangle (see Figure 23.1). This organ, which is wider than the small intestine but less than half as long (1.5 meters), has the following subdivisions: *cecum, vermiform appendix, colon, rectum,* and *anal canal* (Figure 23.21a).

Over most of its length, the large intestine exhibits three special features: teniae coli, haustra, and epiploic appendages. **Teniae (taeniae) coli** (te′ne-e ko′li; "ribbons of the colon") are three longitudinal strips, spaced at equal intervals around the circumference of the cecum and colon. They are thickenings of the longitudinal layer of the muscularis externa, which is thin except at these sites. Because the teniae maintain muscle tone, they cause the large intestine to pucker into sacs, or **haustra** (haw′strah; "to draw up"). **Epiploic appendages** (ep″ĭ-plo′ik; "membrane-covered"), also called *omental appendices,* are fat-filled pouches of visceral peritoneum that hang from the intestine. Their significance is unknown.

The Cecum and Vermiform Appendix The large intestine begins with the saclike **cecum** (se′kum; "blind pouch") in the right iliac fossa. The opening of the ileum of the small intestine into the cecum's medial wall is surrounded internally by the **ileocecal valve** (Figure 23.21a), which is formed by two raised edges of the mucosa. A sphincter in the distal ileum keeps the valve closed until there is food in the stomach, at which time the sphincter reflexively relaxes, opening the valve. As the cecum fills, its walls stretch, pulling the edges of the ileocecal valve together and closing the opening. This action prevents reflux of feces from the cecum back into the ileum.

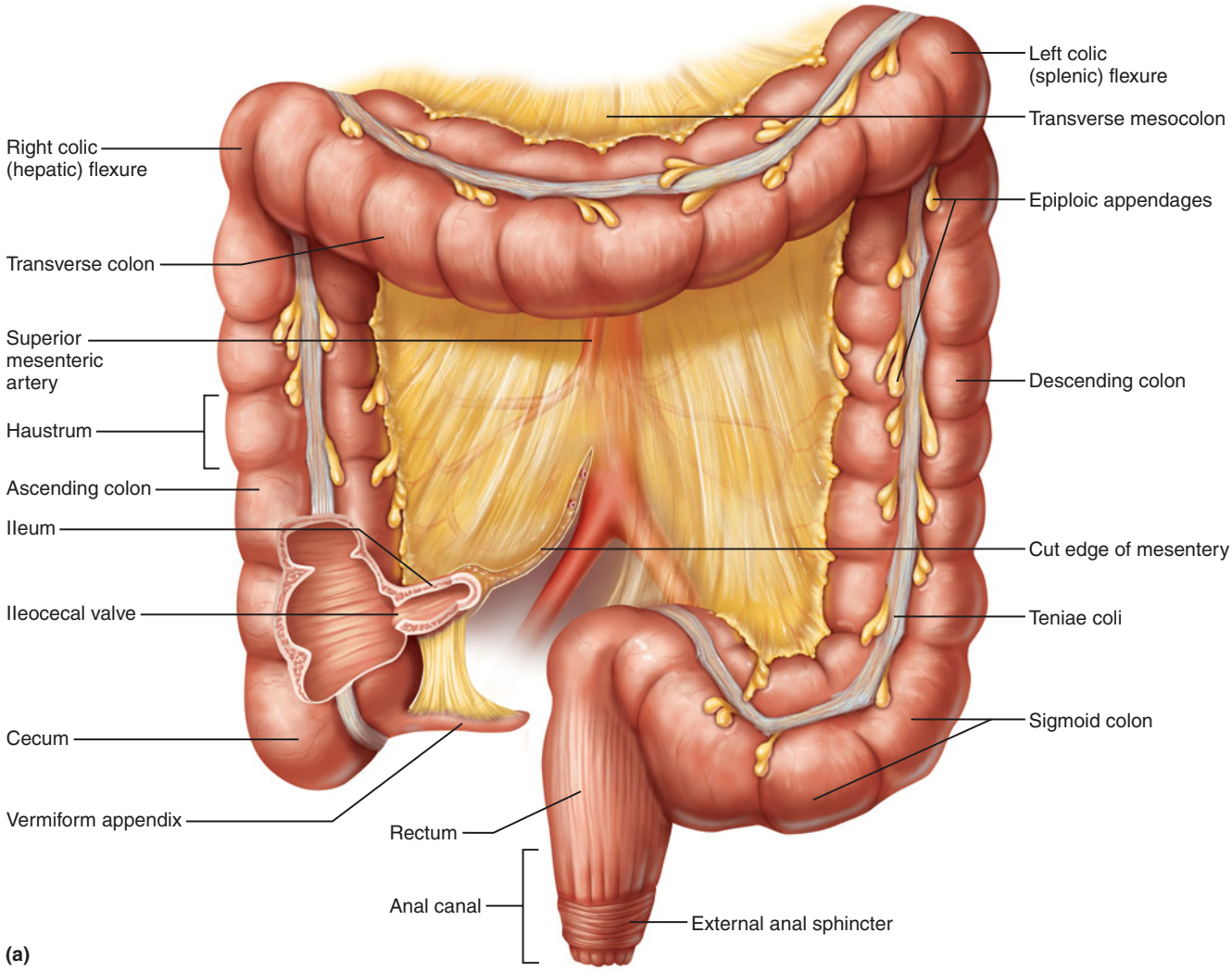
The **vermiform appendix** (ver′mĭ-form; "worm-shaped") is a blind tube that opens into the posteromedial wall of the cecum. Although almost always illustrated as hanging inferiorly, it more often lies "tucked up" posterior to the cecum in the right iliac fossa. The appendix has large masses of lymphoid tissue in its wall. Commonly considered a vestigial organ, current research proposes that the appendix functions as a safe haven for the beneficial bacteria that inhabit the large intestine. According to this theory, beneficial bacteria from the appendix can repopulate the gut following an infectious disease that causes diarrhea and flushes out the intestinal flora.

APPENDICITIS Acute inflammation of the appendix, called **appendicitis,** results from a blockage that traps infectious bacteria within its lumen. The blockage often is caused by a lump of feces or by a virus-induced swelling of the lymphoid tissue of the appendix wall. Unable to empty its contents, the blocked appendix swells with the mucus it secretes, squeezing off its venous drainage and leading to ischemic necrosis and infection. If the appendix ruptures, bacteria and feces are released into the peritoneum, causing peritonitis.

Because the symptoms of appendicitis vary greatly, this condition is notoriously difficult to diagnose. Often, however, the first symptom is pain in the umbilical region, followed by loss of appetite, fever, nausea, vomiting, and relocalization of pain to the lower right quadrant of the abdominal surface. Palpation of this region that causes strong pain after the pressure is removed (so-called rebound tenderness) can indicate appendicitis.

Immediate surgical removal of the appendix, called **appendectomy** (ap″en-dek′to-me), is the usual treatment.

The Colon The **colon** (ko′lon) has several distinct segments (Figure 23.21a). From the cecum, the **ascending colon** ascends along the right side of the posterior abdominal wall in a secondarily retroperitoneal position and reaches the level of the right kidney, where it makes a right-angle turn, the **right colic flexure** (also called the **hepatic flexure** because the liver lies directly superior to it). From this flexure, the **transverse colon** extends intraperitoneal to the left across the peritoneal cavity. Directly anterior to the



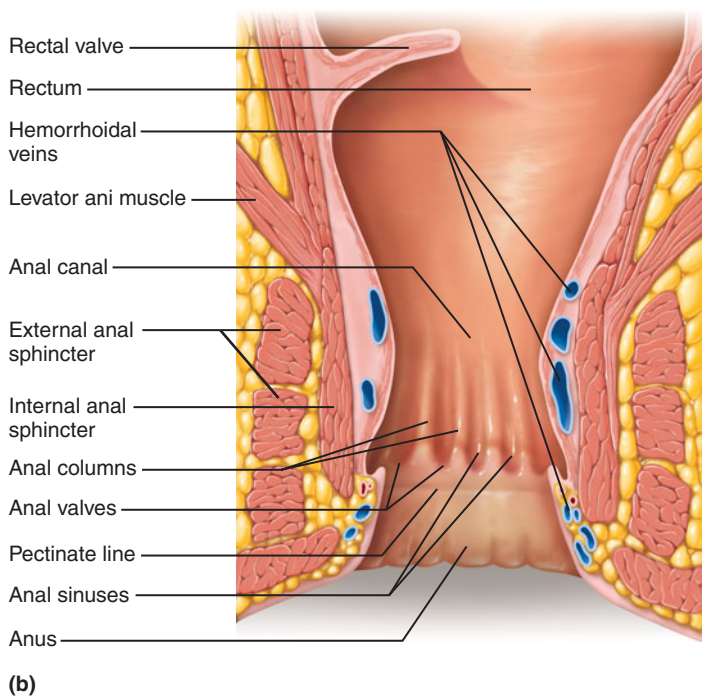


FIGURE 23.21 Gross anatomy of the large intestine. **(a)** Entire large intestine. **(b)** The inferior rectum and anal canal in frontal section.

spleen, it bends acutely downward at the **left colic (splenic) flexure** and descends along the left side of the posterior abdominal wall again in a secondarily retroperitoneal position as the **descending colon.** Inferiorly, the colon becomes intraperitoneal and enters the true pelvis as the S-shaped **sigmoid colon** (*sigma* = the Greek letter corresponding to the letter *s*).

DIVERTICULOSIS AND DIVERTICULITIS When the diet lacks fiber, the contents of the colon are reduced in volume, and the contractions of the circular muscle in the colon exert greater pressures on its wall. This pressure promotes the formation of multiple sacs called *diverticula* (dī″ver-tik′u-lah), which are small outward herniations of the mucosa through the colon wall. The resulting condition is termed **diverticulosis.** This condition arises most frequently in the sigmoid colon. Occurring in 30% to 40% of all Americans over age 50, and in half of those over 70, diverticulosis generally leads to nothing more than dull pain, although it may rupture an artery in the colon and produce bleeding from the anus. Increasing the amount of fiber in the diet generally relieves the symptoms.

In about 20% of diverticulosis cases, however, patients develop the more serious condition called **diverticulitis,** in which the inflamed diverticula become infected and may perforate, leaking feces into the peritoneal cavity. In serious cases, the affected region of the colon is removed by surgery and antibiotics are given to fight the peritonitis.

The Rectum In the pelvis, the sigmoid colon joins the **rectum** (Figure 23.21a), which descends along the inferior half of the sacrum in a secondarily retroperitoneal position. The rectum has no teniae coli; instead, its longitudinal muscle layer is complete and well developed, so that it can generate strong contractions for defecation. Even though the word *rectum* means "straight," the rectum actually has several tight bends. Internally, these bends are represented as three *transverse folds of the rectum,* or **rectal valves** (Figure 23.21b), which prevent feces from being passed along with flatus (gas).

The Anal Canal The last subdivision of the large intestine is the **anal canal** (see Figure 23.21b). About 3 cm long, it begins where the rectum passes through the levator ani, the muscle that forms the pelvic floor. A portion of the levator ani is responsible for maintaining the anorectal angle, an acute angle between the anus and the rectum that contributes to fecal continence. The anal canal lies entirely external to the abdominopelvic cavity in the perineum.

Internally, the superior half of the anal canal contains longitudinal folds of mucosa, the **anal columns**. These columns contain the terminal portions of the superior rectal artery and vein (the hemorrhoidal vessels). Neighboring anal columns join each other inferiorly at crescent-shaped transverse folds called **anal valves.** The pockets just superior to these valves are **anal sinuses,** which release mucus when they are compressed by feces, providing lubrication that eases fecal passage during defecation.

The horizontal line along which the anal valves lie is called the *pectinate* ("comb-shaped") or *dentate* ("tooth-shaped") *line.* Because the mucosa superior to this line is innervated by visceral sensory fibers, it is relatively insensitive to pain. Inferior to the pectinate line, however, the mucosa is sensitive to pain because it is innervated by somatic nerves.

