

# UNIT Seven

## Alterations in the Gastrointestinal System

### CHAPTER 26

## Structure and Function of the Gastrointestinal System

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Structurally, the gastrointestinal tract is a long, hollow tube with its lumen inside the body and its wall acting as an interface between the internal and external environments. The wall does not normally allow harmful agents to enter the body, nor does it permit body fluids and other materials to escape. The process of digestion and absorption of nutrients requires an intact and healthy gastrointestinal tract epithelial lining that can resist the effects of its own digestive secretions. The process also involves movement of materials through the gastrointestinal tract at a rate that facilitates absorption, and it requires the presence of enzymes for the digestion and absorption of nutrients.

As a matter of semantics, the gastrointestinal tract also is referred to as the *digestive tract*, the *alimentary canal*, and at times, the *gut*. The intestinal portion also may be called the *bowel*. For the purposes of this text, the salivary glands, the liver, and the pancreas, which produce secretions that aid in digestion, are considered *accessory organs*.

## STRUCTURE AND ORGANIZATION OF THE GASTROINTESTINAL TRACT

In the digestive tract, food and other materials move slowly along its length as they are systematically broken down into ions and molecules that can be absorbed into the body. In the large intestine, unabsorbed nutrients and wastes are collected for later elimination. Although the gastrointestinal tract is located inside the body, it is a long, hollow tube, the lumen (*i.e.*, hollow center) of which is an extension of the external environment. Nutrients do not become part of the internal environment until they have passed through the intestinal wall and have entered the blood or lymph channels.

For simplicity and understanding, the digestive system can be divided into four parts (Fig. 26-1). The upper part—the mouth, esophagus, and stomach—acts as an intake source and receptacle through which food passes and in which initial digestive processes take place. The middle portion consists of the small intestine—the duodenum, jejunum, and ileum. Most digestive and absorptive processes occur in the small intestine. The lower segment—the cecum, colon, and rectum—serves as a storage channel for the efficient elimination of waste. The fourth part consists of the accessory organs—the salivary glands, liver, and pancreas. These structures produce digestive secretions that help dismantle foods and regulate the use and storage of nutrients. The discussion in this chapter focuses on

the first three parts of the gastrointestinal tract. The liver and pancreas are discussed in Chapter 28.

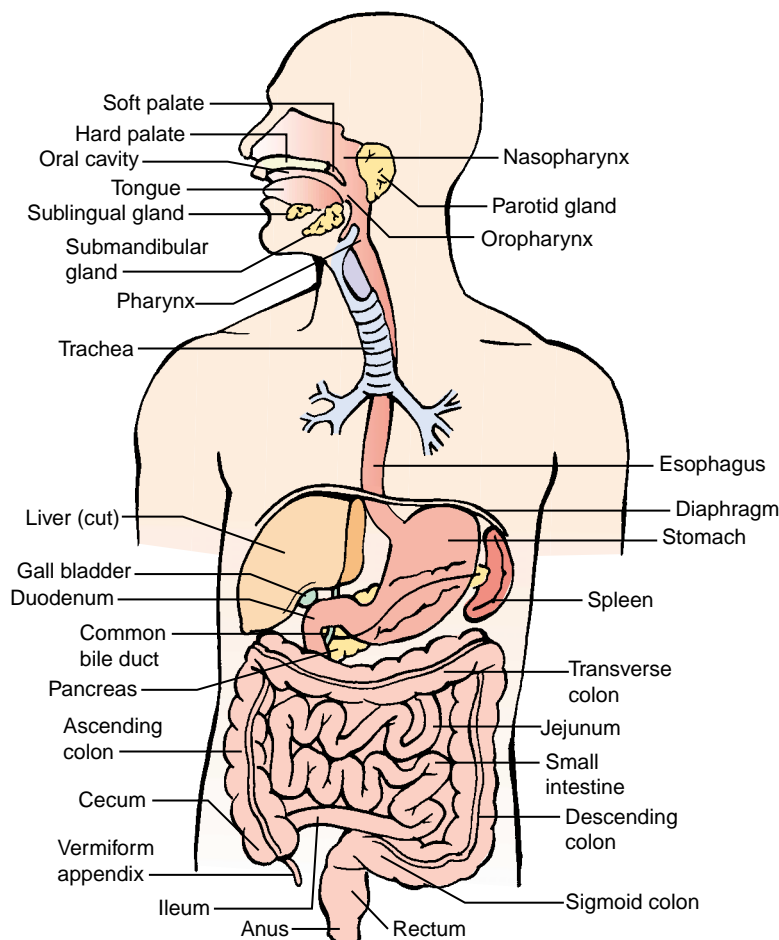
### Upper Gastrointestinal Tract

The mouth forms the entryway into the gastrointestinal tract for food; it contains the teeth, used in the mastication of food, and the tongue and other structures needed to direct food toward the pharyngeal structures and the esophagus.

### Esophagus

The esophagus is a tube that connects the oropharynx with the stomach. The esophagus begins at the lower end of the pharynx. It is a muscular, collapsible tube, approximately 25 cm (10 in) long, that lies behind the trachea. The muscular walls of the upper third of the esophagus are skeletal-type striated muscle; these muscle fibers are gradually replaced by smooth muscle fibers until, at the lower third of the esophagus, the muscle layer is entirely smooth muscle.

The esophagus functions primarily as a conduit for passage of food from the pharynx to the stomach, and the structures of its walls are designed for this purpose: the smooth muscle layers provide the peristaltic movements needed to move food along its length, and the epithelial layer secretes mucus, which protects its surface and aids in lubricating food. There are sphincters at either end of the esophagus: an upper esophageal



■ FIGURE 26-1 ■ The digestive system.

**KEY CONCEPTS****STRUCTURE AND FUNCTION OF THE GASTROINTESTINAL TRACT**

- The gastrointestinal tract is a long, hollow tube that extends from the mouth to the anus; food and fluids that enter the gastrointestinal tract do not become part of the internal environment until they have been broken down and absorbed into the blood or lymph channels.
- The wall of the gastrointestinal tract is essentially a five-layered tube: an inner mucosal layer; a supporting submucosal layer of connective tissue; a fourth and fifth layer of circular and longitudinal smooth muscle that functions to propel its contents in a proximal-to-distal direction; and an outer, two-layered peritoneum that encloses and prevents friction between the continuously moving segments of the intestine.
- The nutrients contained in ingested foods and fluids must be broken down into molecules that can be absorbed across the wall of the intestine. Gastric acids and pepsin from the stomach begin the digestive process; bile from the liver, digestive enzymes from the pancreas, and brush border enzymes break carbohydrates, fats, and proteins into molecules that can be absorbed from the intestine.

sphincter and a lower esophageal sphincter. The upper esophageal, or pharyngoesophageal, sphincter consists of a circular layer of striated muscle. The lower esophageal, or gastroesophageal, sphincter is an area approximately 3 cm above the junction with the stomach. The circular muscle in this area normally remains tonically contracted, creating a zone of high pressure that serves to prevent reflux of gastric contents into the esophagus. During swallowing, there is “receptive relaxation” of the lower esophageal sphincter, which allows easy propulsion of the esophageal contents into the stomach. The lower esophageal sphincter passes through an opening, or hiatus, in the diaphragm as it joins with the stomach, which is located in the abdomen. The portion of the diaphragm that surrounds the lower esophageal sphincter helps to maintain the zone of high pressure needed to prevent reflux of stomach contents into the esophagus.

