The Digestive System

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Introduction

- Food is also vital to life because it is our only source of chemical energy. However, most of the food we eat consists of molecules that are too large to be used by body cells. Therefore, *foods must be broken down into molecules that are small enough to enter body cells*, a process known as **digestion.**
- The organs involved in the breakdown of food—collectively called the **digestive system**

- The medical specialty that deals with the structure, function, diagnosis, and treatment of diseases of the stomach and intestines is called **gastroenterology**.
- The medical specialty that deals with the diagnosis and treatment of disorders of the rectum and anus is called **proctology**.

Overview of the Digestive System

Two groups of organs compose the digestive system (Figure 24.1):

1- **The gastrointestinal (GI) tract,** or *alimentary canal* (*alimentary* nourishment), is a continuous tube that extends from the mouth to the anus through the thoracic and abdominopelvic cavities.

- **Organs** of the gastrointestinal tract include the mouth, most of the pharynx, esophagus, stomach, small intestine, and large intestine.

2- **The accessory digestive organs include** the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.

- Teeth aid in the physical breakdown of food, and the tongue assists in chewing and swallowing.
- The other accessory digestive organs, however, never come into direct contact with food. They produce or store secretions that flow into the GI tract through ducts; the secretions aid in the chemical breakdown of food.

Overview of the Digestive System (continued)

- **Muscular contractions** in the wall of the GI tract physically break down the food by **churning it and propel** the food along the tract, from the esophagus to the anus.

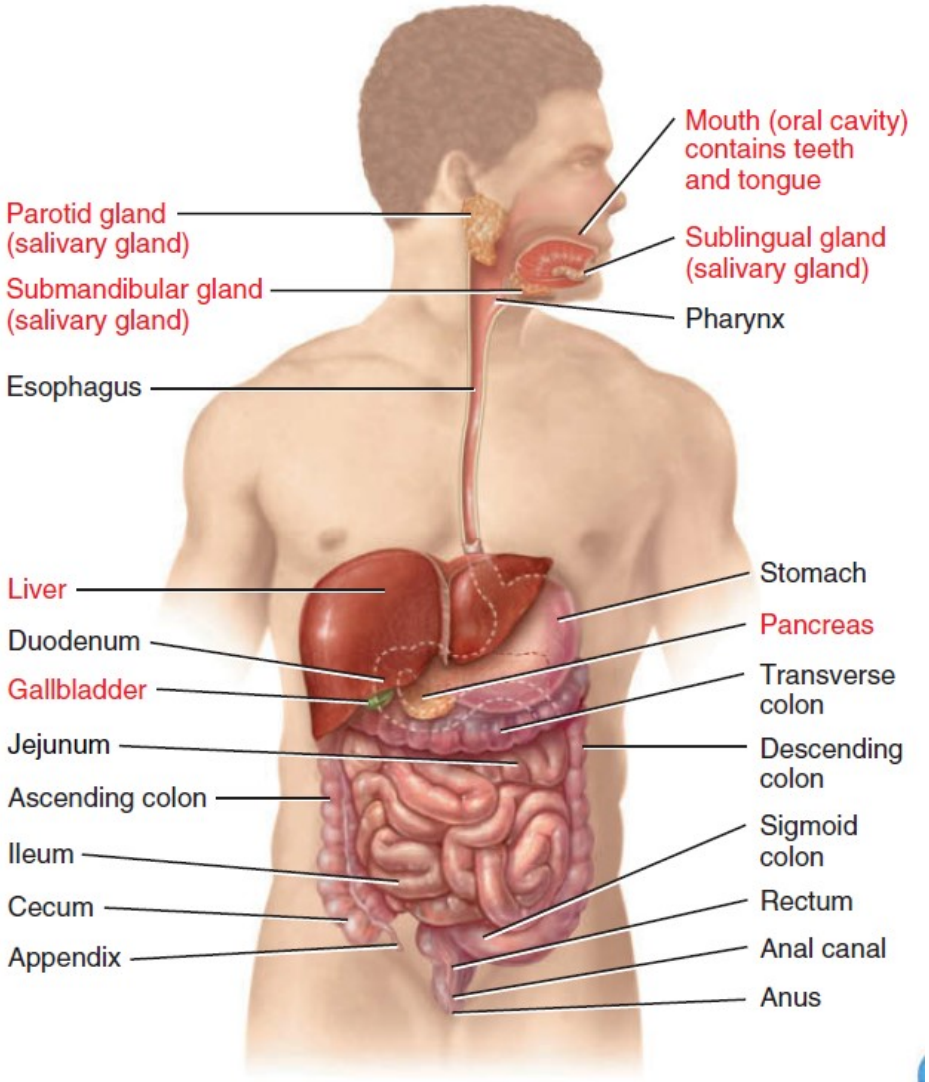
→ The contractions also help to **dissolve foods** by mixing them with fluids secreted into the tract.

- **Enzymes** secreted by accessory digestive organs and cells that line the tract **break down** the food chemically.

Figure 24.1 Organs of the digestive system.

Organs of the gastrointestinal (GI) tract are the mouth, pharynx, esophagus, stomach, small intestine, and large intestine.

Accessory digestive organs include the teeth, tongue, salivary glands, liver, gallbladder, and pancreas and are indicated in red.



(a) Right lateral view of head and neck and anterior view of trunk

Functions of the digestive system

1. **Ingestion: taking food into mouth.**
2. **Secretion: release of water, acid, buffers, and enzymes into lumen of GI tract.**
3. **Mixing and propulsion: churning and movement of food through GI tract.**
4. **Digestion: mechanical and chemical breakdown of food.**
5. **Absorption: passage of digested products from GI tract into blood and lymph.**
6. **Defecation: elimination of feces from GI tract.**

Layers of the GI Tract

Mucosa

The inner lining of the GI tract, is a mucous membrane. It is composed of:

(1) a layer of **epithelium** in direct contact with the contents of the GI tract

A- Nonkeratinized stratified squamous epithelium that serves a protective function.

B- Simple columnar epithelium, which functions in secretion and absorption, lines the stomach and intestines.

(2) a layer of connective tissue called the **lamina propria** containing lymph nodules,

(3) a thin layer of **smooth muscle** (muscularis mucosae).

Submucosa

- ✓ Consists of **areolar connective tissue** that binds the mucosa to the muscularis.
- ✓ It contains many **blood and lymphatic** vessels that receive absorbed food molecules.
- ✓ Also located in the submucosa is an extensive **network of neurons** known as the **submucosal plexus**.
- ✓ The submucosa may also contain **glands and lymphatic tissue**.