The wall of the anal canal contains two sphincter muscles: an **internal anal sphincter** of smooth muscle and an **external anal sphincter** of skeletal muscle (Figure 23.21b). The former is a thickening of the circular layer of the muscularis, whereas the latter is a distinct muscle (shown in Figure 11.15b on p. 295). The external sphincter contracts voluntarily to inhibit defecation, whereas the internal sphincter contracts involuntarily, both to prevent feces from leaking from the anus between defecations and to inhibit defecation during emotional stress. During toilet training, children learn to control the external anal sphincter.

Vessels and Nerves The first half of the large intestine—to a point two-thirds of the way along the transverse colon—is supplied by the superior mesenteric vessels. Its sympathetic innervation is from the superior mesenteric and celiac ganglia and plexuses, and its parasympathetic innervation is from the vagus nerve.

The distal half of the large intestine, up to the proximal portion of the rectum, is supplied by the inferior mesenteric vessels. The lower rectum and the anal canal are served by rectal branches of the internal iliac vessels. The sympathetic innervation of the distal half of the large intestine is via the inferior mesenteric and hypogastric plexuses, and the parasympathetic innervation is from the pelvic splanchnic nerves. The final part of the anal canal below the pectinate line is innervated by somatic nerves, such as the pudendal nerve.

Defecation The rectum is usually empty and the anal sphincters contracted. When feces are squeezed into the rectum by mass peristaltic movements, the stretching of the rectal wall initiates the defecation reflex (**Figure 23.22**, ①). Mediated by the sacral spinal cord, this parasympathetic reflex signals the walls of the sigmoid colon and rectum to contract and the anal sphincters to relax (Figure 23.22, ②). If one decides to delay defecation, the reflexive contractions end, and the rectum relaxes. Another mass movement occurs a few minutes later, initiating the defecation reflex again—and so on, until one chooses to defecate (Figure 23.22, ③) or the urge to defecate becomes unavoidable.

During defecation, the musculature of the rectum contracts to expel the feces. This process is supplemented by the voluntary contraction of the diaphragm and the abdominal wall muscles, which increases intra-abdominal pressure, and of the levator ani muscle (diagrammed on p. 295), which lifts the anal canal superiorly, leaving the feces inferior to the anus and thus outside the body.

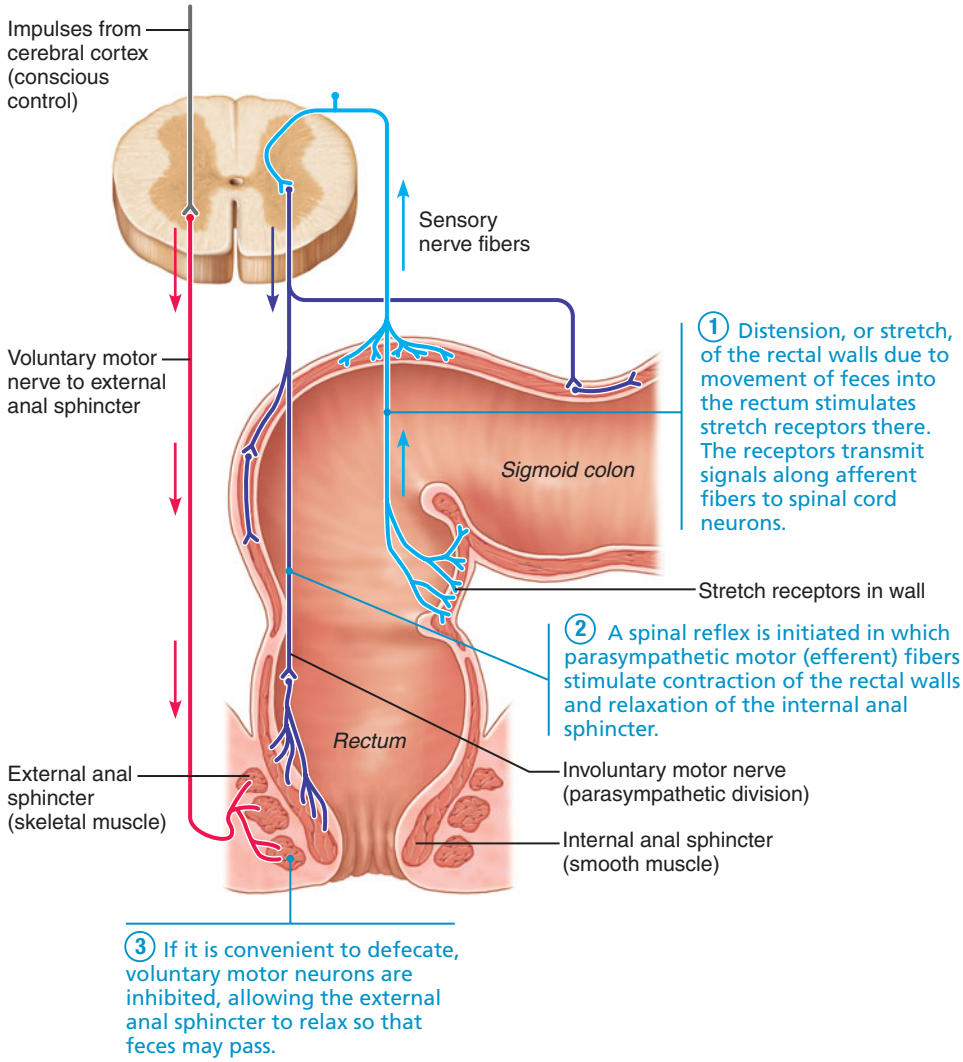


FIGURE 23.22 **Defecation reflex.**

HEMORRHOIDS Varicose veins of the hemorrhoidal veins in the anal canal (see Figure 23.21b) are called **hemorrhoids;** they often result from straining to deliver a baby or to defecate. Because they are stretched and inflamed, the swollen veins throb and bulge into the lumen of the anal canal. Internal hemorrhoids occur above the pectinate line, and external hemorrhoids occur below the pectinate line. External hemorrhoids are itchier and more painful, but only internal hemorrhoids tend to bleed. About 75% of Americans develop hemorrhoids at some time in their lives.

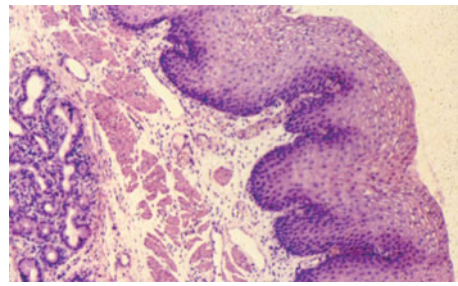
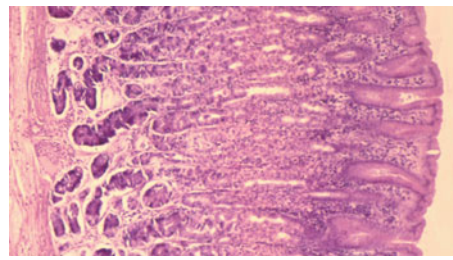
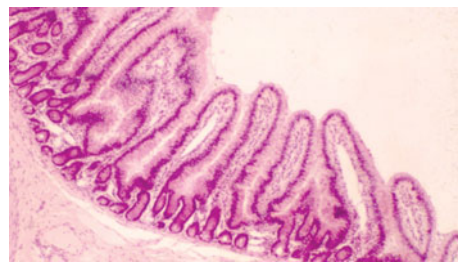
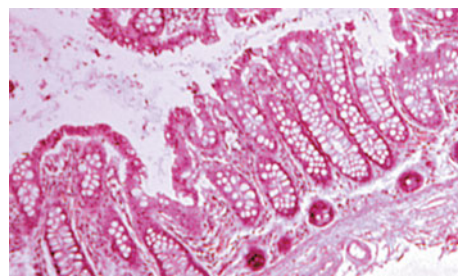
Severe hemorrhoids are often treated by tying them at their base with small rubber bands, whereupon they wither and fall away. They can also be injected with a hardening agent or exposed to electricity or strong infrared light to coagulate the blood within them. These unpleasant-sounding treatments are simple and effective and have largely eliminated the difficult surgical removals that were formerly performed.

Microscopic Anatomy

The wall of the large intestine **(Figure 23.23)** resembles that of the small intestine in some ways and differs from it in others. The internal surface of the colon is lined by a simple columnar epithelium containing the same cell types as in the small intestine. Goblet cells are more abundant in the large intestine, for they secrete large amounts of lubricating mucus that eases the passage of feces toward the end of the alimentary canal. The *absorptive cells* take in water and electrolytes. Villi are absent, which reflects the fact that fewer nutrients are absorbed in the large intestine. Intestinal crypts are present as simple tubular glands containing many goblet cells. Finally, undifferentiated stem cells occur at the bases of the intestinal crypts, and epithelial cells are fully replaced every week or so.

The other layers of the wall are rather typical. The lamina propria and submucosa contain more lymphoid tissue than occurs elsewhere in the alimentary canal, but this is not surprising, considering the extensive bacterial flora of the large intestine. The specializations of the muscularis externa and serosa, namely the teniae coli and epiploic appendages, were discussed previously.

TABLE 23.2 Overview of the Functions of the Gastrointestinal Organs

Organ	Major Functions*	Histology of the Mucosa
Mouth and associated accessory organs Pharynx and esophagus	■ Ingestion: food is voluntarily placed into oral cavity. ■ Propulsion: swallowing initiated by tongue; propels food into pharynx. ■ Mechanical digestion: mastication (chewing) by teeth and mixing movements by tongue. ■ Chemical digestion: chemical breakdown of starch is begun by salivary amylase present in saliva produced by salivary glands. ■ Propulsion: peristaltic waves move food bolus to stomach.	 Mucosal epithelium composed of stratified squamous cells (21×).
Stomach	■ Mechanical digestion and propulsion: peristaltic waves mix food with gastric juice and propel it into the duodenum. ■ Chemical digestion: digestion of proteins begun by pepsin. ■ Absorption: absorbs a few fat-soluble substances (aspirin, alcohol, some drugs).	 Gastric glands in the mucosa of simple columnar epithelium secrete mucus, hydrochloric acid, and enzymes (21×).
Small intestine and associated accessory organs (liver, gallbladder, pancreas)	■ Mechanical digestion and propulsion: segmentation by smooth muscle of the small intestine mixes contents with digestive juices, and peristalsis moves food along tract and through ileocecal valve at a slow rate. ■ Chemical digestion: digestive enzymes conveyed in from pancreas and brush border enzymes attached to microvilli membranes complete digestion of all classes of foods. ■ Absorption: breakdown products of carbohydrate, protein, fat, and nucleic acid digestion, plus vitamins, electrolytes, and water, are absorbed by active and passive mechanisms.	 Villi, projections of the mucosa, and microvilli on the absorptive cells increase the surface area for digestion and absorption (21×).
Large intestine	■ Chemical digestion: some remaining food residues are digested by enteric bacteria (which also produce vitamin K and some B vitamins). ■ Absorption: absorbs most remaining water, electrolytes (largely NaCl), and vitamins produced by bacteria. ■ Propulsion: propels feces toward rectum by peristalsis, haustral churning, and mass movements. ■ Defecation: reflex triggered by rectal distension; eliminates feces from body.	 Large numbers of goblet cells secrete mucus to aid the passage of feces (21×).

*The colored boxes beside the functions correspond to the color coding of digestive functions illustrated in Figure 23.2.

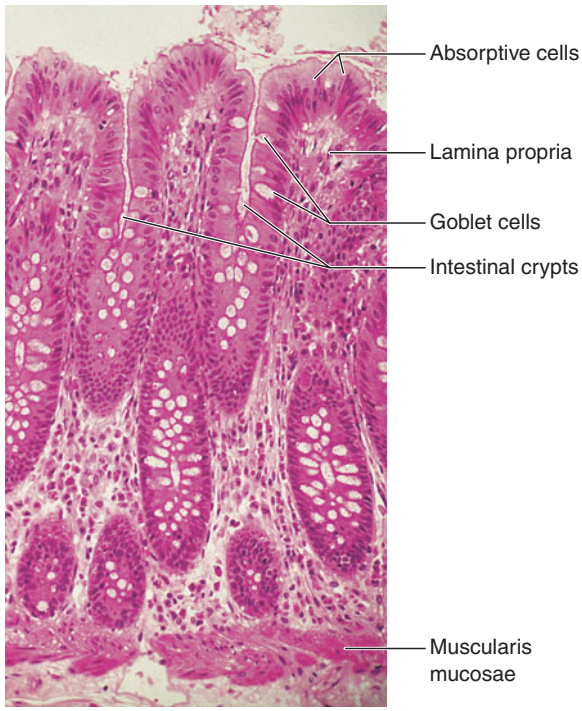


FIGURE 23.23 The mucosa of the large intestine. Photomicrograph. Note the abundance of goblet cells (140×).