**Stomach**

The stomach is a pouchlike structure that lies in the upper part of the abdomen and serves as a food storage reservoir during the early stages of digestion. Although the residual volume of the stomach is only approximately 50 mL, it can increase to almost 1000 mL before the intraluminal pressure begins to rise. The esophagus opens into the stomach through an opening called the *cardiac orifice*, so named because of its proximity to the heart. The part of the stomach that lies above and to the left of the cardiac orifice is called the *fundus*, the central portion is

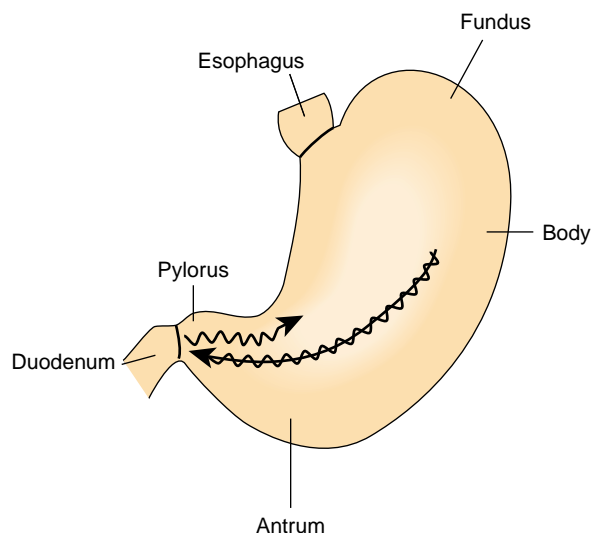
called the *body*, the orifice encircled by a ringlike muscle that opens into the small intestine is called the *pylorus*, and the portion between the body and pylorus is called the *antrum* (Fig. 26-2). The presence of a true pyloric sphincter is a matter of controversy. Regardless of whether an actual sphincter exists, contractions of the smooth muscle in the pyloric area control the rate of gastric emptying.

**Middle Gastrointestinal Tract**

The small intestine, which forms the middle portion of the digestive tract, consists of three subdivisions: the duodenum, the jejunum, and the ileum. The duodenum, which is approximately 22 cm (10 in) long, connects the stomach to the jejunum and contains the opening for the common bile duct and the main pancreatic duct. Bile and pancreatic juices enter the intestine through these ducts. It is in the jejunum and ileum, which together are approximately 7 m (23 ft) long and must be folded onto themselves to fit into the abdominal cavity, that food is digested and absorbed.

**Lower Gastrointestinal Tract**

The large intestine, which forms the lower gastrointestinal tract, is approximately 1.5 m (4.5 to 5 ft) long and 6 to 7 cm (2.4 to 2.7 in) in diameter. It is divided into the cecum, colon, rectum, and anal canal. The cecum is a blind pouch that projects down at the junction of the ileum and the colon. The ileocecal valve lies at the upper border of the cecum and prevents the return of feces from the cecum into the small intestine. The appendix arises from the cecum approximately 2.5 cm (1 in) from the ileocecal valve. The colon is further divided into ascending, transverse, descending, and sigmoid portions. The ascending colon extends from the cecum to the undersurface of the liver, where it turns abruptly to form the right colic (hepatic) flexure. The transverse colon crosses the upper half of the abdominal cavity from right to left and then curves sharply downward beneath the lower end of the spleen, forming the left colic



■ **FIGURE 26-2** ■ Structures of the stomach, showing the pacemaker area and the direction of chyme movement resulting from peristaltic contractions.

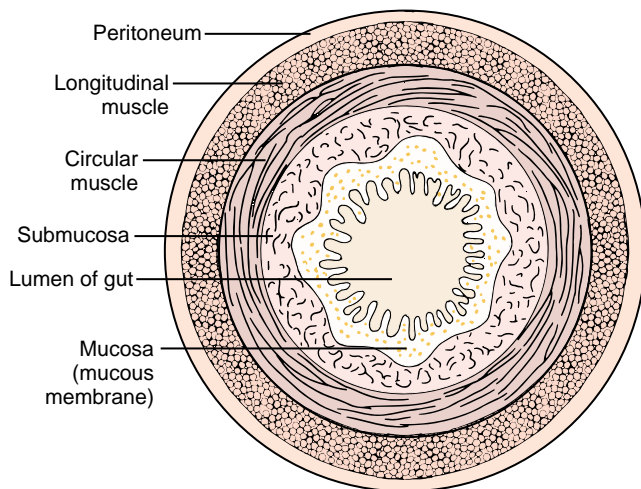
(splenic) flexure. The descending colon extends from the colic flexure to the rectum. The rectum extends from the sigmoid colon to the anus. The anal canal passes between the two medial borders of the levator ani muscles. Powerful sphincter muscles guard against fecal incontinence.

## Gastrointestinal Wall Structure

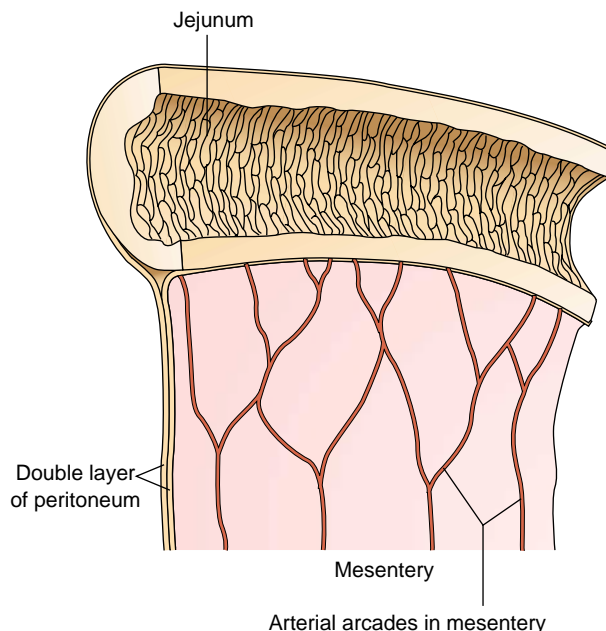
The digestive tract is essentially a five-layered tube (Fig. 26-3). The inner luminal layer, or *mucosal layer*, is so named because its cells produce mucus that lubricates and protects the inner surface of the alimentary canal. The epithelial cells in this layer have a rapid turnover rate and are replaced every 4 to 5 days. Approximately 250 g of these cells are shed each day in the stool. Because of the regenerative capabilities of the mucosal layer, injury to this layer of tissue heals rapidly without leaving scar tissue. The *submucosal layer* consists of connective tissue. This layer contains blood vessels, nerves, and structures responsible for secreting digestive enzymes. The third and fourth layers, the *circular* and *longitudinal muscle layers*, facilitate movement of the contents of the gastrointestinal tract. The outer layer, the *peritoneum*, is loosely attached to the outer wall of the intestine.

The peritoneum is the largest serous membrane in the body, having a surface area approximately equal to that of the skin. The peritoneum consists of two continuous layers—the parietal and the visceral peritoneum. The *parietal peritoneum* comes in contact with and is loosely attached to the abdominal wall, whereas the *visceral peritoneum* invests the viscera such as the stomach and intestines. A thin layer of serous fluid separates the parietal and visceral peritoneum, forming a potential space called the *peritoneal cavity*. The serous fluid forms a moist and slippery surface that prevents friction between the continuously moving abdominal structures. In certain pathologic states, the amount of fluid in the potential space of the peritoneal cavity is increased, causing a condition called *ascites*.

The jejunum and ileum are suspended by a double-layered fold of peritoneum called the *mesentery* (Fig. 26-4). The mesentery contains the blood vessels, nerves, and lymphatic vessels

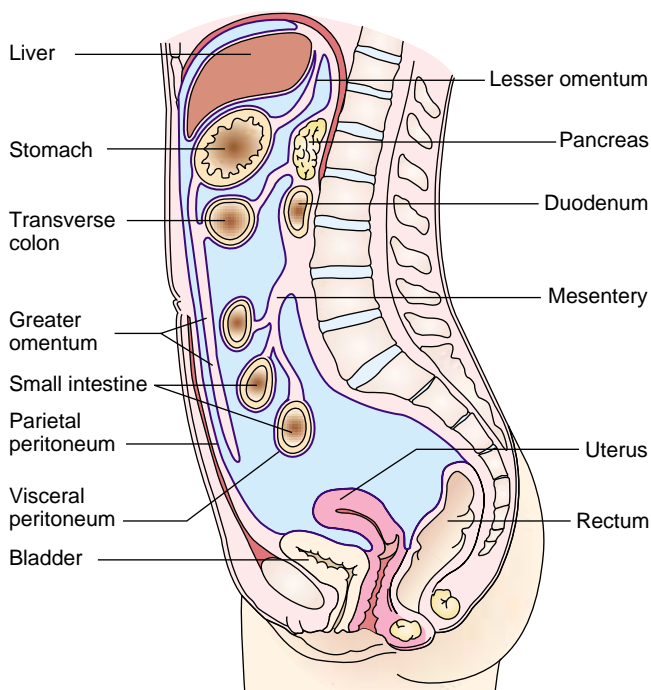


■ **FIGURE 26-3** ■ Transverse section of the digestive system. (Thomson J.S. [1977]. *Core textbook of anatomy*. Philadelphia: J.B. Lippincott)



■ **FIGURE 26-4** ■ The attachment of the mesentery to the small bowel. (Thomson J.S. [1977]. *Core textbook of anatomy*. Philadelphia: J.B. Lippincott)

that supply the intestinal wall. The mesentery is gathered in folds that attach to the dorsal abdominal wall along a short line of insertion, giving a fan-shaped appearance, with the intestines at the edge. A filmy, double fold of peritoneal membrane called the *greater omentum* extends from the stomach to cover the transverse colon and folds of the intestine (Fig. 26-5).