Layers of the GI Tract (continued)

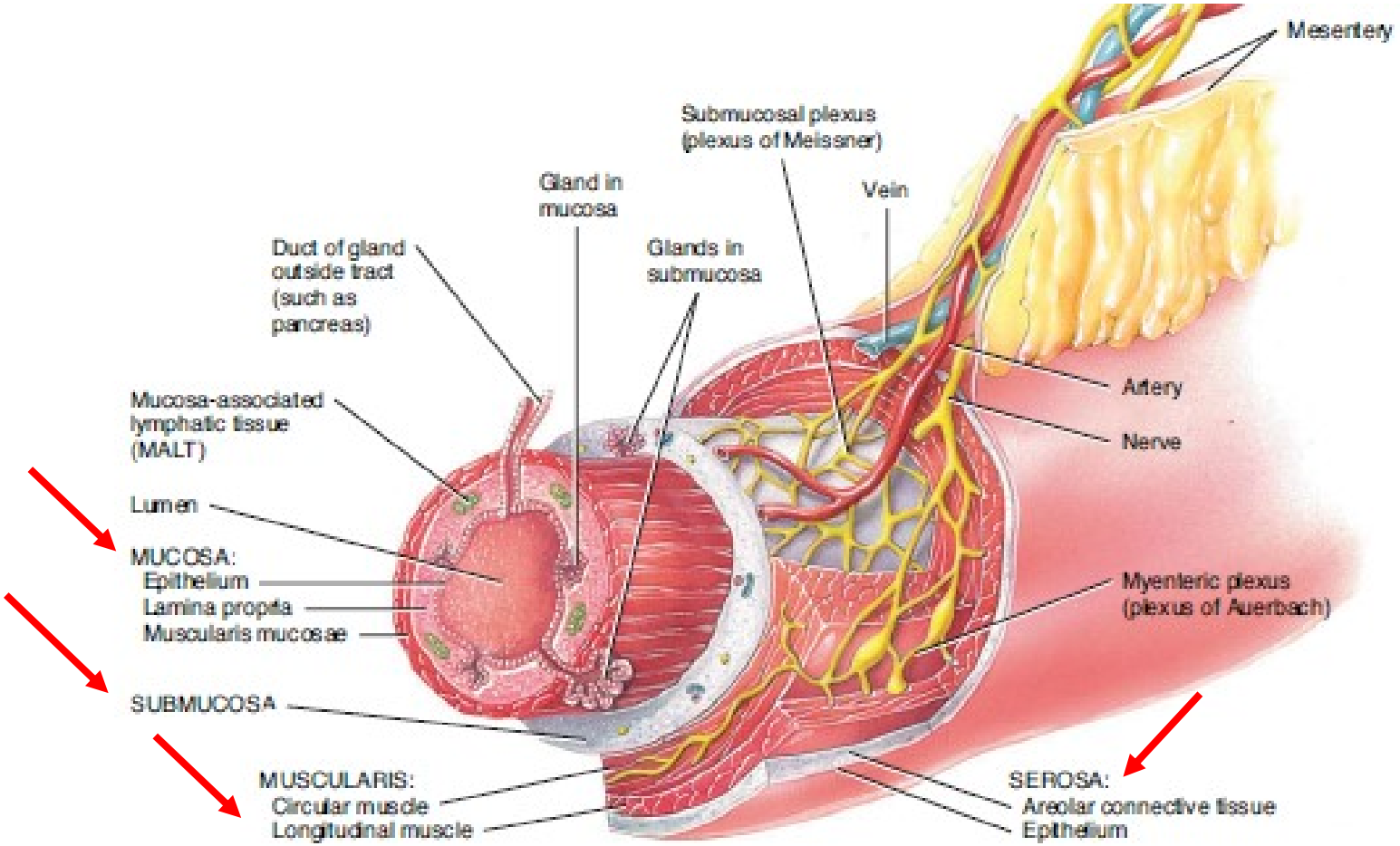
Muscularis

- The **muscularis** of the mouth, pharynx, and superior and middle parts of the esophagus contains *skeletal muscle* that produces voluntary swallowing.
- Skeletal muscle also forms the external anal sphincter, which permits voluntary control of defecation.
- Throughout the rest of the tract, the muscularis consists of *smooth muscle* that is generally found in two sheets: an inner sheet of circular fibers and an outer sheet of longitudinal fibers.
- Involuntary contractions of the smooth muscle help break down food, mix it with digestive secretions, and propel it along the tract.
- **Between** the layers of the muscularis is a second plexus of neurons—the **myenteric plexus.**

Serosa

- Those portions of the GI tract that are suspended in the abdominal cavity have a superficial layer called the **serosa**.
- As its name implies, the serosa is a **serous membrane composed of areolar connective tissue and simple squamous epithelium** (**mesothelium**).
- The serosa is also called the ***visceral peritoneum*** because it forms a portion of the peritoneum.
- The esophagus lacks a serosa; instead, only a single layer of areolar connective tissue called the *adventitia* forms the superficial layer of this organ.

Figure 24.2. Layers of the gastrointestinal tract. Variations in this basic plan may be seen in the esophagus (Figure 24.9), stomach (Figure 24.12), small intestine (Figure 24.19), and large intestine (Figure 24.24).
The four layers of the GI tract, from **deep** to **superficial**, are **the mucosa, submucosa, muscularis, and serosa.**



Neural Innervation of the GI Tract

1- Enteric Nervous System → intrinsic set of nerves , The "brain of the gut,"

1- The **myenteric plexus**, or *plexus of Auerbach*, is located between the longitudinal and circular smooth muscle layers of the muscularis. This plexus mostly controls GI tract motility (movement), particularly the frequency and strength of contraction of the muscularis

2- The **submucosal plexus**, or *plexus of Meissner*, is found within the submucosa. The motor neurons of the submucosal plexus supply the secretory cells of the mucosal epithelium, controlling the secretions of the organs of the GI tract.

- The plexuses of the ENS consist of motor neurons, interneurons, and sensory neurons, The interneurons of the ENS interconnect the neurons of the myenteric and submucosal plexuses.

The sensory neurons of the ENS supply the mucosal epithelium and contain receptors that detect stimuli in the lumen of the GI tract. The wall of the GI tract contains two major types of sensory receptors:

(1) *Chemoreceptors*, which respond to certain chemicals in the food present in the lumen,

(2) *Mechanoreceptors*, such as stretch receptors, that are activated when food distends (stretches) the wall of a GI organ.

Neural Innervation of the GI Tract (continued)

2- Autonomic Nervous System → extrinsic set of nerves

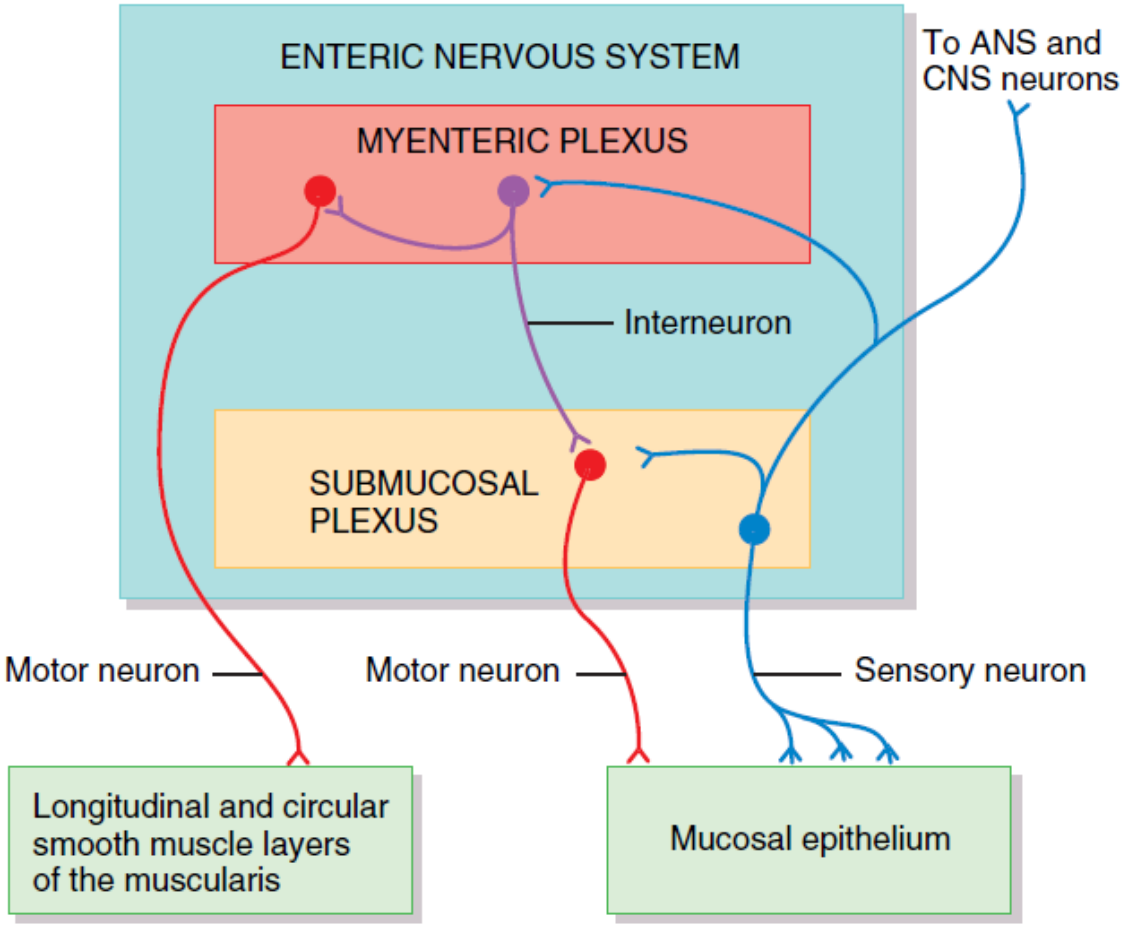
1- The vagus (X) nerves supply ***parasympathetic*** fibers to most parts of the GI tract, with the exception of the last half of the large intestine, which is supplied with parasympathetic fibers from the sacral spinal cord. The parasympathetic nerves that supply the GI tract form neural connections with the ENS.