The *anal canal* is a zone of epithelial transition in which the simple columnar epithelium of the intestine abruptly changes to stratified squamous epithelium near the level of the pectinate line. At the extreme inferior end of the anal canal, the mucosa merges with the true skin that surrounds the anus.

Table 23.2 summarizes the digestive activities in each portion of the alimentary canal. The histology of the mucosa in each region is also illustrated, allowing a visual comparison of the distinctive features of this layer throughout the alimentary canal. Modifications of the mucosal layer most obviously differentiate the regions of the alimentary canal.

check your understanding

14. What is the typical life span for an intestinal epithelial cell? How are the cells of the epithelium replaced?
15. Name all the parts of the large intestine, beginning with its junction with the ileum.
16. Name the structures within the villus that receive absorbed nutrients. Which types of nutrients are absorbed into each structure?

For answers, see Appendix B.

ANATOMY OF THE ACCESSORY ORGANS

➤ Describe the gross and microscopic anatomy and functions of the liver, gallbladder, and pancreas.

The Liver

The ruddy **liver** is the largest gland in the body, weighing about 1.4 kg (3 pounds) in an average adult. Amazingly versatile, it performs over 500 functions. Its digestive function is to produce **bile,** a green alkaline liquid that is stored in the gallbladder and secreted into the duodenum. Bile salts emulsify fats in the small intestine; that is, they break up fatty nutrients into tiny particles, just as dish detergent breaks up a pool of fat drippings in a roasting pan. These smaller particles are more accessible to digestive enzymes from the pancreas. The liver also performs many metabolic functions: It picks up glucose from nutrient-rich blood returning from the alimentary canal and stores this carbohydrate as glycogen for subsequent use by the body; it processes fats and amino acids and stores certain vitamins; it detoxifies many poisons and drugs in the blood; and it makes the blood proteins. Almost all of these functions are carried out by a type of cell called a **hepatocyte** (hep′ah-to-sīt″), or simply a *liver cell.*

Gross Anatomy

The liver lies inferior to the diaphragm in the right superior part of the abdominal cavity (Figure 23.4), filling much of the right hypochondriac and epigastric regions and extending into the left hypochondriac region. It lies almost entirely within the rib cage, which protects this highly vascular organ from blows that could rupture it. The liver is shaped like a wedge, the wide base of which faces right and the narrow apex of which lies just inferior to the level of the left nipple.

The liver has two surfaces: the *diaphragmatic* and *visceral* surfaces (Figures 23.24 and 23.25). The **diaphragmatic surface** faces anteriorly and superiorly, whereas the **visceral surface** faces posteroinferiorly. Even though most of the liver is covered with a layer of visceral peritoneum, the superior part, called the **bare area,** is fused to the diaphragm and is therefore devoid of peritoneum.

The liver has a **right lobe** and a **left lobe,** which traditionally were considered to be divided by the **falciform ligament** on the anterior part of the diaphragmatic surface (Figure 23.24) and the **fissure** on the visceral surface (Figure 23.25). The falciform ligament is a vertical mesentery that binds the liver to the anterior abdominal wall, and the fissure is a deep groove in the same sagittal plane as the falciform ligament. Two other lobes, the **quadrate lobe** and the **caudate lobe,** are visible on the visceral surface just to the right of the fissure. Long considered part of the right lobe, these lobes are now considered part of the left lobe, with which they share nerves and vessels.

Nerves and Vessels An important area near the center of the visceral surface is the **porta hepatis** (por′tah hep-ah′tis; "gateway to the liver"), where most of the major vessels and nerves enter and leave the liver (Figure 23.25). The right and left branches of the *hepatic portal vein,* which carry nutrient-rich blood from the stomach and intestines, enter the porta hepatis, as do the right and left branches of the *hepatic artery* carrying oxygen-rich blood to the liver. The **right** and **left hepatic ducts,** which carry bile from the respective liver lobes, exit from the porta hepatis and fuse to form the

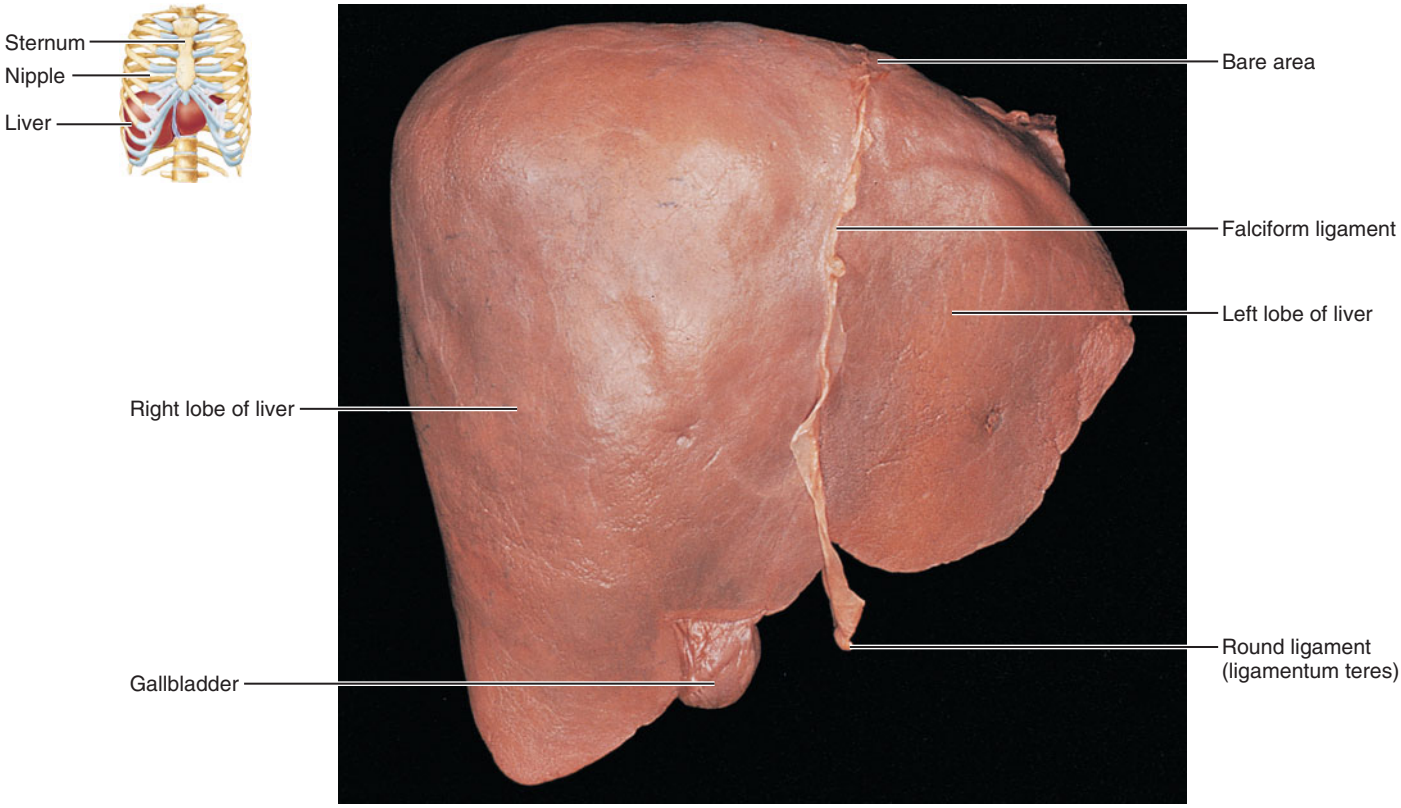


FIGURE 23.24 Anterior view of the liver. (See *A Brief Atlas of the Human Body,* Second Edition, Figure 64a).

common hepatic duct, which extends inferiorly toward the duodenum (shown in Figure 23.19). Autonomic nerves reach the liver from the celiac plexus and consist of both sympathetic and parasympathetic (vagal) fibers. Other important structures on the liver's visceral surface are the *gallbladder* and the *inferior vena cava,* which lie to the right of the quadrate and caudate lobes, respectively. The inferior vena cava receives the *hepatic veins* carrying blood out of the liver.

Several structures pass through the liver's fissure. Lying in the fissure's inferior half is the **ligamentum teres** (*teres* = round), or **round ligament.** This cordlike ligament, the remnant of the umbilical vein in the fetus, ascends to the liver from the navel, within the inferior margin of the falciform ligament. Additionally, the superior half of the liver's fissure contains the **ligamentum venosum** (Figure 23.25), a cordlike remnant of the ductus venosus of the fetus (see pp. 611–612 for a review of fetal circulation).

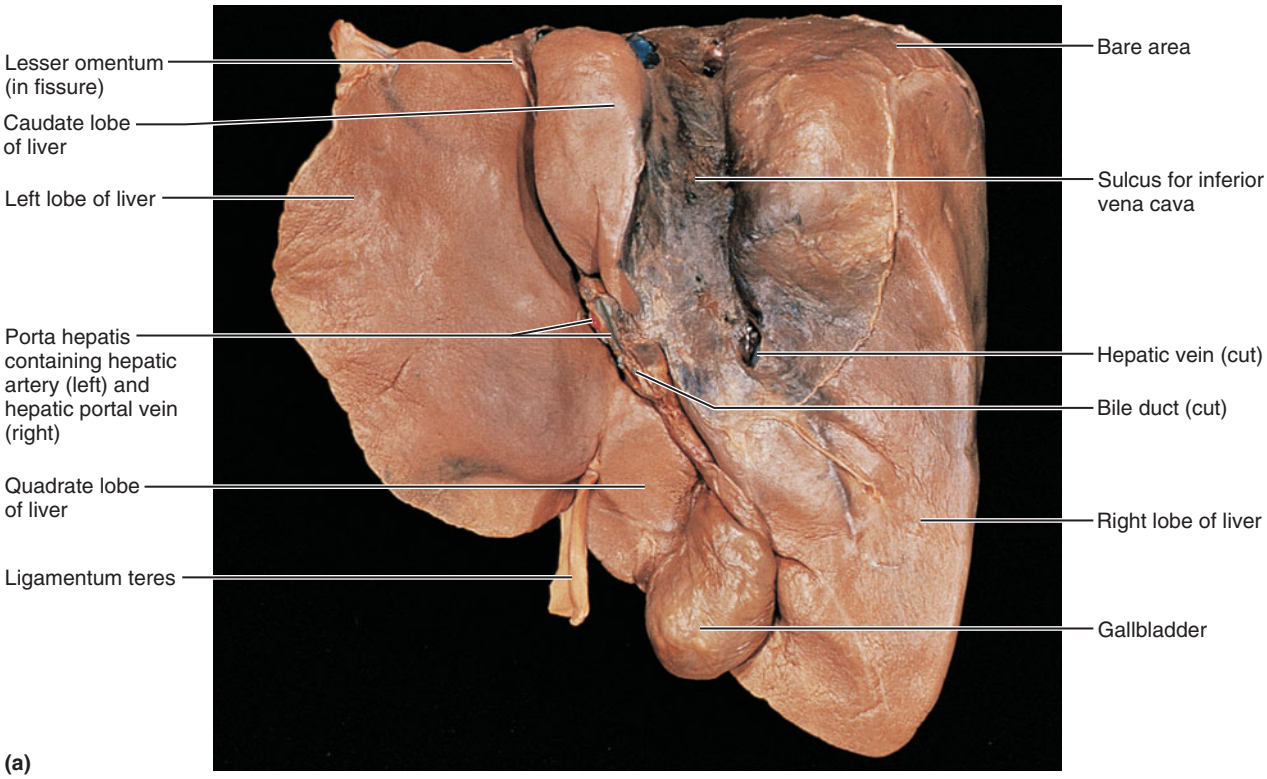
Microscopic Anatomy

The liver contains over a million classical **liver lobules** (Figure 23.26a), each about the size of a sesame seed. Each lobule is shaped like a hexagonal (six-sided) solid and consists of plates of liver cells, or **hepatocytes,** radiating out from a **central vein** (Figure 23.26b and c). If you were to look at the top of a thick paperback book opened so wide that its two covers touched each other, you would have a rough model of the liver lobule, with the spreading pages representing the plates of hepatocytes, and the hollow cylinder formed by the rolled spine representing the central vein. The hepatocytes in each plate are organized like bricks in a wall.

