18 Digestive System

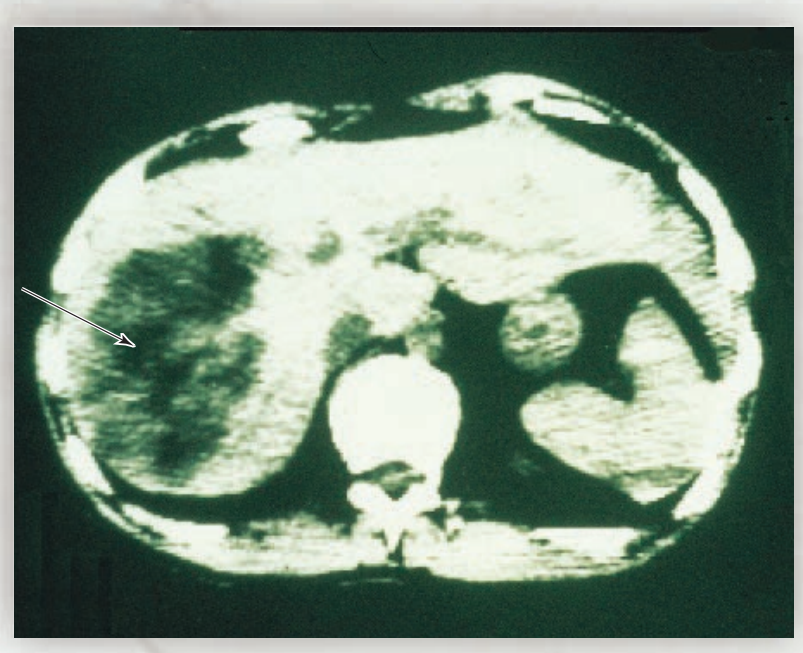


FIGURE: Positioned in the upper right quadrant of the abdominal cavity, the liver is the largest visceral organ. Its size and density make it vulnerable to trauma.

Clinical Case Study

A 25-year-old male construction worker was admitted to the emergency room after suffering a blow to the upper abdomen from a swinging beam. Initial assessment was significant for marked tenderness in the right upper quadrant of the abdomen and for vital signs and examination findings consistent with mild hemorrhagic shock. Intravenous fluids were administered, causing stabilization of vital signs. A chest radiograph revealed no abnormalities. Peritoneal lavage (see chapter 2, Clinical Case Study) was likewise negative for blood. There were no externally detectable signs of hemorrhage. A CT scan demonstrated a significant hematoma (collection of blood) deep within the substance of the liver (see arrow on CT scan), as well as a notable amount of blood in the small intestine. The decision was made to operate. Initial exploration revealed no trauma to the stomach or small intestine.

What is the likely source of the bleeding? Explain anatomically how the blood found its way into the small intestine, noting each step of its path. Given that the hepatic arterial system and hepatic venous system are possible sources of the bleeding, is there another system of blood vessels relative to the liver that could also be a source of hemorrhage?

Hint: As you study the digestive system, pay close attention to the location of each accessory digestive organ and note how each connects to the lumen of the gastrointestinal (GI) tract.

INTRODUCTION TO THE DIGESTIVE SYSTEM

The organs of the digestive system are specialized for the digestion and absorption of food. The digestive system consists of a tubular gastrointestinal tract and accessory digestive organs.

Objective 1 Describe the activities of the digestive system and distinguish between digestion and absorption.

Objective 2 Identify the major structures and regions of the digestive system.

Objective 3 Define the terms *viscera* and *gut.*

Food is necessary to sustain life. It provides the essential nutrients the body cannot produce for itself. The food is utilized at the cellular level, where nutrients are required for chemical reactions involving synthesis of enzymes, cellular division and growth, repair, and the production of heat energy. Most of the food we eat, however, is not suitable for cellular utilization until it is mechanically and chemically reduced to forms that can be absorbed through the intestinal wall and transported to the cells by the blood. Ingested food is not technically inside the body until it is absorbed; and, in fact, a large portion of this food remains undigested and passes through the body as waste material.

The principal function of the digestive system is to prepare food for cellular utilization. This involves the following functional activities:

- **Ingestion**—the taking of food into the mouth
- **Mastication**—chewing movements to pulverize food and mix it with saliva
- **Deglutition**—the swallowing of food to move it from the mouth to the pharynx and into the esophagus
- **Digestion**—the mechanical and chemical breakdown of food material to prepare it for absorption
- **Absorption**—the passage of molecules of food through the mucous membrane of the small intestine and into the blood or lymph for distribution to cells
- **Peristalsis**—rhythmic, wavelike intestinal contractions that move food through the gastrointestinal tract
- **Defecation**—the discharge of indigestible wastes, called *feces*, from the gastrointestinal tract

Anatomically and functionally, the digestive system can be divided into a tubular **gastrointestinal tract** (GI tract), or *digestive tract*, and **accessory digestive organs.** The GI tract, which extends from the mouth to the anus, is a continuous tube approximately 9 m (30 ft) long. It traverses the thoracic cavity and enters the abdominal cavity at the level of the diaphragm.

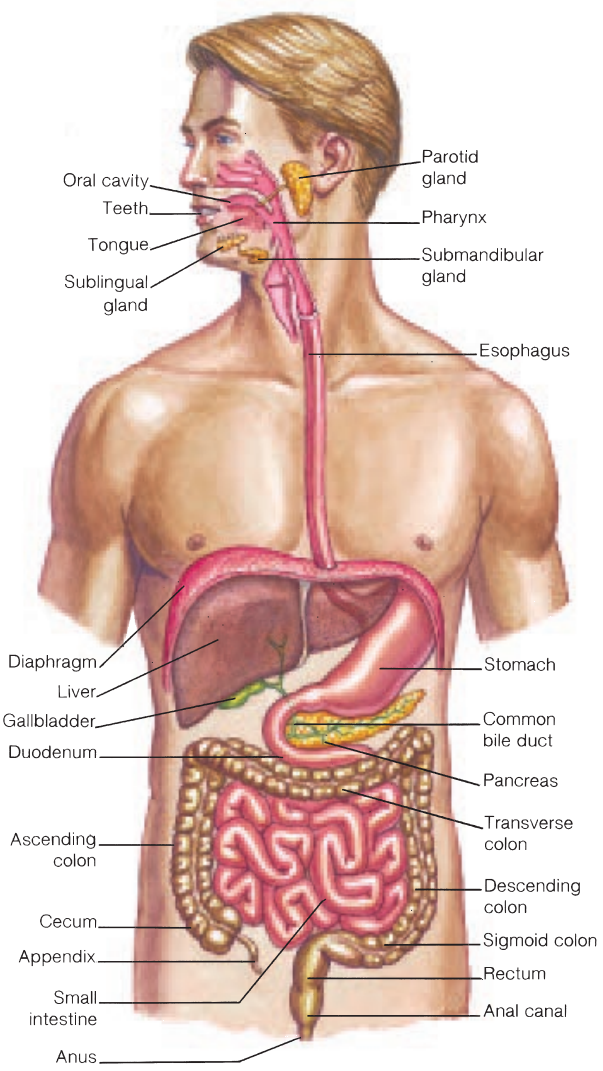


FIGURE 18.1 The digestive system.

The organs of the GI tract include the **oral cavity, pharynx, esophagus, stomach, small intestine,** and **large intestine** (fig. 18.1). The accessory digestive organs include the **teeth, tongue, salivary glands, liver, gallbladder,** and **pancreas.** The term **viscera** is frequently used to refer to the abdominal organs of digestion, but actually viscera can be any of the organs (lungs, stomach, spleen, etc.) of the thoracic and abdominal cavities. **Gut** is an anatomical term that generally refers to the developing stomach and intestines in the embryo (see Developmental Exposition, p. 665).

ingestion: L. *ingerere*, carry in
mastication: Gk. *mastichan*, gnash the teeth
deglutition: L. *deglutire*, swallow down
peristalsis: Gk. *peri*, around; *stellein*, compress
defecation: L. *de*, from, away; *faecare*, cleanse

TABLE 18.1 The GI Tract: Regions and Basic Functions

Region	Function
Oral cavity	Ingests food; receives saliva; grinds food and mixes it with saliva (mastication); initiates digestion of carbohydrates; forms and swallows soft mass of chewed food called bolus (deglutition)
Pharynx	Receives bolus from oral cavity; autonomically continues deglutition of bolus to esophagus
Esophagus	Transports bolus to stomach by peristalsis; lower esophageal sphincter restricts backflow of food
Stomach	Receives bolus from esophagus; churns bolus with gastric juice; initiates digestion of proteins; carries out limited absorption; moves mixture of partly digested food and secretions (chyme) into duodenum and prohibits backflow of chyme; regurgitates when necessary; generates hunger pangs, which cause a desire to eat
Small intestine	Receives chyme from stomach and secretions from liver and pancreas; chemically and mechanically breaks down chyme; absorbs nutrients; transports wastes through peristalsis to large intestine; prohibits backflow of intestinal wastes from large intestine
Large intestine	Receives undigested wastes from small intestine; absorbs water and electrolytes; forms, stores, and expels feces when activated by a defecation reflex

It usually takes about 24 to 48 hours for food to travel the length of the GI tract. Food ingested through the mouth passes in assembly-line fashion through the tract, where complex molecules are progressively broken down. Each region of the GI tract has specific functions in preparing food for utilization (table 18.1).

Although there is an abundance of food in the United States, so many people are malnourished that eating patterns have become a critical public health concern. Obesity is a major health problem. Grossly overweight people are at greater risk for cardiovascular disease, hypertension, osteoarthritis, and diabetes mellitus. People with good nutritional habits are better able to withstand trauma, are less likely to get sick, and are usually less seriously ill when they do become sick.

Knowledge Check

1. Which functional activities of the digestive system break down food? Which functional activities move the food through the GI tract? Where does absorption take place?
2. List in order the regions of the GI tract through which ingested food passes from the mouth to the anus.
3. List organs of the GI tract and the accessory digestive organs.
4. Write a sentence in which the term *gut* is used correctly.

CHAPTER 18

SEROUS MEMBRANES AND TUNICS OF THE GASTROINTESTINAL TRACT

Protective and lubricating serous membranes line the abdominal cavity and cover the visceral organs. Specialized serous membranes support the GI tract and provide a structure through which nerves and vessels pass. The wall of the GI tract is composed of four tunics.

Objective 4 Describe the arrangement of the serous membranes within the abdominal cavity.

Objective 5 Describe the generalized structure of the four tunics that form the wall of the GI tract.

Serous Membranes

Most of the digestive viscera are positioned within the abdominopelvic cavity. These organs are supported and covered by serous membranes that line the cavities of the trunk and cover the organs within these cavities. Serous membranes are composed of simple squamous epithelium, portions of which are reinforced with connective tissue. Serous membranes secrete a lubricating **serous fluid** that continuously moistens the associated organs. The *parietal portion* of the serous membrane lines the body wall, and a *visceral portion* covers the internal organs. As described in the previous chapter, the serous membranes associated with the lungs are called pleurae (see fig. 17.21). The serous membranes of the abdominal cavity are called **peritoneal membranes,** or **peritoneum** (*per''ĭ-tŏ-ne'um*).

The **parietal peritoneum** lines the wall of the abdominal cavity (fig. 18.2). Along the posterior abdominal cavity, the parietal peritoneum comes together to form a double-layered peritoneal fold called the **mesentery** (*mes'en-ter''e*). The mesentery supports the GI tract, at the same time allowing the small intestine freedom for peristaltic movement. It also provides a structure for the passage of intestinal nerves and vessels. The **mesocolon** is a specific portion of the mesentery that supports the large intestine (fig. 18.3*c*, *d*).

The peritoneal covering continues around the intestinal viscera as the **visceral peritoneum.** The **peritoneal cavity** is the space between the parietal and visceral portions of the peritoneum. Certain abdominal organs lie posterior to the parietal peritoneum, and are therefore said to be *retroperitoneal*. Retroperitoneal organs include most of the pancreas, the kidneys, the adrenal glands, portion of the duodenum and colon, and the abdominal aorta.

peritoneum: Gk. *peritonaion*, stretched over
mesentery: Gk. *mesos*, middle; *enteron*, intestine

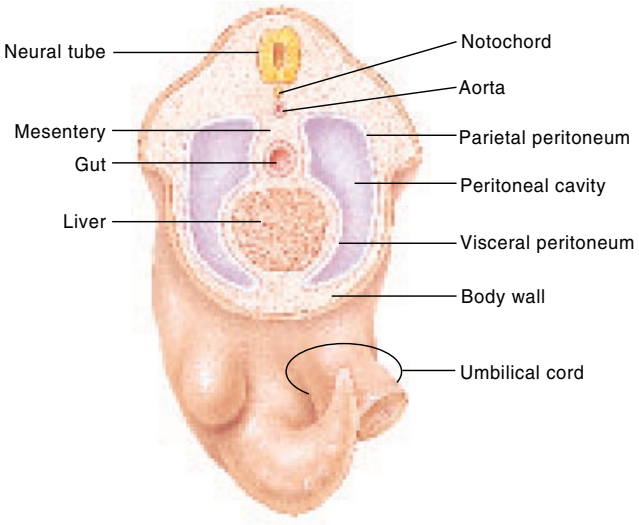


FIGURE 18.2 A diagram of the developing abdominal serous membranes from a cross section of an embryo.

Peritonitis is a bacterial inflammation of the peritoneum. It may be caused by trauma, rupture of a visceral organ, an ectopic pregnancy, or postoperative complications. Peritonitis is usually extremely painful and serious. Treatment usually involves the injection of massive doses of antibiotics, and perhaps peritoneal intubation (insertion of a tube) to permit drainage.

Extensions of the parietal peritoneum serve to suspend or anchor numerous organs within the peritoneal cavity (fig. 18.3). The **falciform** (*fal''sĭ-form*) **ligament,** a serous membrane reinforced with connective tissue, attaches the liver to the diaphragm and anterior abdominal wall. The **greater omentum** (*o-men'tum*) (fig. 18.3*a*) extends from the greater curvature of the stomach to the transverse colon, forming an apronlike structure over most of the small intestine. Functions of the greater omentum include storing fat, cushioning visceral organs, supporting lymph nodes, and protecting against the spread of infections. In cases of localized inflammation, such as appendicitis, the greater omentum may actually compartmentalize the inflamed area, sealing it off from the rest of the peritoneal cavity. The **lesser omentum** (fig. 18.3*b*) passes from the lesser curvature of the stomach and the upper duodenum to the inferior surface of the liver.

The peritoneal cavity provides a warm, moist, normally aseptic environment for the abdominal viscera. In a male, the peritoneal cavity is totally closed off from the outside body environment. In a female, however, it is not isolated from the outside, which presents the potential for contamination through the entry of microorganisms. A fairly common gynecological condition is *pelvic inflammatory disease (PID),* which results from the entry of pathogens into the peritoneal cavity at the sites of the open-ended uterine (fallopian) tubes.

omentum: L. *omentum,* apron

Layers of the Gastrointestinal Tract

The GI tract from the esophagus to the anal canal is composed of four layers, or **tunics.** Each tunic contains a dominant tissue type that performs specific functions in the digestive process. The four tunics of the GI tract, from the inside out, are the *mucosa, submucosa, muscularis,* and *serosa* (fig. 18.4*a*).

Mucosa

The mucosa, which lines the lumen of the GI tract, is both an absorptive and a secretory layer. It consists of a simple columnar epithelium supported by the **lamina propria** (*lam' ĭ-nă pro'pre-ă*) (fig. 18.4*b*), a thin layer of connective tissue. The lamina propria contains numerous lymph nodules, which are important in protecting against disease. External to the lamina propria are thin layers of smooth muscle called the **muscularis mucosae,** which provide limited involuntary churning movements. Specialized **goblet cells** in the mucosa throughout most of the GI tract secrete mucus.

Submucosa

The relatively thick submucosa is a highly vascular layer of connective tissue serving the mucosa. Absorbed molecules that pass through the columnar epithelial cells of the mucosa enter into blood vessels or lymph ductules of the submucosa. In addition to blood vessels, the submucosa contains glands and nerve plexuses. The *submucosal plexus* (*Meissner's plexus*) (fig. 18.4*b*) provides autonomic innervation to the muscularis mucosae.

Tunica Muscularis

The tunica muscularis is responsible for segmental contractions and peristaltic movement through the GI tract. This tunic has an inner circular and an outer longitudinal layer of smooth muscle. Contractions of these layers move the food through the tract and physically pulverize and churn the food with digestive enzymes.

The *myenteric plexus* (*Auerbach's plexus*), located between the two muscle layers, provides the major nerve supply to the GI tract. It includes neurons and ganglia from both the sympathetic and parasympathetic divisions of the ANS.

tunica: L. *tunica,* covering or coat

Meissner's plexus: from Georg Meissner, German histologist, 1829–1905

Auerbach's plexus: from Leopold Auerbach, German anatomist, 1828–97

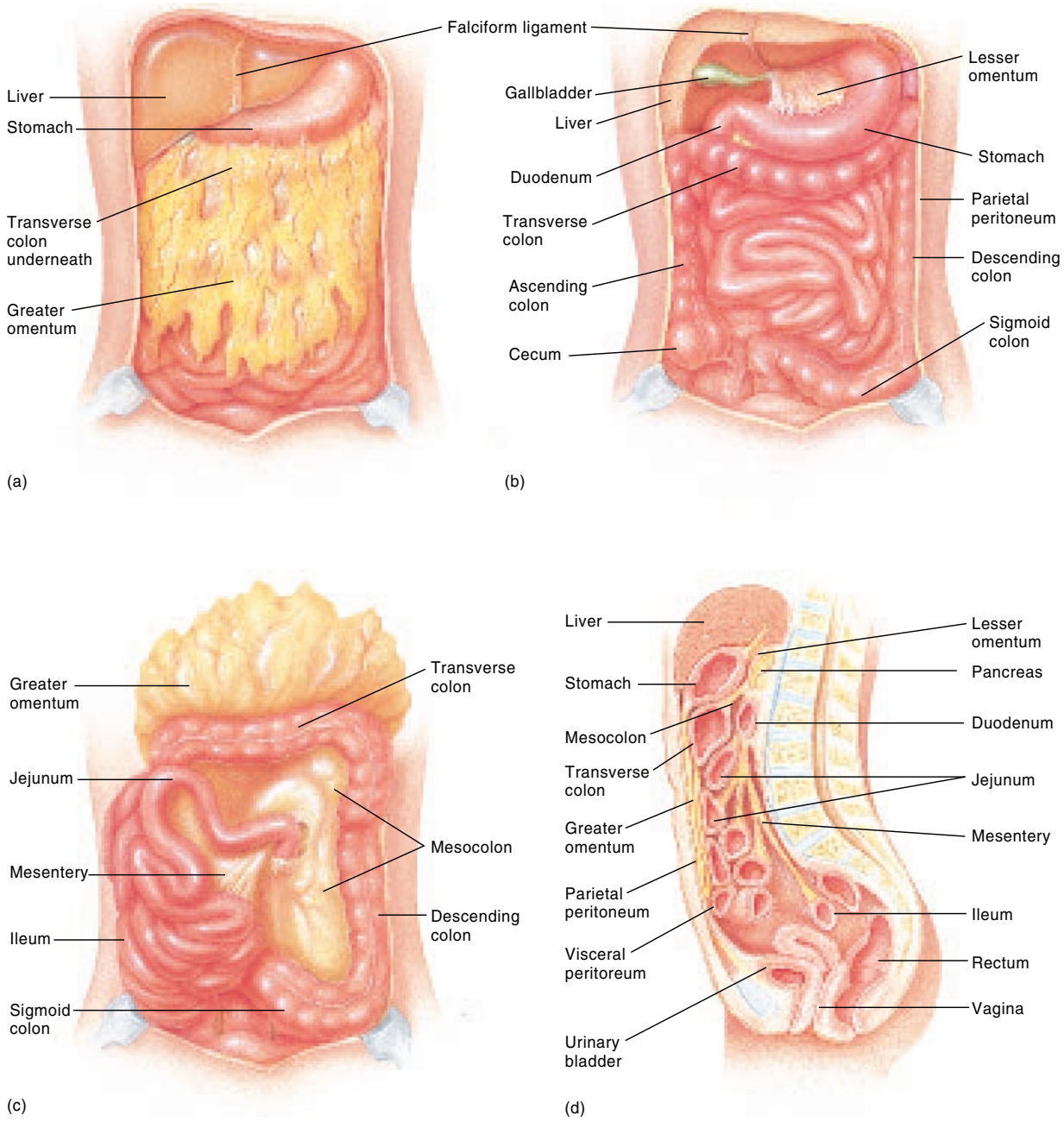


FIGURE 18.3 The structural arrangement of the abdominal organs and peritoneal membranes. (*a*) The greater omentum, (*b*) the lesser omentum with the liver lifted, (*c*) the mesentery with the greater omentum lifted, and (*d*) the relationship of the peritoneal membranes to the visceral organs as shown in a sagittal view.

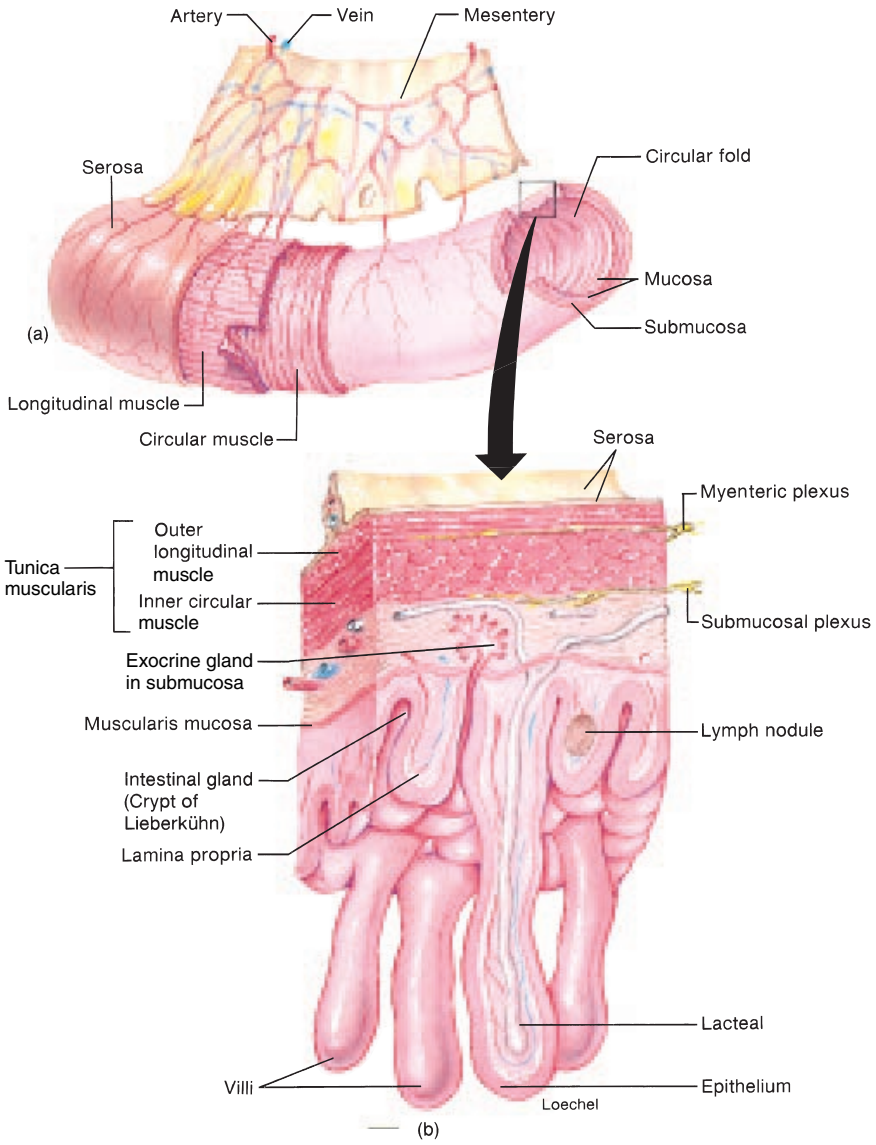


FIGURE 18.4 The tunics (layers) of the GI tract. (*a*) A section of the small intestine with each of the four tunics exposed and (*b*) a section showing the detailed structure and relative thickness of each tunic. (Note the location of the exocrine gland and the innervation of the small intestine.)