- Stimulation of the parasympathetic nerves that innervate the GI tract causes an increase in GI secretion and motility by increasing the activity of ENS neurons.

2- Sympathetic nerves that supply the GI tract arise from the thoracic and upper lumbar regions of the spinal cord. Like the parasympathetic nerves, these sympathetic nerves form neural connections with the ENS.

- The sympathetic nerves that supply the GI tract cause a decrease in GI secretion and motility by inhibiting the neurons of the ENS. Emotions such as anger, fear, and anxiety may slow digestion because they stimulate the sympathetic nerves that supply the GI tract.

Figure 24.3 Organization of the enteric nervous system.
The enteric nervous system consists of neurons arranged into the myenteric and submucosal plexuses.



Mouth

oral or *buccal* **cavity**

There are three pairs of major salivary glands: the parotid, submandibular, and sublingual glands

TABLE 24.1

Summary of Digestive Activities in the Mouth

STRUCTURE	ACTIVITY	RESULT
Cheeks and lips	Keep food between teeth.	Foods uniformly chewed during mastication.
Salivary glands	Secrete saliva.	Lining of mouth and pharynx moistened and lubricated. Saliva softens, moistens, and dissolves food and cleanses mouth and teeth. Salivary amylase splits starch into smaller fragments (maltose, maltotriose, and α-dextrins).
Tongue		
Extrinsic tongue muscles	Move tongue from side to side and in and out.	Food maneuvered for mastication, shaped into bolus, and maneuvered for swallowing.
Intrinsic tongue muscles	Alter shape of tongue.	Swallowing and speech.
Taste buds	Serve as receptors for gustation (taste) and presence of food in mouth.	Secretion of saliva stimulated by nerve impulses from taste buds to salivatory nuclei in brain stem to salivary glands.
Lingual glands	Secrete lingual lipase.	Triglycerides broken down into fatty acids and diglycerides.
Teeth	Cut, tear, and pulverize food.	Solid foods reduced to smaller particles for swallowing.

Pharynx and Esophagus

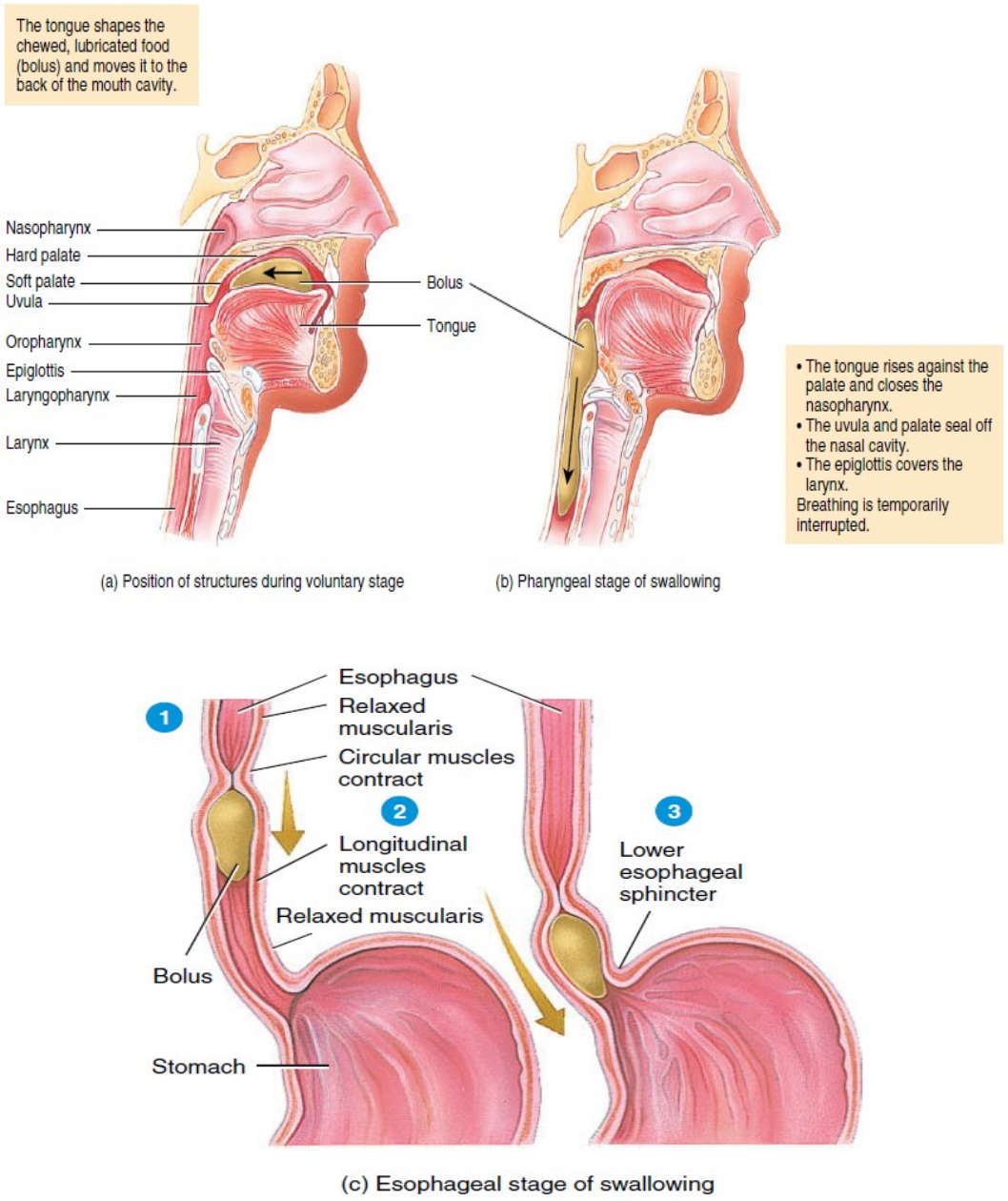
TABLE 24.2

Summary of Digestive Activities in the Pharynx and Esophagus

STRUCTURE	ACTIVITY	RESULT
Pharynx	Pharyngeal stage of deglutition.	Moves bolus from oropharynx to laryngopharynx and into esophagus; closes air passageways.
Esophagus	Relaxation of upper esophageal sphincter.	Permits entry of bolus from laryngopharynx into esophagus.
	Esophageal stage of deglutition (peristalsis).	Pushes bolus down esophagus.
	Relaxation of lower esophageal sphincter.	Permits entry of bolus into stomach.
	Secretion of mucus.	Lubricates esophagus for smooth passage of bolus.