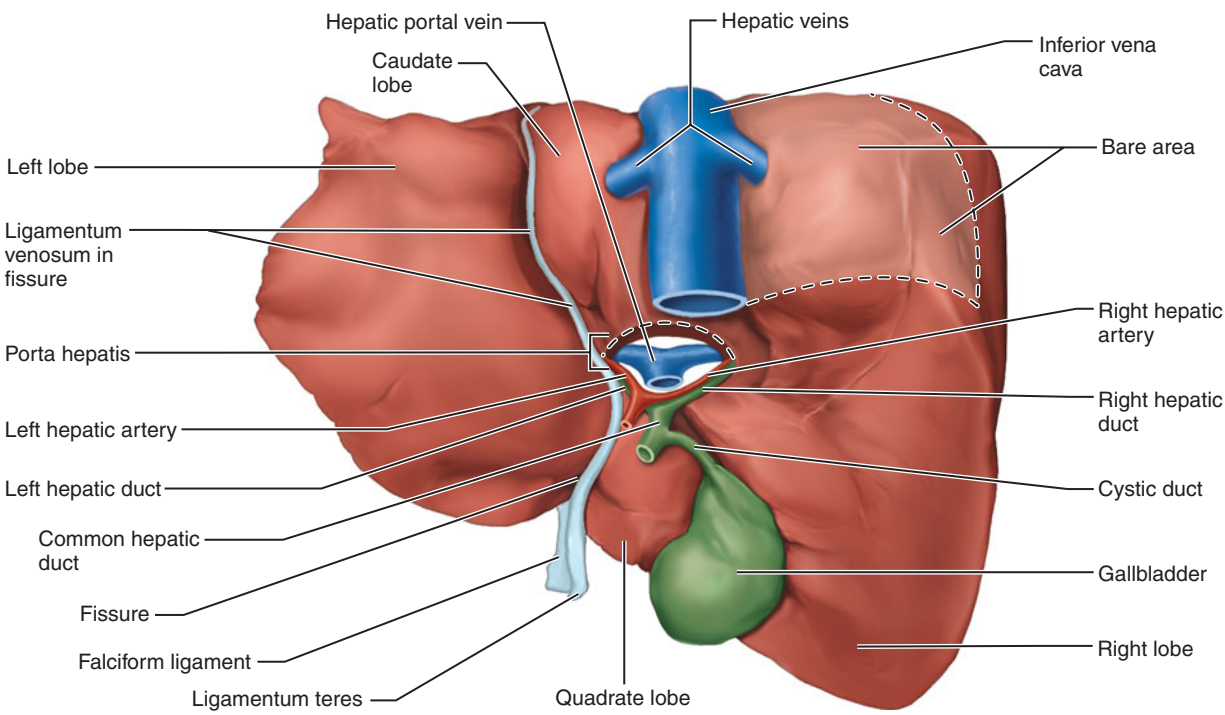
At almost every corner of the lobule is a **portal triad** (tri′ad; "three"; Figure 23.26c). The portal triad contains three main vessels: a portal arteriole that is a branch of the hepatic artery, a portal venule that is a branch of the hepatic portal vein, and a **bile duct** (which carries bile away from the liver lobules). Note that the blood vessels bring both arterial and venous blood to the lobule. The arterial blood supplies the hepatocytes with oxygen, and blood from the portal vein delivers substances from the intestines for processing by the hepatocytes.

Between the plates of hepatocytes are large capillaries, the **liver sinusoids.** Near the portal triads, these sinusoids receive blood from both the portal arteriole and venule and carry this blood inward to reach the central vein (Figure 23.26c). From there, the central veins form tributaries (interlobular veins) that ultimately lead to the hepatic veins and then to the inferior vena cava outside the liver.

In the walls of the sinusoids are **hepatic macrophages,** which destroy bacteria and other foreign particles in the blood flowing past them. Thus, even though microorganisms in the intestine may enter the intestinal capillaries, few of them make it past the liver. Besides cleansing the blood of microorganisms, the hepatic macrophages also destroy worn-out blood cells—as do macrophages of the spleen and bone marrow.



(a)



(b)

FIGURE 23.25 Visceral surface of the liver (posteroinferior view). (a) Photograph. **(b)** Illustration. Note the vessels and ducts that enter and leave the liver. (See *A Brief Atlas of the Human Body,* Second Edition, Figure 65.)

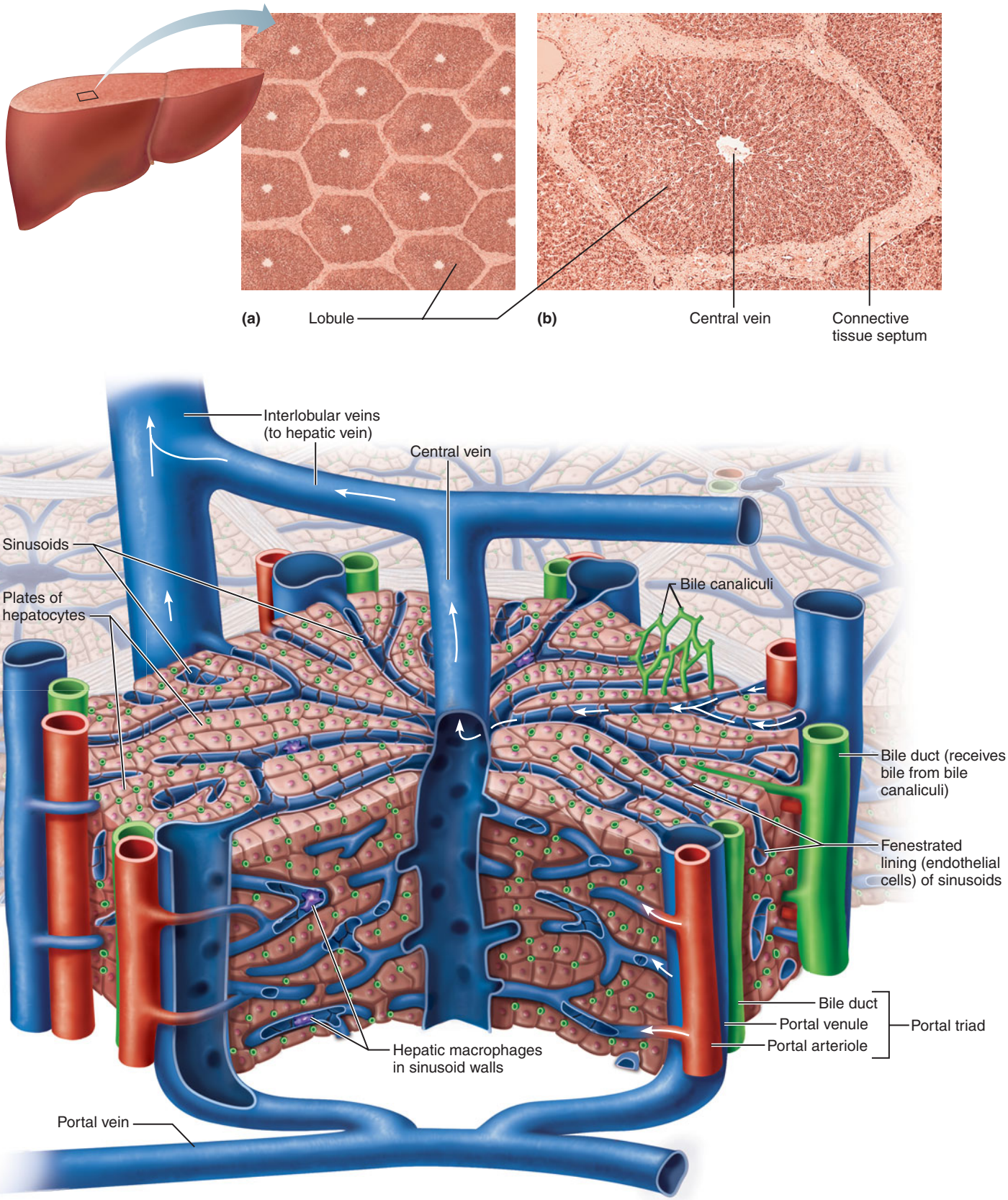


FIGURE 23.26 Microscopic anatomy of the liver. (a) Normal lobular pattern of the liver. **(b)** Enlarged view of one liver lobule. **(c)** Three-dimensional representation of a small portion of one liver lobule, showing the structure of sinusoids. Arrows indicate the direction of blood flow.

The liver sinusoids are lined by an exceptionally leaky, fenestrated endothelium (Figure 23.26c). Vast quantities of blood plasma pour out of the sinusoids, bathing the hepatocytes with fluid. Hepatocytes require proximity to such a large blood supply because so many of their functions depend on interactions with the fluid portion of blood.

Hepatocytes possess a large number of many different organelles that enable them to carry out their many functions:

- The abundant rough ER manufactures the blood proteins.
- The well-developed smooth ER helps produce bile salts and detoxifies bloodborne poisons.
- Abundant peroxisomes detoxify other poisons (including alcohol; the mechanism for this process is discussed on p. 33).
- The large Golgi apparatus packages the abundant secretory products from the ER.
- Large numbers of mitochondria provide energy for all these processes.
- The numerous glycosomes store sugar, reflecting the role of hepatocytes in blood sugar regulation.

Collectively, hepatocytes produce about 500–1000 ml of bile each day. The secreted bile enters tiny intercellular spaces or channels, called **bile canaliculi** ("little canals"), that lie between adjacent hepatocytes (Figure 23.26c). These canaliculi carry bile outward through each lobule, emptying into the bile ducts in the portal triads. From there, the bile flows into progressively larger ducts, exiting the liver through the hepatic ducts at the porta hepatis. Beyond this, additional bile-carrying ducts lead to the duodenum, as described shortly.

Finally, hepatocytes have a great capacity for cell division and regeneration: Judging from experiments on laboratory animals, if half of a person's liver were removed, it would regenerate in a few weeks! Cellular replacement occurs through the division of mature hepatocytes and of *liver stem cells,* which are located near the bile ducts at the portal triads.

CIRRHOSIS A progressive inflammation of the liver is called **cirrhosis** (sĭ-ro′sis; "orange-colored"); it usually results from chronic alcoholism. Even though the alcohol poisoned hepatocytes are continuously replaced, the liver's connective tissue regenerates faster, so the liver becomes fibrous and fatty, and its function declines. The scar tissue impedes the flow of blood through the liver, causing portal hypertension, elevation of blood pressure in the hepatic portal vessels. The patient may grow confused or comatose as toxins accumulate in the blood and depress brain functions. Besides alcoholism, other causes of cirrhosis include hepatitis (see "Viral Hepatitis" on p. 700) and autoimmune attack on the bile ducts.