Serosa

The outer serosa completes the wall of the GI tract. It is a binding and protective layer consisting of loose connective tissue covered with a layer of simple squamous epithelium and subjacent connective tissue. The simple squamous epithelium is actually the visceral peritoneum. Retroperitoneal organs lack a serosa.

The body has several defense mechanisms to protect against ingested material that may be harmful if absorbed. The acidic environment of the stomach and the lymphatic system kill many harmful bacteria. A mucous lining throughout the GI tract serves as a protective layer. Vomiting, and in certain cases diarrhea, are reactions to substances that irritate the GI tract. Vomiting is a reflexive response to many toxic chemicals; thus, even though unpleasant, it can be beneficial.

Innervation of the Gastrointestinal Tract

The GI tract is innervated by the sympathetic and parasympathetic divisions of the autonomic nervous system (see fig. 13.6). The vagus nerves are the source of parasympathetic activity in

the esophagus, stomach, pancreas, gallbladder, small intestine, and upper portion of the large intestine. The lower portion of the large intestine receives parasympathetic innervation from spinal nerves in the sacral region. The submucosal plexus and myenteric plexus are the sites where preganglionic neurons synapse with postganglionic neurons that innervate the smooth muscle of the GI tract. Stimulation of the parasympathetic neurons increases peristalsis and the secretions of the GI tract.

Postganglionic sympathetic fibers pass through the submucosal and myenteric plexuses and innervate the GI tract. The effects of sympathetic nerve stimulation are antagonistic to those of parasympathetic nerve stimulation. Sympathetic impulses inhibit peristalsis, reduce secretions, and constrict muscle sphincters along the GI tract.

Knowledge Check

5. Describe the position of the peritoneal membranes. What are the functions of the mesentery and greater omentum? Which organs are retroperitoneal?
6. List the four tunics of the GI tract and identify their major tissue types. What are the functions of these four tunics?
7. Compare the effects of parasympathetic and sympathetic innervation of the GI tract.

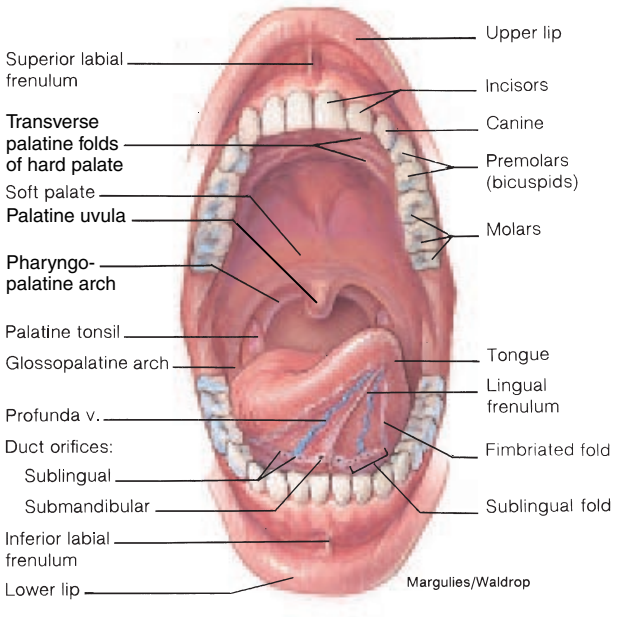


FIGURE 18.5 The superficial structures of the oral cavity.

MOUTH, PHARYNX, AND ASSOCIATED STRUCTURES

Ingested food is changed into a bolus by the mechanical action of teeth and by the chemical activity of saliva. The bolus is swallowed in the process of deglutition.

Objective 6 Describe the anatomy of the oral cavity.

Objective 7 Contrast the deciduous and permanent dentitions and describe the structure of a typical tooth.

Objective 8 Describe the location and histological structures of the salivary glands and list the functions of saliva.

CHAPTER 18

The functions of the *mouth* and associated structures are to form a receptacle for food, to initiate digestion through mastication, to swallow food, and to form words in speech. The mouth can also assist the respiratory system in breathing air. The *pharynx*, which is posterior to the mouth, serves as a common passageway for both the respiratory and digestive systems. Both the mouth and pharynx are lined with nonkeratinized stratified squamous epithelium, which is constantly moistened by the secretion of saliva.

The **mouth,** also known as the **oral cavity** (fig. 18.5), is formed by the *cheeks*, *lips*, *hard palate* and *soft palate*. The **vestibule** of the oral cavity is the depression between the cheeks and lips externally and the gums and teeth internally (fig. 18.6). The opening of the oral cavity is referred to as the **oral orifice,** and the opening between the oral cavity and the pharynx is called the **fauces** (*faw/sēz*).

Cheeks, Lips, and Palate

The **cheeks** form the lateral walls of the oral cavity. They consist of outer layers of skin, subcutaneous fat, facial muscles that assist in manipulating food in the oral cavity, and inner linings of moistened stratified squamous epithelium. The anterior portion of the cheeks terminates in the superior and inferior lips that surround the oral orifice.

The **lips** are fleshy, highly mobile organs whose principal function in humans is associated with speech. Lips also serve for suckling, manipulating food, and keeping food between the upper and lower teeth. Each lip is attached from its inner surface to the gum by a midline fold of mucous membrane called the **labial frenulum** (*fren′yŭ-lum*) (fig. 18.5). The lips are formed from the orbicularis oris muscle and associated connective tissue, and are covered with soft, pliable skin. Between the outer skin and the mucous membrane of the oral cavity is a transition zone called the **vermilion.** Lips are red to reddish brown because of blood vessels close to the surface. The numerous sensory receptors in the lips aid in determining the temperature and texture of food.

pharynx: L. *pharynx*, throat

fauces: L. *fauces*, throat

vermilion: O.E. vermeylion, red-colored

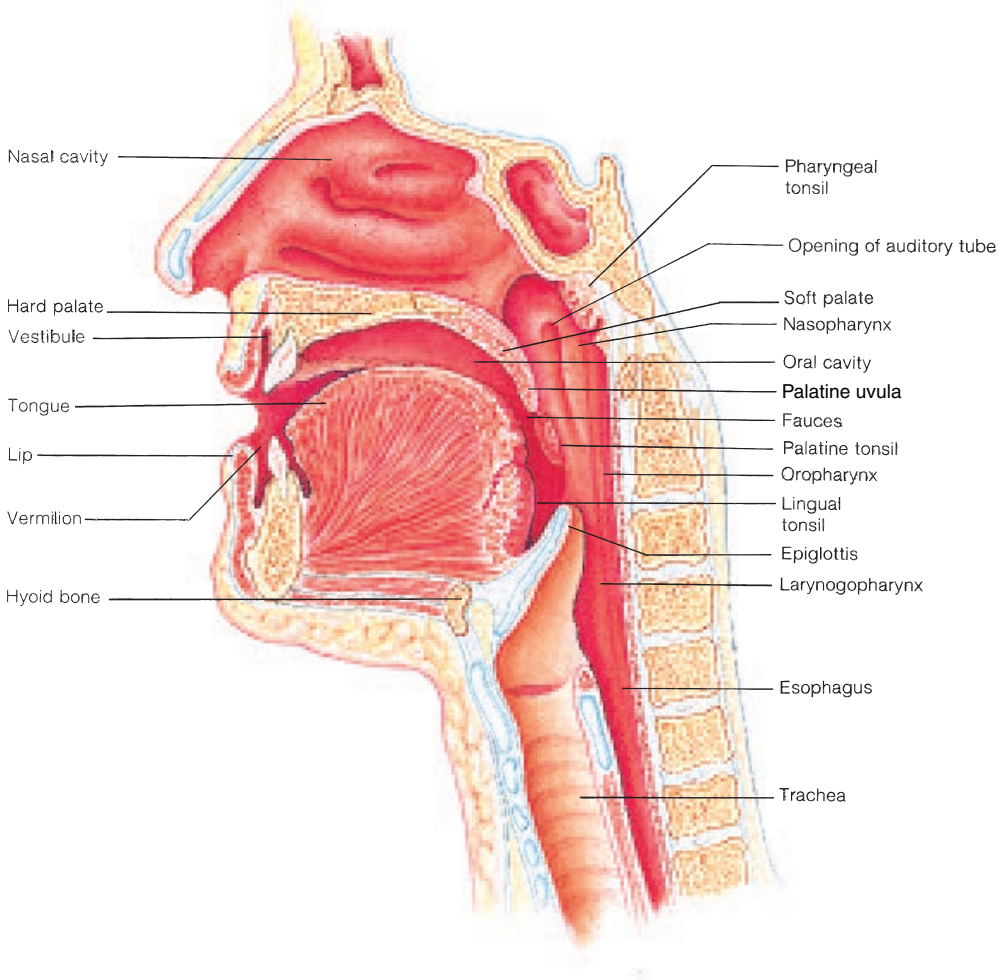


FIGURE 18.6 A sagittal section of the facial region showing the oral cavity, nasal cavity, and pharynx.

Suckling is innate to newborns. Their lips are well formed for this activity and even contain blisterlike milk pads that aid in suckling. The receding lower jaw and wide nostrils of infants also facilatate suckling by permitting the baby to tightly cup the entire nipple while breathing through its nostrils

The **palate,** which forms the roof of the oral cavity, consists of the bony hard palate anteriorly and the soft palate posteriorly (figs. 18.5 and 18.6). The **hard palate,** formed by the palatine processes of the maxillae and the horizontal plates of the palatine bones, is covered with a mucous membrane. **Transverse palatine folds,** or *palatal rugae* (*roo'je*), are located along the mucous membrane of the hard palate. These structures serve as friction ridges against which the tongue is placed during swallowing. The **soft palate** is a muscular arch covered with mucous membrane and is continuous with the hard palate anteriorly. Suspended from the middle lower border of the soft palate is a cone-shaped projection called the **palatine uvula** (*yoo'vyŭ-lă*). During swallowing, the soft palate and palatine uvula are drawn upward, closing the nasopharynx and preventing food and fluid from entering the nasal cavity.

Two muscular folds extend downward from both sides of the base of the palatine uvula (figs. 18.5 and 18.6). The anterior fold is called the **glossopalatine arch,** and the posterior fold is the **pharyngopalatine arch.** Between these two arches is the **palatine tonsil.**

uvula: L. *uvula,* small grapes

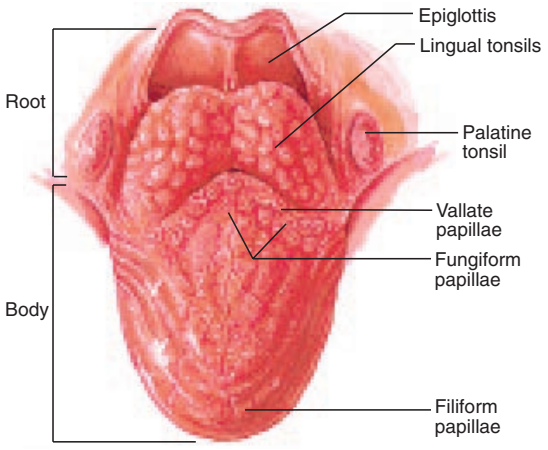


FIGURE 18.7 The surface of the tongue.

Tongue

As a digestive organ, the **tongue** functions to move food around in the mouth during mastication and to assist in swallowing food. It is also essential in producing speech. The tongue is a mass of skeletal muscle covered with a mucous membrane. Extrinsic tongue muscles (those that insert upon the tongue) move the tongue from side to side and in and out. Only the anterior two-thirds of the tongue lies in the oral cavity; the remaining one-third lies in the pharynx (fig. 18.6) and is attached to the hyoid bone. Rounded masses of **lingual tonsils** are located on the superior surface of the base of the tongue (fig. 18.7). The inferior surface of the tongue is connected along the midline anteriorly to the floor of the mouth by the vertically positioned **lingual frenulum** (see fig. 18.5).

When a short lingual frenulum restricts tongue movements, the person is said to be "tongue-tied." If this developmental problem is severe, the infant may have difficulty suckling. Older children with this problem may have faulty speech. These functional problems can be easily corrected through surgery.

On the surface of the tongue are numerous small elevations called **papillae** (*pă-pil'ē*). The papillae give the tongue a distinct roughened surface that aids the handling of food. As described in chapter 15, some of them also contain taste buds that respond to sweet, salty, sour, and bitter chemical stimuli. (see figs. 15.6 and 15.7) Three types of papillae are present on the surface of the tongue: **filiform, fungiform,** and **vallate** (fig. 18.7). Filiform papillae are sensitive to touch, have tapered tips, and are by far the most numerous. These papillae lack taste buds and are not involved in the perception of taste. The larger, rounded fungiform papillae are scattered among the filiform type. The few vallate papillae are arranged in a V shape on the posterior surface of the tongue (see fig. 15.6).

Teeth

Humans and other mammals have *heterodont dentition*. This means that they have various types of **teeth** (fig. 18.8) that are adapted to handle food in particular ways. The four pairs (upper and lower jaws) of anteriormost teeth are the **incisors** (*in-si'sorz*). The chisel-shaped incisors are adapted for cutting and shearing food. The two pairs of cone-shaped **canines** (*cuspids*) are located at the anterior corners of the mouth; they are adapted for holding and tearing. Incisors and canines are further characterized by a single root on each tooth. Located behind the canines are the **premolars** (*bicuspids*), and **molars.** These teeth have two or three roots and somewhat rounded, irregular surfaces called **dental cusps** for crushing and grinding food. The **buccal surface** of the premolars and molars is adjacent to the cheek. The **labial surface** of the incisors and canines is adjacent to the lip. The **lingual surface** of all teeth is adjacent to the tongue.

Humans are *diphyodont* (*di-fi'ŏ-dont*); that is, normally two sets of teeth develop in a person's lifetime. Twenty **deciduous** (milk) **teeth** begin to erupt at about 6 months of age (fig. 18.9 and tables 18.2 and 18.3), beginning with the incisors. All of the deciduous teeth normally erupt by the age of 2 1/2. Thirty-two **permanent teeth** replace the deciduous teeth in a predictable sequence. This process begins at about age 6 and continues until about age 17. The *third molars* ("wisdom teeth") are the last to erupt. There may not be room in the jaw to accommodate the wisdom teeth, however, in which case they may grow sideways and become impacted, or emerge only partially. If they do erupt at all, it is usually between the ages of 17 and 25. Presumably, a person has acquired some wisdom by then—hence, the popular name for the third molars.

A **dental formula** is a graphic representation of the types, number, and position of teeth in the oral cavity. Such a formula can be written for each species of mammal with heterodontia. Following are the deciduous and permanent dental formulae for humans:

Formula for deciduous dentition:

I 2/2, **C** 1/1, **DM** 2/2 = 10 × 2 = 20 teeth

Formula for permanent dentition:

I 2/2, **C** 1/1, **P** 2/2, **M** 3/3 = 16 × 2 = 32 teeth

where **I** = incisor; **C** = canine; **P** = premolar; **DM** = deciduous molar; **M** = molar.

papilla: L. *papula*, little nipple
filiform: L. *filum*, thread; *forma*, form
fungiform: L. *fungus*, fungus; *forma*, form
vallate: L. *vallatus*, surrounded with a rampart

heterodont: Gk. *heteros*, other; *odous*, tooth
incisor: L. *incidere*, to cut
canine: L. *canis*, dog
molar: L. *mola*, millstone
deciduous: L. *deciduus*, to fall away

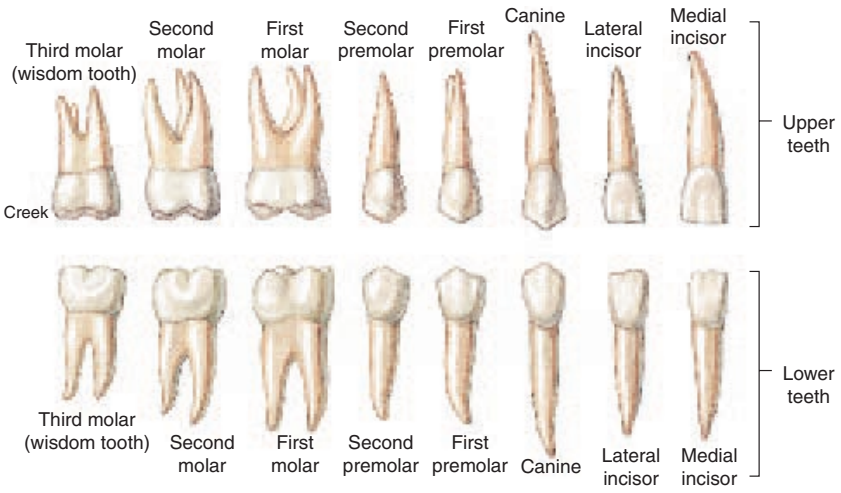


FIGURE 18.8 The buccal (cheek) and labial (lip) surfaces and roots of the right permanent teeth.

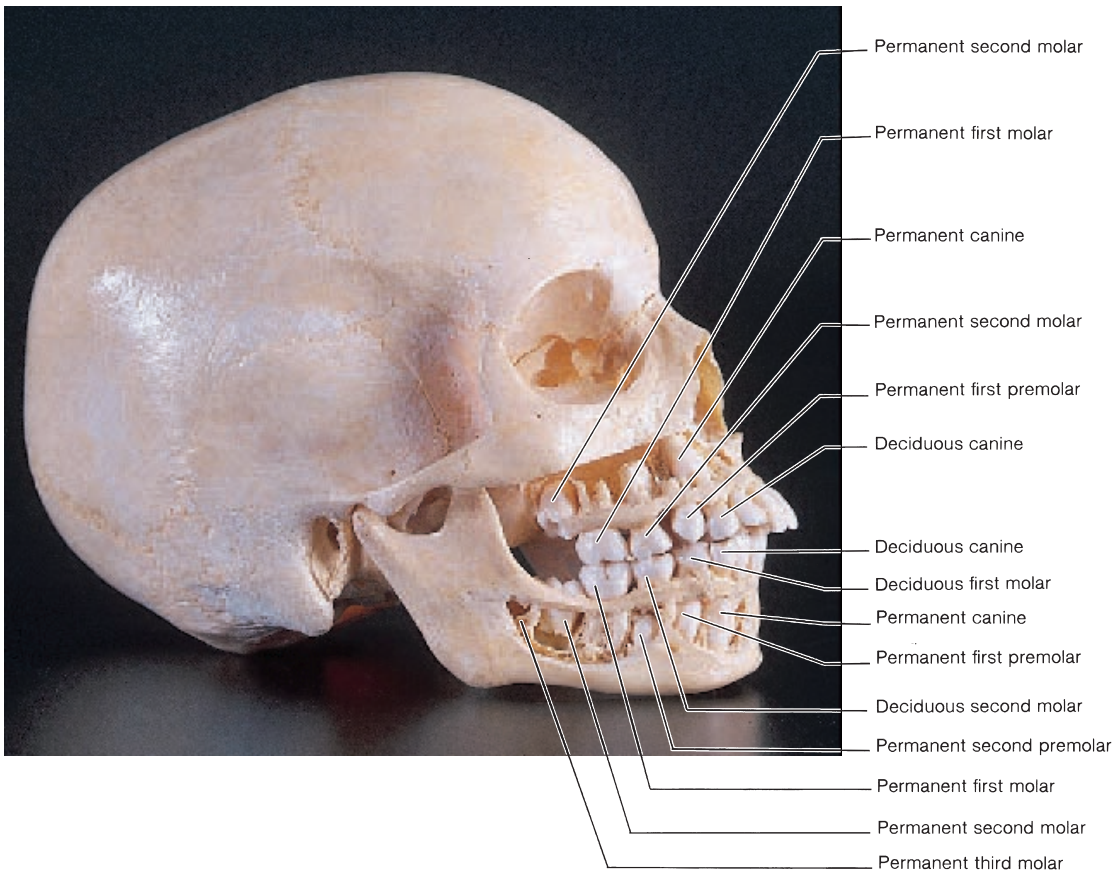


FIGURE 18.9 A skull showing the eruption of teeth in a youth about 10 years old.

TABLE 18.2 Eruption Sequence and Loss of Deciduous Teeth

	Average Age of Eruption		
Type of Tooth	Lower	Upper	Average Age of Loss
Central incisors	6–8 mos	7–9 mos	7 yrs
Lateral incisors	7–9 mos	9–11 mos	8 yrs
First molars	12–14 mos	14–16 mos	10 yrs
Canines (cuspids)	16–18 mos	18–20 mos	10 yrs
Second molars	20–22 mos	24–26 mos	11–12 yrs

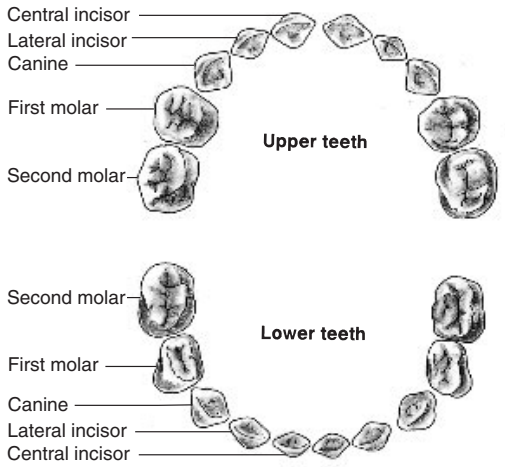
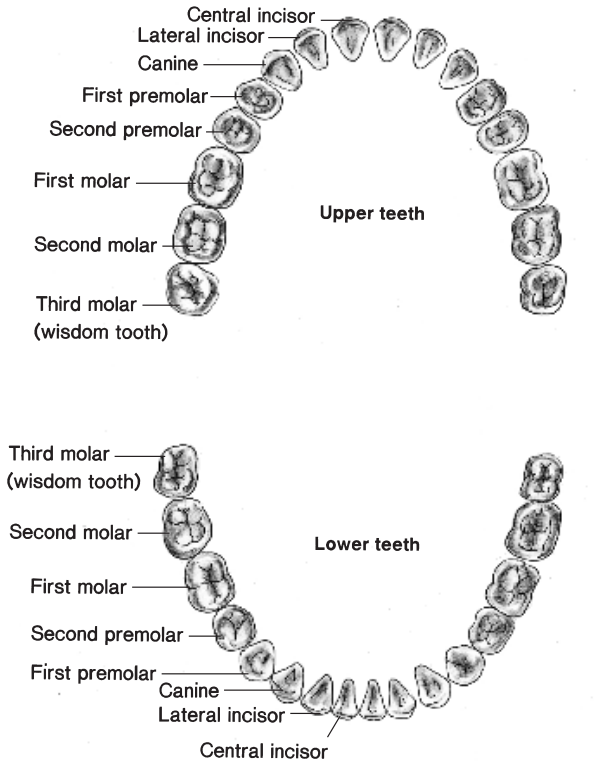


TABLE 18.3 Eruption Sequence of Permanent Teeth

	Average Age of Eruption	
Type of Tooth	Lower	Upper
First molars	6–7 yrs	6–7 yrs
Central incisors	6–7 yrs	7–8 yrs
Lateral incisors	7–8 yrs	8–9 yrs
Canines (cuspids)	9–10 yrs	11–12 yrs
First premolars (bicuspids)	10–12 yrs	10–11 yrs
Second premolars (bicuspids)	11–12 yrs	10–12 yrs
Second molars	11–13 yrs	12–13 yrs
Third molars (wisdom)	17–25 yrs	17–25 yrs



CHAPTER 18

The dental cusps of the upper and lower premolars and molars occlude for chewing food, whereas the upper incisors normally form an overbite with the incisors of the lower jaw. An overbite of the upper incisors creates a shearing action as these teeth slide past one another. Masticated food is mixed with saliva, which initiates chemical digestion and aids swallowing. The soft, flexible mass of food that is swallowed is called a *bolus* (*bo'lus*).