■ **FIGURE 26-5** ■ Reflections of the peritoneum as seen in sagittal section.



The greater omentum protects the intestines from cold. It always contains some fat, which in obese persons can be a considerable amount. The omentum also controls the spread of infection from gastrointestinal contents. In the case of infection, the omentum adheres to the inflamed area so that the infection is less likely to enter the peritoneal cavity. The lesser omentum extends between the transverse fissure of the liver and the lesser curvature of the stomach.

**In summary,** the gastrointestinal tract is a long, hollow tube, the lumen of which is an extension of the external environment. The digestive tract can be divided into four parts: an upper part, consisting of the mouth, esophagus, and stomach; a middle part, consisting of the small intestine; a lower part, consisting of the cecum, colon, and rectum; and the accessory organs, consisting of the salivary glands, the liver, and the pancreas. Throughout its length, except for the mouth, throat, and upper esophagus, the gastrointestinal tract is composed of five layers: an inner mucosal layer, a submucosal layer, a layer of circular smooth muscle fibers, a layer of longitudinal smooth muscle fibers, and an outer serosal layer that forms the peritoneum and is continuous with the mesentery.

## INNERVATION AND MOTILITY

The motility of the gastrointestinal tract propels food products and fluids along its length, from mouth to anus, in a manner that facilitates digestion and absorption. Except in the pharynx and upper third of the esophagus, smooth muscle provides the contractile force for gastrointestinal motility (the actions of smooth muscle are discussed in Chapter 1). The rhythmic movements of the digestive tract are self-perpetuating, much like the activity of the heart, and are influenced by local, humoral (*i.e.*, blood-borne), and neural influences. The ability to initiate impulses is a property of the smooth muscle itself. Impulses are conducted from one muscle fiber to another.

The smooth muscle movements of the gastrointestinal tract are tonic and rhythmic. The *tonic movements* are continuous movements that last for minutes or even hours. Tonic contractions occur at sphincters. The *rhythmic movements* consist of intermittent contractions that are responsible for mixing and moving food along the digestive tract. *Peristaltic movements* are rhythmic propulsive movements that occur when the smooth muscle layer constricts, forming a contractile band that forces the intraluminal contents forward. During peristalsis, the segment that lies distal to, or ahead of, the contracted portion relaxes, and the contents move forward with ease. Normal peristalsis always moves in the direction from the mouth toward the anus.

### Innervation

Gastrointestinal function is controlled by the *enteric nervous system*, which lies entirely within the wall of the gastrointestinal tract, and by the parasympathetic and sympathetic divisions of the autonomic nervous system (ANS).

### Enteric Nervous System

The intramural neurons (*i.e.*, those contained within the wall of the gastrointestinal tract) consist of two networks: the myenteric and submucosal plexuses. Both plexuses are aggregates of ganglionic cells that extend along the length of the gastrointestinal wall. The myenteric (Auerbach's) plexus is located between the circular muscle and longitudinal muscle layers, and the submucosal (Meissner's) plexus is between the mucosal layer and the circular muscle layers (Fig. 26-6). The activity of the neurons in the myenteric and submucosal plexuses is regulated by local influences, input from the ANS, and by interconnecting fibers that transmit information between the two plexuses.

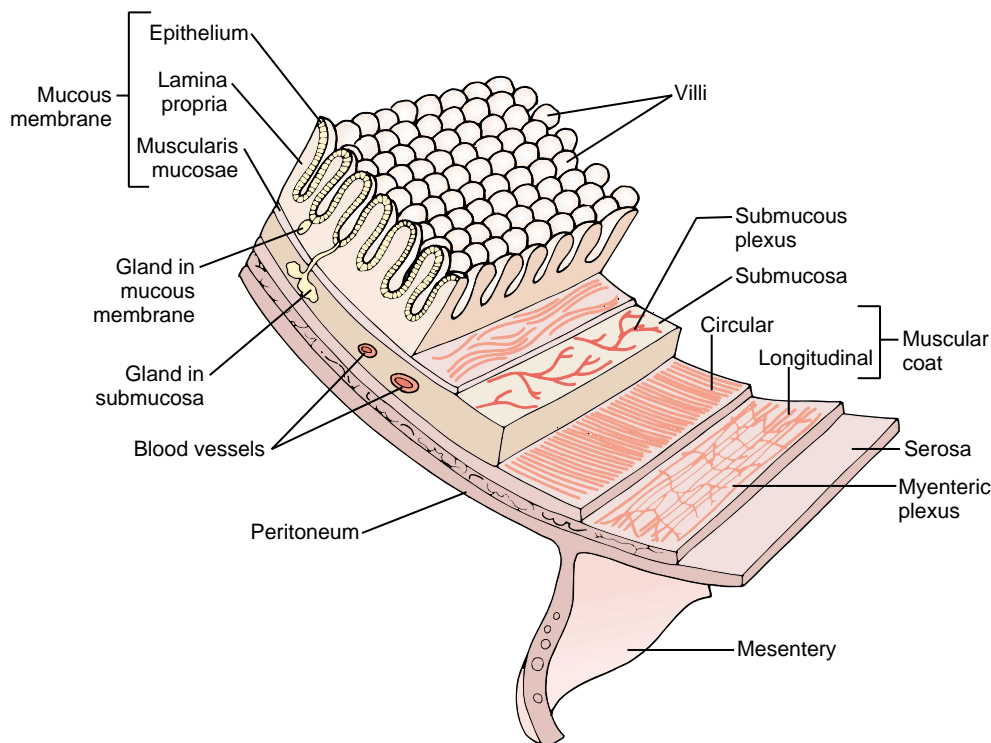
The myenteric plexus consists mainly of a linear chain of interconnecting neurons that extend the full length of the gastrointestinal tract. Because it extends all the way down the intestinal wall and because it lies between the two muscle layers, it is concerned mainly with motility along the length of the gut. The submucosal plexus, which lies between the mucosal and circular muscle layers of the intestinal wall, is mainly concerned with controlling the function of each segment of the intestinal tract. It integrates signals received from the mucosal layer into local control of motility, intestinal secretions, and absorption of nutrients.

Intramural plexus neurons also communicate with receptors in the mucosal and muscle layers. Mechanoreceptors monitor the stretch and distention of the gastrointestinal tract wall, and chemoreceptors monitor the chemical composition (*i.e.*, osmolality, pH, and digestive products of protein and fat metabolism) of its contents. These receptors can communicate directly with ganglionic cells in the intramural plexuses or with visceral afferent fibers that influence ANS control of gastrointestinal function.

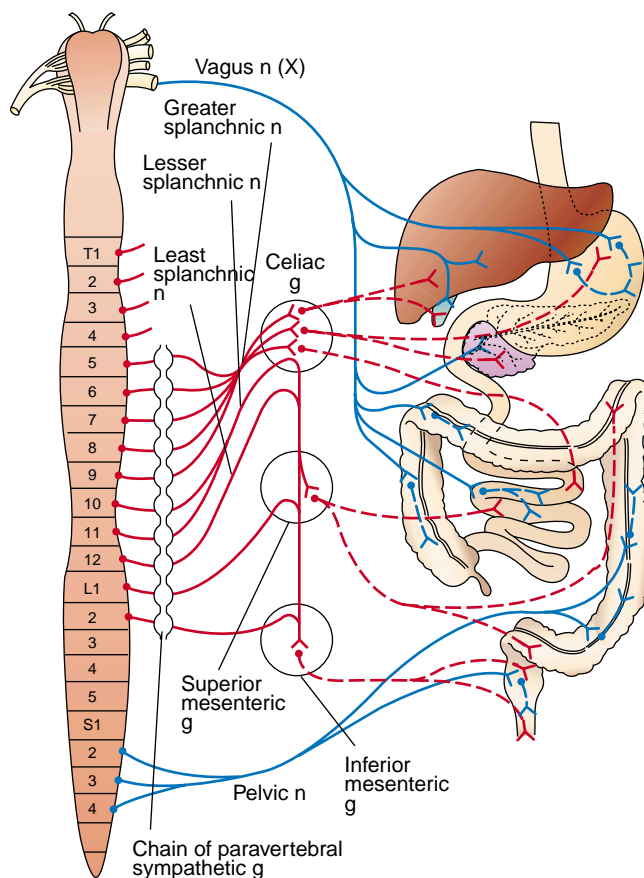
### Autonomic Nervous System

The gastrointestinal tract is innervated by both the sympathetic and parasympathetic nervous systems. Parasympathetic innervation to the stomach, small intestine, cecum, ascending colon, and transverse colon occurs by way of the vagus nerve (Fig. 26-7). The remainder of the colon is innervated by parasympathetic fibers that exit the sacral segments of the spinal cord by way of the pelvic nerve. Preganglionic parasympathetic fibers can synapse with intramural plexus neurons, or they can act directly on intestinal smooth muscle. Most parasympathetic fibers are excitatory. Numerous vagovagal reflexes influence motility and secretions of the digestive tract.