Figure 24.10 Deglutition (swallowing).
During the pharyngeal stage (b) the tongue rises against the palate, the nasopharynx is closed off, the larynx rises, the epiglottis seals off the larynx, and the **BOLUS** is passed into the esophagus. During the esophageal stage (c), food moves through the esophagus into the stomach via **PERISTALSIS**.

Deglutition is a mechanism that moves food from the mouth into the stomach.



Stomach

- Empty stomach, it is about the size of a large sausage, but it is the **most distensible part of the GI tract** and can accommodate a large quantity of food.
- In the stomach, digestion of **starch** and **triglycerides** continues, digestion of **proteins** begins, the semisolid **bolus** is converted to a liquid, and certain substances are absorbed.
- Only a small amount of nutrients are absorbed in the stomach because its epithelial cells are impermeable to most materials.
- However, mucous cells of the stomach absorb some water, ions, and short-chain fatty acids, as well as certain drugs (especially aspirin) and alcohol.

FUNCTIONS of the stomach:

1. Mixes saliva, food, and gastric juice to form chyme.
2. Serves as reservoir for food before release into small intestine.
3. Secretes **gastric juice**, which contains HCl (kills bacteria and denatures proteins), pepsin (begins the digestion of proteins), intrinsic factor (aids absorption of vitamin B12), and gastric lipase (aids digestion of triglycerides).
4. Secretes gastrin into blood.

Figure 24.11 External and internal anatomy of the stomach. The four regions of the stomach are the cardia, fundus, body, and pyloric part.

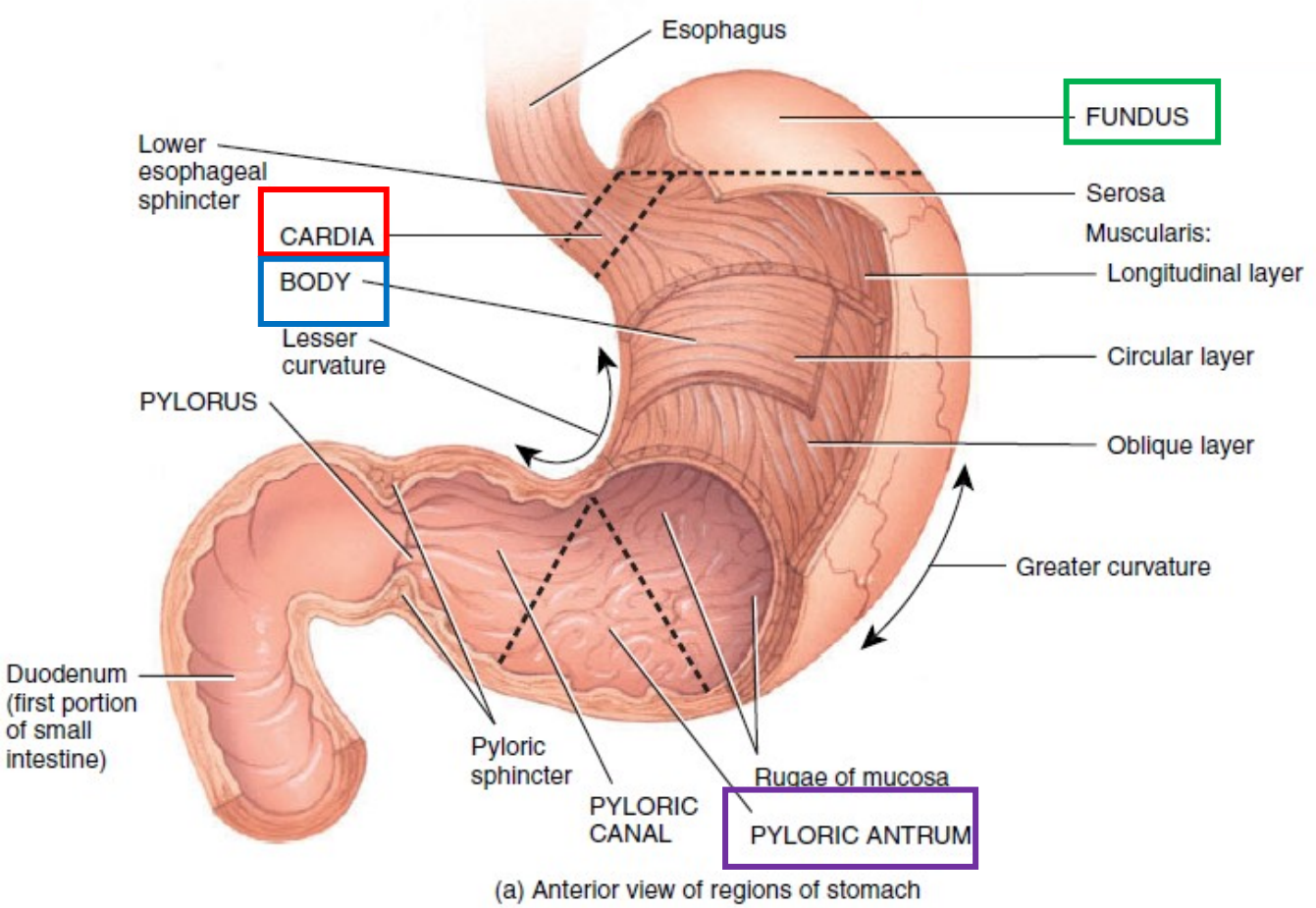
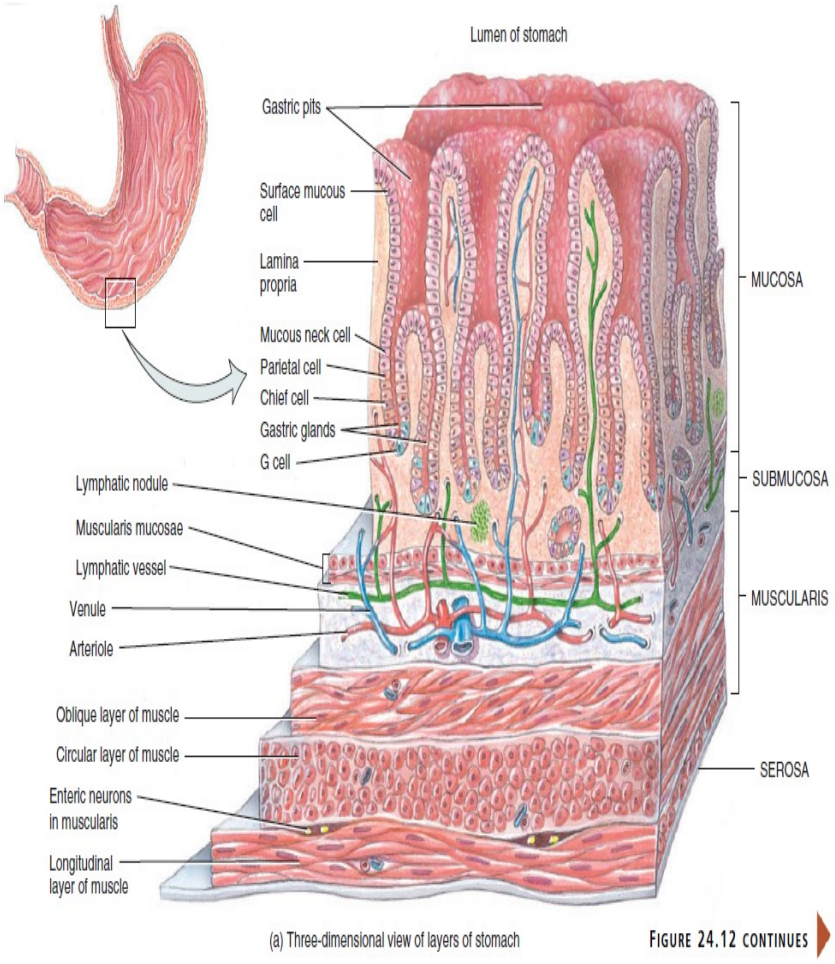