A tooth consists of an exposed **crown,** which is supported by a **neck** that is anchored firmly into the jaw by one or more **roots** (fig. 18.10). The roots of teeth fit into sockets, called **dental alveoli,** in the alveolar processes of the mandible and maxillae. Each socket is lined with a connective tissue periosteum, specifically called the **periodontal membrane.** The root of a tooth is covered with a bonelike material called the **cementum;** fibers in the periodontal membrane insert into the cementum and fasten the tooth in its dental alveolus. The **gingiva** (*jĭn-ji'vă*) (*gum*) is the mucous membrane surrounding the alveolar processes in the oral cavity.

The bulk of a tooth consists of **dentin,** a substance similar to bone but harder. Covering the dentin on the outside and forming

bolus: Gk. *bolos*, lump

gingiva: L. *gingiva*, gum

dentin: L. *dens*, tooth

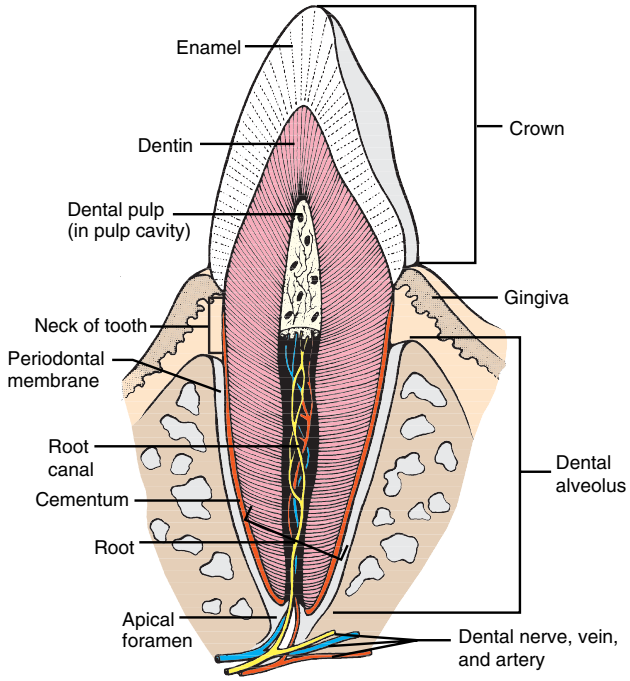


FIGURE 18.10 The structure of a tooth shown in a vertical section through one of the canines.

the crown is a tough, durable layer of **enamel.** Enamel is composed primarily of calcium phosphate and is the hardest substance in the body. The central region of the tooth contains the **pulp cavity.** The pulp cavity contains the **pulp,** which is composed of connective tissue with blood vessels, lymph vessels, and nerves. A **root canal,** continuous with the pulp cavity, opens to the connective tissue surrounding the root through an **apical foramen.** The tooth receives nourishment through vessels traversing the apical foramen. Proper nourishment is particularly important during embryonic development. The diet of the mother should contain an abundance of calcium and vitamin D during pregnancy to ensure the proper development of the baby's teeth.

Even though enamel is the hardest substance in the body, bacterial activity may result in *dental caries* (*kar'ēz*), or *tooth decay.* Refluxed stomach acids also destroy tooth enamel and constant vomiting, as in the eating disorder *bulimia nervosa,* contributes to the development of dental caries. Cavities in the teeth must be artificially filled because new enamel is not produced after a tooth erupts. The rate of tooth decay decreases after age 35, but then problems with the gums may develop. *Periodontal diseases* result from plaque or tartar buildup at the gum line. This buildup pulls the gum away from the teeth, allowing bacterial infections to develop.

Salivary Glands

The **salivary glands** are accessory digestive glands that produce a fluid secretion called *saliva.* Saliva functions as a solvent in cleansing the teeth and dissolving food molecules so that they can be tasted. Saliva also contains starch-digesting enzymes and lubricating mucus, which aids swallowing. Saliva is secreted continuously, but usually only in sufficient amounts to keep the mucous membranes of the oral cavity moist. The amount of saliva secreted daily ranges from 1.0 to 1.5 L.

Numerous minor salivary glands are located in the mucous membranes of the palatal region of the oral cavity. However, three pairs of salivary glands that lie outside the oral cavity produce most of the saliva, which is transported to the oral cavity via **salivary ducts.** The three major pairs of extrinsic salivary glands are the *parotid, submandibular,* and *sublingual glands* (fig. 18.11).

The **parotid** (*pă-rot'id*) **gland** is the largest of the salivary glands. It is positioned below and in front of the auricle of the ear, between the skin and the masseter muscle. Saliva produced in the parotid gland drains through the **parotid** (Stensen's) **duct.** The parotid duct parallels the zygomatic arch across the masseter muscle, pierces the buccinator muscle, and empties into the oral cavity opposite the second upper molar. It is the parotid gland that becomes infected and swollen with the mumps.

The **submandibular gland** lies inferior to the body of the mandible, about midway along the inner side of the jaw. This gland is covered by the more superficial mylohyoid muscle. Saliva produced in the submandibular gland drains through the **submandibular** (Wharton's) **duct** and empties into the floor of the mouth on the lateral side of the lingual frenulum.

The **sublingual gland** lies under the mucous membrane of the floor of the mouth. Each sublingual gland contains several small **sublingual ducts** (Rivinus' ducts) that empty into the floor of the mouth in an area posterior to the papilla of the submandibular duct.

Two types of secretory cells, **serous** and **mucous cells,** are found in all salivary glands in various proportions (fig. 18.12). Serous cells produce a watery fluid containing digestive enzymes; mucous cells secrete a thick, stringy mucus. Cuboidal epithelial cells line the lumina of the salivary ducts.

The salivary glands are innervated by both divisions of the autonomic nervous system. Sympathetic impulses stimulate the secretion of small amounts of viscous saliva. Parasympathetic stimulation causes the secretion of large volumes of watery saliva. Physiological responses of this type occur whenever a person sees, smells, tastes, or even thinks about desirable food. Information about the salivary glands is summarized in table 18.4.

Pharynx

The funnel-shaped **pharynx** (*far'ingks*) is a muscular organ that contains a passageway approximately 13 cm (5 in.) long connecting the oral and nasal cavities to the esophagus and larynx. The pharynx has both digestive and respiratory functions. The supporting walls of the pharynx are composed of skeletal muscle,

parotid: Gk. *para,* beside; *otos,* ear
Stensen's duct: from Nicholaus Stensen, Danish anatomist, 1638–86
Wharton's duct: from Thomas Wharton, English physician, 1614–73
Rivinus' ducts: from August Quirinus Rivinus, German anatomist, 1652–1723

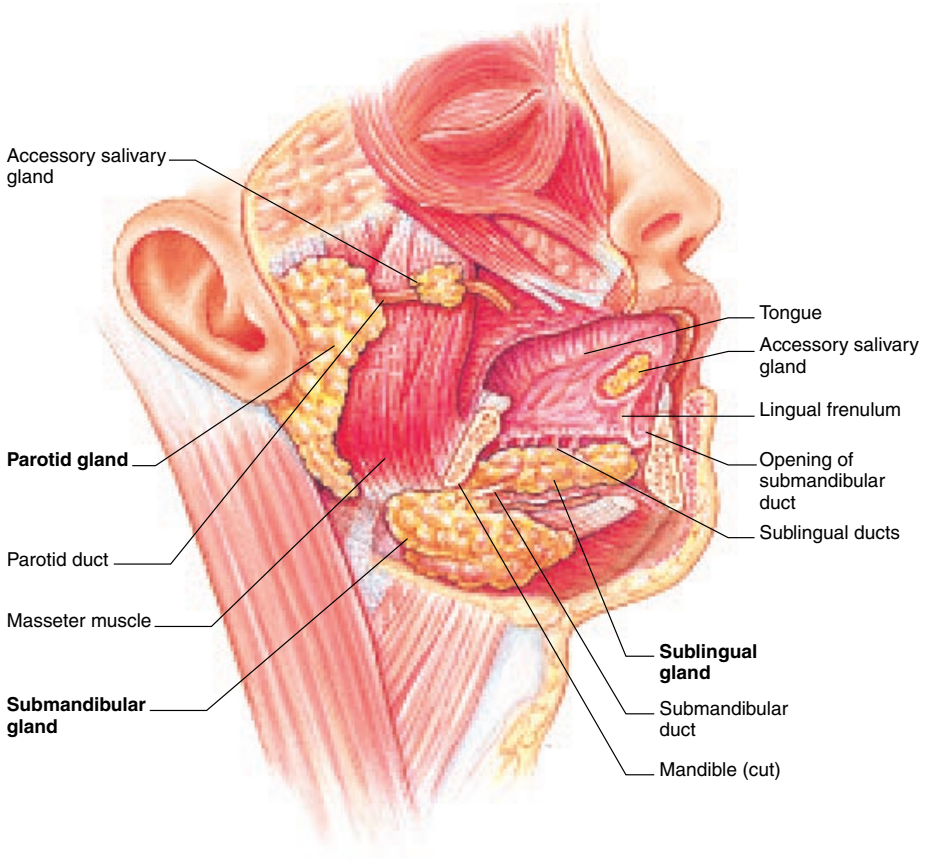


FIGURE 18.11 The salivary glands.

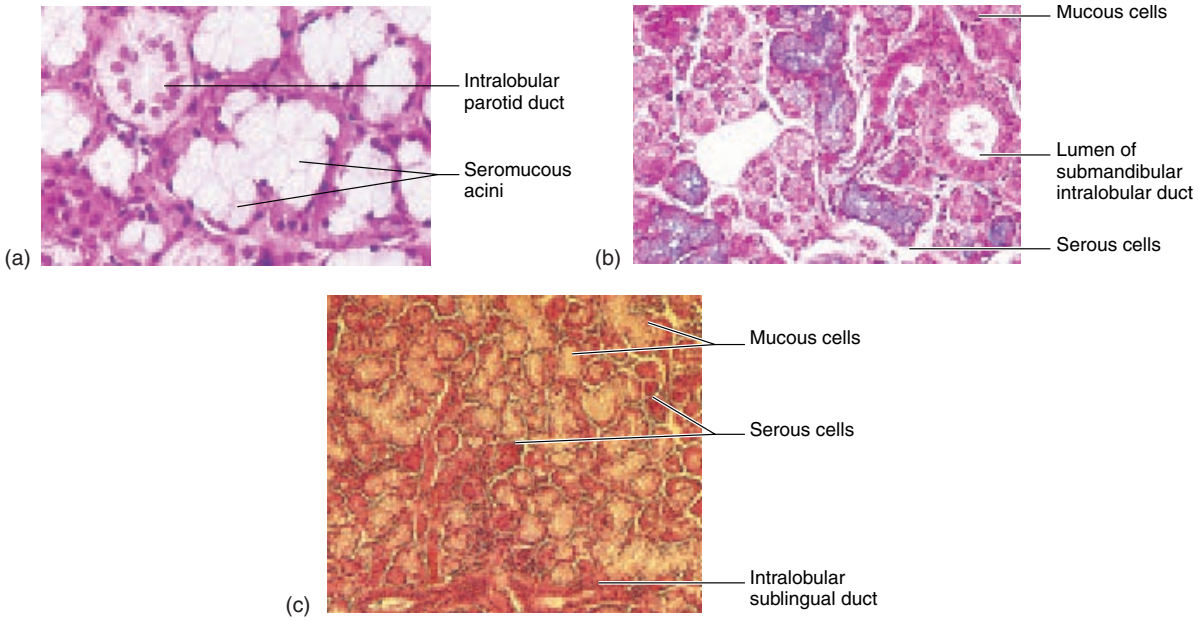


FIGURE 18.12 The histology of the salivary glands. (*a*) The parotid gland, (*b*) the submandibular gland, and (*c*) the sublingual gland.

TABLE 18.4 Major Salivary Glands

Gland	Location	Duct	Entry into Oral Cavity	Type of Secretion
Parotid gland	Anterior and inferior to auricle; subcutaneous over masseter muscle	Parotid (Stensen's) duct	Lateral to upper second molar	Watery serous fluid, salts, and enzyme
Submandibular gland	Inferior to the base of the tongue	Submandibular (Wharton's) duct	Papilla lateral to lingual frenulum	Watery serous fluid with some mucus
Sublingual gland	Anterior to submandibular gland under the tongue	Several small sublingual ducts (Rivinus' ducts)	Ducts along the base of the tongue	Mostly thick, stringy mucus; salts; and enzyme (salivary amylase)

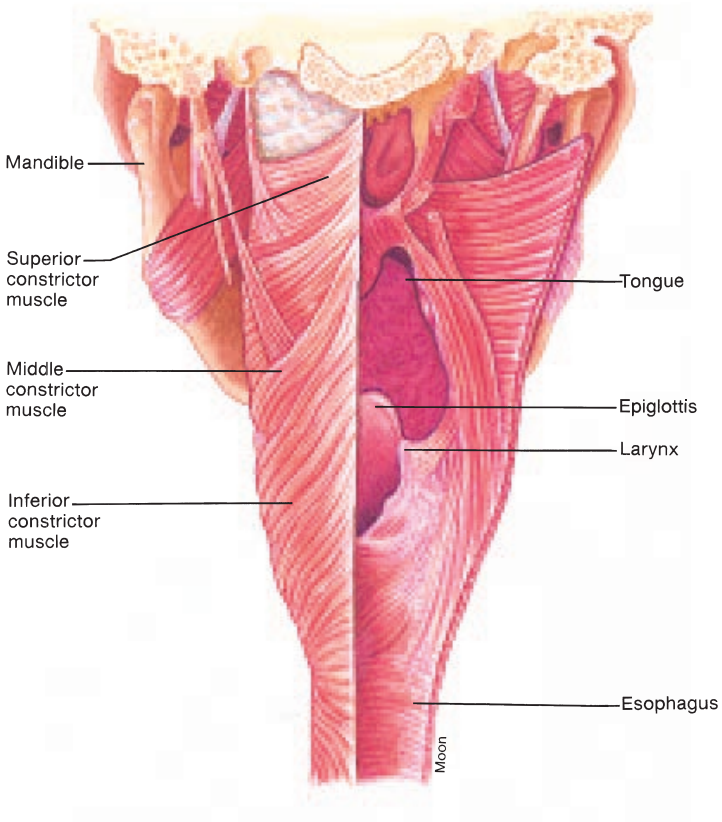


FIGURE 18.13 A posterior view of the constrictor muscles of the pharynx. The right side has been cut away to illustrate the interior structures in the pharynx.

and the lumen is lined with a mucous membrane containing stratified squamous epithelium. The pharynx is divided into three regions: the *nasopharynx*, posterior to the nasal cavity; the *oropharynx*, posterior to the oral cavity; and the *laryngopharynx*, at the level of the larynx (see fig. 17.3).

The external *circular layer* of pharyngeal muscles, called **constrictors** (fig. 18.13), compresses the lumen of the pharynx involuntarily during swallowing. The **superior constrictor muscle** attaches to bony processes of the skull and mandible and encircles the upper portion of the pharynx. The **middle constrictor muscle** arises from the hyoid bone and stylohyoid ligament and encircles the middle portion of the pharynx. The **inferior constrictor muscle** arises from the cartilages of the larynx and encircles the lower portion of the pharynx. During breathing, the lower portion of the inferior constrictor muscle is contracted, preventing air from entering the esophagus.

The motor and most of the sensory innervation to the pharynx is via the pharyngeal plexus, situated chiefly on the middle constrictor muscle. It is formed by the pharyngeal branches of the glossopharyngeal and vagus nerves, together with a deep sympathetic branch from the superior cervical ganglion.

The pharynx is served principally by ascending pharyngeal arteries, which branch from the external carotid arteries. The pharynx is also served by small branches from the inferior thyroid arteries, which arise from the thyrocervical trunk. Venous return is via the internal jugular veins.

Knowledge Check

8. Define the terms *heterodont* and *diphyodont*. Which of the four kinds of teeth is not found in deciduous dentition?
9. Where are the enamel, dentin, cementum, and pulp of a tooth located? Explain how a tooth is anchored into its socket.
10. Describe the location of the parotid, submandibular, and sublingual ducts and state where they empty into the oral cavity.

ESOPHAGUS AND STOMACH

A bolus of food is passed from the esophagus to the stomach, where it is churned and mixed with gastric secretions. The chyme thus produced is sent past the pyloric sphincter of the stomach to the duodenum.

Objective 9 Describe the steps in deglutition.

Objective 10 Describe the location, gross structure, and functions of the stomach.

Objective 11 Describe the histological structure of the esophagus and stomach. List the cell types in the gastric mucosa, along with their secretory products.

CHAPTER 18

Esophagus

The **esophagus** is that portion of the GI tract that connects the pharynx to the stomach (see figs. 18.1 and 18.15). It is a collapsible tubular organ, approximately 25 cm (10 in.) long, originating at the larynx and lying posterior to the trachea.

The esophagus is located within the mediastinum of the thorax and passes through the diaphragm just above the opening into the stomach. The opening through the diaphragm is called the **esophageal hiatus** (*ĕ-sof''ă-je'al hi-a'tus*) The esophagus is lined with a nonkeratinized stratified squamous epithelium (fig. 18.14); its walls contain either skeletal or smooth muscle, depending on the location. The upper third of the esophagus contains skeletal muscle; the middle third, a combination of skeletal and smooth muscle; and the terminal portion, smooth muscle only.

esophagus: Gk. *oisein*, to carry; *phagema*, food

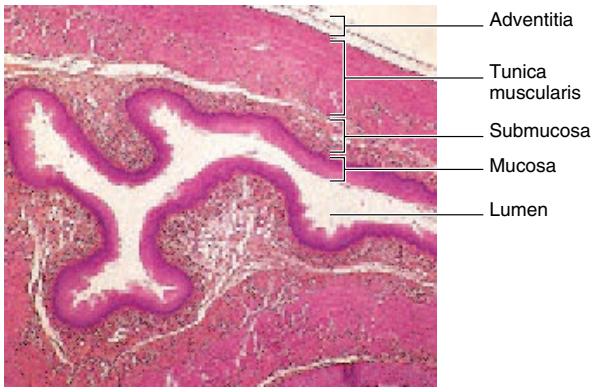


FIGURE 18.14 The histology of the esophagus seen in cross section.

The **lower esophageal** (gastroesophageal) **sphincter** is a slight thickening of the circular muscle fibers at the junction of the esophagus and the stomach. After food or fluid pass into the stomach, this sphincter constricts to prevent the stomach contents from regurgitating into the esophagus. There is a normal tendency for this to occur because the thoracic pressure is lower than the abdominal pressure as a result of the air-filled lungs.

The lower esophageal sphincter is not a well-defined sphincter muscle comparable to others located elsewhere along the GI tract, and it does at times permit the acidic contents of the stomach to enter the esophagus. This can create a burning sensation commonly called *heartburn,* although the heart is not involved. In infants under a year of age, the lower esophageal sphincter may function erratically, causing them to "spit up" following meals. Certain mammals, such as rodents, have a true lower esophageal sphincter and cannot regurgitate, which is why poison grains are effective in killing mice and rats.

Swallowing Mechanisms

Swallowing, or **deglutition** (*de''gloo-tish'un*), is the complex mechanical and physiological act of moving food or fluid from the oral cavity to the stomach. For descriptive purposes, deglutition is divided into three stages.

The first deglutitory stage is voluntary and follows mastication, if food is involved. During this stage, the mouth is closed and breathing is temporarily interrupted. A bolus is formed as the tongue is elevated against the transverse palatine folds (palatal rugae) of the hard palate (see fig. 18.5) through contraction of the mylohyoid and styloglossus muscles and the intrinsic muscles of the tongue.

The second stage of deglutition is the passage of the bolus through the pharynx. The events of this stage are involuntary and are elicited by stimulation of sensory receptors located at the opening of the oropharynx. Pressure of the tongue against the transverse palatine folds seals off the nasopharynx from the oral cavity, creates a pressure, and forces the bolus into the oropharynx. The soft palate and pendulant palatine uvula are elevated to close the nasopharynx as the bolus passes. The hyoid bone and

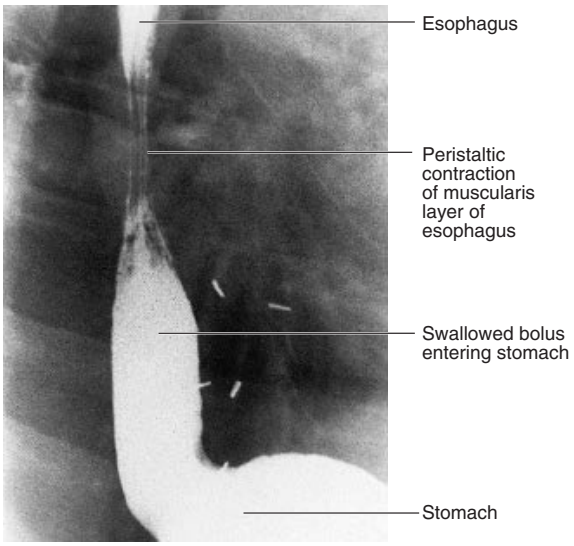


FIGURE 18.15 An anteroposterior radiograph of the esophagus showing peristaltic contraction and movement of a bolus into the stomach.

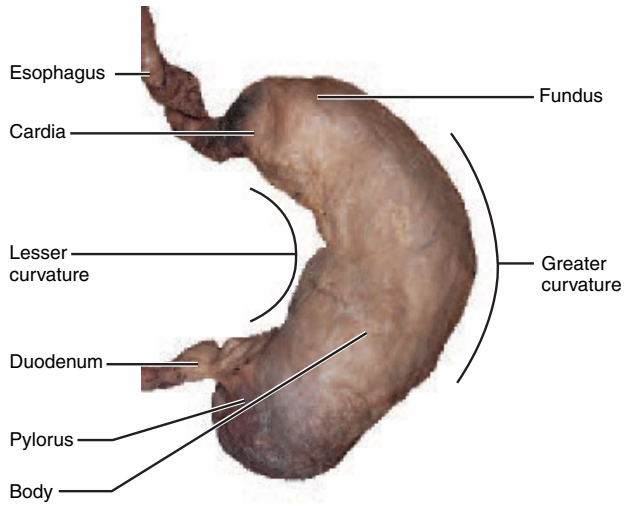
the larynx are also elevated. Elevation of the larynx against the epiglottis seals the glottis so that food or fluid is less likely to enter the trachea. Sequential contraction of the constrictor muscles of the pharynx moves the bolus through the pharynx to the esophagus. This stage is completed in just a second or less.

The third stage, the entry and passage of food through the esophagus, is also involuntary. The bolus is moved through the esophagus by peristalsis (fig. 18.15). In the case of fluids, the entire process of deglutition takes place in slightly more than a second; for a typical bolus, the time frame is 5 to 8 seconds.