Sympathetic innervation of the gastrointestinal tract occurs through the thoracic chain of sympathetic ganglia and the celiac, superior mesenteric, and inferior mesenteric ganglia. Sympathetic control of gastrointestinal function is largely mediated by altering the activity of neurons in the intramural plexuses. The sympathetic nervous system exerts several effects on gastrointestinal function. It controls mucus secretion by the mucosal glands, reduces motility by inhibiting the activity of intramural plexus neurons, enhances sphincter function, and increases the vascular smooth muscle tone of the blood vessels that supply the gastrointestinal tract. The sympathetic fibers that supply the lower esophageal, pyloric, and internal and external anal sphincters are largely excitatory, but their role in controlling these sphincters is poorly understood.



■ **FIGURE 26-6** ■ Diagram of the four main layers of the wall of the digestive tube: mucosa, submucosa, muscular, and serosa (below the diaphragm).



■ **FIGURE 26-7** ■ The autonomic innervation of the gastrointestinal tract (g, ganglion; n, nerve).

## Swallowing and Esophageal Motility

The movement of foods and fluids in the gastrointestinal tract begins with chewing, in the case of solid foods, and swallowing. Chewing begins the digestive process; it breaks the food into particles of a size that can be swallowed, lubricates it by mixing it with saliva, and mixes starch-containing food with salivary amylase. Although chewing usually is considered a voluntary act, it can be carried out involuntarily by a person who has lost the function of the cerebral cortex.

The swallowing reflex is a rigidly ordered sequence of events that results in the propulsion of food from the mouth to the stomach through the esophagus. Although swallowing is initiated as a voluntary activity, it becomes involuntary as food or fluid reaches the pharynx. Sensory impulses for the reflex begin at tactile receptors in the pharynx and esophagus and are integrated with the motor components of the response in an area of the reticular formation of the medulla and lower pons called the *swallowing center*. The motor impulses for the oral and pharyngeal phases of swallowing are carried in the trigeminal (V), glossopharyngeal (IX), vagus (X), and hypoglossal (XII) cranial nerves, and impulses for the esophageal phase are carried by the vagus nerve. Diseases that disrupt these brain centers or their cranial nerves disrupt the coordination of swallowing and predispose an individual to food and fluid lodging in the trachea and bronchi, leading to risk of asphyxiation or aspiration pneumonia.

Swallowing consists of three phases: an oral, or voluntary phase; a pharyngeal phase; and an esophageal phase. During the *oral phase*, the bolus is collected at the back of the mouth so the tongue can lift the food upward until it touches the posterior wall of the pharynx. At this point, the *pharyngeal phase* of

swallowing is initiated. The soft palate is pulled upward, the palatopharyngeal folds are pulled together so that food does not enter the nasopharynx, the vocal cords are pulled together, and the epiglottis is moved so that it covers the larynx. Respiration is inhibited, and the bolus is moved backward into the esophagus by constrictive movements of the pharynx. Although the striated muscles of the pharynx are involved in the second stage of swallowing, it is an involuntary stage.

The third phase of swallowing is the *esophageal stage*. As food enters the esophagus and stretches its walls, local and central nervous system reflexes that initiate peristalsis are triggered. There are two types of peristalsis: primary and secondary. Primary peristalsis is controlled by the swallowing center in the brain stem and begins when food enters the esophagus. Secondary peristalsis is partially mediated by smooth muscle fibers in the esophagus and occurs when primary peristalsis is inadequate to move food through the esophagus. Peristalsis begins at the site of distention and moves downward. Before the peristaltic wave reaches the stomach, the lower esophageal sphincter relaxes to allow the bolus of food to enter the stomach. The pressure in the lower esophageal sphincter normally is greater than that in the stomach, an important factor in preventing the reflux of gastric contents.

## Gastric Motility

The stomach serves as a reservoir for ingested solids and liquids. Motility of the stomach results in the churning and grinding of solid foods and regulates the emptying of the gastric contents, or chyme, into the duodenum. Peristaltic mixing and churning contractions begin in a pacemaker area in the middle of the stomach and move toward the antrum (see Fig. 26-2). They occur at a frequency of three to five contractions per minute, each with a duration of 2 to 20 seconds. As the peristaltic wave approaches the antrum, it speeds up, and the entire terminal 5 to 10 cm of the antrum contracts, occluding the pyloric opening. Contraction of the antrum reverses the movement of the chyme, returning the larger particles to the body of the stomach for further churning and kneading. Because the pylorus is contracted during antral contraction, the gastric contents are emptied into the duodenum between contractions.

Although the pylorus does not contain a true anatomic sphincter, it does function as a physiologic sphincter to prevent the backflow of gastric contents and allow them to flow into the duodenum at a rate commensurate with the ability of the duodenum to accept them. This is important because the regurgitation of bile salts and duodenal contents can damage the mucosal surface of the antrum and lead to gastric ulcers. Likewise, the duodenal mucosa can be damaged by the rapid influx of highly acid gastric contents.

Like other parts of the gastrointestinal tract, the stomach is richly innervated by the enteric nervous system and its connections with the sympathetic and parasympathetic nervous systems. Axons from the intramural plexuses innervate the smooth muscles and glands of the stomach. Parasympathetic innervation is provided by the vagus nerve and sympathetic innervation by the celiac ganglia. The emptying of the stomach is regulated by hormonal and neural mechanisms. The hormones cholecystikinin and gastric inhibitory peptide, which are thought to control gastric emptying, are released in response to the pH and the osmolar and fatty acid composition of the chyme. Local and central circuitry are involved in the neural

control of gastric emptying. Afferent receptor fibers synapse with the neurons in the intramural plexus or trigger intrinsic reflexes by means of vagal or sympathetic pathways that participate in extrinsic reflexes.

Disorders of gastric motility can occur when the rate is too slow or too fast (see Chapter 27). A rate that is too slow leads to gastric retention. It can be caused by obstruction or gastric atony. Gastric atony can occur as a complication of visceral neuropathies in diabetes mellitus. Surgical procedures that disrupt vagal activity also can result in gastric atony. Abnormally fast emptying occurs in the dumping syndrome, which is a consequence of certain types of gastric operations. This condition is characterized by the rapid dumping of highly acidic and hyperosmotic gastric secretions into the duodenum and jejunum.

## Small Intestinal Motility

The small intestine is the major site for the digestion and absorption of food; its movements are mixing and propulsive. Regular peristaltic movements begin in the duodenum near the entry sites of the common duct and the main hepatic duct. A series of local pacemakers maintains the frequency of intestinal contraction. The peristaltic movements (approximately 12 per minute in the jejunum) become less frequent as they move further from the pylorus, becoming approximately 9 per minute in the ileum.

The peristaltic contractions produce segmentation waves and propulsive movements of the small intestine. With segmentation waves, slow contractions of circular muscle occlude the lumen and drive the contents forward and backward. Most of the contractions that produce segmentation waves are local events involving only 1 to 4 cm at a time. They function mainly to mix the chyme with the digestive enzymes from the pancreas and to ensure adequate exposure of all parts of the chyme to the mucosal surface of the intestine, where absorption takes place. The frequency of segmenting activity increases after a meal, presumably stimulated by receptors in the stomach and intestine.