The Gallbladder

Gross Anatomy

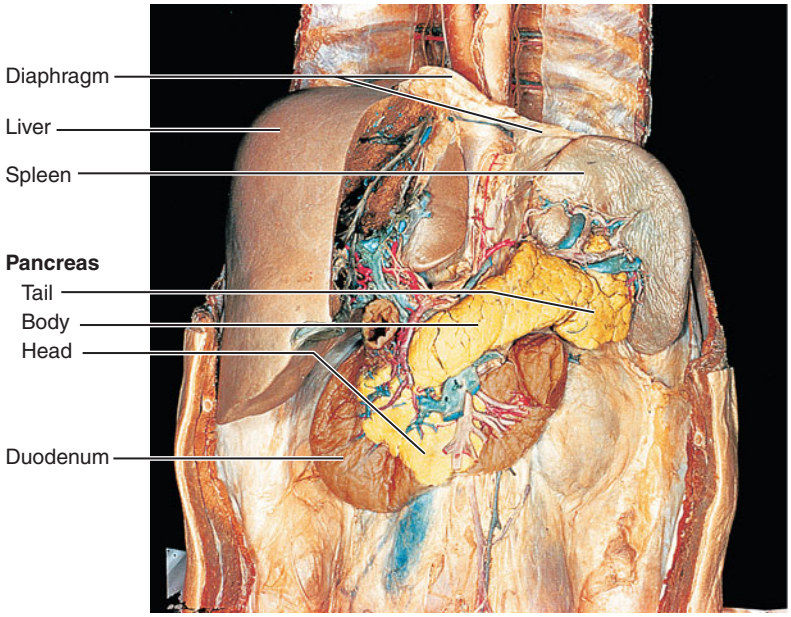
The **gallbladder** is a muscular sac, resting in a shallow depression on the visceral surface of the right lobe of the liver (Figure 23.25). It stores and concentrates bile produced by the liver. Its rounded head, or *fundus,* protrudes from the liver's inferior margin (Figure 23.24). The position of the fundus of the gallbladder can be identified superficially on the abdominal wall. It is located on the right side just deep to where the lateral margin of the rectus abdominis muscle crosses the costal margin of the rib cage. This point is diagrammed on Figure 11.31, p. 333, at the intersection of the linea semilunaris and the costal margin. Internally, a honeycomb pattern of mucosal foldings (see Figure 23.19) enables the mucosa to expand as the gallbladder fills.

The gallbladder's duct, the **cystic duct** (*cyst* = bladder; Figure 23.19), joins the common hepatic duct from the liver to form the **bile duct,** which empties into the duodenum. The liver secretes bile continuously, but sphincters at the end of the bile duct and at the hepatopancreatic ampulla are closed when bile is not needed for digestion. At these times, bile backs up through the cystic duct into the gallbladder for storage. When fatty chyme from a meal enters the duodenum, the gallbladder's muscular wall contracts in response to the hormone *cholecystokinin,* which is released from the enteroendocrine cells of the duodenum. The sphincters at the end of the duct system relax, and bile is expelled from the gallbladder through the cystic duct to the bile duct into the duodenum.

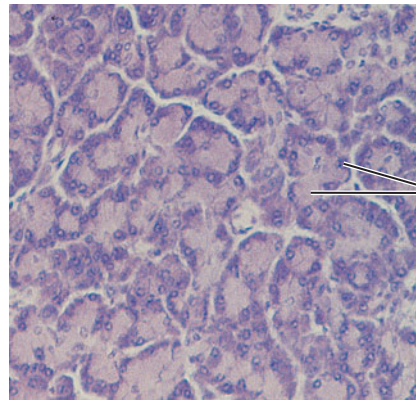
Microscopic Anatomy

Histologically, the wall of the gallbladder has fewer layers than the wall of the alimentary canal: (1) a mucosa consisting of a simple columnar epithelium and a lamina propria, (2) one layer of smooth muscle, and (3) a thick outer layer of connective tissue that is covered by a serosa wherever it is not in direct contact with the liver. The columnar cells of the lining epithelium concentrate the bile by absorbing some of its water and ions.

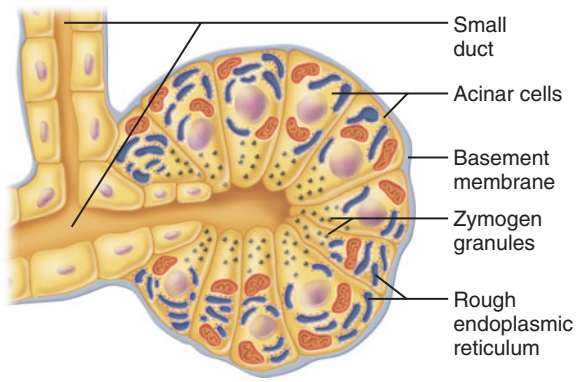
GALLSTONES Bile is the normal vehicle in which cholesterol is excreted from the body, and bile salts keep the cholesterol dissolved within bile. Either too much cholesterol or too few bile salts can lead to the crystallization of cholesterol in the gallbladder, producing **gallstones** that can plug the cystic duct and cause agonizing pain when the gallbladder or its duct contracts. Gallstones are easy to diagnose because they show up well with ultrasound imaging. Treatments include administering drugs that might dissolve the stones, and *laparoscopic cholecystectomy* (ko″le-sis-tek′to-me), a minimally invasive surgical technique for removing the gallbladder. In this procedure, a viewing scope and surgical tools threaded through small holes in the anterior abdominal wall at the location of the fundus are used to excise the gallbladder. Any gallstones remaining in the common bile duct are vaporized using a laser.



(a) Dissection illustrating the pancreas and its relationship to surrounding organs in the superior abdomen



(b) Photomicrograph of the exocrine acinar cells of the pancreas (160×)



(c) Illustration of the pancreatic acinar cells

FIGURE 23.27 The gross and microscopic anatomy of the pancreas.
In (a), the stomach and much of the liver have been removed.

The Pancreas

The **pancreas** ("all meat") is both an exocrine gland and an endocrine gland. In its endocrine function, the pancreas secretes two major hormones, insulin and glucagon, which lower and raise blood sugar levels, respectively. The endocrine pancreas is discussed in detail in Chapter 17. Its exocrine function is to produce most of the enzymes that digest foodstuffs in the small intestine.

Gross Anatomy

The pancreas, which is secondarily retroperitoneal, lies in the epigastric and left hypochondriac regions of the abdomen. It is shaped like a tadpole, with head, body, and tail regions **(Figure 23.27a)**, its head lies in the C-shaped curvature of the duodenum, and its tail extends to the left to touch the spleen.

The **main pancreatic duct** extends through the length of the pancreas (Figure 23.19). As previously mentioned, this duct joins the bile duct to form the hepatopancreatic ampulla and empties into the duodenum at the major duodenal papilla. An **accessory pancreatic duct** lies in the head of the pancreas and either drains into the main duct or drains directly into the duodenum.

Nerves and Vessels The pancreas receives blood through branches of the hepatic, splenic, and superior mesenteric vessels. Its autonomic nerves are from the celiac plexus. Sympathetic input derives from the thoracic splanchnic nerves, whereas parasympathetic input is from the vagus nerve.

Microscopic Anatomy

Microscopically, the pancreas consists of many exocrine glands intermixed with fewer clusters of endocrine cells. These exocrine glands—compound acinar glands that open into the two large ducts like clusters of grapes attached to two main vines—will be considered first. The acini of these glands consist of serous **acinar cells** (Figure 23.27b and c), which make, store, and secrete at least 22 kinds of pancreatic enzymes capable of digesting the various categories of foodstuffs. The enzymes are stored in inactive form in intracellular secretory granules called **zymogen granules** (zī′mo-jen; "fermenting"). The acinar cells also contain an elaborate rough ER and Golgi apparatus, typical features of cells that secrete proteins. From each acinus, the secreted product travels through the pancreatic duct system to the duodenum, where the enzymes are activated. Furthermore, the epithelial cells that line the smallest pancreatic ducts secrete a

bicarbonate-rich fluid that helps neutralize acidic chyme in the duodenum. Also among the duct cells are stem cells that form new acini and endocrine cells.

PANCREATITIS Inflammation of the pancreas, or **pancreatitis** (pan″kre-ah-tī′tis), usually accompanied by necrosis of pancreatic tissue, is a painful condition that is usually caused by the blockage of the pancreatic duct, either by gallstones or by an alcoholism-induced precipitation of protein. The blockage results in activation of the pancreatic enzymes in the pancreas instead of the small intestine. Pancreatitis can lead to nutritional deficiencies, diabetes, pancreatic infections, and, finally, to death through circulatory shock as the mediators of inflammation pour into the bloodstream from the damaged pancreas.

check your understanding

17. Name the vessels and ducts that pass through the porta hepatis. Indicate what is found within each structure and whether its content goes into the liver or away from the liver.
18. Trace the path of blood drained from the digestive tract through a liver lobule.
19. Which cells in the pancreas produce and secrete digestive enzymes? Where do these secretions empty into the alimentary canal?

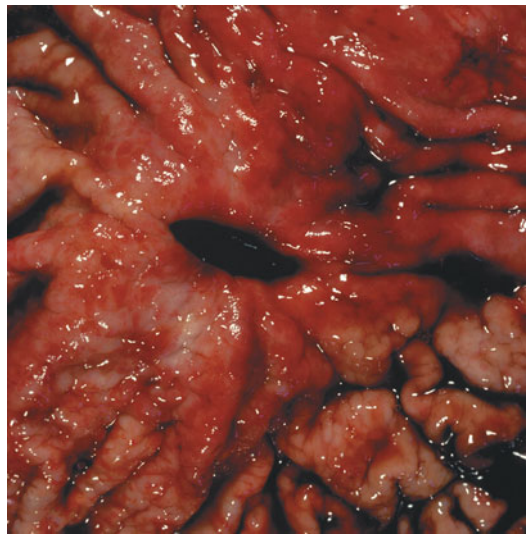
For answers, see Appendix B.

DISORDERS OF THE DIGESTIVE SYSTEM

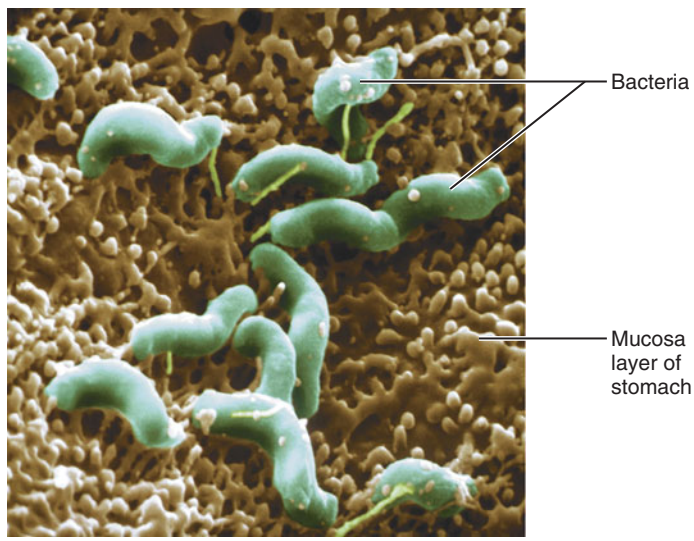
➤ Describe some disorders of the digestive organs.

Peptic Ulcers

Ulcers are craterlike erosions of the mucosa in any region of the alimentary canal that is exposed to stomach secretions **(Figure 23.28a)**. The majority of peptic ulcers occur in the pyloric region of the stomach (**gastric ulcers**) or in the duodenum of the small intestine (**duodenal ulcers**). The typical symptom of a peptic ulcer is a chronic burning sensation in the epigastric region usually 1–3 hours after a meal. Ulcers, traditionally thought to be caused by stress, are now known to be an infectious disease caused by a spiral-shaped, acid-resistant bacterium, *Helicobacter pylori* (Figure 23.28b). *H. pylori* binds to the gastric epithelium and induces oversecretion of acid and inflammation, which lead to ulcers. Approximately 20% of people in the United States under the age of 40 and 50% over age 60 harbor *H. pylori*, although most are either resistant or have a harmless strain. The bacterium is spread via fecal contamination of food or water. A simple 2-week regimen of antibiotics permanently cures peptic ulcers in most patients.



(a) A gastric ulcer lesion



(b) *H. pylori* bacteria

FIGURE 23.28 Peptic ulcers.

Intestinal Obstruction

Any hindrance to the movement of chyme or feces through the intestine is called **intestinal obstruction.** Most obstructions are *mechanical*—due to hernias of the bowel or twists that pinch the bowel shut, intestinal tumors or adhesions, or foreign objects lodged in the bowel. *Nonmechanical* obstruction, by contrast, is due to a halt in peristalsis. This can occur when movement of the intestine is inhibited by trauma or when the intestine is touched during surgery. About 85% of all obstructions occur in the small intestine; the remainder affect the large intestine. Common symptoms include cramps, vomiting, nausea, and failure to pass gas and feces.