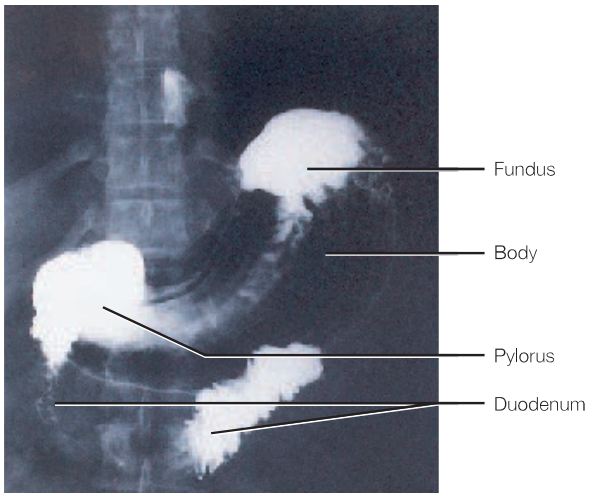
Stomach

The **stomach**—the most distensible part of the GI tract—is located in the upper left abdominal quadrant, immediately below the diaphragm. Typically J-shaped when empty, the stomach is continuous with the esophagus superiorly and empties into the duodenal portion of the small intestine inferiorly (fig. 18.16). In the stomach, which serves as a "holding organ" for ingested food, the food is mechanically churned with gastric secretions to form a pasty material called **chyme** (*kīm*). Once formed, chyme is moved from the stomach to the small intestine.

The stomach is divided into four regions: the cardia, fundus, body, and pylorus (fig. 18.17). The **cardia** is the narrow upper region immediately below the lower esophageal sphincter. The **fundus** is the dome-shaped portion to the left of and in direct contact with the diaphragm. The **body** is the large central portion, and the **pylorus** is the funnel-shaped terminal portion. The **pyloric sphincter** is the modified circular muscle at the end of the pylorus, where it joins the small intestine. *Pylorus* is a



(a)



(b)

FIGURE 18.16 The stomach. (*a*) As seen from a cadaver, the stomach is a J-shaped organ. (*b*) A radiograph of the stomach is of clinical value for detecting ulcers, constrictions, or ingested objects. A patient swallows radiopaque barium, which coats the lining of the stomach and duodenum. These structures and certain abnormalities may then show up in the radiograph.

CHAPTER 18

chyme: L. *chymus*, juice
cardia: Gk. *kardia*, heart (upper portion, nearer the heart)

fundus: L. *fundus*, bottom
pylorus: Gk. *pyloros*, gatekeeper

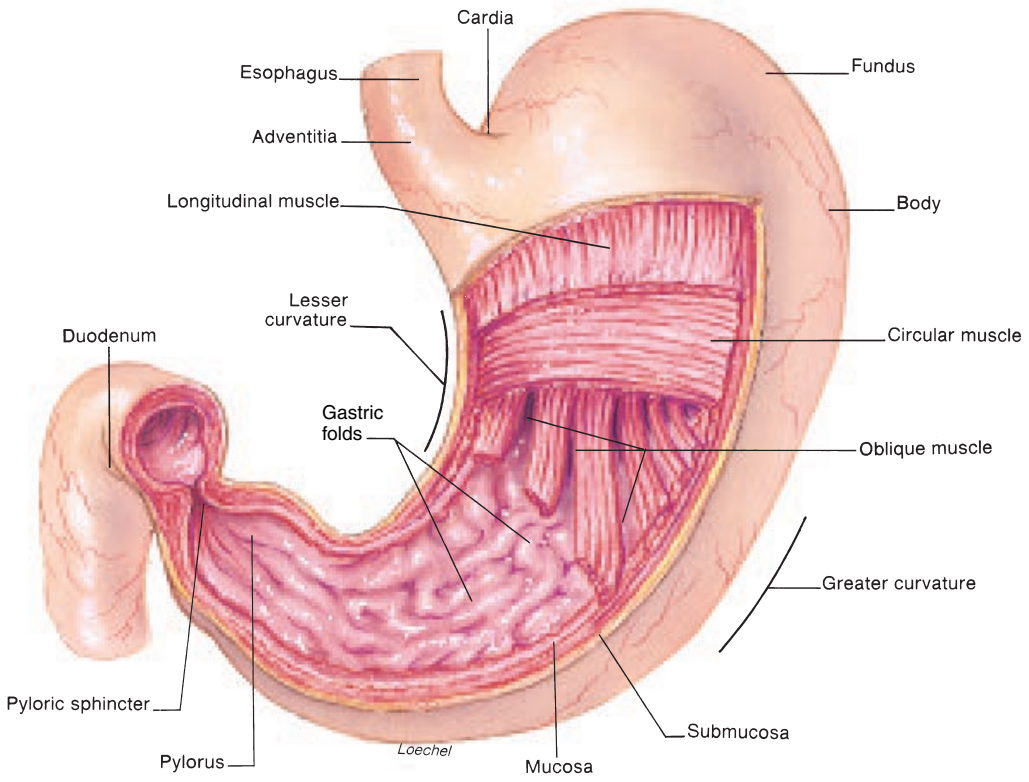


FIGURE 18.17 The major regions and structures of the stomach.

Greek word meaning "gatekeeper," and this junction is just that, regulating the movement of chyme into the small intestine and prohibiting backflow.

The stomach has two surfaces and two borders. The broadly rounded surfaces are referred to as the **anterior** and **posterior surfaces.** The medial concave border is the **lesser curvature** (fig. 18.17), and the lateral convex border is the **greater curvature.** The lesser omentum extends between the lesser curvature and the liver, and the greater omentum is attached to the greater curvature (see fig. 18.3*d*).

The wall of the stomach is composed of the same four tunics found in other regions of the GI tract, with two principal modifications: (1) an extra *oblique muscle layer* is present in the muscularis, and (2) the mucosa is thrown into numerous longitudinal folds, called **gastric folds** or *gastric rugae*, which permit stomach distension. The mucosa is further characterized by the presence of microscopic **gastric pits** and **gastric glands** (figs. 18.18 and 18.19).

There are five types of cells in the gastric glands that secrete specific products.

- **Goblet cells** secrete protective mucus.
- **Parietal cells** secrete hydrochloric acid (HCl).
- **Principal cells** (chief cells) secrete pepsinogen, an inactive form of the protein-digesting enzyme pepsin.

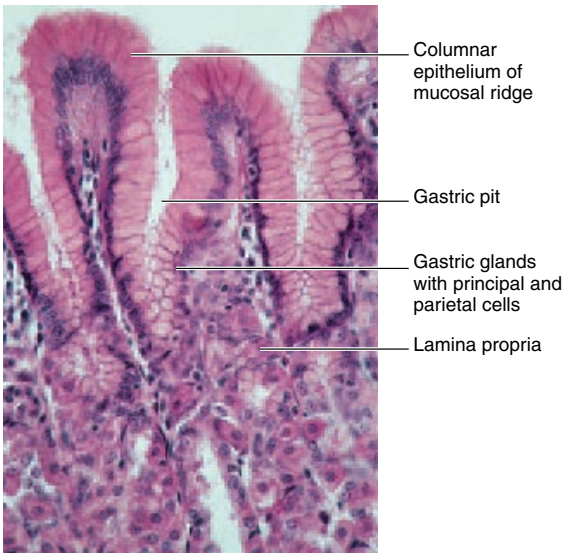


FIGURE 18.18 The histology of the mucosa of the stomach.

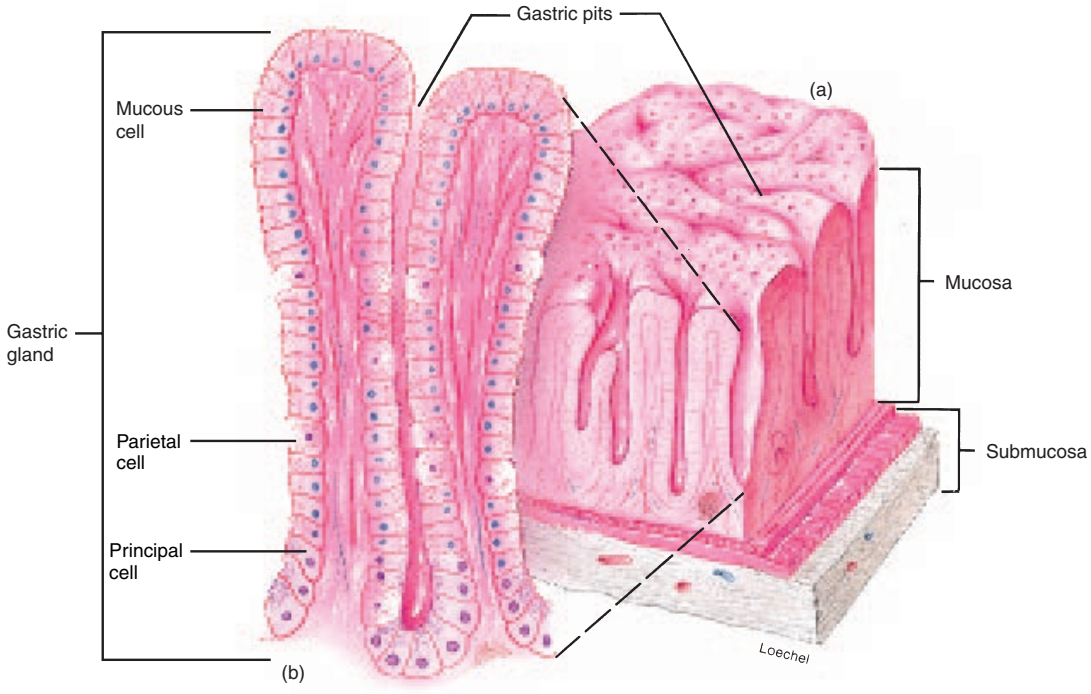


FIGURE 18.19 Gastric pits and gastric glands of the stomach mucosa. (*a*) Gastric pits are the openings of the gastric glands. (*b*) Gastric glands consist of mucous cells, principal cells, and parietal cells, each type producing a specific secretion.

- **Argentaffin** (*ar-jent′ă-fin*) **cells** secrete serotonin, histamine, and autocrine regulators.
- **Endocrine cells** (G cells) secrete the hormone gastrin into the blood.

In addition to these products, the gastric mucosa (probably the parietal cells) secretes *intrinsic factor*, a polypeptide that is required for absorption of vitamin B_{12} in the small intestine. Continued gastric activity when the stomach is empty causes hunger sensations known as *hunger pangs*. Eating fills the stomach resulting in hunger satiety, or a perception of "fullness."

The stomach is sensitive to emotional stress. Mucus, secreted by mucous cells of the stomach, is important in preventing hydrochloric acid and the digestive enzyme pepsin from eroding the stomach wall. *Peptic ulcers* may be caused by an increase in cellular secretion or by insufficient secretions of protective mucus. Another protective feature is the rapid mitotic activity of the columnar epithelium of the stomach. The entire lining of the stomach is usually replaced every few days. Nevertheless, in the United States approximately 10% of the male population and 4% of the female population develop peptic ulcers.

Regulation of gastric activity is autonomic. The sympathetic neurons arise from the celiac plexus, and the parasympathetic neurons arise from the vagus nerves. Parasympathetic neurons synapse in the myenteric plexus between the muscular layers and in the submucosal plexus in the submucosa. Parasympathetic impulses promote gastric activity, the phases of which are presented in table 18.5.

argentaffin: L. *argentum*, silver; *affinis*, attraction (become colored with silver stain)

TABLE 18.5 **Phases of Gastric Secretion**

Phase	Response
Cephalic phase	Sight, taste, small or mental stimuli evoke parasympathetic response via vagus nerves; 50–150 ml of gastric juice is secreted
Gastric phase	Food in the stomach stretches the mucosa, and chemical breakdown of protein stimulates the release of gastrin; gastrin stimulates the production of 600–750 ml of gastric juice
Intestinal phase	Chyme entering the duodenum stimulates intestinal cells to release intestinal gastrin; intestinal gastrin stimulates the production of additional small quantities of gastric juice

Vomiting is the reflexive response of emptying the stomach through the esophagus, pharynx, and oral cavity. This action is controlled by the **vomiting center** of the medulla oblongata. Stimuli within the GI tract, especially the duodenum, may activate the vomiting center, as may nauseating odors or sights, motion sickness, or body stress. Various drugs called *emetics* can also stimulate a vomiting reflex. The mechanics of vomiting are as follows: (1) strong, sustained contractions of the upper small intestine, followed by a contraction of the pyloric sphincter; (2) relaxation of

the lower esophageal sphincter and contraction of the pyloric portion of the stomach; (3) a shallow inspiration and closure of the glottis; and (4) compression of the stomach against the liver by contraction of the diaphragm and the abdominal muscles. This reflexive sequence causes a forceful ejection of vomit. The feeling of *nausea* is caused by stimuli in the vomiting center and may or may not cause vomiting.

The only function of the stomach that appears to be essential for life is the secretion of *intrinsic factor*. This polypeptide is needed for the intestinal absorption of vitamin B_{12}, which is required for maturation of red blood cells in the bone marrow. Following surgical removal of the stomach (gastrectomy), a patient has to receive vitamin B_{12} (together with intrinsic factor) orally or through injections, so that he or she will not develop *pernicious anemia*.

Knowledge Check

11. Describe the three stages of deglutition with reference to the structures involved.
12. Describe the structure and function of the lower esophageal sphincter.
13. List the functions of the stomach. What is the function of the gastric folds?
14. Describe the modifications of the stomach that aid in mechanical and chemical digestion.

SMALL INTESTINE

The small intestine, consisting of the duodenum, jejunum, and ileum, is the site where digestion is completed and nutrients are absorbed. The surface area of the intestinal wall is increased by plicae circulares, intestinal villi, and microvilli.

Objective 12 Describe the location and regions of the small intestine and the way in which it is supported.

Objective 13 List the functions of the small intestine and describe the structural adaptations through which these functions are accomplished.

Objective 14 Describe the movements that occur within the small intestine.

The **small intestine** is that portion of the GI tract between the pyloric sphincter of the stomach and the ileocecal valve that opens into the large intestine. It is positioned in the central and lower portions of the abdominal cavity and is supported, except for the first portion, by the **mesentery** (fig. 18.20). The fan-shaped mesentery permits movement of the small intestine but leaves little chance for it to become twisted or kinked. Enclosed within the mesentery are blood vessels, nerves, and lymphatic vessels that supply the intestinal wall.

The small intestine is approximately 3 m (12 ft) long and 2.4 cm (1 in.) wide in a living person, but it will measure nearly twice this length in a cadaver when the muscular wall is relaxed. It is called the "small" intestine because of its relatively small diameter compared to that of the large intestine. The small intestine is the body's major digestive organ and the primary site of nutrient absorption. Its digestive enzymes, along with those of the salivary glands, gastric glands, and pancreas, are summarized in table 18.6.

The small intestine is innervated by the superior mesenteric plexus. The branches of the plexus contain sensory fibers, postganglionic sympathetic fibers, and preganglionic parasympathetic fibers. The arterial blood supply to the small intestine is through the superior mesenteric artery and branches from the celiac trunk and the inferior mesenteric artery. The venous drainage is through the superior mesenteric vein. This vein unites with the splenic vein to form the hepatic portal vein, which carries nutrient-rich blood to the liver (see fig. 16.41).

Regions of the Small Intestine

On the basis of function and histological structure, the small intestine is divided into three regions.

1. The **duodenum** (*doo''ŏ-de'num, doo-od'ĕ-num*) is a relatively fixed, C-shaped tubular organ, measuring approximately 25 cm (10 in.) from the pyloric sphincter of the stomach to the **duodenojejunal** (*doo-od''ĕ-no''jĕ-joo'nal*) **flexure.** Except for a short portion near the stomach, the duodenum is retroperitoneal. Its concave surface faces to the left, where it receives bile secretions from the liver and gallbladder through the **common bile duct** and pancreatic secretions through the **pancreatic duct** of the pancreas (fig. 18.21). These two ducts unite to form a common entry into the duodenum called the **hepatopancreatic ampulla** (ampulla of Vater), which pierces the duodenal wall and drains into the duodenum from an elevation called the **duodenal papilla.** It is here that bile and pancreatic juice enter the small intestine. The duodenal papilla can be opened or closed by the action of the **sphincter of ampulla** (of Oddi). The duodenum differs histologically from the rest of the small intestine by the presence of **duodenal** (Brunner's) **glands** in the submucosa (fig. 18.22). These compound tubuloalveolar glands secrete mucus and are most numerous near the superior end of the duodenum.
2. The **jejunum** (*jĕ-joo'num*), which extends from the duodenum to the ilium, is approximately 1 m (3 ft) long. It has a slightly larger lumen and more internal folds than does the ileum, but its histological structure is similar to that of the ileum.

duodenum: L. *duodeni,* 12 each (length of 12 fingers' breadth)
ampulla of Vater: from Abraham Vater, German anatomist, 1684–1751
sphincter of Oddi: from Rugger Oddi, Italian physician, 1864–1913
Brunner's glands: from Johann C. Brunner, Swiss anatomist, 1653–1727

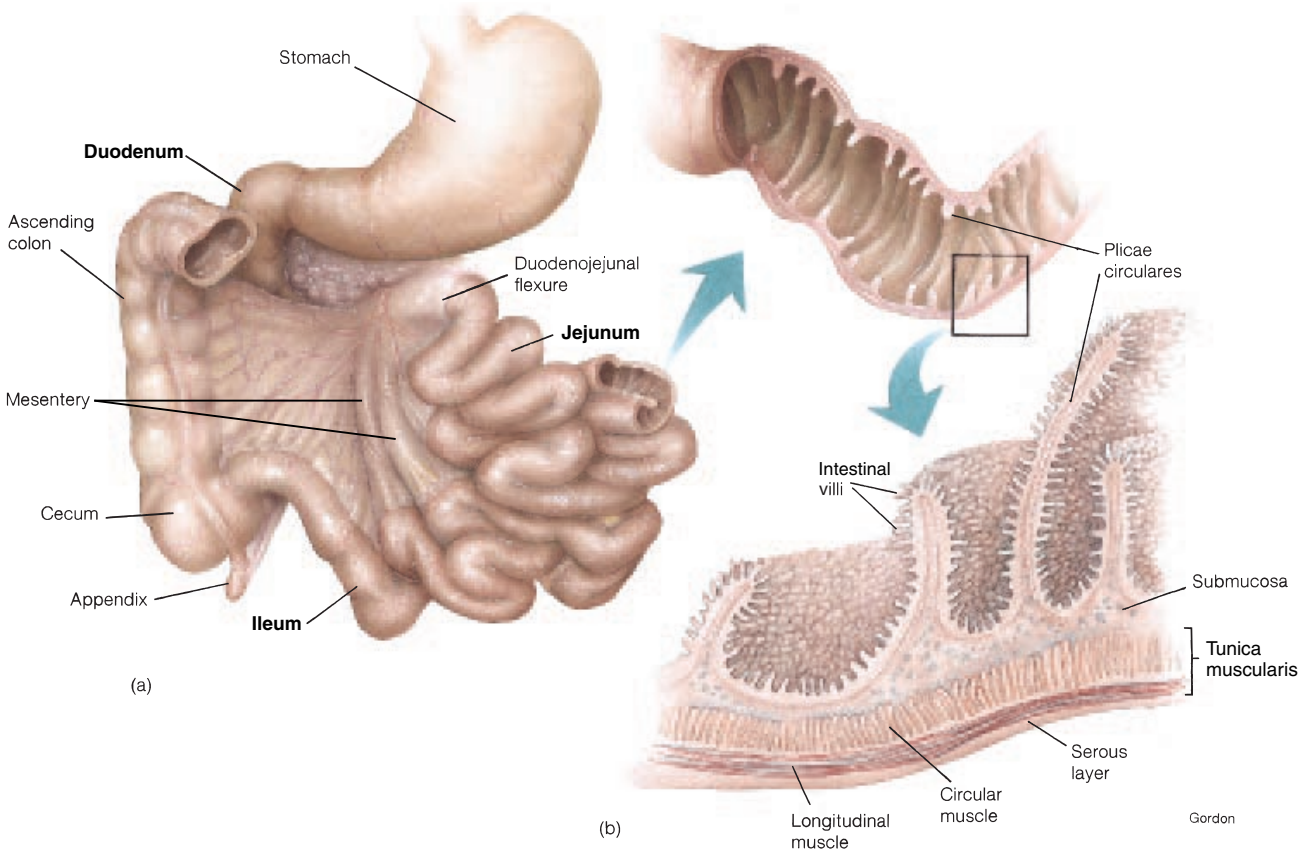


FIGURE 18.20 The small intestine in relation to the stomach and a part of the large intestine. (*a*) The regions and mesenteric attachment. (*b*) A section of the intestinal wall showing the mucosa and submucosa folded into structures called plicae circulares. (The regions of the small intestine are labeled in boldface type.)

3. The **ileum** (*il′e-um*)—not to be confused with the ilium of the os coxae—makes up the remaining 2 m (6–7 ft) of the small intestine. The terminal portion of the ileum empties into the medial side of the cecum through the **ileocecal valve.** Lymph nodules, called **mesenteric** (Peyer's) **patches,** are abundant in the walls of the ileum.

Structural Modifications of the Small Intestine

The products of digestion are absorbed across the epithelial lining of the intestinal mucosa. Absorption occurs primarily in the jejunum, although some also occurs in the duodenum and ileum. Absorption occurs at a rapid rate as a result of four specializations that increase the intestinal surface area.

- The three meter length of the small intestine.
- The **plicae** (*pli′se*) **circulares** are large macroscopic folds of mucosa (see fig. 18.20).
- The **intestinal villi** (*vil′e*) are fingerlike macroscopic folds of the mucosa that project into the lumen of the small intestine (fig. 18.23).
- The **microvilli** are microscopic projections formed by the folding of each epithelial cell membrane. In a light microscope, the microvilli display a somewhat vague brush

Peyer's patches: from Johann K. Peyer, Swiss anatomist, 1653–1712

plica: L. *plicatus*, folded
villus: L. *villosus*, shaggy

TABLE 18.6 Digestive Enzymes

Enzyme	Source	Digestive Action
Salivary enzyme		
Amylase	Salivary glands	Begins carbohydrate digestion by converting starch and glycogen to disaccharides
Gastric juice enzyme		
Pepsin	Gastric glands	Begins the digestion of nearly all types of proteins
Intestinal juice enzymes		
Peptidase	Intestinal glands	Converts proteins into amino acids
Sucrase	Intestinal glands	Converts disaccharides into monosaccharides
Maltase		
Lactase		
Lipase	Intestinal glands	Converts fats into fatty acids and glycerol
Amylase	Intestinal glands	Converts starch and glycogen into disaccharides
Nuclease	Intestinal glands	Converts nucleic acids into nucleotides
Enterokinase	Intestinal glands	Activates trypsin
Pancreatic juice enzymes		
Amylase	Pancreas	Converts starch and glycogen into disaccharides
Lipase	Pancreas	Converts fats into fatty acids and glycerol
Peptidases	Pancreas	Convert proteins or partially digested proteins into amino acids
Trypsin		
Chymotrypsin		
Carboxypeptidase		
Nuclease	Pancreas	Converts nucleic acids into nucleotides

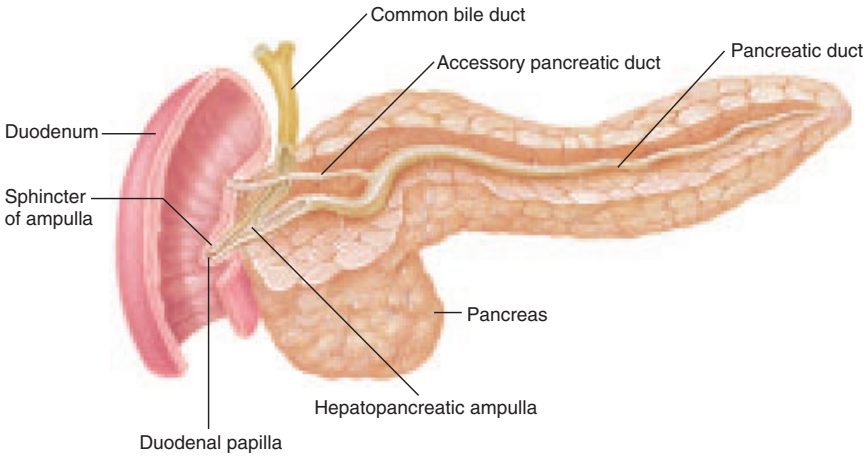


FIGURE 18.21 A section of the duodenum showing the location of entry of the common bile duct and the pancreatic duct.