Propulsive movements occur with synchronized activity in a section 10 to 20 cm long. They are accomplished by contraction of the proximal portion of the intestine with the sequential relaxation of its distal, or anal, portion. After material has been propelled to the ileocecal junction by peristaltic movement, stretching of the distal ileum produces a local reflex that relaxes the sphincter and allows fluid to squirt into the cecum.

Motility disturbances of the small bowel are common, and auscultation of the abdomen can be used to assess bowel activity. Inflammatory changes increase motility. In many instances, it is not certain whether changes in motility occur because of inflammation or occur secondary to toxins and unabsorbed materials. Delayed passage of materials in the small intestine also can be a problem. Transient interruption of intestinal motility often occurs after gastrointestinal surgery. Intubation with suction often is required to remove the accumulating intestinal contents and gases until activity is resumed.

## Colonic Motility

The storage function of the colon dictates that movements in this section of the gut are different from those in the small intestine. Movements in the colon are of two types. First are the segmental mixing movements, called *haustrations*, so named

because they occur within sacculations called *haustra*. These movements produce a local digging-type action, which ensures that all portions of the fecal mass are exposed to the intestinal surface. Second are the propulsive mass movements, in which a large segment of the colon ( $\geq 20$  cm) contracts as a unit, moving the fecal contents forward as a unit. Mass movements last approximately 30 seconds, followed by a 2- to 3-minute period of relaxation, after which another contraction occurs. A series of mass movements lasts only for 10 to 30 minutes and may occur only several times a day. Defecation normally is initiated by the mass movements.

## Defecation

Defecation is controlled by the action of two sphincters, the internal and external anal sphincters. The internal sphincter is a several-centimeters long circular thickening of smooth muscle that lies inside the anus. The external sphincter, which is composed of striated voluntary muscle, surrounds the internal sphincter. Defecation is controlled by defecation reflexes. One of these reflexes is the intrinsic myenteric reflex mediated by the local enteric nervous system. It is initiated by distention of the rectal wall, with initiation of reflex peristaltic waves that spread through the descending colon, sigmoid colon, and rectum. A second defecation reflex, the parasympathetic reflex, is integrated at the level of the sacral cord. When the nerve endings in the rectum are stimulated, signals are transmitted first to the sacral cord and then reflexly back to the descending colon, sigmoid colon, rectum, and anus by way of the pelvic nerves (Fig. 26-7). These impulses greatly increase peristaltic movements as well as relax the internal sphincter.

To prevent involuntary defecation from occurring, the external anal sphincter, which is supplied by nerve fibers in the pudendal nerve, is under the conscious control of the cortex. As afferent impulses arrive at the sacral cord, signaling the presence of a distended rectum, messages are transmitted to the cortex. If defecation is inappropriate, the cortex initiates impulses that constrict the external sphincter and inhibit efferent parasympathetic activity. Normally, the afferent impulses in this reflex loop fatigue easily, and the urge to defecate soon ceases. At a more convenient time, contraction of the abdominal muscles compresses the contents in the large bowel, reinitiating afferent impulses to the cord.

**In summary,** motility of the gastrointestinal tract propels food products and fluids along its length from mouth to anus. Although the activity of gastrointestinal smooth muscle is self-propagating and can continue without input from the nervous system, its rate and strength of contractions are regulated by a network of intramural neurons that receive input from the ANS and local receptors that monitor wall stretch and the chemical composition of luminal contents. Parasympathetic innervation occurs by means of the vagus nerve and nerve fibers from sacral segments of the spinal cord; it increases gastrointestinal motility. Sympathetic activity occurs by way of thoracolumbar output from the spinal cord, its paravertebral ganglia, and celiac, superior mesenteric, and inferior mesenteric ganglia. Sympathetic stimulation enhances sphincter function and reduces motility by inhibiting the activity of intramural plexus neurons.

## HORMONAL AND SECRETORY FUNCTION

Each day, approximately 7000 mL of fluid is secreted into the gastrointestinal tract (Table 26-1). Approximately 50 to 200 mL of this fluid leaves the body in the stool; the remainder is reabsorbed in the small and large intestines. These secretions are mainly water and have sodium and potassium concentrations similar to those of extracellular fluid. Because water and electrolytes for digestive tract secretions are derived from the extracellular fluid compartment, excessive secretion or impaired absorption can lead to extracellular fluid deficit.

The secretory activity of the gut is influenced by local, humoral, and neural influences. Neural control of gastrointestinal secretory activity is mediated through the ANS. Secretory activity, like motility, is increased with parasympathetic stimulation and inhibited with sympathetic activity. Many of the local influences, including pH, osmolality, and chyme, consistently act as stimuli for neural and humoral mechanisms.

## Gastrointestinal Hormones

The gastrointestinal tract is the largest endocrine organ in the body. It produces hormones that pass from the portal circulation into the general circulation and then back to the digestive tract, where they exert their actions. Among the hormones produced by the gastrointestinal tract are gastrin, secretin, and cholecystokinin. These hormones influence motility and the secretion of electrolytes, enzymes, and other hormones. The gastrointestinal tract hormones and their functions are summarized in Table 26-2.

The primary function of *gastrin* is the stimulation of gastric acid secretion. Gastrin also has a trophic, or growth-producing, effect on the mucosa of the small intestine, colon, and oxyntic (acid-secreting) gland area of the stomach. Removal of the tissue that produces gastrin results in atrophy of these structures. This atrophy can be reversed by the administration of exogenous gastrin.

*Secretin* is secreted by S cells in the mucosa of the duodenum and jejunum in an inactive form called *prosecretin*. When an acid chyme with a pH of less than 4.5 to 5.0 enters the intestine, secretin is activated and absorbed into the blood. Secretin causes the pancreas to secrete large quantities of fluid with a high bicarbonate concentration and low chloride concentration.

**TABLE 26-1** Secretions of the Gastrointestinal Tract

Secretions	Amount Daily (mL)
Salivary	1200
Gastric	2000
Pancreatic	1200
Biliary	700
Intestinal	2000
Total	7100



**TABLE 26-2** Major Gastrointestinal Hormones and Their Actions

Hormone	Site of Secretion	Stimulus for Secretion	Action
Cholecystokinin	Duodenum, jejunum	Products of protein digestion and long chain fatty acids	Stimulates contraction of the gallbladder; stimulates secretion of pancreatic enzymes; slows gastric emptying
Gastrin	Antrum of the stomach, duodenum	Vagal stimulation; epinephrine; neutral amino acids; calcium-containing fluids such as milk; and alcohol. Secretion is inhibited by acid contents in the antrum of the stomach (below pH 2.5)	Stimulates secretion of gastric acid and pepsinogen; increases gastric blood flow; stimulates gastric smooth muscle contraction; stimulates growth of gastric, small intestine, and colon mucosa
Secretin	Duodenum	Acid pH or chyme entering duodenum (below pH 3.0)	Stimulates secretion of bicarbonate-containing solution by pancreas and liver

The primary function of *cholecystokinin* is stimulation of pancreatic enzyme secretion. It potentiates the action of secretin, increasing the pancreatic bicarbonate response to low circulating levels of secretin. In addition to its effects on the pancreas, cholecystokinin also stimulates biliary secretion of fluid and bicarbonate and it regulates gallbladder contraction and gastric emptying.

Two other hormones that contribute to gastrointestinal function are gastric inhibitory peptide and motilin. *Gastric inhibitory peptide*, which is released from the intestinal mucosa in response to increased concentration of glucose and fats, inhibits gastric acid secretion, gastric motility, and gastric emptying. *Motilin*, which stimulates intestinal motility and contributes to the control of the interdigestive actions of the intestinal neurons, is released from the upper small intestine.

## Gastrointestinal Secretions

### Salivary Secretions

Saliva is secreted by the salivary glands. The salivary glands consist of the parotid, submaxillary, sublingual, and buccal glands. Saliva has three functions. The first is protection and lubrication. Saliva is rich in mucus, which protects the oral mucosa and coats the food as it passes through the mouth, pharynx, and esophagus. The sublingual and buccal glands produce only mucus-type secretions. The second function of saliva is its protective antimicrobial action. The saliva cleans the mouth and contains the enzyme lysozyme, which has an antibacterial action. Third, saliva contains ptyalin and amylase, which initiate the digestion of dietary starches. Secretions from the salivary glands are primarily regulated by the ANS. Parasympathetic stimulation increases flow, and sympathetic stimulation decreases flow. The dry mouth that accompanies anxiety attests to the effects of sympathetic activity on salivary secretions.