Inflammatory Bowel Disease

Up to 2 of every 1000 people are affected by **inflammatory bowel disease,** a noncontagious, periodic inflammation of the intestinal wall characterized by chronic leukocyte infiltration of this wall. Symptoms include cramping, diarrhea, weight loss, and intestinal bleeding. Of the two subtypes of this condition, the form called *Crohn's disease* is the more serious, with deep ulcers and fissures developing along the entire intestine, but primarily in the terminal ileum. The other form, *ulcerative colitis,* is characterized by a shallow inflammation of the mucosa of the large intestine, mainly in the rectum. Although formerly thought to be a nervous condition, inflammatory bowel disease is now understood to be an abnormal immune and inflammatory response to bacterial antigens that normally occur in the intestine. Treatment involves adopting a special diet that is low in fiber and in dairy products, reducing stress, taking antibiotics, and, most effectively, administering anti-inflammatory and immunosuppressant drugs.

Viral Hepatitis

Hepatitis, the general term for any inflammation of the liver, is largely of viral origin. Upon infection, most types of **viral hepatitis** lead to flulike symptoms and jaundice (yellow skin and mucous membranes, an indication that the liver is not removing bile pigments from the blood to make bile). The major types of hepatitis are A, B, C, and G.

Hepatitis A, spread by the fecal-oral route, often in contaminated food or water, is characterized by an acute infection without long-term damage followed by recovery and lifelong immunity. Treatments include administration of antibodies, and effective preventive vaccines are available.

Hepatitis B is transmitted via infected blood or body fluids, or from mothers to newborns at birth. Most infected individuals recover and gain immunity, but some develop chronic liver disease and eventually cirrhosis, with an increased likelihood of developing liver cancer. Many hepatitis B patients can be helped with interferon (a substance that enhances the immune response against viruses) plus a combination of drugs that stops viral replication; an effective vaccine is also available.

Hepatitis C, like hepatitis B, is transmitted via body fluids and can lead to cirrhosis and liver cancer, but it has raised greater concern because it usually produces no short-term symptoms. As a result, it is difficult to diagnose, and many individuals do not know they are infected until they have spread the virus or develop serious symptoms, sometimes 20 years after infection. Some 4 million Americans have hepatitis C, and its spread is a serious health concern. No vaccine yet exists, but interferon and a drug that inhibits viral replication can help many patients.

Hepatitis G is as widespread as type C but seems to cause little liver damage.

Cystic Fibrosis and the Pancreas

Cystic fibrosis (described in more detail on p. 657) primarily disrupts secretions in the respiratory system, but most of the body's other secretory epithelia are affected as well. The pancreas and intestinal glands, submandibular glands, and bile ducts in the liver all become blocked with thick secretions. The most serious is the effect on the pancreas, in which the clogged ducts prevent the pancreatic juices from reaching the small intestine. As a result, fats and other nutrients are not digested or absorbed, and the feces are bulky and fat laden. This problem can be treated by administering pancreatic enzymes with meals. Eventually, the pancreas may become a mass of cystically dilated ducts surrounded by dense fibrous tissue and no acini.

THE DIGESTIVE SYSTEM THROUGHOUT LIFE

➤ Explain how the digestive organs develop in the embryo, and define the foregut, midgut, and hindgut.

Embryonic Development

Recall from Chapter 3 (p. 55) that the alimentary canal originates when the flat embryo folds into the shape of a cylinder, enclosing a tubular part of the yolk sac within its body. This folding produces the *primitive gut,* a tube of endoderm that is covered by splanchnic mesoderm. The endoderm gives rise to the lining epithelium of the alimentary canal, the epithelial lining of the gut-derived organs (liver, pancreas, and gallbladder), and all the secretory cells of the digestive glands; the splanchnic mesoderm gives rise to all other layers in the wall of the alimentary canal and the gut-derived organs.

Initially, the middle region of the primitive gut is open to the yolk sac through the **vitelline duct** (vi-tel′in; "yolk"), shown in **Figure 23.29a**. The vitelline duct is a key landmark that divides the embryonic gut into three basic regions: foregut, superior to the vitelline duct; midgut, open to the vitelline duct; and hindgut, inferior to the vitelline duct. The embryonic **foregut** develops into the first segment of the digestive system, from the pharynx to the point in the duodenum where the bile duct enters. The embryonic **midgut** becomes the segment beginning at the duodenum and extending to a point two-thirds of the way along the transverse colon. The **hindgut** forms the rest of the large intestine. The abdominal foregut, midgut, and hindgut—and their derivatives—are supplied by the celiac, superior mesenteric, and inferior mesenteric arteries, respectively.

The caudal part of the early hindgut joins a tubelike outpocketing called the **allantois** (ah-lan′to-is; "sausage"). The expanded junction between the hindgut and the allantois is the **cloaca** (klo-a′kah; "sewer"), which gives rise to the rectum and most of the anal canal, among other structures.

In the mouth region of the embryo, the endoderm-lined gut touches the surface ectoderm to form an **oral membrane,** which lies in a depression called the **stomodeum** (sto″mo-de′um; "on the way to becoming the mouth"). Similarly, at the end of the hindgut, endoderm meets ectoderm to form the **cloacal membrane** in a pit called the **proctodeum** (prok″to-de′um; "on the way to becoming the anus"). The oral membrane lies at the future mouth-pharynx boundary (the fauces), and the cloacal membrane lies in the future anal canal, roughly where the pectinate line will occur.

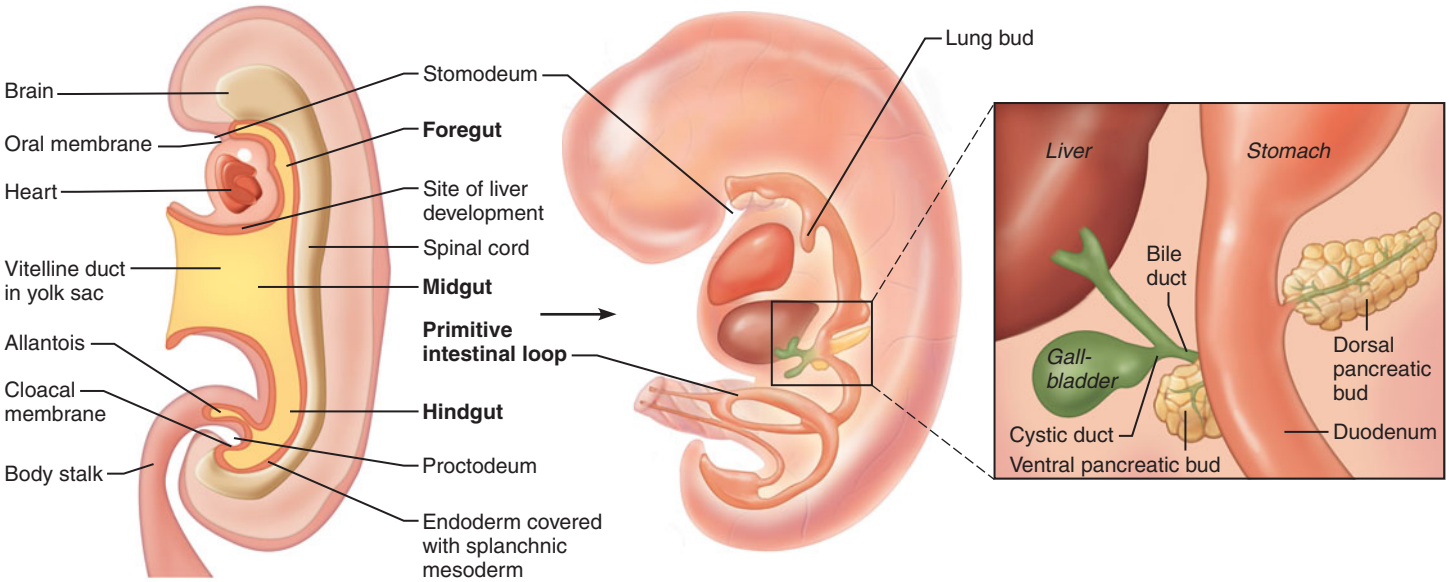


FIGURE 23.29 Development of the digestive system. (a) The primitive gut (composed of foregut, midgut, and hindgut) has formed. The midgut is still open and continuous with the yolk sac. The oral and cloacal membranes will be reabsorbed in a few weeks to form the oral and anal openings. **(b)** The liver and pancreas are budding off of the distal foregut. The pancreas forms from two pancreatic buds (ventral and dorsal) that later join.

The oral and cloacal membranes are reabsorbed during month 2, thereby opening the alimentary canal to the outside.

During weeks 4 and 5, the embryonic gut starts to elongate, bend, and form outpocketings (Figure 23.29b). Salivary glands arise as outpocketings from the mouth; the pharynx develops four or five pairs of lateral *pharyngeal pouches* (see Figure 1.5b, p. 10); and the future lungs and trachea bud off the distal pharynx (see p. 660). A spindle-shaped enlargement of the abdominal foregut is the first sign of the stomach; the liver and pancreas arise as buds from the last part of the foregut; and the midgut elongates into the **primitive intestinal loop.** In months 2 and 3, this loop rotates and elongates to bring the intestines into their final positions.

DEVELOPMENTAL ABNORMALITIES Failure of the vitelline duct to close completely can result in an outpocketing of the ileum, called **Meckel's diverticulum.** This is the most common developmental abnormality of the digestive system, occuring in 2% of the population, and is often asymptomatic. If the tissue within the diverticulum is of pancreatic or gastric origin, ulceration or bleeding may occur.

Abnormal rotation during development can cause the intestine to twist around itself, a condition called **volvulus,** which can disrupt the blood supply to the intestine, lead to death of the tissue in the affected portion, and cause intestinal blockage. Volvulus is treated by surgical removal of the affected portion of the gut.

The Digestive System in Later Life

Unless abnormal interferences occur, the digestive system operates through childhood and adulthood with relatively few problems. However, contaminated foods sometimes cause an inflammation of the alimentary canal called **gastroenteritis** (gas″tro-en″tĕ-ri′tis), the symptoms of which include nausea, vomiting, cramps, loss of appetite, or diarrhea. As previously mentioned, appendicitis is common in teenagers and young adults. Gallstones and ulcers are problems of middle age.

During old age, the activity of the digestive organs declines: Fewer digestive juices are produced; the absorption of nutrients becomes less efficient; and peristalsis slows. So much water is reabsorbed from the slow-moving fecal mass in the large intestine that the feces become hard and compacted. The result is a decrease in the frequency of bowel movements and, often, constipation.

Diverticulosis and cancer of the digestive organs are other common problems of the aged. Cancer of the stomach, colon, liver, or pancreas rarely exhibits early signs, and the cancer has often metastasized before the person seeks medical attention. These forms of cancer are deadly—colon cancer is the second leading cause of cancer deaths in the United States. However, if detected early, cancers of the digestive viscera are sometimes curable, colon and liver cancer more so than pancreatic or gallbladder cancer. The best advice is to have regular medical checkups. Half of all rectal cancers can be felt digitally during rectal exams, and nearly 80% of colon cancers can be seen during a colonoscopy (see pp. 96, 702).

Evidence suggests that diets high in plant fiber decrease the incidence of colon cancer.

check your understanding

20. Why is it so important to wash your hands after using the restroom?
21. What embryonic germ layer forms the epithelium of the mucosa? What germ layer forms the submucosa and muscularis externa?
22. What blood vessel supplies the structures derived from the embryonic midgut?

For answers, see Appendix B.

RELATED CLINICAL TERMS

ANAL FISSURE A longitudinal tear in the mucosa of the anal canal, often caused by the passage of hard, dry feces. Usually heals naturally, but most fissures that do not heal are in the posterior midline, which is poorly vascularized. Symptoms include pain and bleeding during defecation. Treatment includes using laxatives to soften the feces, glycerin suppositories, or in persistent cases, surgery.