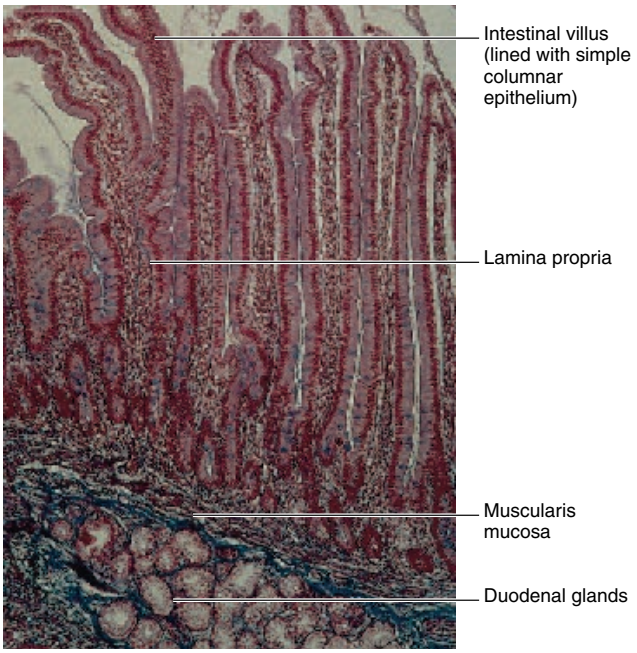


FIGURE 18.22 The histology of the duodenum.

border on the edges of the columnar epithelium (fig. 18.24). The terms **brush border** and **microvilli** are often used interchangeably in describing the small intestine.

The intestinal villi are covered with columnar epithelial cells, among which are interspersed the mucus-secreting goblet cells. The lamina propria, which forms the connective tissue core of each intestinal villus, contains numerous lymphocytes, blood capillaries, and a lymphatic vessel called the **lacteal** (*lak'te-al*) (fig. 18.23). Absorbed monosaccharides and amino acids enter the blood capillaries; absorbed fatty acids and cholesterols enter the lacteals. Intestinal villi are considered the functional units of the digestive system because absorption through these structures is how digested molecules enter the blood or lymph.

Epithelial cells at the tips of the intestinal villi are continuously shed and are replaced by cells that are pushed up from the bases of the intestinal villi. The epithelium at the base of the intestinal villi invaginates downward at various points to form narrow pouches that open through pores into the intestinal lumen. These structures are called the **intestinal crypts** (crypts of Lieberkühn) (see fig. 18.23).

Mechanical Activities of the Small Intestine

Contractions of the longitudinal and circular muscles of the small intestine produce three distinct types of movement: *rhythmic segmentation*, *pendular movements*, and *peristalsis*.

lacteal: L. *lacteus*, milk

crypts of Lieberkühn: from Johann N. Lieberkühn, German anatomist, 1711–56

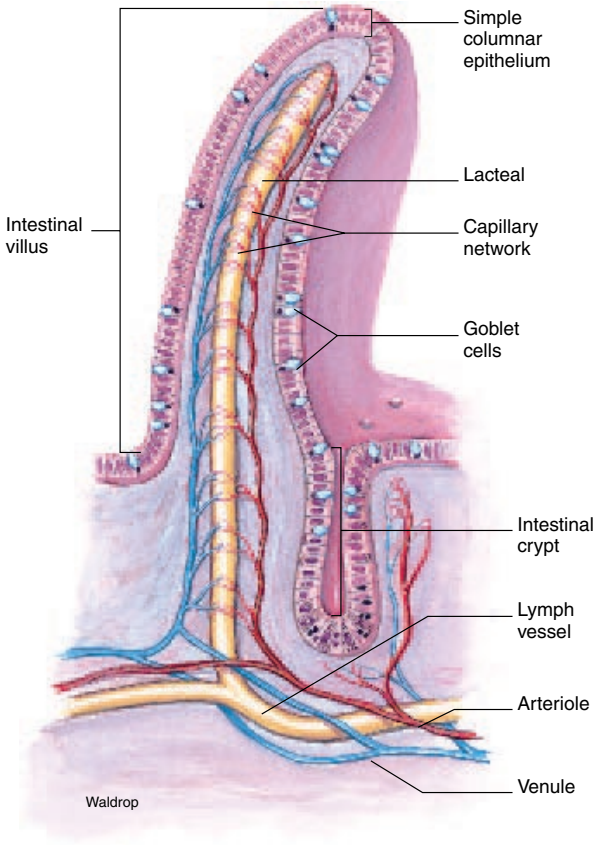


FIGURE 18.23 The structure of an intestinal villus and intestinal crypt.

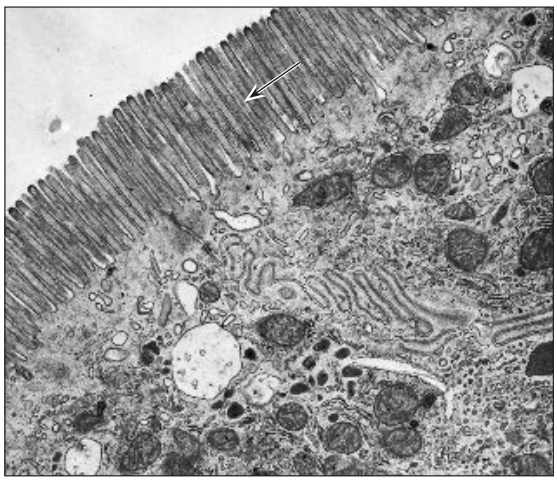


FIGURE 18.24 An electron photomicrograph of microvilli (arrow) at the exposed surface of a columnar epithelial cell in the small intestine.

Rhythmic segmentations are local contractions of the circular muscular layer. They occur at the rate of about 12 to 16 per minute in regions containing chyme. Rhythmic segmentations churn the chyme with digestive juices and bring it into contact with the mucosa. During these contractions, the vigorous motion of the intestinal villi stirs the chyme and facilitates absorption.

Pendular movements primarily occur in the longitudinal muscle layer. In this motion, a constrictive wave moves along a segment of the small intestine and then reverses and moves in the opposite direction, moving the chyme back and forth. Pendular movements also mix the chyme but do not seem to have a particular frequency.

Peristalsis (*per″ĭ-stal′sis*) is responsible for the propulsive movement of the chyme through the small intestine. These wavelike contractions are usually weak and relatively short, occurring at a frequency of about 15 to 18 per minute. Chyme requires 3 to 10 hours to travel the length of the small intestine. Both muscle layers are involved in peristalsis.

The sounds of digestive peristalsis can be easily heard through a stethoscope placed at various abdominal locations. These sounds can be detected even through clothing. The sounds, mostly clicks and gurgles, occur at a frequency of 5 to 30 per minute.

Knowledge Check

15. Describe the small intestine. Where is it located? How is it subdivided? How is it supported?
16. What are the primary functions of the small intestine?
17. List four structural modifications of the small intestine that increase its absorptive surface area.
18. Describe the movements of the small intestine. Which movements are produced by the circular layer of the tunica muscularis?
19. Which region of the small intestine is the longest? Which is the shortest? How long does it take a portion of chyme to move through the small intestine?

CHAPTER 18

LARGE INTESTINE

The large intestine receives undigested food from the small intestine, absorbs water and electrolytes from chyme, and passes feces out of the GI tract.

Objective 15 Identify the regions of the large intestine and describe its gross and histological structure.

Objective 16 Describe the functions of the large intestine and explain how defecation is accomplished.

The **large intestine** averages 1.5 m (5 ft) in length and 6.5 cm (2.5 in.) in diameter. It is called the "large" intestine because of its relatively large diameter compared to that of the small intestine. The large intestine begins at the end of the ileum in the lower right quadrant of the abdomen. From there, it leads superiorly on the right side to a point just below the liver; it then crosses to the left, descends into the pelvis, and terminates at the anus. A specialized portion of the mesentery, the **mesocolon,** supports the transverse portion of the large intestine along the posterior abdominal wall.

The large intestine has little or no digestive function, but it does absorb water and electrolytes from the remaining chyme. In addition, the large intestine functions to form, store, and expel *feces* from the body.

Regions and Structures of the Large Intestine

The large intestine is structurally divided into the *cecum*, *colon*, *rectum*, and *anal canal* (figs. 18.25 and 18.26). The **cecum** (*se′kum*) is a dilated pouch positioned slightly below the ileocecal valve. The **ileocecal valve** is a fold of mucous membrane at the junction of the small intestine and large intestine that prohibits the backflow of chyme. A fingerlike projection called the **appendix** is attached to the inferior medial margin of the cecum. The 8 cm (3 in.) appendix contains an abundance of lymphatic tissue (fig. 18.27) that may serve to resist infection. Although the appendix serves no digestive function, it is thought to be a vestigial remnant of an organ that was functional in human ancestors.

A common disorder of the large intestine is inflammation of the appendix, or *appendicitis.* Wastes that accumulate in the appendix cannot be moved easily by peristalsis, because the appendix has only one opening. Although the symptoms of appendicitis are quite variable, they often include a high white blood cell count, localized pain in the lower right quadrant, and loss of appetite. Vomiting may or may not occur. Rupture of the appendix (a "burst appendix") spreads infectious material throughout the peritoneal cavity, resulting in *peritonitis.*

The superior portion of the cecum is continuous with the **colon,** which consists of ascending, transverse, descending, and sigmoid portions (fig. 18.25). The **ascending colon** extends superiorly from the cecum along the right abdominal wall to the inferior surface of the liver. Here the colon bends sharply to the left at the **hepatic flexure** (right colic flexure) and continues across the upper abdominal cavity as the **transverse colon.** At the left abdominal wall, another right-angle bend called the **splenic flexure** (left colic flexure) marks the beginning of the **descending colon.** From the splenic flexure, the descending colon extends inferiorly along the left abdominal wall to the pelvic region. The colon then angles medially from the brim of the pelvis to form an S-shaped bend, known as the **sigmoid colon.**

cecum: L. *caecum*, blind pouch
appendix: L. *appendix*, attachment
colon: Gk. *kolon*, member of the whole
sigmoid: Gk. *sigmoeides*, shaped like a sigma, Σ

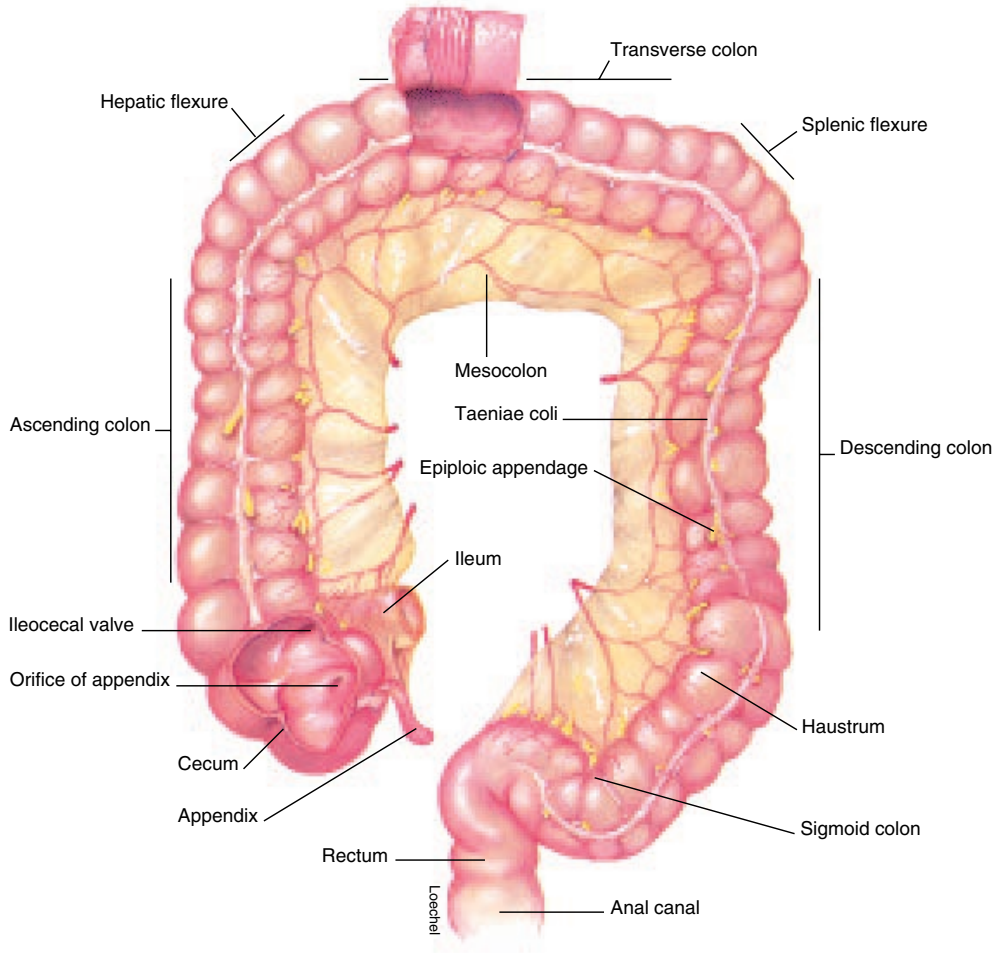


FIGURE 18.25 The large intestine.

The terminal 20 cm (7.5 in.) of the GI tract is the **rectum,** and the last 2 to 3 cm of the rectum is referred to as the **anal canal** (fig. 18.28). The rectum lies anterior to the sacrum, where it is firmly attached by peritoneum. The **anus** is the external opening of the anal canal. Two sphincter muscles guard the anal opening: the **internal anal sphincter,** which is composed of smooth muscle fibers, and the **external anal sphincter,** composed of skeletal muscle. The mucous membrane of the anal canal is arranged in highly vascular, longitudinal folds called **anal columns.**

A *hemorrhoid (hem'ŏ-roīd*) is a mass of varicose veins in the anal area caused, in part, by difficulty in defecating. Hemorrhoids, in reference to the condition in which such masses occur, are also called *piles.* A first-degree hemorrhoid is contained within the anal canal. A second-degree hemorrhoid prolapses, or extends outward during defecation. A third-degree hemorrhoid remains prolapsed through the anal orifice. Rubber band constriction is a common medical treatment for a prolapsed hemorrhoid. In this technique, a rubber band is tied around the hemorrhoid, constricting its blood supply, so that the tissue dries and falls off. In a relatively new treatment, infrared photocoagulation, a high-energy light beam coagulates the hemorrhoid.

Although the large intestine consists of the same tunics as the small intestine, there are some structural differences. The large intestine lacks intestinal villi but does have numerous goblet cells in the mucosal layer (fig. 18.29). The longitudinal muscle layer of the muscularis forms three distinct muscle bands called **taeniae coli** (*te'ne-e ko'li*) that run the length of the large intestine. A series of bulges in the walls of the large intestine form sacculations, or **haustra** (*haws'tra*), along its entire length (see figs. 18.25 and 18.26).

rectum: L. *rectum*, straight tube
anus: L. *anus*, ring

taenia: L. *tainia*, a ribbon
haustrum: L. *haustrum*, bucket or scoop

FIGURE 18.26 An anteroposterior radiograph after a barium enema showing the regions, flexures, and the haustra of the large intestine.

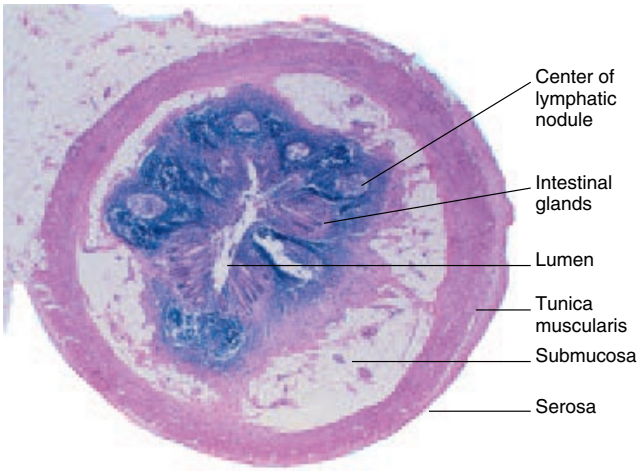


FIGURE 18.27 The histology of the appendix shown in cross section.

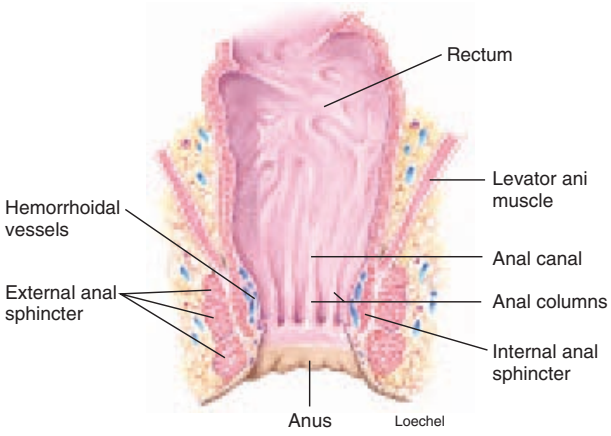
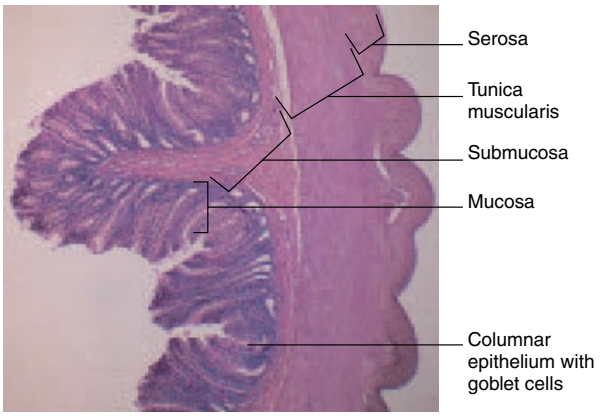
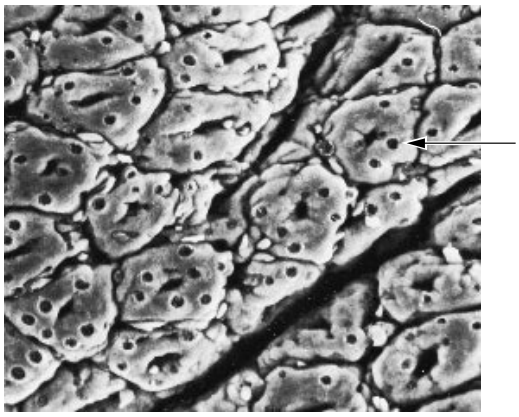


FIGURE 18.28 The anal canal.



(a)



(b)

FIGURE 18.29 The histology of the rectum. (*a*) A photomicrograph of the tunics. (*b*) A scanning electron photomicrograph of the mucosa from a section of the colon. The arrow indicates the opening of a goblet cell into the intestinal lumen.
(*From R.G. Kessel and R.H. Kardon.* Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy, © 1979 W.H. Freeman and Company.)

TABLE 18.7 Mechanical Activity in the GI Tract

Region	Type of Motility	Frequency	Stimulus	Result
Oral cavity	Mastication	Variable	Initiated voluntarily; proceeds reflexively	Pulverization: mixing with saliva
Oral cavity and pharynx	Deglutition	Maximum of 20 per min	Initiated voluntarily; reflexively controlled by swallowing center	Clears oral cavity of food
Esophagus	Peristalsis	Depends on frequency of swallowing	Initiated by swallowing	Movement through the esophagus
Stomach	Receptive relaxation	Matches frequency of swallowing	Unknown	Permits filling of stomach
	Tonic contraction	15–20 per min	Autonomic plexuses	Mixing and churning
	Peristalsis	1–2 per min	Autonomic plexuses	Evacuation of stomach
	Hunger contractions	3 per min	Low blood sugar level	Feeding
Small intestine	Peristalsis	15–18 per min	Autonomic plexuses	Transfer through intestine
	Rhythmic segmentation	12–16 per min	Autonomic plexuses	Mixing
	Pendular movements	Variable	Autonomic plexuses	Mixing
Large intestine	Peristalsis	3–12 per min	Autonomic plexuses	Transport
	Mass movements	2–3 per day	Stretch	Fills sigmoid colon
	Haustral churning	3–12 per min	Autonomic plexuses	Mixing
	Defecation	Variable: 1 per day to 3 per week	Reflex triggered by rectal distension	Defecation

Finally, the large intestine has small but numerous fat-filled pouches called **epiploic** (*ep-ĭ-plo′ik*) **appendages** (see fig. 18.25) that are attached superficially to the taeniae coli.

The sympathetic innervation of the large intestine arises from superior and inferior mesenteric plexuses, as well as from the celiac plexus. The parasympathetic innervation arises from the paired pelvic splanchnic and vagus nerves. Sensory fibers from the large intestine respond to bowel pressure and signal the need to defecate. Blood is supplied to the large intestine by branches from the superior mesenteric and inferior mesenteric arteries. Venous blood is returned through the superior and inferior mesenteric veins, which in turn drain into the hepatic portal vein that enters the liver.

Mechanical Activities of the Large Intestine

Chyme enters the large intestine through the ileocecal valve. About 15 ml of pasty material enters the cecum with each rhythmic opening of the valve. The ingestion of food intensifies peristalsis of the ileum and increases the frequency with which the ileocecal valve opens; this is called the **gastroileal reflex.** Material entering the large intestine accumulates in the cecum and ascending colon.

Three types of movements occur throughout the large intestine: peristalsis, haustral churning, and mass movement. **Peristaltic movements** of the colon are similar to those of the small intestine, although they are usually more sluggish in the colon. In **haustral churning,** a relaxed haustrum fills with food residues until a point of distension is reached that stimulates the muscularis to contract. Besides moving the material to the next haustrum, this contraction churns the material and exposes it to the mucosa, where water and electrolytes are absorbed. As a result of water absorption, the material becomes solid or semisolid, and is now known as *feces* (*fe′sēz*). **Mass movement** is a very strong peristaltic wave, involving the action of the taeniae coli, which moves the fecal material toward the rectum. Mass movements generally occur only two or three times a day, usually during or shortly after a meal. This response to eating, called the **gastrocolic reflex,** can best be observed in infants who have a bowel movement during or shortly after feeding.

As material passes through the large intestine, Na^+ K^+, and water are absorbed. It has been estimated that an average volume of 850 ml of water per day is absorbed across the mucosa of the colon. The fecal material that is left then passes to the rectum, leading to an increase in rectal pressure and the urge to defecate. If the urge to defecate is denied, feces are prevented from entering the anal canal by the external anal sphincter. In this case, the feces remain in the rectum and may even back up into the sigmoid colon.

The **defecation reflex** normally occurs when the rectal pressure rises to a particular level that is determined largely by habit. At this point, the internal anal sphincter relaxes to admit feces into the anal canal.

During the act of defecation, the longitudinal rectal muscles contract to increase rectal pressure, and the internal and external anal sphincter muscles relax. Excretion is aided by contractions of abdominal and pelvic skeletal muscles, which raise the intraabdominal pressure and help push the feces from the rectum through the anal canal and out the anus.