Mumps, or parotitis, is an infection of the parotid glands. Although most of us associate mumps with the contagious viral form of the disease, inflammation of the parotid glands can occur in the seriously ill person who does not receive adequate oral hygiene and who is unable to take fluids orally. Potassium iodide increases the secretory activity of the salivary glands, including the parotid glands. In a small percentage of persons, parotid swelling may occur in the course of treatment with this drug.

### Gastric Secretions

In addition to mucus-secreting cells that line the entire surface of the stomach, the stomach mucosa has two types of glands: oxyntic (or gastric) glands and pyloric glands. The *oxyntic glands* are located in the proximal 80% (body and fundus) of the stomach. They secrete hydrochloric acid, pepsinogen, intrinsic factor, and mucus. The *pyloric glands* are located in the distal 20%, or antrum, of the stomach. The pyloric glands secrete mainly mucus, some pepsinogen, and the hormone gastrin.

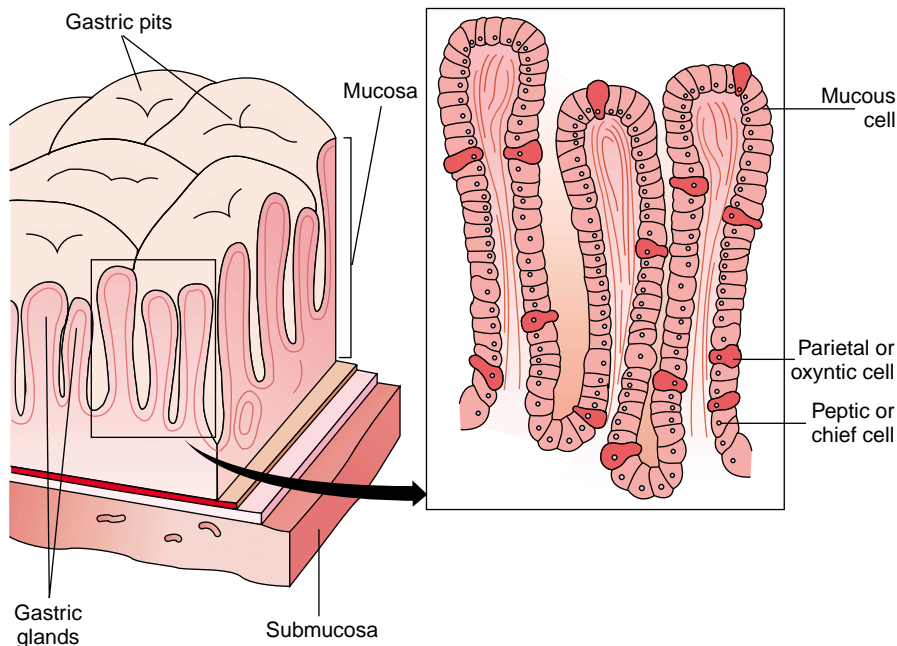
The oxyntic gland area of the stomach is composed of glands and pits (Fig. 26-8). The surface area and gastric pits are lined with mucus-producing epithelial cells. The bases of the gastric pits contain the parietal (or oxyntic) cells, which secrete hydrochloric acid and intrinsic factor, and the chief (peptic) cells, which secrete large quantities of pepsinogen. There are approximately 1 billion parietal cells in the stomach; together they produce and secrete approximately 20 mEq of hydrochloric acid in several hundred milliliters of gastric juice each hour. Gastric intrinsic factor, which is produced by the parietal cells, is necessary for the absorption of vitamin B<sub>12</sub>. The pepsinogen that is secreted by the chief cells is rapidly converted to pepsin when exposed to the low pH of the gastric juices.

One of the important characteristics of the gastric mucosa is resistance to the highly acid secretions that it produces. When the gastric mucosa is damaged by aspirin, nonsteroidal anti-inflammatory drugs (NSAIDs), ethyl alcohol, or bile salts, this resistance is disrupted, and hydrogen ions move into the mucosal cells. As the hydrogen ions accumulate in the mucosal cells, intracellular pH decreases, enzymatic reactions become impaired, and cellular structures are disrupted. The result is local ischemia and tissue necrosis. The mucosal surface is further protected by prostaglandins.

Parasympathetic stimulation (through the vagus nerve) and gastrin increase gastric secretions. Histamine increases gastric acid secretions. Gastric acid secretion and its relation to peptic ulcer are discussed in Chapter 27.

### Intestinal Secretions

The small intestine secretes digestive juices and receives secretions from the liver and pancreas (see Chapter 28). An extensive array of mucus-producing glands, called *Brunner's glands*,



■ **FIGURE 26-8** ■ Gastric pit from body of the stomach.

are concentrated at the site where the contents from the stomach and secretions from the liver and pancreas enter the duodenum. These glands secrete large amounts of alkaline mucus that protect the duodenum from the acid content in the gastric chyme and from the action of the digestive enzymes. The activity of Brunner's glands is strongly influenced by ANS activity. For example, sympathetic stimulation causes a marked decrease in mucus production, leaving this area more susceptible to irritation.

In addition to mucus, the intestinal mucosa produces two other types of secretions. The first is a serous fluid (pH 6.5 to 7.5) secreted by specialized cells (*i.e.*, crypts of Lieberkühn) in the intestinal mucosal layer. This fluid, which is produced at the rate of 2000 mL/day, acts as a vehicle for absorption. The second type of secretion consists of surface enzymes that aid absorption. These enzymes are the peptidases, or enzymes that separate amino acids, and the disaccharidases, or enzymes that split sugars.

The large intestine usually secretes only mucus. ANS activity strongly influences mucus production in the bowel, as in other parts of the digestive tract. During intense parasympathetic stimulation, mucus secretion may increase to the point that the stool contains large amounts of obvious mucus. Although the bowel normally does not secrete water or electrolytes, these substances are lost in large quantities when the bowel becomes irritated or inflamed.

**In summary**, the secretions of the gastrointestinal tract include saliva, gastric juices, bile, and pancreatic and intestinal secretions. Each day, more than 7000 mL of fluid is secreted into the digestive tract; all but 50 to 200 mL of this fluid is reabsorbed. Water, derived from the extracellular fluid compartment, is the major component of gastrointestinal

tract secretions. Neural, humoral, and local mechanisms contribute to the control of these secretions. The parasympathetic nervous system increases secretion, and sympathetic activity exerts an inhibitory effect. In addition to secreting fluids containing digestive enzymes, the gastrointestinal tract produces and secretes hormones, such as gastrin, secretin, and cholecystokinin, that contribute to the control of gastrointestinal function.

## DIGESTION AND ABSORPTION

Digestion and absorption occur mainly in the small intestine. The stomach is a poor absorptive structure, and only a few lipid-soluble substances, including alcohol, are absorbed from the stomach.

Digestion is the process of dismantling foods into their constituent parts. Digestion requires hydrolysis, enzyme cleavage, and fat emulsification. Hydrolysis is breakdown of a compound that involves a chemical reaction with water. The importance of hydrolysis to digestion is evidenced by the amount of water (7 to 8 L) that is secreted into the gastrointestinal tract daily. The intestinal mucosa is impermeable to most large molecules. Most proteins, fats, and carbohydrates must be broken down into smaller particles before they can be absorbed. Although some digestion of carbohydrates and proteins begins in the stomach, digestion takes place mainly in the small intestine. The breakdown of fats to free fatty acids and monoglycerides takes place entirely in the small intestine. The liver, with its production of bile, and the pancreas, which supplies a number of digestive enzymes, play important roles in digestion.