Figure 24.12 Histology of the stomach

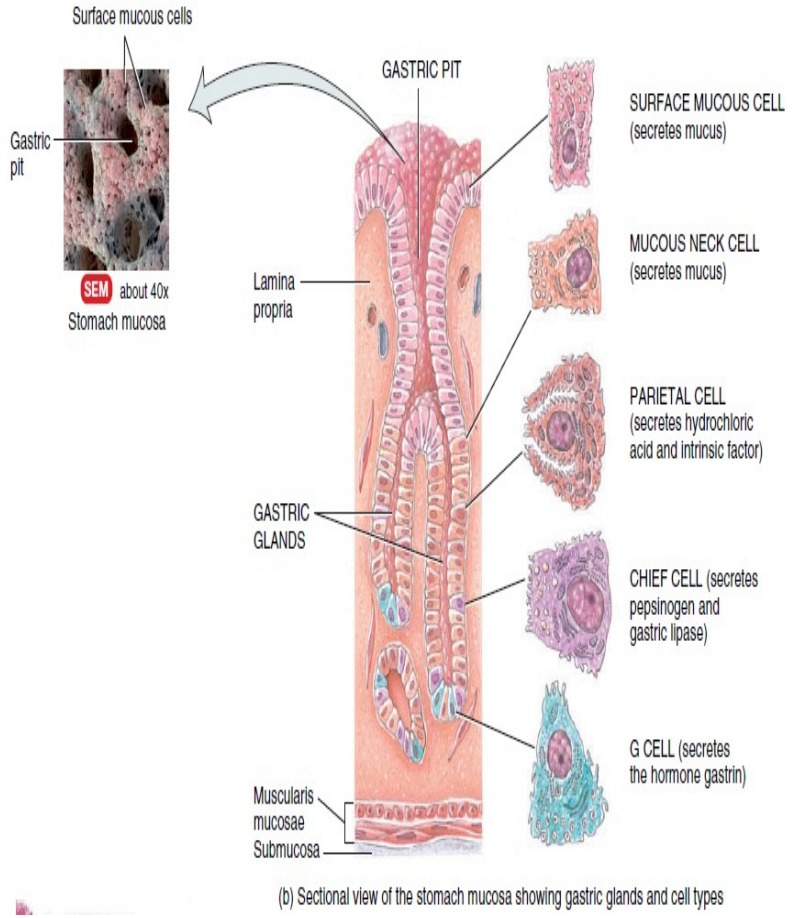
Gastric juice is the combined secretions of mucous cells, parietal cells, and chief cells.



(a) Three-dimensional view of layers of stomach

FIGURE 24.12 CONTINUES

FIGURE 24.12 CONTINUED



(b) Sectional view of the stomach mucosa showing gastric glands and cell types

TABLE 24.3

Summary of Digestive Activities in the Stomach

STRUCTURE	ACTIVITY	RESULT
Mucosa		
Surface mucous cells and mucous neck cells	Secrete mucus.	Forms protective barrier that prevents digestion of stomach wall.
	Absorption.	Small quantity of water, ions, short-chain fatty acids, and some drugs enter bloodstream.
Parietal cells	Secrete intrinsic factor.	Needed for absorption of vitamin B_{12} (used in red blood cell formation, or erythropoiesis).
	Secrete hydrochloric acid.	Kills microbes in food; denatures proteins; converts pepsinogen into pepsin.
Chief cells	Secrete pepsinogen.	Pepsin (activated form) breaks down proteins into peptides.
	Secrete gastric lipase.	Splits triglycerides into fatty acids and monoglycerides.
G cells	Secrete gastrin.	Stimulates parietal cells to secrete HCl and chief cells to secrete pepsinogen; contracts lower esophageal sphincter, increases motility of stomach, and relaxes pyloric sphincter.
Muscularis	Mixing waves (gentle peristaltic movements).	Churns and physically breaks down food and mixes it with gastric juice, forming chyme. Forces chyme through pyloric sphincter.
Pyloric sphincter	Opens to permit passage of chyme into duodenum.	Regulates passage of chyme from stomach to duodenum; prevents backflow of chyme from duodenum to stomach.

Figure 24.13 Secretion of HCl (hydrochloric acid) by parietal cells in the stomach. Proton pumps, powered by ATP, secrete the H+; Cl- diffuses into the stomach lumen through Cl- channels.