The various mechanical activities of the GI tract are summarized in table 18.7.

epiploic: Gk. *epiplein*, to float on

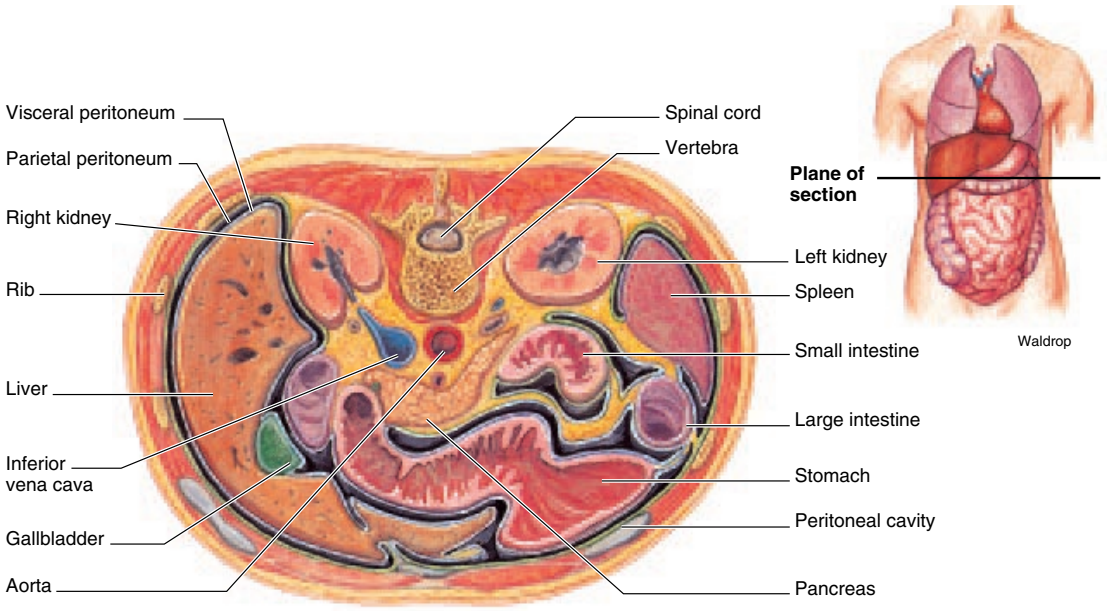


FIGURE 18.30 A cross section of the abdomen showing the relative position of the liver to other abdominal organs.

Constipation occurs when fecal material accumulates because of longer than normal periods between defecations. The slower rate of elimination allows more time for water absorption, so that the waste products become harder. Although uncomfortable and sometimes painful, this condition is usually not serious. *Diarrhea* occurs when waste material passes too quickly through the colon, so that insufficient time is allowed for water absorption. Excessive diarrhea can result in dangerous levels of dehydration and electrolyte imbalance, particularly in infants because of their small body size.

Knowledge Check

20. Identify the four principal regions of the large intestine and describe the functions of the colon.
21. Describe the haustra and the taeniae coli and explain their role in the movements of the large intestine.
22. Describe the location of the rectum, anal canal, and anal sphincter muscles and explain how defecation is accomplished.

CHAPTER 18

LIVER, GALLBLADDER, AND PANCREAS

The liver, consisting of four lobes, processes nutrients and secretes bile, which is stored and concentrated in the gallbladder prior to discharge into the duodenum. The pancreas, consisting of endocrine (islet) cells and exocrine (acini) cells, secretes important hormones into the blood and essential digestive enzymes into the duodenum.

Objective 17 Describe the location, structure, and functions of the liver.

Objective 18 Describe the location of the gallbladder and trace the flow of bile through the systems of ducts into the duodenum.

Objective 19 Describe the location, structure, and functions of the pancreas.

Three accessory digestive organs in the abdominal cavity aid in the chemical breakdown of food. These are the *liver*, *gallbladder* and *pancreas*. The liver and pancreas function as exocrine glands in this process because their secretions are transported to the lumen of the GI tract via ducts.

Liver

The **liver** is the largest internal organ of the body, weighing about 1.3 kg (3.5–4.0 lbs) in an adult. It is positioned immediately beneath the diaphragm in the epigastric and right hypochondriac regions (see fig. 2.15 and table 2.4) of the abdomen (fig. 18.30). Its reddish brown color is due to its great vascularity.

The liver has four lobes and two supporting ligaments. Anteriorly, the **right lobe** is separated from the smaller **left lobe** by the **falciform ligament** (fig. 18.31). Inferiorly, the **caudate**

falciform: L. *falcis*, sickle; forma, form

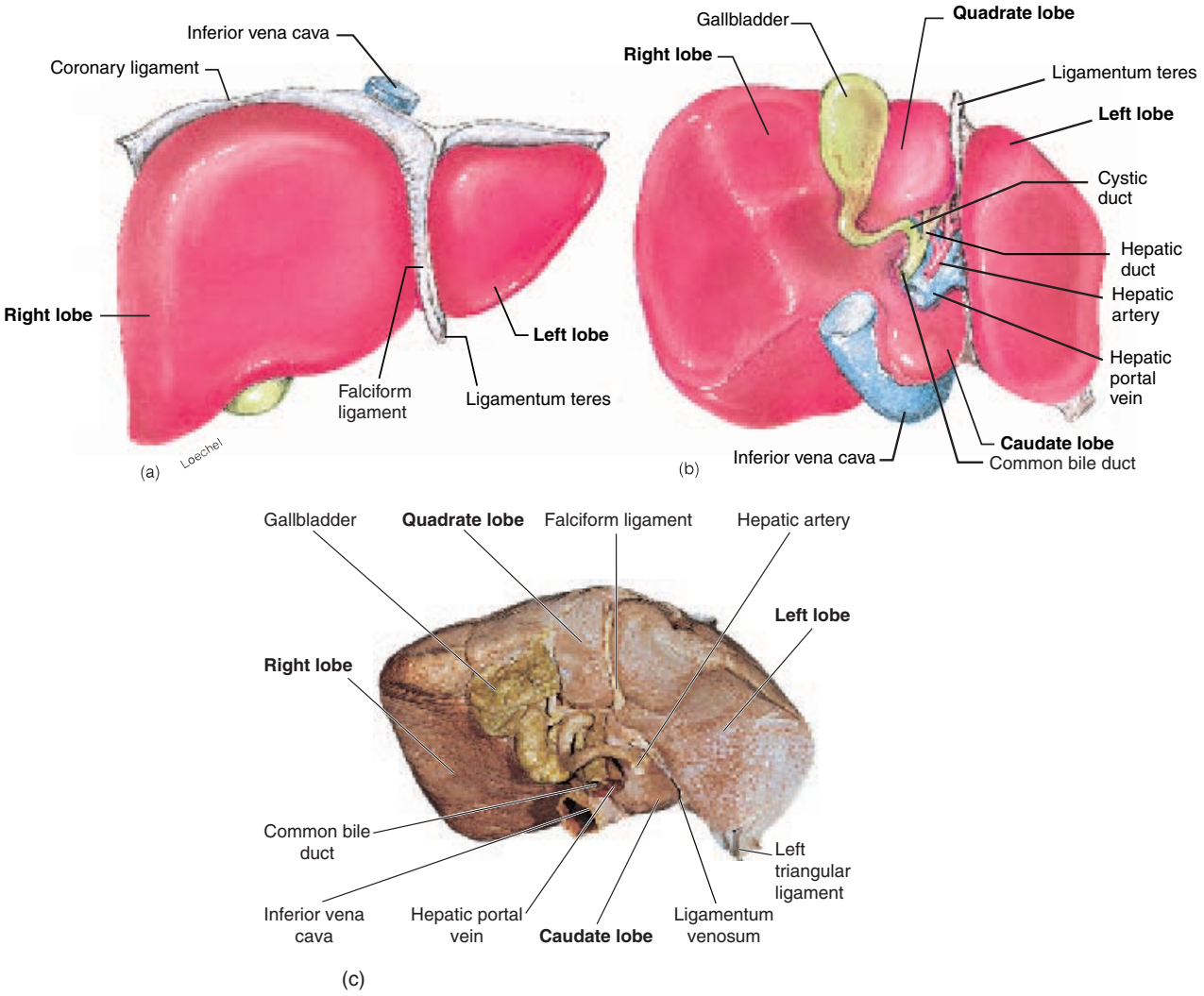


FIGURE 18.31 The liver and gallbladder. (*a*) An anterior view and (*b*) a rotated inferior view, and (*c*) a photograph of a rotated inferior view. (The lobes of the liver are labeled in boldface type.)

(*kaw'dàt*) **lobe** is positioned near the inferior vena cava, and the **quadrate lobe** is adjacent to the gallbladder. The falciform ligament attaches the liver to the anterior abdominal wall and the diaphragm. The **ligamentum teres** (round ligament) extends from the falciform ligament to the umbilicus. This ligament is the remnant of the umbilical vein of the fetus (see table 16.6).

Although the liver is the largest internal organ, it is, in a sense, only one to two cells thick. This is because the liver cells, or **hepatocytes,** form **hepatic plates** that are one to two cells thick and separated from each other by large capillary spaces called **liver** (hepatic) **sinusoids** (fig. 18.32). The sinusoids are lined with phagocytic **Kupffer** (*koop'fer*) **cells,** but the large intercellular gaps between adjacent Kupffer cells make these sinusoids more highly permeable than other capillaries. The plate structure of the liver and the high permeability of the sinusoids allow each hepatocyte to be in direct contact with the blood.

The hepatic plates are arranged to form functional units called **liver lobules** (fig. 18.33). In the middle of each lobule is a **central vein,** and at the periphery of each lobule are branches of the hepatic portal vein and of the hepatic artery, which open into the spaces *between* hepatic plates. Portal venous blood, containing molecules absorbed in the GI tract, thus mixes with

hepatic: Gk. *hepatos*, liver

Kupffer cells: from Karl Wilhelm von Kupffer, Bavarian anatomist and embryologist, 1829–1902

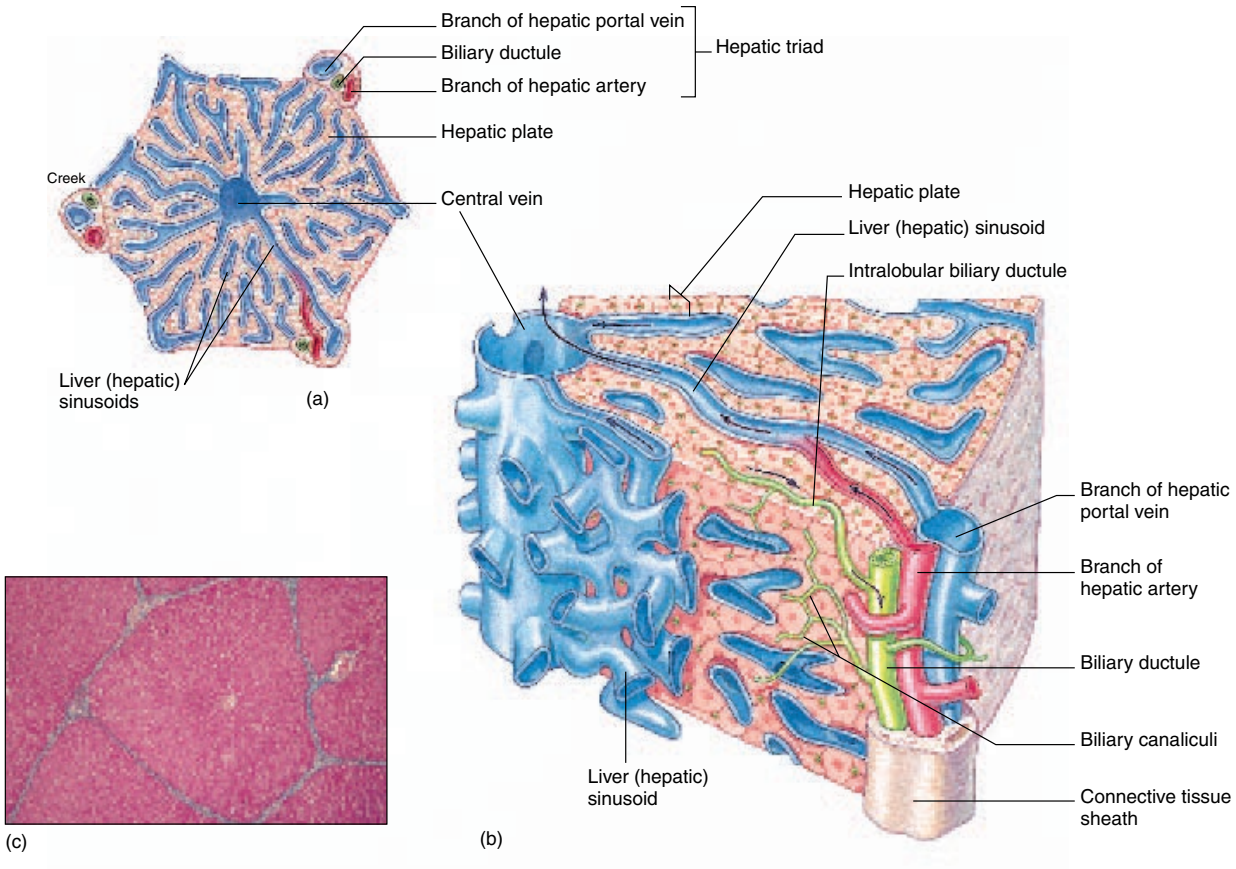


FIGURE 18.32 A liver lobule and the histology of the liver. (*a*) A cross section of a liver lobule and (*b*) a longitudinal section. Blood enters a liver lobule through the vessels in a hepatic triad, passes through hepatic sinusoids, and leaves the lobule through a central vein. The central veins converge to form hepatic veins that transport venous blood from the liver. (*c*) A photomicrograph of a liver lobule in cross section.

CHAPTER 18

arterial blood as the blood flows within the liver sinusoids from the periphery of the lobule to the central vein (fig. 18.33). The central veins of different liver lobules converge to form the hepatic vein, which carries blood from the liver to the inferior vena cava.

The liver lobules have numerous functions, including synthesis, storage, and release of vitamins; synthesis, storage, and release of glycogen; synthesis of blood proteins; phagocytosis of old red blood cells and certain bacteria; removal of toxic substances; and production of bile. Bile is stored in the gallbladder and is eventually secreted into the duodenum for the emulsification (breaking down into smaller particles) and absorption of fats.

Bile is produced by the hepatocytes and secreted into tiny channels called **bile canaliculi** (*kan''ă-lik'yŭ-li*) located *within* each hepatic plate (fig. 18.33). These bile canaliculi are drained at the periphery of each lobule by **bile ducts,** which in turn drain into **hepatic ducts** that carry bile away from the liver. Because blood travels in the sinusoids and bile travels in the opposite direction within the hepatic plates, blood and bile do not mix in the liver lobules.

The liver receives parasympathetic innervation from the vagus nerves and sympathetic innervation from thoracolumbar nerves through the celiac ganglia.

Gallbladder

The **gallbladder** is a saclike organ attached to the inferior surface of the liver (figs. 18.31 and 18.34). This organ stores and concentrates bile. A sphincter valve at the neck of the gallbladder allows a storage capacity of about 35 to 50 ml. The inner mucosal layer of the gallbladder is thrown into folds similar to the gastric folds of the stomach. When the gallbladder fills with bile, it expands to the size and shape of a small pear. Bile is a yellowish green fluid containing bile salts, bilirubin (a product resulting from the breakdown of blood), cholesterol, and other compounds. Contraction of the muscularis ejects bile from the gallbladder.

Bile is continuously produced by the liver and drains through the hepatic ducts and common bile duct to the duodenum. When the small intestine is empty of food, the **sphincter of ampulla** (see fig. 18.21) constricts, and bile is forced up the cystic duct to the gallbladder for storage.

The gallbladder is supplied with blood from the cystic artery, which branches from the right hepatic artery. Venous blood is returned through the cystic vein, which empties into the hepatic portal vein. Autonomic innervation of the gallbladder is

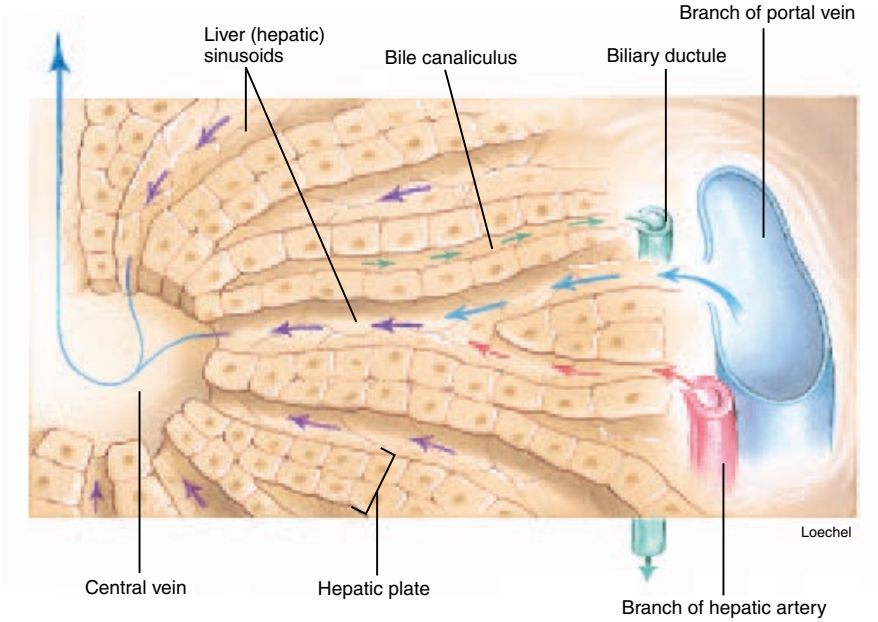


FIGURE 18.33 The flow of blood and bile in a liver lobule. Blood flows within sinusoids from branches of the hepatic portal vein to the central vein (from the periphery to the center of a lobule). Bile flows within hepatic plates from the center of a lobule to biliary ductules at the periphery.

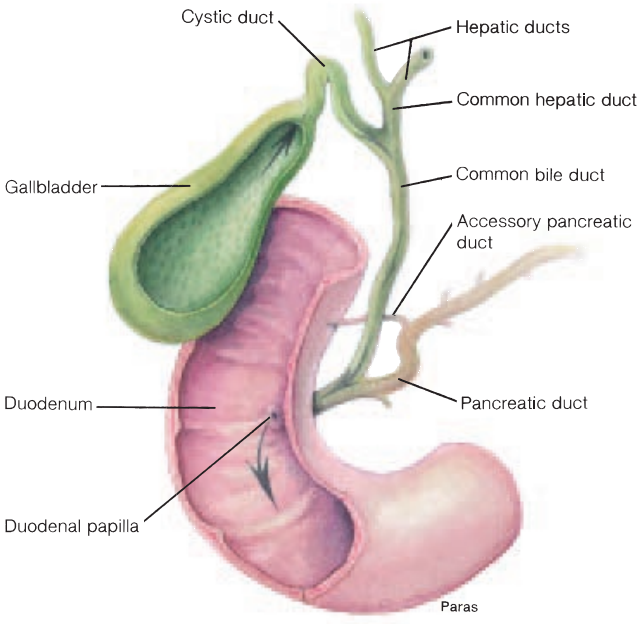


FIGURE 18.34 The pancreatic duct joins the bile duct to empty its secretions through the duodenal papilla into the duodenum. The release of bile and pancreatic juice into the duodenum is controlled by the sphincter of ampulla (see fig. 18.21).

similar to that of the liver; both receive parasympathetic innervation from the vagus nerves and sympathetic innervation from thoracolumbar nerves through the celiac ganglia.

A common clinical problem of the gallbladder is the development of *gallstones*. Bile is composed of various salts, pigments, and cholesterols that become concentrated as water is removed. Cholesterols normally remain in solution, but under certain conditions they precipitate to form solid crystals. Large crystals may block the bile duct and have to be surgically removed. The radiograph in figure 18.35 shows gallstones in position, and the photograph shows removed gallstones.

Pancreas

The soft, lobulated **pancreas** is known as a *mixed gland* because it has both exocrine and endocrine functions. The endocrine function is performed by clusters of cells called the **pancreatic islets** (islets of Langerhans). The islet cells secrete the hormones *insulin* and *glucagon* into the blood. As an exocrine gland, the pancreas secretes *pancreatic juice* through the pancreatic duct (fig. 18.36), which empties into the duodenum.

pancreas: Gk. *pan*, all; *kreas*, flesh

islets of Langerhans: from Paul Langerhans, German anatomist, 1847–88

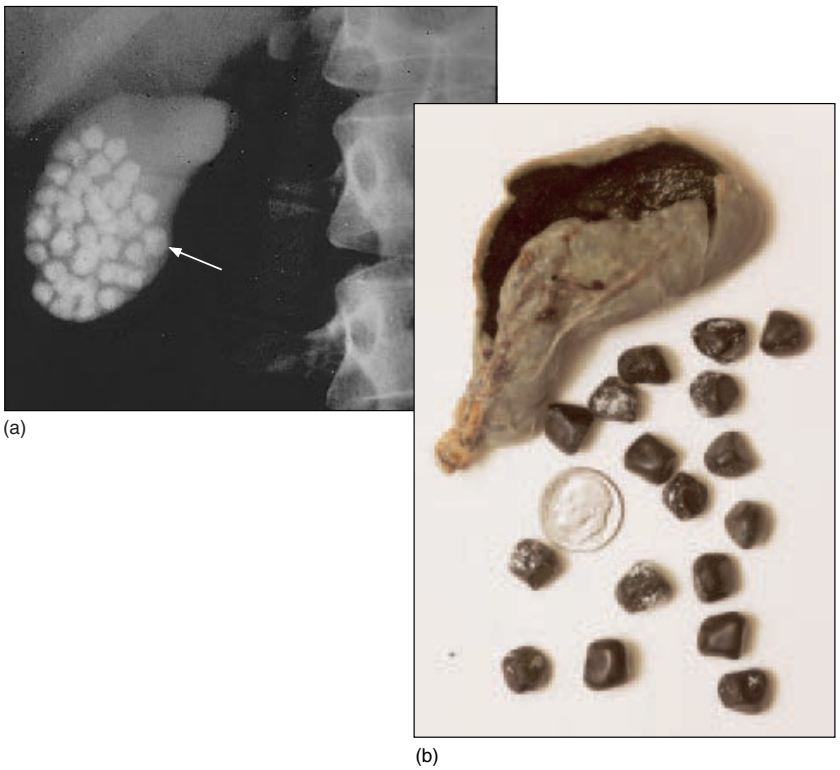


FIGURE 18.35 (*a*) A radiograph of a gallbladder that contains gallstones (biliary calculi). (*b*) Following surgical removal of the gallbladder (cholecystectomy), it has been cut open to reveal its gallstones. (Note their size relative to that of a dime.)

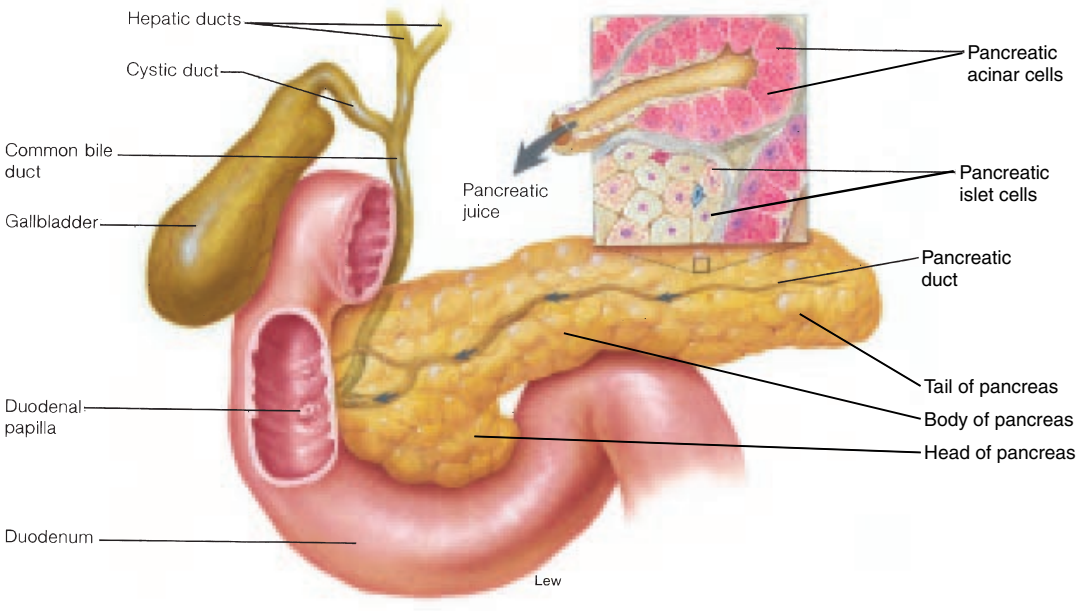


FIGURE 18.36 The pancreas is both an exocrine and an endocrine gland. Pancreatic juice—the exocrine product—is secreted by acinar cells into the pancreatic duct. Scattered islands of cells, called pancreatic islets (islets of Langerhans), secrete the hormones insulin and glucagon into the blood.