ASCITES (ah-si′tēz; *asci* = bag, bladder) Abnormal accumulation of serous fluid that has leaked out of peritoneal capillaries into the peritoneal cavity; may be caused by portal hypertension following liver cirrhosis or by heart or kidney disease. Excessive ascites causes visible bloating of the abdomen.

ENDOSCOPY (en-dos′ko-pe; *endo* = inside; *scopy* = viewing) The viewing of the lining of a ventral body cavity or tubular organ with a flexible, tubelike device called an endoscope, which contains a lens and a light radiating from its tip. Endoscopes are used to view the internal surfaces of various parts of the alimentary canal, including the stomach (gastroscopy), the colon (colonoscopy), and the sigmoid colon (sigmoidoscopy). **Laparoscopy** (lap″ah-ros′ko-pe; "flank viewing") is the use of an endoscope inserted into the peritoneal cavity through the anterior abdominal wall, typically to assess the condition of the digestive organs and the pelvic reproductive organs in women.

ENTERITIS (*enteron* = intestine) Inflammation of the intestine, especially the small intestine.

LIVER BIOPSY (bi′op-se; *bio* = living; *opsis* = vision, viewing) Removal from the liver of a small piece of living tissue, which is then examined for signs of disease. The puncturing needle is inserted through the seventh, eighth, or ninth intercostal space, in the right midaxillary line (straight inferiorly from the axilla) after the patient has exhaled as much air as possible. (Exhalation minimizes the chances that the needle will pierce the lung.)

PYLORIC STENOSIS (*stenosis* = narrowing, constriction) Congenital condition in about 1 in 400 newborns, in which the pyloric sphincter of the stomach is abnormally constricted; the condition's characteristic sign, projectile vomiting, usually does not appear until the baby begins to eat solid food. This condition can usually be repaired surgically. Can also occur in adults through scarring caused by an ulcer or by a tumor that blocks the pyloric opening.

RECTOCELE (rek′to-sēl; *recto* = rectum; *cele* = sac) Condition in women in which the rectum pushes on the vagina and bulges into the posterior vaginal wall. Usually results from tearing of the supportive muscles of the pelvic floor during childbirth, which then allows the unsupported pelvic viscera to sink inferiorly. May also be associated with *rectal prolapse,* in which the rectal mucosa protrudes from the anus.

CHAPTER SUMMARY

You can use the following media study tool for additional help when you review specific key topics in Chapter 23.

PAL = **Practice Anatomy Lab™**

Overview (pp. 666–671)

1. The digestive system includes the alimentary canal (mouth, pharynx, esophagus, stomach, and small and large intestines) and accessory digestive organs (teeth, tongue, salivary glands, liver, gallbladder, and pancreas).

Digestive Processes (pp. 667–668)

2. The digestive system carries out the processes of ingestion, propulsion, mechanical digestion, chemical digestion, absorption, and defecation.

Abdominal Regions (p. 668)

3. The nine regions of the anterior abdominal wall are defined by two horizontal planes (subcostal and transtubercular planes) and by the vertical midclavicular lines. There are one epigastric and two hypochondriac regions superiorly, one umbilical and two lumbar regions in the middle, and one hypogastric (pelvic) and two iliac (inguinal) regions inferiorly. The anterior abdominal wall can also be divided into four quadrants.

The Peritoneal Cavity and Peritoneum (pp. 669–671)

4. The serous membrane in the abdominopelvic cavity is the peritoneum, which has a parietal layer (on the internal surface of the body wall) and a visceral layer (on the viscera). The slit between the visceral and parietal peritoneum, the peritoneal cavity, contains slippery serous fluid, which decreases friction as the organs move.
5. A mesentery is a double layer of peritoneum that tethers the movable digestive organs to the body wall. Mesenteries also store fat and carry blood vessels and nerves.
6. The mesenteries associated with the intraperitoneal abdominal organs are (1) the ventral mesenteries, the falciform ligament and lesser omentum; and (2) the dorsal mesenteries, the greater omentum, mesentery proper, transverse mesocolon, and sigmoid mesocolon. Digestive organs that lack a mesentery and are fused to the posterior body wall are called secondarily retroperitoneal organs.

Anatomy of the Alimentary Canal (pp. 671–692)

Histology (pp. 671–673)

7. The esophagus, stomach, and intestine share the same tissue layers: an inner mucosa, a fibrous submucosa, a muscularis externa, and an outer serosa (visceral peritoneum) or adventitia. The mucosa consists of a lining epithelium, lamina propria, and muscularis mucosae.

Smooth Muscle (pp. 673–675)

8. Smooth muscle fibers are elongated cells with tapering ends and one central nucleus. They have no striations or sarcomeres, but are filled with myofilaments that contract by the sliding filament mechanism. Intermediate filaments of the cytoskeleton run in lattice-like arrangement through the cell and beneath the sarcolemma. Actin myofilaments attach to these filaments at dense bodies.

9. Smooth muscle fibers are most often arranged in circular and longitudinal sheets.

10. Smooth muscle contracts for extended periods at low energy cost and without fatigue.

11. Smooth muscle is innervated by involuntary nerve fibers, which usually contact only a few muscle fibers per sheet. The impulse that signals contraction usually spreads from fiber to fiber through gap junctions. This is called single-unit innervation.

12. Visceral motor neurons do not form elaborate neuromuscular junctions with the visceral muscle and glands they innervate. Their axon terminals (varicosities) may even end some distance from the effector cells.

13. Visceral nerve plexuses (myenteric and submucosal) occur in the wall of the alimentary canal. These plexuses contain parasympathetic, sympathetic, and visceral sensory fibers as well as enteric neurons.

The Mouth and Associated Organs (pp. 675–680)

14. Food enters the alimentary canal through the mouth (oral cavity), which consists of an external vestibule and an internal oral cavity proper.

15. The mouth is lined by a stratified squamous epithelium, which resists abrasion by food fragments.

16. The lips and cheeks keep food inside the mouth during chewing. The red margin is the red part of the lips that borders the oral orifice.

17. The tongue is predominantly a mucosa-covered skeletal muscle. Its intrinsic muscles change its shape, and its extrinsic muscles change its position. Three classes of papillae occur on the tongue's superior surface: filiform papillae, which grip food during chewing, and fungiform and circumvallate papillae, which contain taste buds.

18. Saliva is produced by intrinsic salivary glands in the oral mucosa and by three pairs of large extrinsic salivary glands—the parotid, submandibular, and sublingual glands. The salivary glands are compound tubuloalveolar glands containing varying amounts of serous and mucous cells.

19. Teeth tear and grind food in the chewing process (mastication). The 20 deciduous teeth begin to fall out at age 6 and are gradually replaced during childhood and youth by the 32 permanent teeth.

20. Teeth are classified as incisors, canines, premolars, and molars. Each tooth has an enamel-covered crown and a cementum-covered root. The bulk of the tooth is dentin (dentine), which surrounds the central pulp cavity. A periodontal ligament (periodontium) secures the tooth to the bony alveolus.

The Pharynx (p. 680)

21. During swallowing, food passes from the mouth through the oropharynx and laryngopharynx, which are lined by a stratified squamous epithelium. The pharyngeal constrictor muscles squeeze food into the esophagus during swallowing.

The Esophagus (pp. 680–682)

22. The esophagus descends from the pharynx through the posterior mediastinum and into the abdomen. There it joins the stomach at the cardiac orifice, where a sphincter prevents superior regurgitation of stomach contents.

23. The esophageal mucosa contains a stratified squamous epithelium. The muscularis consists of skeletal muscle superiorly and smooth muscle inferiorly. The esophagus has an adventitia rather than a serosa.

The Stomach (pp. 682–685)

24. The J-shaped stomach churns food into chyme and secretes HCl and pepsin, which begins the breakdown of food proteins. Lying in the superior left part of the abdomen, its major regions are the cardia, fundus, body, pyloric region, and pylorus (containing the pyloric sphincter). Its right and left borders are the lesser and greater curvatures. When the stomach is empty, its internal surface exhibits rugae.

25. The internal surface of the stomach is lined by simple columnar epithelial cells that secrete mucus and dotted with gastric pits that lead into tubular gastric glands. Secretory cells in the gastric glands include pepsinogen-producing chief cells, parietal cells that secrete HCl, mucous neck cells, and enteroendocrine cells that secrete hormones (including gastrin).

26. The stomach wall is protected against self-digestion and acid by an internal coat of mucus and by the rapid regeneration of its lining epithelium.

The Small Intestine (pp. 685–688)

27. The small intestine is the main site of digestion and nutrient absorption. Its segments are the duodenum, jejunum, and ileum.

28. The duodenum lies secondarily retroperitoneally in the superior right quadrant of the abdomen. The bile duct and main pancreatic duct join to form the hepatopancreatic ampulla and empty into the duodenum through the major duodenal papilla.

29. The small intestine has four features that increase its surface area and allow rapid absorption of nutrients: its great length, circular folds of the mucosa, villi, and abundant microvilli on the absorptive cells. Absorbed nutrients enter capillaries in the core of the villi.

30. The epithelium lining the internal intestinal surface contains absorptive, goblet, and enteroendocrine cells. Between the villi are the intestinal crypts, which secrete intestinal juice and continuously renew the lining epithelium.

31. Other special features of the small intestine are (1) aggregated lymphoid nodules in the ileum and (2) the duodenal mucous glands.

The Large Intestine (pp. 688–693)

32. The large intestine, which concentrates feces by absorbing water, forms an open rectangle around the small intestine. Its subdivisions are the cecum and vermiform appendix, colon (ascending, transverse, descending, and sigmoid), rectum, and anal canal. Special features on the external surface of the colon and cecum are teniae coli, haustra, and epiploic appendages.

33. The cecum lies in the right iliac fossa and contains the ileocecal valve. Attached to the cecum is the vermiform appendix, which contains abundant lymphoid tissue.

34. Near the end of the large intestine, the sigmoid colon enters the pelvis and joins the rectum. The rectum pierces the pelvic floor and joins the anal canal, which ends at the anus. Internally, the rectum contains the transverse rectal folds, and the anal canal contains anal columns, anal valves, the pectinate line, and anal sinuses.

35. The defecation reflex produces a contraction of the rectal walls when feces enter the rectum. During defecation, contraction of the diaphragm and abdominal muscles increases the intra-abdominal pressure and lifts the anal canal. Defecation can be inhibited by the anal sphincters.

36. Like the small intestine, the large intestine is lined by a simple columnar epithelium with absorptive and goblet cells and contains intestinal glands. It lacks villi, secretes more mucus than the small intestine, and contains more lymphoid tissue than the small intestine.

Anatomy of the Accessory Organs (pp. 693–699)

The Liver (pp. 693–697)

37. The liver performs many functions, including processing of absorbed nutrients, secreting fat-emulsifying bile, and removing toxins from the blood.

38. The liver lies in the superior right region of the abdomen. It has diaphragmatic and visceral surfaces and four lobes (right, left, quadrate, and caudate). The quadrate and caudate lobes are parts of the left lobe. The bare area lies against the diaphragm.

39. Most vessels enter or leave the liver through the porta hepatis. Other structures on the visceral surface are the inferior vena cava, hepatic veins, gallbladder, fissure, round ligament, and ligamentum venosum.

40. Classical liver lobules are hexagonal structures consisting of plates of hepatocytes that are separated by blood sinusoids and converge on a central vein. Portal triads (venule branch of portal vein, arteriole branch of hepatic artery, bile duct) occur at most corners of the lobule.

41. Blood flows through the liver in the following sequence: through the branches of the hepatic artery and portal vein, through the sinusoids to supply the hepatocytes, and then to the central veins, hepatic veins, inferior vena cava, and heart. In the sinusoids, Kupffer cells (macrophages) remove bacteria and other foreign material from the blood.

42. Hepatocytes perform almost all liver functions: They manufacture blood proteins; detoxify poisons; metabolize glucose, fats, and amino acids; and produce bile. These liver cells secrete bile into the bile canaliculi. The bile proceeds to the bile ducts in the portal triads, to the hepatic ducts, and through the common hepatic duct to the gallbladder and duodenum.