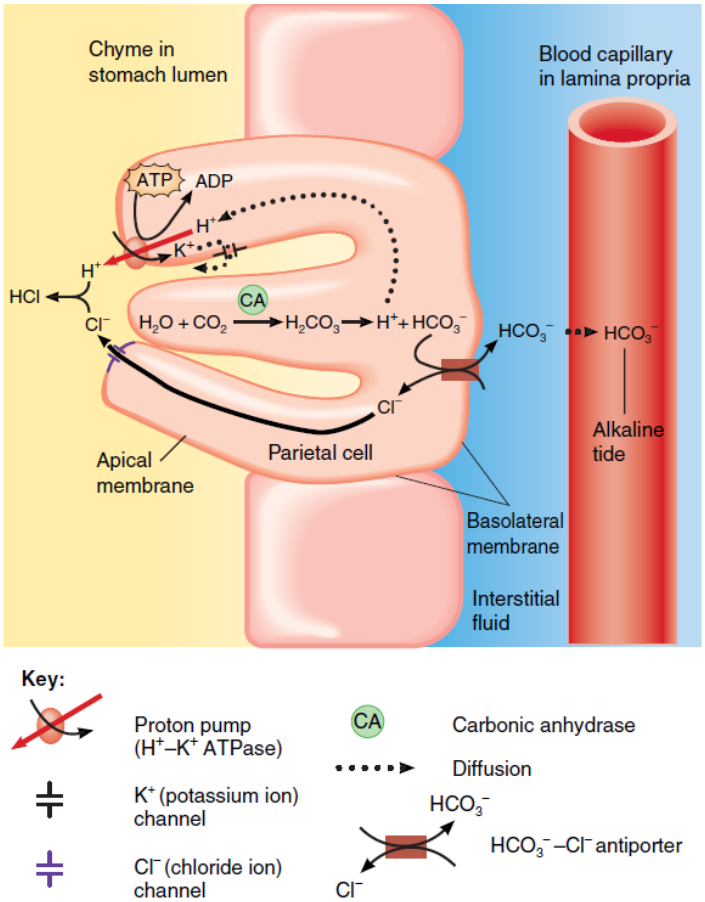
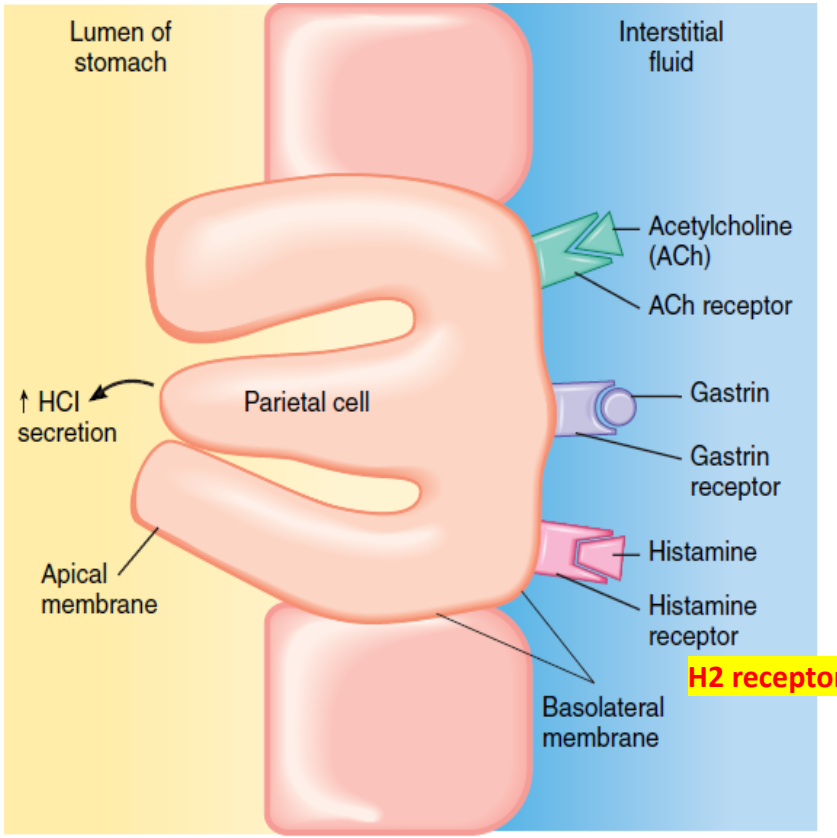


Figure 24.14 Regulation of HCl secretion. HCl secretion by parietal cells can be stimulated by several sources: **acetylcholine (ACh), gastrin, and histamine.**



Protective Mechanisms of Stomach

Why pepsin and HCL can not damage the stomach lining?

- Parietal and chief cells impermeable to HCl.
- Alkaline mucus contains HCO^-_3
- Tight junctions between adjacent epithelial cells.
- Rapid rate of cell division (entire epithelium is replaced in 3 days).
- Prostaglandins inhibit gastric secretions.
- Pepsin is secreted in an inactive form.

- **Propulsion in the Stomach (peristaltic wave moves gastric contents from the body of the stomach down into the antrum)**

➢ Food must first be well mixed.

➢ Rippling peristalsis occurs in the lower stomach.

➢ The pylorus meters out chyme into the small intestine (3 ml at a time).

➢ The stomach empties in four to six hours.

Pancreas

1. The pancreas consists of a head, a body, and a tail and is connected to the duodenum via the pancreatic duct and accessory duct.

2. Endocrine pancreatic islets secrete hormones, and **exocrine** acini secrete pancreatic juice.

3. Pancreatic juice contains enzymes that digest:

✓Starch (pancreatic amylase)

✓Proteins (trypsin, chymotrypsin, carboxypeptidase, and elastase),

✓Triglycerides (pancreatic lipase),

✓Nucleic acids (ribonuclease and deoxyribonuclease).

Liver and Gallbladder

- **The liver** has left and right lobes; the left lobe. The lobes of the liver are made up of lobules that contain hepatocytes (liver cells), sinusoids, stellate reticuloendothelial (Kupffer) cells (phagocytic cell), and a central vein.
- Hepatocytes produce bile that is carried by a duct system to the gallbladder for concentration and temporary storage.
- **The liver also functions** in carbohydrate, lipid, and protein metabolism; processing of drugs and hormones; excretion of bilirubin; synthesis of bile salts; storage of vitamins and minerals; phagocytosis; and activation of vitamin D.

- **The gallbladder** is a sac located in a depression on the posterior surface of the liver that stores and concentrates bile.
- Bile's contribution to digestion is the emulsification of dietary lipids.

Figure 24.15 Relationship of the pancreas to the liver, gallbladder, and duodenum. The inset (b) shows details of the common bile duct and pancreatic duct forming the hepatopancreatic ampulla (ampulla of Vater) and emptying into the duodenum.

→ Pancreatic enzymes digest starches (polysaccharides), proteins, triglycerides, and nucleic acids.