Developmental Exposition

The Digestive System

EXPLANATION

The entire digestive system develops from modifications of an elongated tubular structure called the **primitive gut.** These modifications are initiated during the fourth week of embryonic development. The primitive gut is composed solely of endoderm and for descriptive purposes can be divided into three regions: the *foregut*, *midgut*, and *hindgut* (exhibit I).

Foregut

The **stomodeum** (*sto''mŏ-de'um*), or **oral pit,** is not part of the foregut but an invagination of ectoderm that breaks through a thin **oral membrane** to become continuous with the foregut and form part of the oral cavity, or mouth. Structures in the mouth, therefore, are ectodermal in origin. The esophagus, pharynx, stomach, a

stomodeum: Gk. *stoma*, mouth; *hodaios*, on the way to

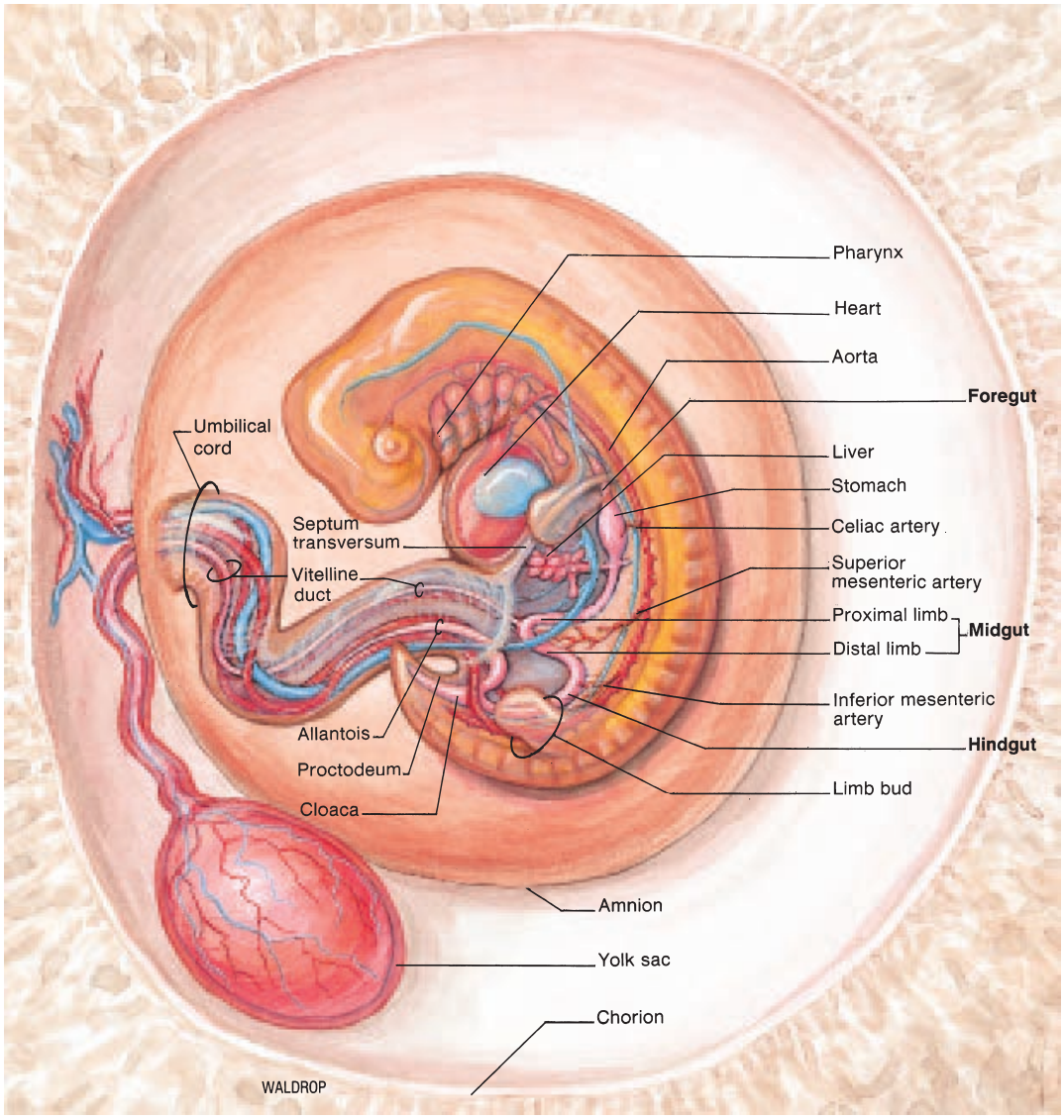


EXHIBIT I A sagittal section of a 5-week-old embryo showing the development of the digestive system and its association with the extraembryonic membranes and organs.

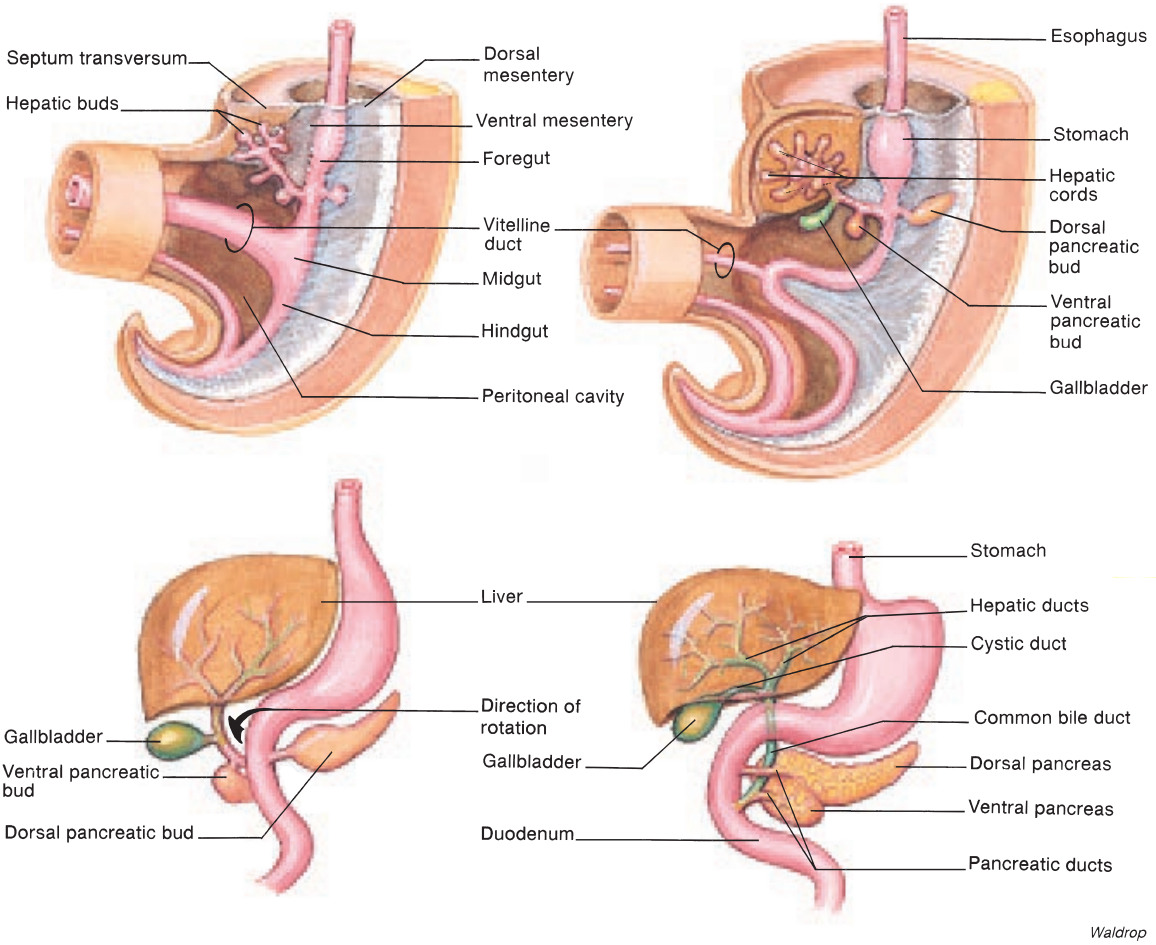


EXHIBIT II Progressive stages of development of the foregut to form the stomach, duodenum, liver, gallbladder, and pancreas: (*a*) 4 weeks, (*b*) 5 weeks, (*c*) 6 weeks, and (*d*) 7 weeks.

portion of the duodenum, the pancreas, liver, and gallbladder are the organs that develop from the foregut (exhibit II). Along the GI tract, only the inside epithelial lining of the lumen is derived from the endoderm of the primitive gut. The vascular portion and smooth muscle layers are formed from mesoderm that develops from the surrounding splanchnic mesenchyme.

The stomach first appears as an elongated dilation of the foregut. The dorsal border of the stomach undergoes more rapid growth than the ventral border, forming a distinct curvature. The caudal portion of the foregut and the cranial portion of the midgut form the duodenum. The liver and pancreas arise from the wall of the duodenum as small **hepatic** and **pancreatic buds,** respectively. The hepatic bud experiences incredible growth to form the gallbladder, associated ducts, and the various lobes of the liver (exhibit II). By the sixth week, the liver is carrying out hemopoiesis (the formation of blood cells). By the ninth week, the liver has developed to the point where it represents 10% of the total weight of the fetus.

The pancreas develops from dorsal and ventral pancreatic buds of endodermal cells. As the duodenum grows, it rotates clockwise, and the two pancreatic buds fuse (exhibit II).

Midgut

During the fourth week of the embryonic stage (exhibit I), the midgut is continuous with the yolk sac. By the fifth week, the midgut has formed a ventral U-shaped **midgut loop,** which projects into the umbilical cord (exhibit III). As development continues, the anterior limb of the midgut loop coils to form most of the small intestine. The posterior limb of the midgut loop expands to form the large intestine and a portion of the small intestine. A **cecal diverticulum** appears during the fifth week.

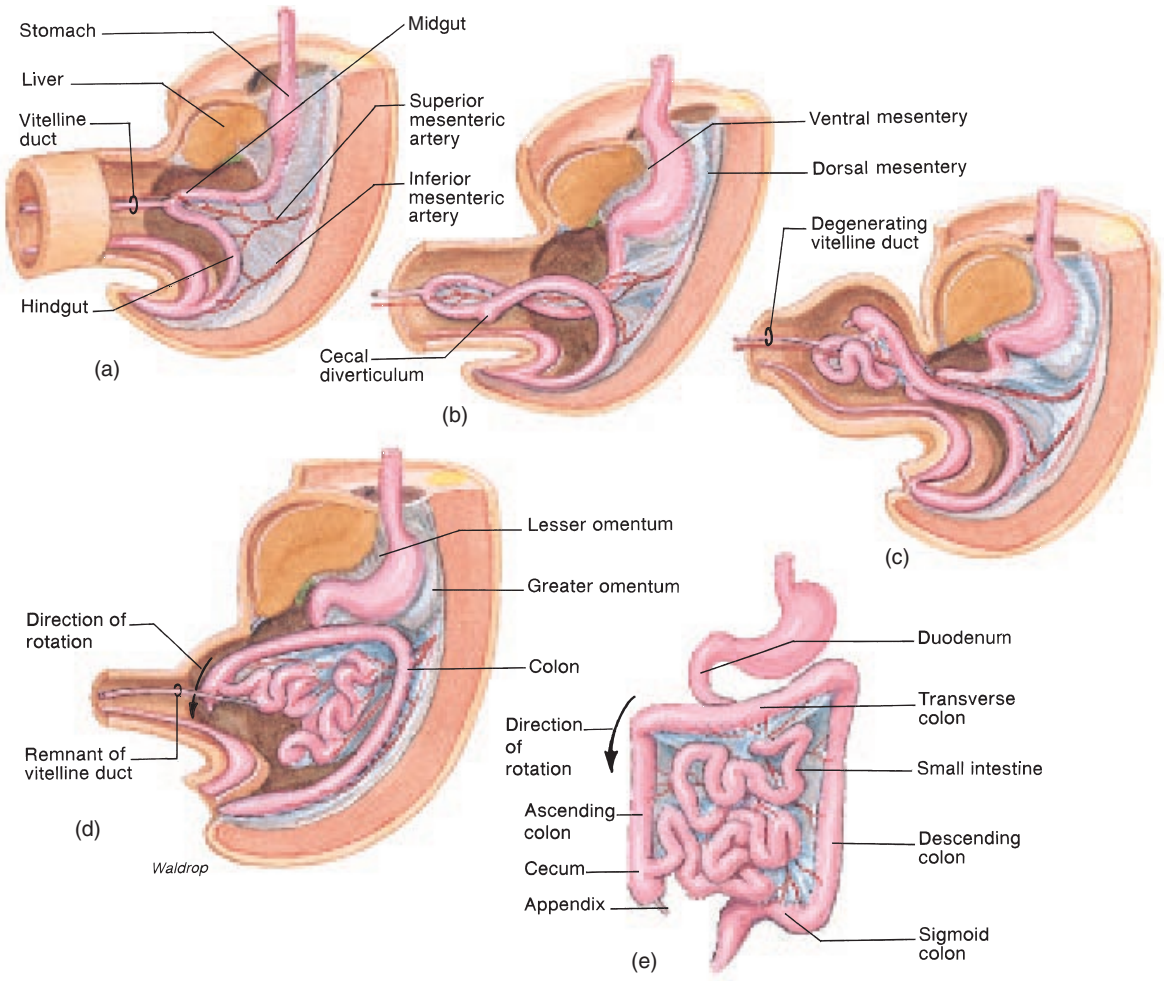


EXHIBIT III Progressive stages of the development of the midgut to form the distal portion of the small intestine and the proximal portion of the large intestine: (*a*) 5 weeks, (*b*) 6 weeks, (*c*) 7 weeks, (*d*) 10 weeks, and (*e*) 18 weeks.

During the tenth week, the intestines are drawn up into the abdominal cavity, and further differentiation and rotation occur. The cecal diverticulum continues to develop, forming the cecum and appendix. The remainder of the midgut gives rise to the ascending colon and hepatic flexure (exhibit III).

Hindgut

The hindgut extends from the midgut to the **cloacal** (*klo-a′kal*) ***membrane*** (exhibit IV). The **proctodeum** (*prok′′tŏ-de′um*), or **anal pit,** is a depression in the anal region formed from an invagination of ectoderm that contributes to the cloacal membrane.

The **allantois** (*ă-lan′′to-is*), which receives urinary wastes from the fetus, connects to the hindgut at a region called the **cloaca,** as seen in exhibit IV. A band of mesenchymal cells called the **urorectal septum** grows caudally between the fourth and seventh week until a complete partition separates the cloaca into a dorsal **anal canal** and a ventral **urogenital sinus.** With the completion of the urorectal septum, the cloacal membrane is divided into an anterior **urogenital membrane** and a posterior **anal membrane.** Toward the end of the seventh week, the anal membrane perforates and forms the anal opening, which is lined with ectodermal cells. About this time, the urogenital membrane ruptures to provide further development of the urinary and reproductive systems.

proctodeum: Gk. *proktos,* anus; *hodaios,* on the way to

cloaca: L. *cloaca,* sewer

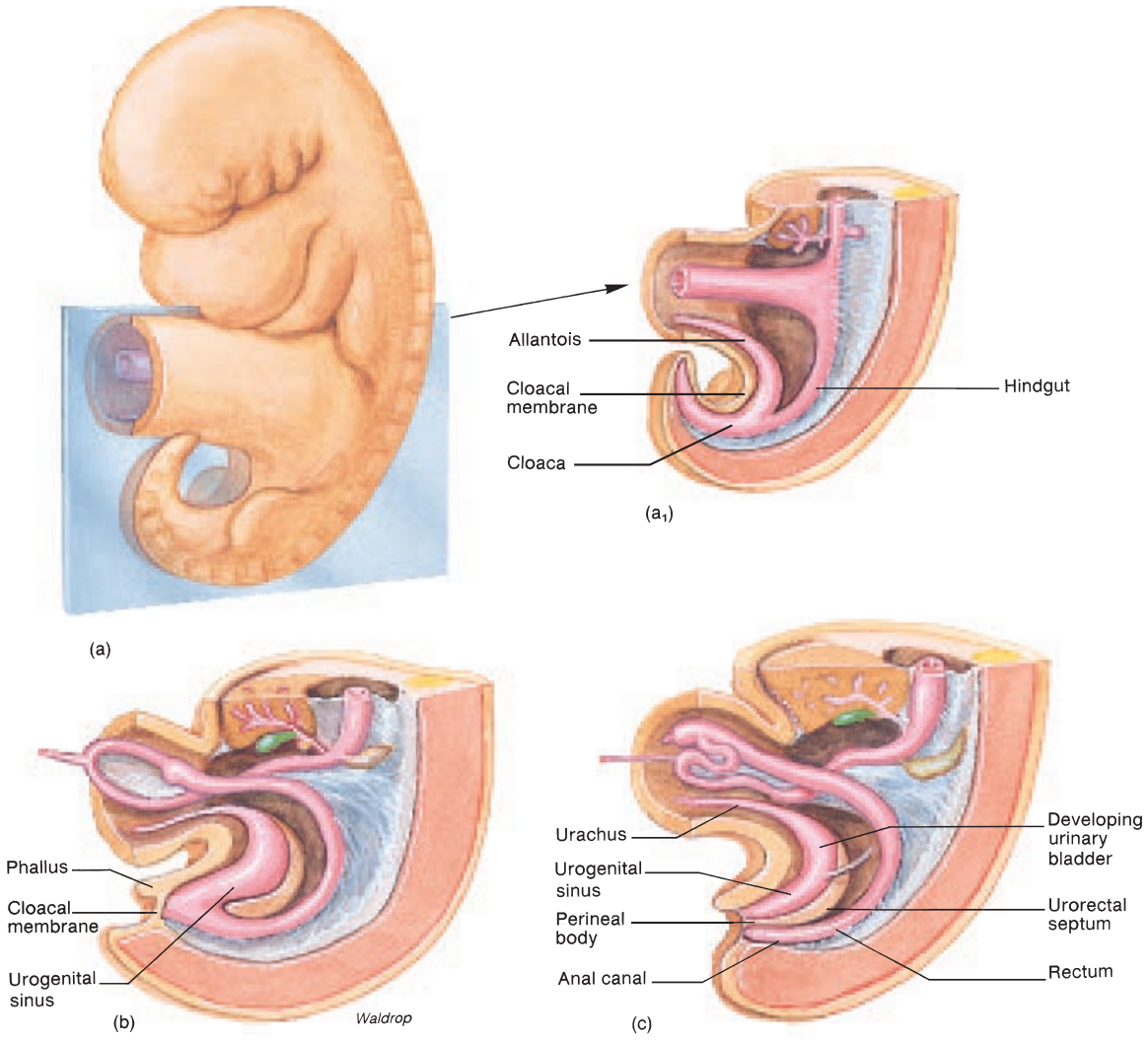


EXHIBIT IV The progressive development of the hindgut illustrating the developmental separation of the digestive system from the urogenital system. (*a*) An anterolateral view of an embryo at 4 weeks showing the position of a sagittal cut depicted in (a_1), (*b*), and (*c*). (a_1) At 4 weeks, the hindgut, cloaca, and allantois are connected. (*b*) At 6 weeks, the connections between the gut and extraembryonic structures are greatly diminished. (*c*) By 7 weeks, structural and functional separation between the digestive system and the urogenital system is almost complete.

The pancreas is positioned horizontally along the posterior abdominal wall, adjacent to the greater curvature of the stomach. It measures about 12.5 cm (6 in.) in length and is approximately 2.5 cm (1 in.) thick. It has an expanded **head,** positioned near the duodenum; a centrally located **body;** and a tapering **tail,** positioned near the spleen. All but a portion of the head is retroperitoneal. Within the lobules of the pancreas are the exocrine secretory units, called **pancreatic acini** (*as'ĭ-ni*), and the endocrine secretory units, called **pancreatic islet cells.** Each acinus consists of a single layer of epithelial acinar cells surrounding a lumen into which the constituents of pancreatic juice are secreted.

The pancreas is innervated by branches of the celiac plexus. The glandular portion of the pancreas receives parasym-

acinus: L. *acinus*, grape

pathetic innervation, whereas the pancreatic blood vessels receive sympathetic innervation. The pancreas is supplied with blood by the pancreatic branch of the splenic artery, which arises from the celiac artery, and by the pancreatoduodenal branches, which arise from the superior mesenteric artery. Venous blood is returned through the splenic and superior mesenteric veins into the hepatic portal vein.

Pancreatic cancer has the worst prognosis of all types of cancer. This is probably because of the spongy, vascular nature of this organ and its vital exocrine and endocrine functions. Pancreatic surgery is a problem because the soft, spongy tissue is difficult to suture.

Knowledge Check

23. Describe the liver. Where is it located? List the lobes of the liver and the supporting ligaments.
24. List the principal functions of the liver.
25. Describe the structure of liver lobules and trace the flow of blood and bile in the lobules.
26. Explain how the liver receives a double blood supply.
27. Explain how the gallbladder fills with bile secretions and how bile and pancreatic secretions enter the duodenum.
28. Briefly state the exocrine and endocrine functions of the pancreas. What are the various cellular secretory units of the pancreas?

CLINICAL CONSIDERATIONS

Developmental Problems of the Digestive System

Most of the congenital disorders of the digestive system develop during the fourth or fifth week of embryonic life. A **cleft palate,** as described in chapter 17, is a congenital opening between the oral and nasal cavities; therefore, it involves both the digestive and respiratory systems (see fig. 17.28). **Esophageal atresia** (*ă-tre′ze-ă*), or failure to develop the normal structure of the esophageal-stomach area, is another disorder of the upper GI tract that requires surgery to correct. **Pyloric stenosis** is a common abnormality in which the pyloric sphincter muscle is hypertrophied, reducing the size of the lumen. This condition affects approximately 1 in 200 newborn males and 1 in 1,000 newborn females. Stenoses, atresias, and malrotations of various portions of the GI tract may occur as the gut develops. Umbilical problems involving the GI tract are fairly common, as is some form of *imperforate anus*, which occurs in about 1 in 5,000 births.

Pathogens and Poisons

The GI tract presents a hospitable environment for an array of parasitic helminths (worms) and microorganisms. Many of these

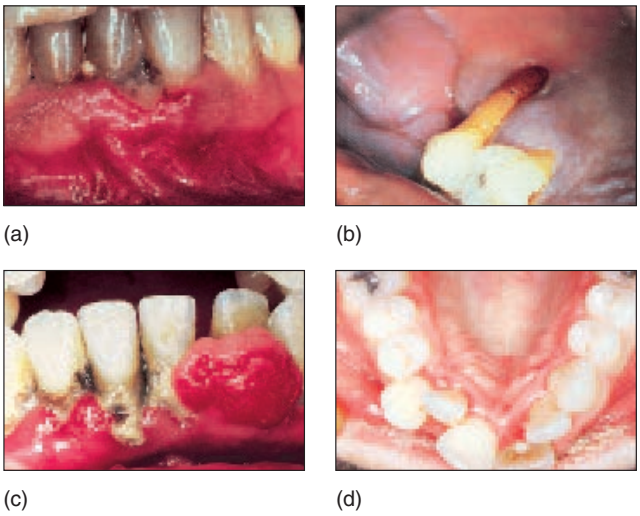


FIGURE 18.37 Clinical problems of the teeth. (*a*) Trench mouth and dental caries, (*b*) severe alveolar bone destruction from periodontitis, (*c*) pyogenic granuloma and dental caries, and (*d*) malposition of teeth.

are beneficial, but some bacteria and protozoa can cause diseases. Only a few examples of the pathogenic microorganisms will be discussed here.