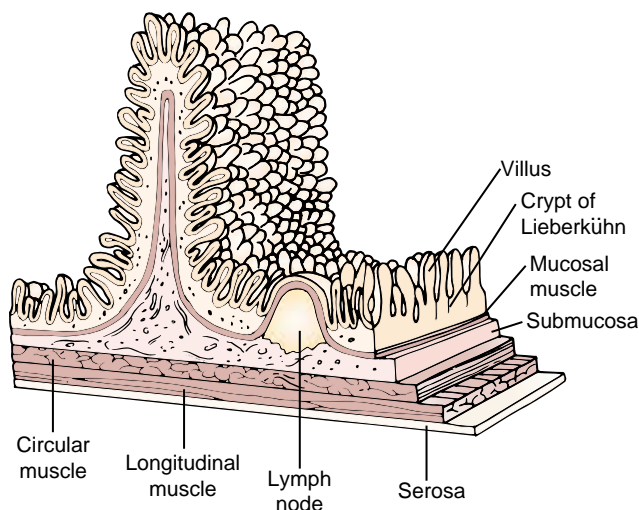
Absorption is the process of moving nutrients and other materials from the external environment of the gastrointestinal

tract into the internal environment. Absorption is accomplished by active transport and diffusion. The absorptive function of the large intestine focuses mainly on water reabsorption. A number of substances require a specific carrier or transport system. For example, vitamin B<sub>12</sub> is not absorbed in the absence of intrinsic factor, which is secreted by the parietal cells of the stomach. Transport of amino acids and glucose occurs mainly in the presence of sodium. Water is absorbed passively along an osmotic gradient.

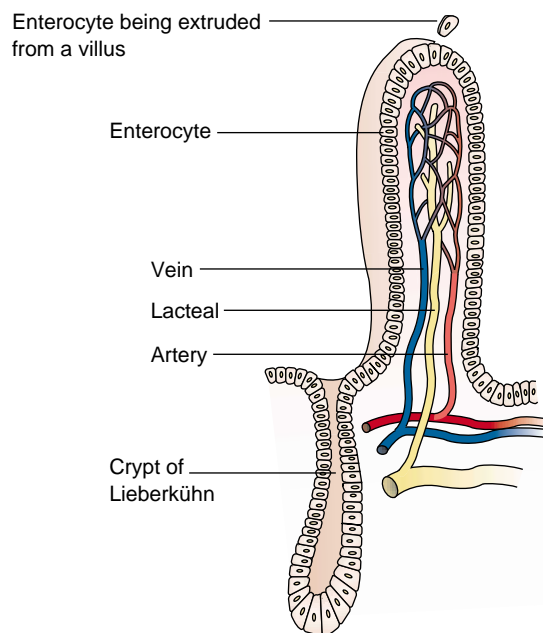
The distinguishing characteristic of the small intestine is its large surface area, which in the adult is estimated to be approximately 250 m<sup>2</sup>. Anatomic features that contribute to this enlarged surface area are the circular folds that extend into the lumen of the intestine and the villi, which are finger-like projections of mucous membrane, numbering as many as 25,000, that line the entire small intestine (Fig. 26-9). Each villus is equipped with an arrangement of blood vessels for the absorption of fluid and dissolved material into the portal blood and a central lacteal for absorption into the lymph (Fig. 26-10). Fats rely largely on the lymphatics for absorption.

Each villus is covered with cells called *enterocytes* that contribute to the absorptive and digestive functions of the small bowel, and goblet cells that provide mucus. The crypts of Lieberkühn are glandular structures that open into the spaces between the villi. The enterocytes have a life span of approximately 4 to 5 days; their replacement cells differentiate from progenitor cells located in the area of the crypts. The maturing enterocytes migrate up the villus and eventually are extruded from the tip.

The enterocytes secrete enzymes that aid in the digestion of carbohydrates and proteins. These enzymes are called *brush border enzymes* because they adhere to the border of the villus structures. In this way they have access to the carbohydrates and protein molecules as they come in contact with the absorptive surface of the intestine. This mechanism of secretion places the enzymes where they are needed and eliminates the need to produce enough enzymes to mix with the entire contents that fill the lumen of the small bowel. The digested mol-



■ **FIGURE 26-9** ■ The mucous membrane of the small intestine. Note the numerous villi on a circular fold.



■ **FIGURE 26-10** ■ A single villus from the small intestine.

ecules diffuse through the membrane or are actively transported across the mucosal surface to enter the blood or, in the case of fatty acids, the lacteal. These molecules are then transported through the portal vein or lymphatics into the systemic circulation.

## Carbohydrates

Carbohydrates must be broken down into monosaccharides, or single sugars, before they can be absorbed from the small intestine. The average daily intake of carbohydrate in the American diet is approximately 350 to 400 g. Starch makes up approximately 50% of this total, sucrose (*i.e.*, table sugar) approximately 30%, lactose (*i.e.*, milk sugar) approximately 6%, and maltose approximately 1.5%.

Digestion of starch begins in the mouth with the action of amylase. Pancreatic secretions also contain an amylase. Amylase breaks down starch into several disaccharides, including maltose, isomaltose, and  $\alpha$ -dextrins. The brush border enzymes convert the disaccharides into monosaccharides that can be absorbed (Table 26-3). Sucrose yields glucose and fructose, lactose is converted to glucose and galactose, and maltose is converted to two glucose molecules. When the disaccharides are not broken down to monosaccharides, they cannot be absorbed but remain as osmotically active particles in the contents of the digestive system, causing diarrhea. Persons who are deficient in lactase, the enzyme that breaks down lactose, experience diarrhea when they drink milk or eat dairy products.

Fructose is transported across the intestinal mucosa by facilitated diffusion, which does not require energy expenditure. In this case, fructose moves along a concentration gradient. Glucose and galactose are transported by way of a sodium-dependent carrier system that uses adenosine triphosphate and the Na<sup>+</sup>/K<sup>+</sup>-ATPase pump as an energy source (Fig. 26-11).

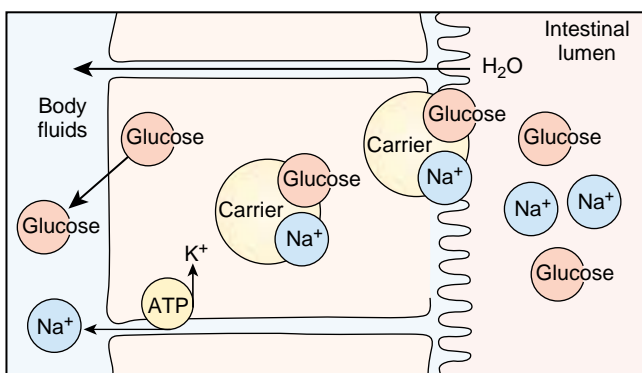
**TABLE 26-3** Enzymes Used in Digestion of Carbohydrates

Dietary Carbohydrates	Enzyme	Monosaccharides Produced
Lactose	Lactase	Glucose and galactose
Sucrose	Sucrase	Fructose and glucose
Starch	Amylase	Maltose, maltotriase, and $\alpha$ -dextrins
Maltose and maltotriose	Maltase	Glucose and glucose
$\alpha$ -Dextrins	$\alpha$ -Dextrinase	Glucose and glucose

Water absorption from the intestine is linked to absorption of osmotically active particles, such as glucose and sodium. It follows that an important consideration in facilitating the transport of water across the intestine (and decreasing diarrhea) after temporary disruption in bowel function is to include sodium and glucose in the fluids that are taken.

## Fats

The average adult eats approximately 60 to 100 g of fat daily, principally as triglycerides containing long-chain fatty acids. These triglycerides are broken down by pancreatic lipase. Bile salts act as a carrier system for the fatty acids and fat-soluble vitamins A, D, E, and K by forming micelles, which transport these substances to the surface of intestinal villi, where they are absorbed by the lacteal. The major site of fat absorption is the upper jejunum. Medium-chain triglycerides, with 6 to 10 carbon atoms in their structures, are absorbed better than longer-chain fatty acids because they are more completely broken down by pancreatic lipase and they form micelles more easily. Because they are easily absorbed, medium-chain triglycerides often are used in the treatment of persons with malabsorption syndrome. The absorption of vitamins A, D, E, and K, which are fat-soluble vitamins, requires bile salts.



■ **FIGURE 26-11** ■ The hypothetical sodium-dependent transport system for glucose. Both sodium and glucose must attach to the transport carrier before either can be transported into the cell. The concentration of glucose builds up in the intestinal cell until a diffusion gradient develops, causing glucose to move into the body fluids. Sodium is transported out of the cell by the energy-dependent  $\text{Na}^+/\text{K}^+$ -ATPase pump. This creates the gradient needed to operate the transport system. Water is passively absorbed along a concentration gradient generated by the absorption of solutes.

Fat that is not absorbed in the intestine is excreted in the stool. *Steatorrhea* is the term used to describe fatty stools. It usually indicates that there is 20 g or more of fat in a 24-hour stool sample. Normally, a chemical test is done on a 72-hour stool collection, during which time the diet is restricted to 80 to 100 g of fat per day.