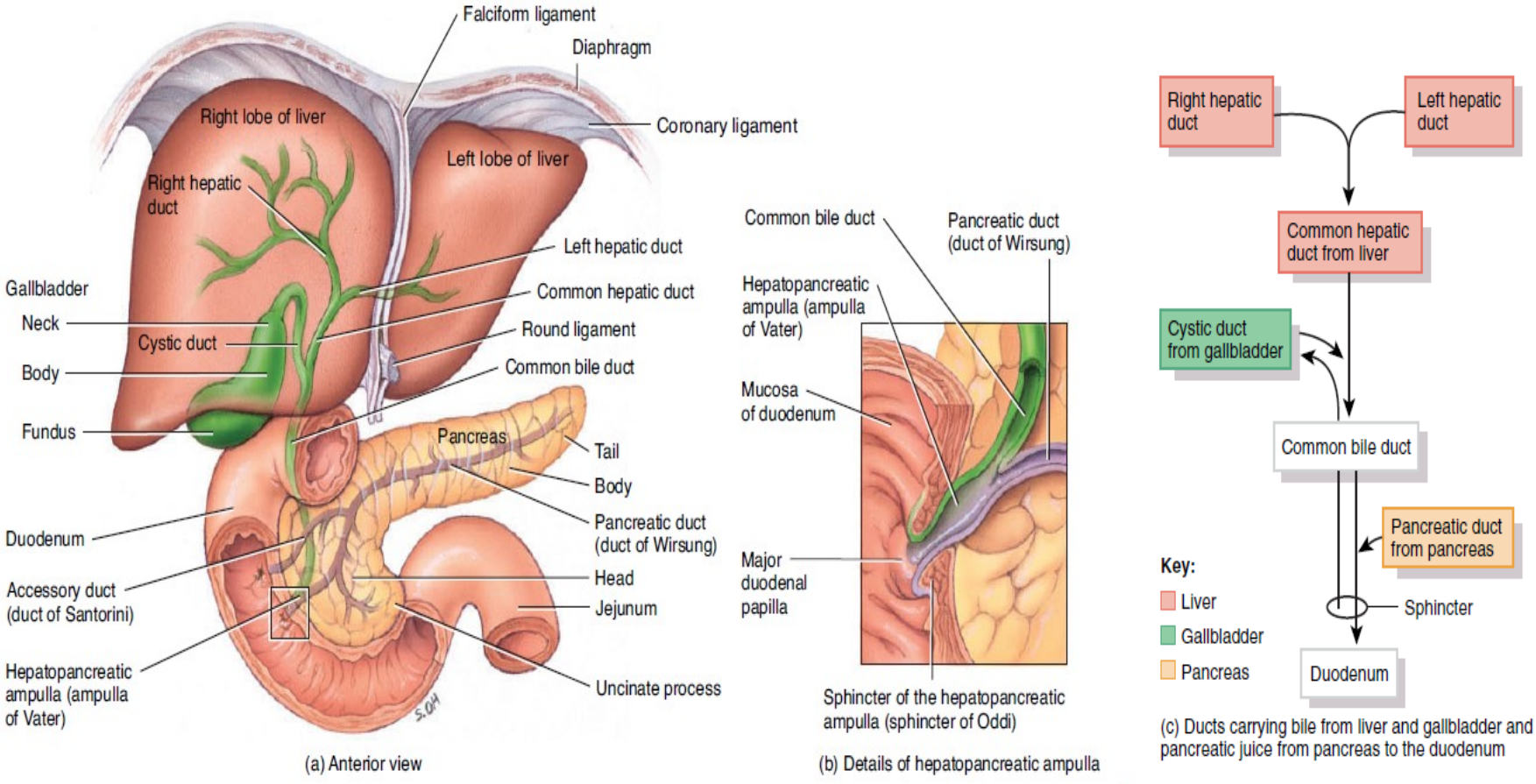
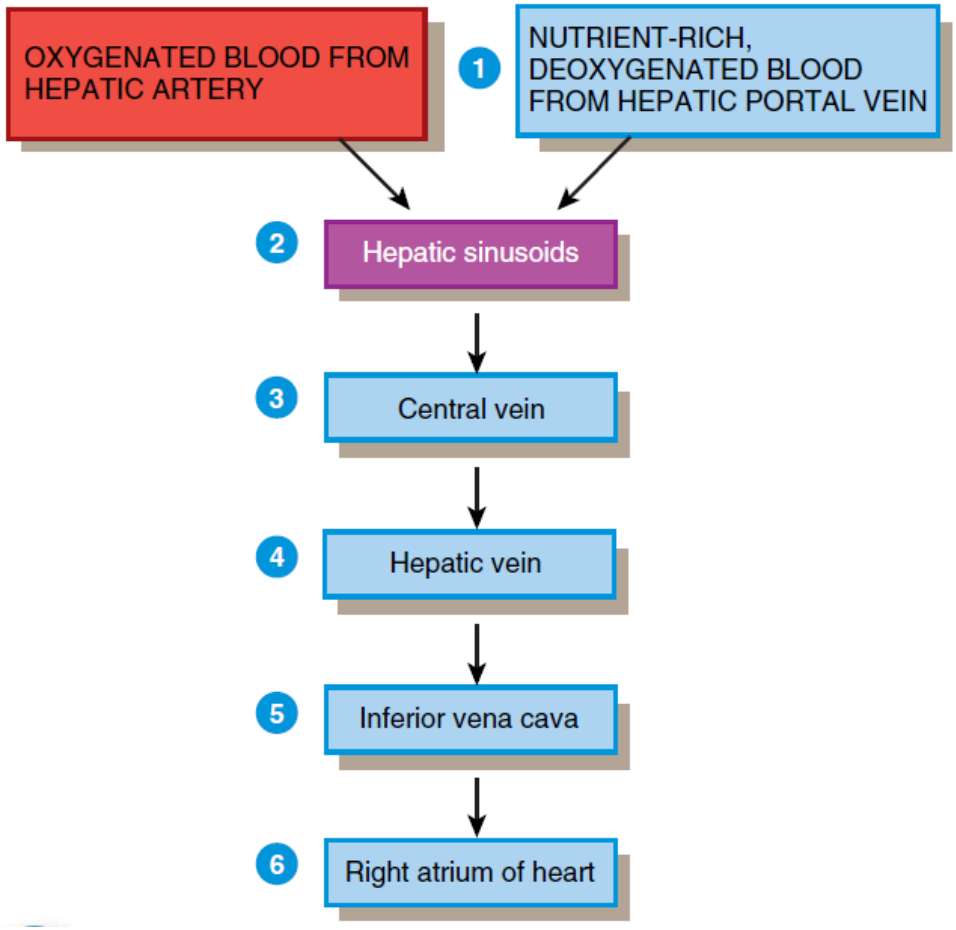


Figure 24.17 Hepatic blood flow: sources, path through the liver, and return to the heart.
The liver receives oxygenated blood via the hepatic artery and nutrient-rich deoxygenated blood via the hepatic portal vein.



Small Intestine : histology

- The small intestine extends from the pyloric sphincter to the ileocecal sphincter. It is divided into duodenum, jejunum, and ileum.
- Its glands secrete fluid and mucus,
- the circular folds, villi, and microvilli of its wall provide a large surface area for digestion and absorption.

→ **Circular folds** or *plicae circulares* are folds of the mucosa and submucosa, that enhance absorption by increasing surface area and causing the chyme to spiral, rather than move in a straight line, as it passes through the small intestine.

→ **Villi** (tufts of hair), which are fingerlike projections of the mucosa, Each villus (singular form) is covered by epithelium and has **goblet cells**, which secrete mucus, and a core of lamina propria; embedded in the connective tissue of the lamina propria are an arteriole, a venule, a blood capillary network, and a **lacteal**, which is a lymphatic capillary.

→ **Microvilli** which are projections of the apical (free) membrane of the absorptive cells.

- **Brush-border enzymes** The **absorptive cells** of the small intestine synthesize several digestive enzymes and digest α-dextrins, maltose, sucrose, lactose, peptides, and nucleotides at the surface of mucosal epithelial cells.

Small Intestine : chemical digestion

Pancreatic and intestinal brush-border enzymes break down:

- Starches into maltose, maltotriose, and α-dextrins (pancreatic amylase), α-dextrins into glucose (α -dextrinase), maltose to glucose (maltase), sucrose to glucose and fructose (sucrase), lactose to glucose and galactose (lactase),
- Proteins into peptides (trypsin, chymotrypsin, and elastase). Also, enzymes break off amino acids at the carboxyl ends of peptides (carboxypeptidases) and break off amino acids at the amino ends of peptides (aminopeptidases). Finally, enzymes split dipeptides into amino acids (dipeptidases),
- Triglycerides to fatty acids and monoglycerides (lipases),
- Nucleotides to pentoses and nitrogenous bases (nucleosidases and phosphatases).

Figure 24.19
Histology of the small intestine.
Circular folds, villi, and microvilli increase the surface area of the small intestine for digestion and absorption.