The Gallbladder (p. 697)

43. The gallbladder, a green muscular sac, stores and concentrates bile. Its duct is the cystic duct. When fatty chyme enters the small intestine, the gallbladder squeezes bile into the bile duct and duodenum.

The Pancreas (pp. 698–699)

44. The tadpole-shaped pancreas is secondarily retroperitoneal. It runs horizontally across the posterior abdominal wall, between the duodenum and the spleen.

45. The pancreas is an exocrine gland containing many compound acinar glands that empty into the main and accessory pancreatic ducts. The serous acinar cells secrete digestive enzymes, and the smallest duct cells secrete an alkaline fluid. Both products are emptied into the duodenum.

46. The pancreas is also an endocrine gland, with hormone-secreting cells that regulate blood sugar.

PAL = **Human Cadaver/Digestive System**

Disorders of the Digestive System (pp. 699–700)

47. Disorders considered in this chapter include hiatal hernia of the esophagus, gastroesophageal reflux disease (p. 681), peptic ulcers, intestinal obstruction, inflammatory bowel disease, viral hepatitis, and the obstructive effect of cystic fibrosis on the pancreatic ducts.

The Digestive System Throughout Life (pp. 700–702)

Embryonic Development (pp. 700–701)

48. As the 3-week-old embryo assumes its cylindrical body shape, it encloses the primitive gut, a tube of endoderm covered by splanchnic mesoderm. The endoderm becomes the lining epithelium (and gland cells), and the splanchnic mesoderm gives rise to all other layers of the wall of the alimentary canal and the gut-derived organs.

49. The embryonic gut is divided into a foregut, midgut, and hindgut, which form distinct regions of the digestive system.

50. The primitive embryonic gut tube, straight at first, soon grows outpocketings (liver, pancreas, pharyngeal pouches), shows swellings (stomach, cloaca), and lengthens into a primitive intestinal loop. This loop rotates and elongates to bring the intestines into their final positions.

The Digestive System in Later Life (pp. 701–702)

51. Various diseases may plague the digestive organs throughout life. Appendicitis is common in young adults; gastroenteritis and food poisoning can occur at any time; and ulcers and gallbladder problems increase in middle age.

52. The efficiency of digestive processes declines in the elderly, and constipation becomes common. Diverticulosis and cancers (such as colon and stomach cancer) appear with increasing frequency among older individuals.

REVIEW QUESTIONS

Multiple Choice/Matching Questions

For answers, see Appendix B.

1. Which of the following organs is secondarily retroperitoneal? (a) pharynx, (b) stomach, (c) ascending colon, (d) ileum.

2. The submucosal nerve plexus of the intestine (a) innervates the mucosa layer, (b) lies in the mucosa layer, (c) controls peristalsis, (d) contains only motor neurons.

3. For each organ in the left-hand column, select the type of epithelium that lines its lumen from the list in the right-hand column.

Organ	**Epithelium types**
—— **(1)** oral cavity	**(a)** simple squamous
—— **(2)** oropharynx	**(b)** simple cuboidal
—— **(3)** esophagus	**(c)** simple columnar
—— **(4)** stomach	**(d)** stratified squamous
—— **(5)** small intestine	**(e)** stratified cuboidal
—— **(6)** colon	

4. Match each of the mesenteries in the key with the appropriate description.

Key:

(a) greater omentum
(b) lesser omentum
(c) falciform ligament
(d) mesentery proper
(e) transverse mesocolon
(f) sigmoid mesocolon

—— **(1)** connects the ileum and jejunum to the posterior abdominal wall

—— **(2)** connects anterior surface of the liver to the anterior abdominal wall

—— **(3)** connects the large intestine to the pelvic wall

—— **(4)** attaches to the greater curvature of the stomach; has the most fat

—— **(5)** runs from the stomach's lesser curvature to the fissure of the liver

—— **(6)** a mesentery of the large intestine that is fused to the underside of the greater omentum

5. The pointed type of tongue papilla that is not involved with taste reception is (a) filiform, (b) fungiform, (c) circumvallate, (d) dermal.

6. Which of the following statements about the gallbladder is *false*? (a) It makes bile. (b) Its duct is called the cystic duct. (c) It has a fundus lying inferior to the liver. (d) It has mucosal folds similar to the stomach rugae.

7. Which of the following correctly describe the flow of blood through the classical liver lobule and beyond? (More than one choice is correct.) (a) portal venule to sinusoids to central vein to hepatic vein to inferior vena cava, (b) porta hepatis to hepatic vein to portal venule, (c) portal venule to central vein to hepatic vein to sinusoids, (d) portal arteriole to sinusoids to central vein to hepatic vein.

8. The exocrine glands in the pancreas are (a) simple tubular, (b) simple acinar, (c) compound tubular, (d) compound acinar, (e) compound tubuloalveolar.

9. Which cell type occurs in the stomach mucosa, has three prongs, contains many mitochondria and many microvilli, and pumps hydrogen ions? (a) absorptive cell, (b) parietal cell, (c) mucus-secreting cell, (d) muscularis externa cell, (e) mucous neck cell.

10. Which one of the following features is shared by both the small and large intestines? (a) intestinal crypts, (b) aggregated lymphoid nodules (Peyer's patches), (c) teniae coli, (d) haustra, (e) circular folds, (f) intestinal villi.

11. A digestive organ that has a head, neck, body, and tail is the (a) pancreas, (b) gallbladder, (c) greater omentum, (d) stomach.

12. From the list of abdominal regions listed in column B, indicate the predominant region where each organ listed in column A is found.

Column A	**Column B**
—— **(1)** small intestine	**(a)** right hypochondriac
—— **(2)** liver	**(b)** left hypochondriac
—— **(3)** stomach	**(c)** right iliac
—— **(4)** ascending colon	**(d)** right lumbar
—— **(5)** cecum	**(e)** umbilical

13. Protein digestion begins (a) in the mouth by saliva, (b) in the stomach by pepsin, (c) in the duodenum by bile, (d) in the small intestine by intestinal secretions.

14. The calcified connective tissue that attaches the tooth to the periodontal ligament is the (a) pulp, (b) enamel, (c) dentine, (d) cementum, (e) peridontium.

15. Which of the following statements about smooth muscle is false? (a) Smooth muscle cells are called fibers. (b) Most smooth muscle cells, like cardiac muscle cells, are joined by gap junctions. (c) Smooth muscle cells have a single, centrally located nucleus. (d) Contraction of smooth muscle is stimulated exclusively by involuntary nerves. (e) Smooth muscle tissue found in the wall of hollow organs is arranged in sheets.

16. Match the digestive organ listed in column B with the function listed in column A.

Column A	**Column B**
—— **(1)** produces bile	**(a)** salivary glands
—— **(2)** absorbs water	**(b)** esophagus
—— **(3)** churning occurs here	**(c)** stomach
—— **(4)** muscular tube connecting the laryngopharynx with the stomach	**(d)** small intestine
—— **(5)** produces both endocrine and exocrine secretions	**(e)** liver
—— **(6)** secretes a substance that initiates carbohydrate digestion	**(f)** gallbladder
—— **(7)** stores bile	**(g)** pancreas
—— **(8)** segmentation occurs here	**(h)** large intestine

17. The salivary gland that contains only serous cells is the (a) parotid gland, (b) submandibular gland, (c) sublingual gland, (d) intrinsic gland.

18. Use the key below to indicate the blood vessel that supplies arterial blood to each of the digestive organs listed.

Key:

(a) celiac trunk
(b) superior mesenteric artery
(c) inferior mesenteric artery

—— **(1)** stomach
—— **(2)** ileum
—— **(3)** descending colon
—— **(4)** liver
—— **(5)** ascending colon
—— **(6)** rectum
—— **(7)** cecum

Short Answer Essay Questions

19. Make a simple drawing of the organs of the alimentary canal, and label each organ. Also label the gross subparts of the stomach and intestines. Then add three more labels to your drawing—*salivary glands, liver,* and *pancreas*—and use arrows to show where each of these three glandular organs empties its secretion into the alimentary canal.

20. Name the layers of the wall of the alimentary canal. Describe the tissue composition and the major function of each layer. Then, identify the embryonic source of each layer.

21. (a) Write the dental formulas for both the deciduous and the permanent teeth. (b) Define dental pulp and describe its location.

22. Bianca went on a trip to the Bahamas during spring vacation and did not study for her anatomy test scheduled early the following week. On the test, she mixed up the following pairs of structures: (a) the rectal valves and the anal valves, (b) pyloric region and pylorus of the stomach, (c) anal canal and anus, (d) villi and microvilli (in the small intestine), (e) hepatic vein and hepatic portal vein, (f) gastric pits and gastric glands. Help her by defining and differentiating between these sound-alike structures.

23. (a) Make a rough sketch of the visceral surface of the liver, and label the following five structures: fissure, porta hepatis, inferior vena cava, gallbladder, caudate lobe. (b) To follow up on part (a), it is easy to learn the structure of the visceral surface of the liver if you can find and mark the big H there. To mark the left vertical limb of the H, draw a line through the fissure. To mark the crossbar of the H, draw a horizontal line through the porta hepatis. Then, to mark the right limb of the H, draw a continuous vertical line through the inferior vena cava and gallbladder. Which two lobes are inside the H? Which limb of the H separates the liver's right and left lobes?

24. Name four structural features that increase the absorptive surface area of the small intestine.

25. (a) List the three major vessels of the portal triad, and describe the location of this triad with respect to the liver lobule. (b) Name three organelles that are abundant within hepatocytes, and explain how each of these organelles contributes to liver functions.

26. Of the three big extrinsic salivary glands, which is the largest? Which one underlies the tongue? Which has only serous glands?

27. Trace the entire duct systems of the liver and pancreas. (Study these ducts in Figure 23.19, and then try to draw them from memory.)

28. On a diagram of the adult digestive tract (such as Figure 23.1), mark the boundaries between the derivatives of the embryonic foregut, midgut, and hindgut.

29. Where in the alimentary canal does chemical digestion begin for each of the three types of food: carbohydrates, proteins, and fats?

30. List all of the sphincters in the gastrointestinal tract and indicate the location of each.

31. Name the five processes of digestion and indicate all the locations in the gastrointestinal tract where each process occurs.

CRITICAL REASONING & CLINICAL APPLICATION QUESTIONS

1. This chapter describes schemes that divided the anterior abdominal wall into nine regions or four quadrants. List the regions that lie either entirely or partially within (a) the upper right quadrant and (b) the lower left quadrant.

2. A 21-year-old man with severe appendicitis did not seek treatment in time and died a week after his abdominal pain and fever began. Explain why appendicitis can quickly lead to death.

3. Duncan, an inquisitive 8-year-old, saw his grandfather's dentures soaking overnight in a glass of water. He asked his grandfather how his real teeth had fallen out. Assuming the grandfather remembered the events correctly but was not a medical expert and used layperson's terms, reconstruct the kind of story the man is likely to have told.

4. Eva, a middle-aged attorney, complains of a burning pain in the "pit of her stomach," usually beginning about 2 hours after eating and lessening after she drinks a glass of milk. When asked to indicate the site of pain, she points to her epigastric region. When her GI tract is examined by endoscopy, a gastric ulcer is visualized. What are the possible consequences of nontreatment?

5. A doctor used an endoscope and located some polyps (precancerous tumors) in the wall of the large intestine of an elderly man. What is an endoscope?

6. The janitor who cleaned the anatomy lab had a protruding abdomen that looked like the biggest "beer-belly" the students had ever seen, even though the rest of his body did not look fat at all. Another janitor on the floor told some students that the man was a recovering alcoholic and that he had "over a hundred pounds of fluid in his belly." What was the man's probable condition? (See this chapter's Related Clinical Terms.)

7. Explain why cancer chemotherapies that stop the replication of cellular DNA throughout the body cause nausea, diarrhea, and vomiting.

8. From what embryonic layer (ectoderm, mesoderm, or endoderm) are the hepatocytes of the liver and the pancreatic acinar cells and islets derived?

9. Why is dehydration a concern for an individual with persistent diarrhea?

10. Rebound tenderness in the lower right quadrant of the abdomen is an indication of what disorder?