## Proteins

Proteins from the diet must be broken into amino acids to be absorbed. Protein digestion begins in the stomach with the action of pepsin. Pepsinogen, the enzyme precursor of pepsin, is secreted by the chief cells in response to a meal and acid pH. Acid in the stomach is required for the conversion of pepsinogen to pepsin. Pepsin is inactivated when it enters the intestine by the alkaline pH.

Proteins are broken down further by pancreatic enzymes, such as trypsin, chymotrypsin, carboxypeptidase, and elastase. As with pepsin, the pancreatic enzymes are secreted as precursor molecules. Trypsinogen, which lacks enzymatic activity, is activated by an enzyme located on the brush border cells of the duodenal enterocytes. Activated trypsin activates additional trypsinogen molecules and other pancreatic precursor proteolytic enzymes. The amino acids are liberated intramurally or on the surface of the villi by brush border enzymes that degrade proteins into peptides that are one, two, or three amino acids long. Similar to glucose, many amino acids are transported across the mucosal membrane in a sodium-linked process that uses the  $\text{Na}^+/\text{K}^+$ -ATPase pump as an energy source.

**In summary,** the digestion and absorption of foodstuffs take place in the small intestine. Digestion is the process of dismantling foods into their constituent parts. Digestion requires hydrolysis, enzyme cleavage, and fat emulsification. Proteins, fats, carbohydrates, and other components of the diet are broken down into molecules that can be transported from the intestinal lumen into the bloodstream. Absorption is the process of moving nutrients and other materials from the external environment of the gastrointestinal tract into the internal environment. Brush border enzymes break carbohydrates into monosaccharides that can be transported across the intestine into the bloodstream. The digestion of proteins begins in the stomach with the action of pepsin and is further facilitated in the intestine by the pancreatic enzymes, such as trypsin, chymotrypsin, carboxypeptidase, and elastase. The absorption of glucose and amino acids is facilitated by a sodium-dependent transport system. Fat in the diet is broken down by pancreatic lipase into triglycerides containing



medium- and long-chain fatty acids. Bile salts form micelles that transport these substances to the surface of intestinal villi, where they are absorbed.

## ANOREXIA, NAUSEA, AND VOMITING

Anorexia, nausea, and vomiting are physiologic responses that are common to many gastrointestinal disorders. These responses are protective to the extent that they signal the presence of disease and, in the case of vomiting, remove noxious agents from the gastrointestinal tract. They also can contribute to impaired intake or loss of fluids and nutrients.

### Anorexia

Anorexia represents a loss of appetite. Several factors influence appetite. One is hunger, which is stimulated by contractions of the empty stomach. Appetite or the desire for food intake is regulated by the hypothalamus and other associated centers in the brain (see Chapter 29). Smell plays an important role, as evidenced by the fact that appetite can be stimulated or suppressed by the smell of food. Loss of appetite is associated with emotional factors, such as fear, depression, frustration, and anxiety. Many drugs and disease states cause anorexia. For example, in uremia the accumulation of nitrogenous wastes in the blood contributes to the development of anorexia. Anorexia often is a forerunner of nausea, and most conditions that cause nausea and vomiting also produce anorexia.

### Nausea

Nausea is an ill-defined and unpleasant subjective sensation. It is the conscious sensation resulting from stimulation of the medullary vomiting center that often precedes or accompanies vomiting. Nausea usually is preceded by anorexia, and stimuli such as foods and drugs that cause anorexia in small doses usually produce nausea when given in larger doses. A common cause of nausea is distention of the duodenum or upper small intestinal tract. Nausea frequently is accompanied by autonomic nervous system manifestations such as watery salivation and vasoconstriction with pallor, sweating, and tachycardia. Nausea may function as an early warning signal of a pathology.

### Vomiting

Vomiting, or emesis, is the sudden and forceful oral expulsion of the contents of the stomach. It usually is preceded by nausea. The contents that are vomited are called vomitus. Vomiting, as a basic physiologic protective mechanism, limits the possibility of damage from ingested noxious agents by emptying the contents of the stomach and portions of the small intestine. Nausea and vomiting may represent a total-body response to drug therapy, including overdose, cumulative effects, toxicity, and side effects.

Vomiting involves two functionally distinct medullary centers: the vomiting center and the chemoreceptor trigger zone. The act of vomiting is integrated by the vomiting center, which is located in the dorsal portion of the reticular formation of the

medulla near the sensory nuclei of the vagus. The chemoreceptor trigger zone is located in a small area on the floor of the fourth ventricle, where it is exposed to both blood and cerebrospinal fluid. It is thought to mediate the emetic effects of blood-borne drugs and toxins.

The act of vomiting consists of taking a deep breath, closing the airways, and producing a strong, forceful contraction of the diaphragm and abdominal muscles along with relaxation of the gastroesophageal sphincter. Respiration ceases during the act of vomiting. Vomiting may be accompanied by dizziness, light-headedness, decrease in blood pressure, and bradycardia.

The vomiting center receives input from the gastrointestinal tract and other organs; from the cerebral cortex; from the vestibular apparatus, which is responsible for motion sickness; and from the chemoreceptor trigger zone, which is activated by many drugs and endogenous and exogenous toxins. Hypoxia exerts a direct effect on the vomiting center, producing nausea and vomiting. This direct effect probably accounts for the vomiting that occurs during periods of decreased cardiac output, shock, environmental hypoxia, and brain ischemia caused by increased intracranial pressure. Inflammation of any of the intra-abdominal organs, including the liver, gallbladder, or urinary tract, can cause vomiting because of the stimulation of the visceral afferent pathways that communicate with the vomiting center. Distention or irritation of the gastrointestinal tract also causes vomiting through the stimulation of visceral afferent neurons.

Several neurotransmitters and receptor subtypes are implicated as neuromediators in nausea and vomiting. Dopamine, serotonin, and opioid receptors are found in the gastrointestinal tract and in the vomiting and chemoreceptor trigger zone. Dopamine antagonists, such as prochlorperazine, depress vomiting caused by stimulation of the chemoreceptor trigger zone. Serotonin is believed to be involved in the nausea and emesis associated with cancer chemotherapy and radiation therapy. Serotonin antagonists (*e.g.*, granisetron and ondansetron) are effective in treating the nausea and vomiting associated with these stimuli. Motion sickness appears to be a central nervous system (CNS) response to vestibular stimuli. Norepinephrine and acetylcholine receptors are located in the vestibular center. The acetylcholine receptors are thought to mediate the impulses responsible for exciting the vomiting center; norepinephrine receptors may have a stabilizing influence that resists motion sickness. Many of the motion sickness drugs (*e.g.*, dimenhydrinate) have a strong CNS anticholinergic effect and act on the receptors in the vomiting center and areas related to the vestibular system.

**In summary,** the signs and symptoms of many gastrointestinal tract disorders are manifested by anorexia, nausea, and vomiting. Anorexia, or loss of appetite, may occur alone or may accompany nausea and vomiting. Nausea, which is an ill-defined, unpleasant sensation, signals the stimulation of the medullary vomiting center. It often precedes vomiting and frequently is accompanied by autonomic responses, such as salivation and vasoconstriction with pallor, sweating, and tachycardia. The act of vomiting, which is integrated by the vomiting center, involves the forceful oral expulsion of the gastric contents. It is a basic physiologic mechanism that rids the gastrointestinal tract of noxious agents.

## REVIEW QUESTIONS

- Describe the physiologic function of the digestive system in terms of transport of food, digestion, absorption of nutrients, and storage of waste products.
- Approximately 7000 mL of fluid is secreted into the gastrointestinal tract, with only about 200 mL being eliminated in the stool. Explain the source, composition, function, and removal of this fluid from the gastrointestinal tract.
- Describe the site of gastric acid and pepsin production and secretion in the stomach.
- Describe the function of the gastric mucosal barrier.
- Relate the characteristics of the small intestine to its absorptive function and explain the function of intestinal brush border enzymes in the digestion and absorption of carbohydrates, fats, and proteins.
- Explain the relationship between the enteric nervous system and the autonomic nervous system in the regulation of gastrointestinal function.
- Describe the innervation of the reflexive and voluntary components of defecation.



Visit the Connection site at [connection.lww.com/go/porth](http://connection.lww.com/go/porth) for links to chapter-related resources on the Internet.

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