Dysentery (*dis′en′ter″e*) is an inflammation of the intestinal mucosa, characterized by frequent loose stools containing mucus, pus, and blood. The most common dysentery is **amoebic dysentery,** which is caused by the protozoan *Entamoeba histolytica*. Cysts from this organism are ingested in contaminated food, and after the protective coat is removed by HCl in the stomach, the vegetative form invades the mucosal walls of the ileum and colon.

Food poisoning is caused by consuming the toxins produced by pathogenic bacteria. *Salmonella* is a bacterium that commonly infects food. **Botulism,** the most serious type of food poisoning, is caused by ingesting food contaminated with the toxin produced by the bacterium *Clostridium botulinum*. This organism is widely distributed in nature, and the spores it produces are frequently found on food being processed by canning. For this reason, food must be heated to 120° C (248° F) before it is canned. It is the toxins produced by the bacterium growing in the food that are pathogenic, rather than the organisms themselves. The poison is a neurotoxin that is readily absorbed into the blood, at which point it can affect the nervous system.

Clinical Problems of the Teeth and Salivary Glands

Dental caries, or tooth decay, is the gradual decalcification of tooth enamel (fig. 18.37) and underlying dentin, caused by the acid products of bacteria. These bacteria thrive between teeth,

dysentery: Gk. *dys*, bad; *entera*, intestine

where food particles accumulate, and form part of the thin layer of bacteria, proteins, and other debris called *plaque* that covers teeth. The development of dental caries can be reduced by brushing at least once a day and by flossing between teeth at regular intervals.

People over the age of 35 are particularly susceptible to **periodontal disease,** which involves inflammation and deterioration of the gingiva, dental alveoli, periodontal membranes, and the cementum that covers the roots of teeth. Some of the symptoms are loosening of the teeth, bad breath, bleeding gums when brushing, and some edema. Periodontal disease may result from impacted plaque, cigarette smoking, crooked teeth, or poor diet. It accounts for 80% to 90% of tooth loss in adults.

Mumps is a viral disease of the parotid glands, and in advanced stages it may involve the pancreas and testes. In children, mumps is generally not serious, but in adults it may cause deafness and destroy the pancreatic islet tissue or testicular cells.

Disorders of the Liver

The liver is a remarkable organ that has the ability to regenerate even if up to 80% has been removed. The most serious diseases of the liver (hepatitis, cirrhosis, and hepatomas) affect the liver throughout, so that it cannot repair itself. **Hepatitis** is inflammation of the liver. Certain chemicals may cause hepatitis, but generally it is caused by infectious viral agents. **Hepatitis A** (infectious hepatitis) is a viral disease transmitted through contaminated foods and liquids. **Hepatitis B** (serum hepatitis) is also caused by a virus and is transmitted in blood plasma during transfusions or by improperly sterilized needles and syringes. Other types of viral hepatitis are designated as hepatitis C, D, E, and G.

In **cirrhosis** (*sĭ-ro′sis*) the liver becomes infused with fibrous tissue. This causes the liver tissue to break down and become filled with fat. Eventually, all functions of the liver are compromised. Cirrhosis is most often the result of long-term alcohol abuse, but it can also result from malnutrition, hepatitis, or other infections.

Jaundice is a yellow staining of the tissues produced by high blood concentrations of either free or conjugated bilirubin. Because free bilirubin is derived from hemoglobin, abnormally high concentrations of this pigment may result from an unusually high rate of red blood cell destruction. This can occur, for example, as a result of Rh disease (erythroblastosis fetalis) in an Rh positive baby born to a sensitized Rh negative mother. Jaundice may also occur in healthy infants, because excess red blood cells are normally destroyed at about the time of birth. This condition is called *physiological jaundice of the newborn* and is not indicative of disease. Premature infants may also develop jaundice due to inadequate amounts of hepatic enzymes necessary to conjugate bilirubin and excrete it in the bile. In adults, jaundice is commonly exhibited when the excretion of bile is blocked by gallstones.

Hepatomas (*hep′′ă-to-′maz*) are tumors (usually malignant) that originate in or secondarily invade the liver. Those that originate in the liver (primary hepatomas) are relatively rare, but those that metastasize to the liver from other organs (secondary hepatomas) are common. Carcinoma of the liver is usually fatal.

cirrhosis: Gk. *kirrhos,* yellow orange

jaundice: *L. galbus,* yellow

Disorders of the GI Tract

Peptic ulcers are erosions of the mucous membranes of the stomach (fig. 18.38) or duodenum produced by the action of HCl. Prolonged exposure to agents that weaken the mucosal lining of the stomach, such as alcohol and aspirin, and abnormally high secretions of HCl increase the likelihood of developing peptic ulcers. Chronic stress can impair mucosal defense mechanisms, thereby increasing mucosal susceptibility to the damaging effects of HCl. A relatively recent finding is that most people who have peptic ulcers are infected with a bacterium known as *Helicobacter pylori,* which resides in the GI tract. Clinical trials have demonstrated that antibiotics that eliminate this bacterium appear to help in the treatment of the peptic ulcers. It is now thought that *H. pylori* does not itself cause the ulcer, but rather contributes to the weakening of the mucosal barriers to gastric acid damage.

Enteritis, an inflammation of the mucosa of the small intestine, is frequently referred to as intestinal flu. Causes of enteritis include bacterial or viral infections, irritating foods or fluids (including alcohol), and emotional stress. The symptoms include abdominal pain, nausea, and diarrhea. *Diarrhea* is the passage of watery, unformed stools. This condition is symptomatic of inflammation, stress, and many other body dysfunctions.

A **hernia** is a protrusion of a portion of a visceral organ, usually the small intestine, through a weakened portion of the abdominal wall. Inguinal, femoral, umbilical, and hiatal hernias are the most common types. With a **hiatal hernia,** a portion of the stomach pushes superiorly through the esophageal hiatus in the diaphragm and protrudes into the thorax. The potential dangers of a hernia are strangulation of the blood supply followed by gangrene, blockage of chyme, or rupture—each of which can threaten life.

Diverticulosis (*di′′ver-tik′′yŭ-lo′sis*) is a condition in which the intestinal wall weakens and an outpouching (diverticulum) occurs. Studies suggest that suppressing the passage of flatus (in-

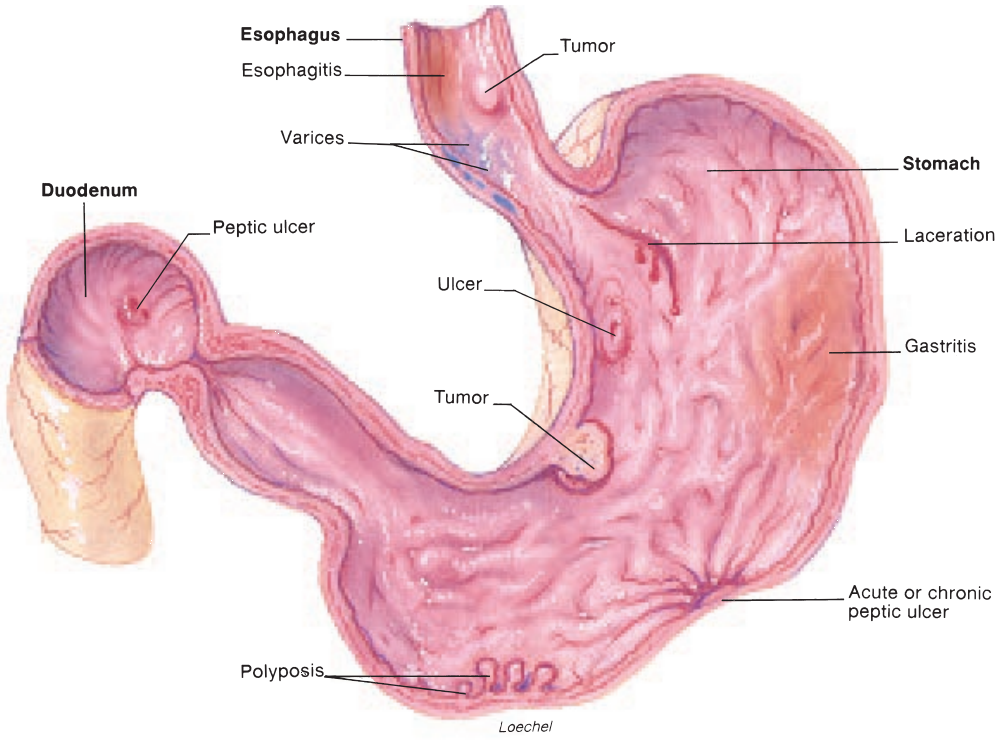


FIGURE 18.38 Common sites of upper GI disorders.

testinal gas) may contribute to diverticulosis, especially in the sigmoid colon. **Diverticulitis,** or inflammation of a diverticulum, can develop if fecal material becomes impacted in these pockets.

Peritonitis is inflammation of the peritoneum lining the abdominal cavity and covering the viscera. The causes of peritonitis include bacterial contamination of the abdominal cavity through accidental or surgical wounds in the abdominal wall or perforation of the intestinal wall (as with an ulcer or a ruptured appendix).

Clinical Case Study Answer

The likely source of bleeding in such a case is from a rupture of the internal portion of the liver involving significant blood vessels, either of the hepatic arterial or venous circulation, but also possibly of the portal venous circulation. Trauma to the hepatic plates (see fig. 18.33) may allow blood to enter bile canaliculi. From there, the course of the blood is as follows: large hepatic ducts → common hepatic duct → common bile duct through duodenal papilla → duodenum of the small intestine.

In some cases, this type of bleeding can be stopped by introducing radiographic-guided catheters into the arterial system to block the blood vessels (angiographic embolization). However, surgery is sometimes required.

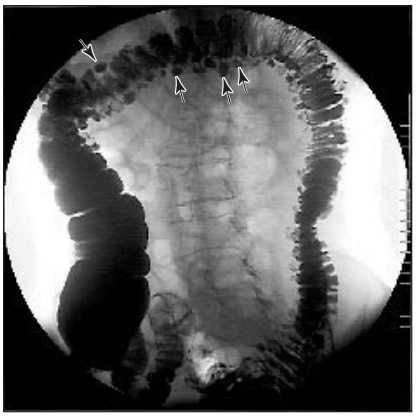
CLINICAL PRACTICUM 18.1

A 69–year-old gentleman comes to your office because of abdominal pain in the left lower quadrant for 2 days. The pain is constant and deep. He has also developed mild diarrhea since the pain started.

In your office the patient does not have a fever. You can hear normal bowel sounds with your stethoscope. His abdominal muscles are relaxed, but the left lower quadrant is indeed tender, and you feel a fullness on deep palpation. A stool sample and lab work are normal. You decide to send him home on a liquid diet and oral antibiotics. He's soon better, and in 2 weeks you order a barium enema (i.e., an abdominal X ray taken after barium is introduced into the colon).

QUESTIONS

1. What are the many blebs seen on the adjacent X ray of the large colon?
2. Explain this man's earlier abdominal pain.
3. What other complication can accompany this condition?



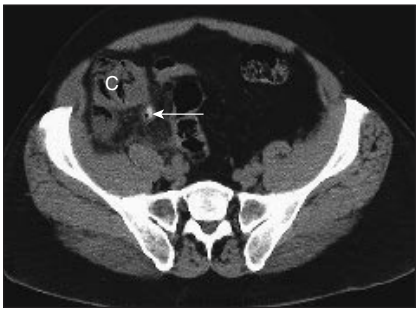
CLINICAL PRACTICUM 18.2

A 47-year-old male presents to the emergency room with worsening abdominal pain and anorexia. He reports the pain began three days ago and was generalized, but has now localized to the lower right quadrant. He describes the pain as a sharp, stabbing pain. He also reports fevers but no diarrhea.

Upon physical exam, the patient is febrile (feverish) and has abdominal tenderness that localizes to the lower right quadrant, specifically McBurney's point. He also has rebound tenderness, a sign of peritoneal irritation. Lab results indicate an increase in the while blood count. You order a CT scan of the abdomen.

QUESTIONS

1. What is McBurney's point?
2. After looking at the CT scan, what is your diagnosis? (The cecum is indicated with the letter C.)
3. What is the white density indicated by the arrow? How does it contribute to the disease process?
4. What is the appropriate treatment for this patient?



CHAPTER 18

Important Clinical Terminology

chilitis *(ki-li′tis)* Inflammation of the lips.
colitis *(kō-li′tis)* Inflammation of the colon.
colostomy *(kŏ-los′tŏ-me)* The formation of an abdominal exit from the GI tract by bringing a loop of the colon through the abdominal wall to its outside surface. If the rectum is removed because of cancer, the colostomy provides a permanent outlet for the feces.
cystic fibrosis An inherited disease of the exocrine glands, particularly the pancreas. Pancreatic secretions are too thick to drain easily, causing the ducts to become inflamed and promoting connective tissue formation that occludes drainage from the ducts still further.
gingivitis *(jin-jī-vi′tis)* Inflammation of the gums. It may result from improper hygiene, poorly fitted dentures, improper diet, or certain infections.
halitosis *(hal-ĭ-to′sis)* Offensive breath odor. It may result from dental caries, certain diseases, eating particular foods, or smoking.
heartburn A burning sensation of the esophagus and stomach. It may result from the regurgitation of gastric juice into the lower portion of the esophagus.
hemorrhoids *(hem′ŏ-roidz)* Varicose veins of the rectum and anus.
nausea Gastric discomfort and sensations of illness with a tendency to vomit. This feeling is symptomatic of motion sickness and other diseases, and may occur during pregnancy.
pyorrhea *(pi′′ŏ-re′ă)* The discharge of pus at the base of the teeth at the gum line.
regurgitation (vomiting) The forceful expulsion of gastric contents into the mouth. Nausea and vomiting are common symptoms of almost any dysfunction of the digestive system.
trench mouth A contagious bacterial infection that causes inflammation, ulceration, and painful swelling of the floor of the mouth. It is generally contracted through direct contact by kissing an infected person. Trench mouth can be treated with penicillin and other medications.
vagotomy *(va-got′ŏ-me)* The surgical removal of a section of the vagus nerve where it enters the stomach in order to eliminate nerve impulses that stimulate gastric secretion. This procedure may be used to treat chronic ulcers.

Chapter Summary

Introduction to the Digestive System (pp. 635–636)

1. The digestive system mechanically and chemically breaks down food to forms that can be absorbed through the intestinal wall and transported by the blood and lymph for use at the cellular level.
2. The digestive system consists of a gastrointestinal (GI) tract and accessory digestive organs.

Serous Membranes and Tunics of the Gastrointestinal Tract (pp. 636–640)

1. Peritoneal membranes line the abdominal wall and cover the visceral organs. The GI tract is supported by a double layer of peritoneum called the mesentery.
   (a) The lesser omentum and greater omentum are folds of peritoneum that extend from the stomach.
   (b) Retroperitoneal organs are positioned behind the parietal peritoneum.
2. The layers (tunics) of the abdominal GI tract are, from the inside outward, the mucosa, submucosa, tunica muscularis, and serosa.
   (a) The mucosa consists of a simple columnar epithelium, a thin layer of connective tissue called the lamina propria, and thin layers of smooth muscle called the muscularis mucosae.
   (b) The submucosa is composed of connective tissue; the tunica muscularis consists of layers of smooth muscle; and the serosa is composed of connective tissue covered with the visceral peritoneum.
   (c) The submucosa contains the submucosal plexus, and the tunica muscularis contains the myenteric plexus of autonomic nerves.

Mouth, Pharynx, and Associated Structures (pp. 640–648)

1. The oral cavity is formed by the cheeks, lips, and hard palate and soft palate. The tongue and teeth are contained in the oral cavity.
   (a) Lingual tonsils and papillae with taste buds are located on the tongue.
   (b) Structures of the palate include palatal folds, a cone-shaped projection called the palatine uvula, and palatine tonsils.
2. The incisors and canines have one root each; the bicuspids and molars have two or three roots.
   (a) Humans are diphyodont; they have deciduous and permanent sets of teeth.
   (b) The roots of teeth fit into sockets called dental alveoli that are lined with a periodontal membrane. Fibers in the periodontal membrane insert into the cementum covering the roots, firmly anchoring the teeth in the sockets.
   (c) Enamel forms the outer layer of the tooth crown; beneath the enamel is dentin.
   (d) The interior of a tooth contains a pulp cavity, which is continuous through the apical foramen of the root with the connective tissue around the tooth.
3. The major salivary glands are the parotid glands, the submandibular glands, and the sublingual glands.
4. The muscular pharynx provides a passageway connecting the oral and nasal cavities to the esophagus and larynx.

Esophagus and Stomach (pp. 648–652)

1. Swallowing (deglutition) occurs in three phases and involves structures of the oral cavity, pharynx, and esophagus.
2. Peristaltic waves of contraction push food through the lower esophageal sphincter into the stomach.
3. The stomach consists of a cardia, fundus, body, and pylorus. It displays greater and lesser curvatures, and contains a pyloric sphincter at its junction with the duodenum.
   (a) The mucosa of the stomach is thrown into distensible gastric folds; gastric pits and gastric glands are present in the mucosa.
   (b) The parietal cells of the gastric glands secrete HCl, and the principal cells secrete pepsinogen.

Small Intestine (pp. 652–656)

1. Regions of the small intestine include the duodenum, jejunum, and ileum; the common bile duct and pancreatic duct empty into the duodenum.
2. Fingerlike extensions of mucosa, called intestinal villi, project into the lumen, and at the bases of the intestinal villi the mucosa forms intestinal glands.
   (a) New epithelial cells are formed in the intestinal crypts.
   (b) The membrane of intestinal epithelial cells is folded to form microvilli; this brush border of the mucosa increases the absorptive surface area.
3. Movements of the small intestine include rhythmic segmentation, pendular movement, and peristalsis.

Large Intestine (pp. 656–660)

1. The large intestine absorbs water and electrolytes from the chyme and passes fecal material out of the body through the rectum and anal canal.
2. The large intestine is divided into the cecum, colon, rectum, and anal canal.
   (a) The appendix is attached to the inferior medial margin of the cecum.
   (b) The colon consists of ascending, transverse, descending, and sigmoid portions.
   (c) Haustra are bulges in the walls of the large intestine.
3. Movements of the large intestine include peristalsis, haustral churning, and mass movement.

Liver, Gallbladder, and Pancreas (pp. 660–669)

1. The liver is divided into right, left, quadrate, and caudate lobes. Each lobe contains liver lobules, the functional units of the liver.
   (a) Liver lobules consist of plates of hepatic cells separated by modified capillaries called sinusoids.
   (b) Blood flows from the periphery of each lobule, where branches of the hepatic artery and hepatic portal vein empty, through the sinusoids and out the central vein.
   (c) Bile flows within the hepatic plates, in bile canaliculi, to the biliary ductules at the periphery of each lobule.
2. The gallbladder stores and concentrates the bile; it releases the bile through the cystic duct and common bile duct into the duodenum.
3. The pancreas is both an exocrine and an endocrine gland.
   (a) The endocrine portion, consisting of the pancreatic islets, secretes the hormones insulin and glucagon.
   (b) The exocrine acini of the pancreas produce pancreatic juice, which contains various digestive enzymes.

Review Activities

Objective Questions

1. Viscera are the only body organs that are
   (a) concerned with digestion.
   (b) located in the abdominal cavity.
   (c) covered with peritoneal membranes.
   (d) located within the thoracic and abdominal cavities.
2. Which of the following types of teeth are found in the permanent but *not* in the deciduous dentition?
   (a) incisors (c) premolars
   (b) canines (d) molars
3. The double layer of peritoneum that supports the GI tract is called
   (a) the visceral peritoneum.
   (b) the mesentery.
   (c) the greater omentum.
   (d) the lesser omentum.
4. Which of the following tissue layers in the small intestine contains the lacteals?
   (a) the submucosa
   (b) the muscularis mucosae
   (c) the lamina propria
   (d) the tunica muscularis
5. Which of the following organs is *not* considered a part of the digestive system?
   (a) the pancreas (c) the tongue
   (b) the spleen (d) the gallbladder
6. The numerous small elevations on the surface of the tongue that support taste buds and aid in handling food are called
   (a) cilia. (c) intestinal villi.
   (b) rugae. (d) papillae.
7. Most digestion occurs in
   (a) the mouth.
   (b) the stomach.
   (c) the small intestine.
   (d) the large intestine.
8. Stenosis (constriction) of the sphincter of ampulla (of Oddi) would interfere with
   (a) transport of bile and pancreatic juice.
   (b) secretion of mucus.
   (c) passage of chyme into the small intestine.
   (d) peristalsis.
9. The first organ to receive the blood-borne products of digestion is
   (a) the liver. (c) the heart.
   (b) the pancreas. (d) the brain.
10. Which of the following statements about hepatic portal blood is *true?*
    (a) It contains absorbed fat.
    (b) It contains ingested proteins.
    (c) It is mixed with bile in the liver.
    (d) It is mixed with blood from the hepatic artery in the liver.

Essay Questions

1. Define *digestion*. Differentiate between the mechanical and chemical aspects of digestion.
2. Distinguish between the gastrointestinal tract, viscera, accessory digestive organs, and gut.
3. List the specific portions or structures of the digestive system formed by each of the three embryonic germ layers.
4. Define *serous membrane*. How are the serous membranes of the abdominal cavity classified and what are their functions?
5. Describe the structures of the four tunics in the wall of the GI tract.
6. Why are there two autonomic innervations to the GI tract? Identify the specific sites of autonomic stimulation in the tunic layers.
7. Define the terms *dental formula*, *diphyodont*, *deciduous teeth*, *permanent teeth*, and *wisdom teeth*.
8. Outline the stages of deglutition. What biomechanical roles do the tongue, hard palate and soft palate, pharynx, and hyoid bone perform in deglutition?
9. How does the stomach protect itself from the damaging effects of HCl?
10. Describe the kinds of movements in the small intestine and explain what they accomplish.
11. Diagram an intestinal villus and explain why intestinal villi are considered the functional units of the digestive system.
12. What are the regions of the large intestine? In what portion of the abdominal cavity and pelvic cavity is each region located?
13. Describe the location and gross structure of the liver. Draw a labeled diagram of a liver lobule.
14. Describe how the gallbladder is filled with and emptied of bile fluid. What is the function of bile?
15. List the functions of the large intestine. What are the biomechanical movements of the large intestine that make these functions possible?
16. Define *cirrhosis* and explain why this condition is so devastating to the liver. What are some of the causes of cirrhosis?

Critical-Thinking Questions

1. Technically, ingested food is not in the body. Neither are feces excreted from within the body (except bile residue). Explain these statements. Why would this information be important to a drug company interested in preparing a new oral medication?
2. The deciduous (milk) teeth don't matter because they fall out anyway. Do you agree or disagree with this statement? Explain.
3. Which surgery do you think would have the most profound effect on digestion: (a) removal of the stomach (gastrectomy), (b) removal of the pancreas (pancreatectomy), or (c) removal of the gallbladder (cholecystectomy)? Explain your reasoning.
4. Describe the adaptations of the GI tract that make it more efficient by either increasing the surface area for absorption or increasing the time of contact between food particles and digestive enzymes.
5. During surgery to determine the cause of an intestinal obstruction, why might the surgeon elect to remove a healthy appendix?
6. Explain why a ruptured appendix may result in peritonitis, while an inflamed kidney (nephritis) generally does not result in peritonitis.