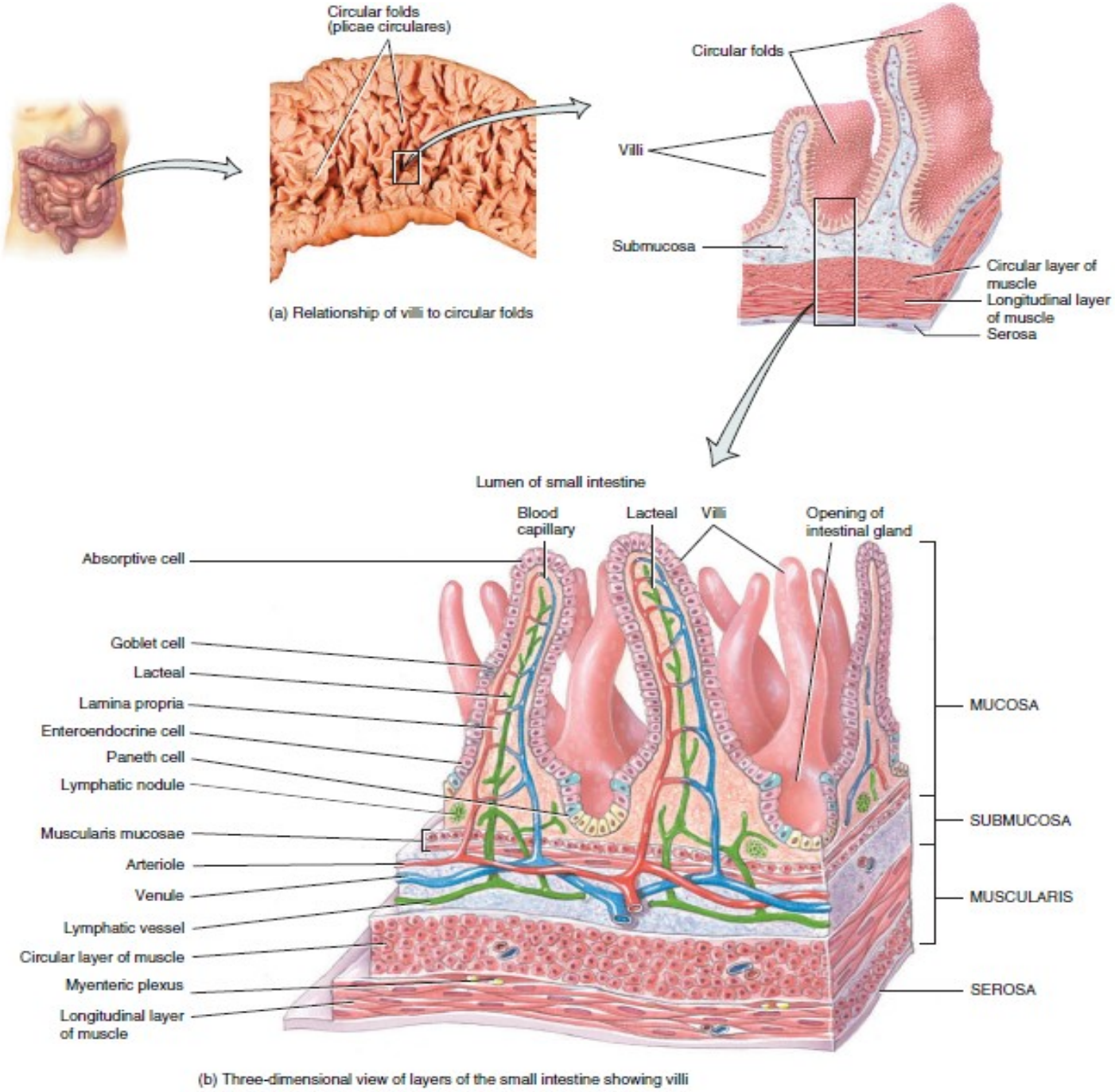
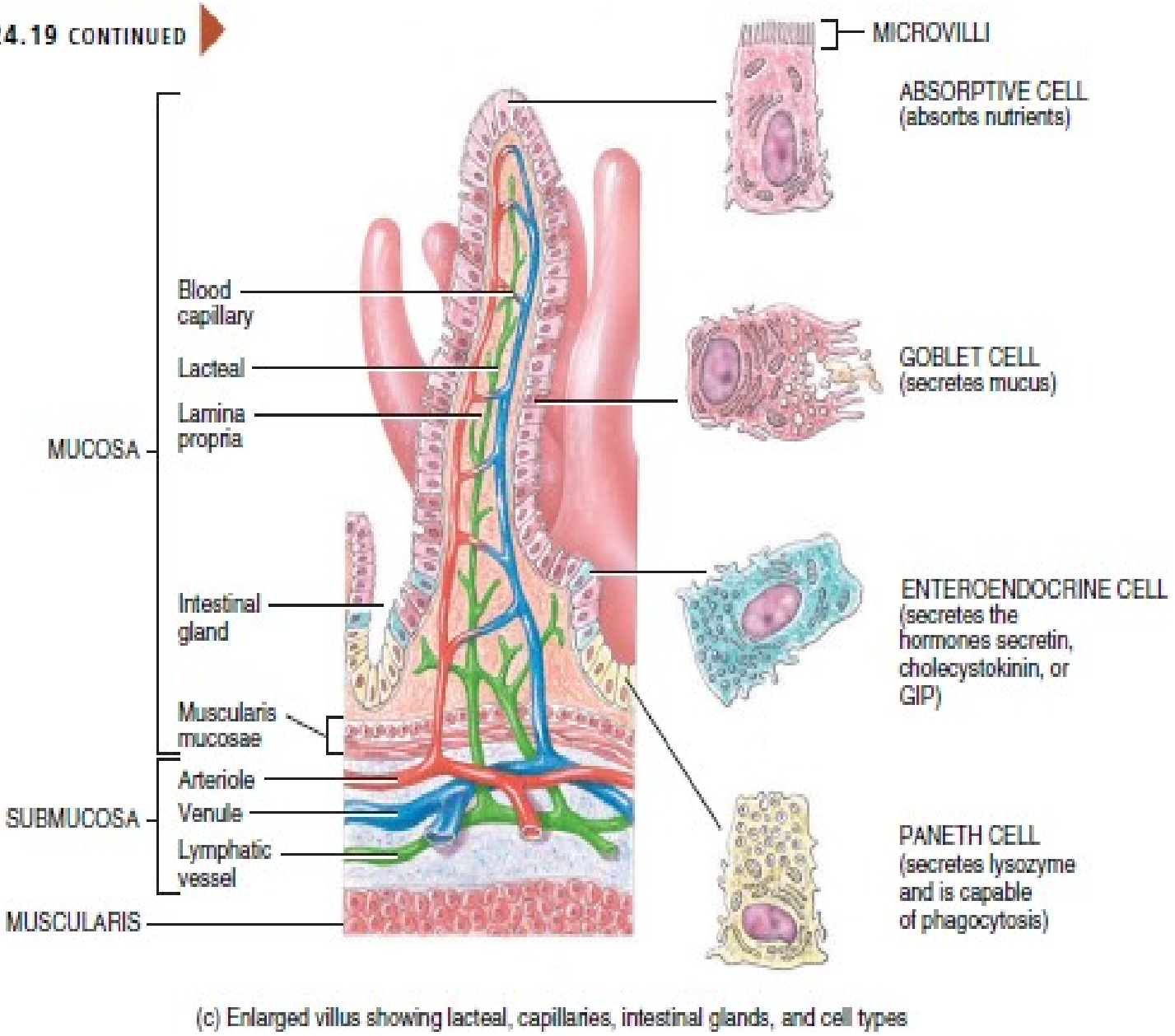


Figure 24.19
Histology of the small intestine. Circular folds, villi, and microvilli increase the surface area of the small intestine for digestion and absorption.



Small Intestine: mechanical digestion and absorption

Mechanical digestion:

- Segmentation: Type of peristalsis: alternating contractions of circular smooth muscle fibers that produce segmentation and resegmentation of sections of small intestine; mixes chyme with digestive juices and brings food into contact with mucosa for absorption.
- Migrating motility complexes: Type of peristalsis: waves of contraction and relaxation of circular and longitudinal smooth muscle fibers passing the length of the small intestine; moves chyme toward ileocecal sphincter.

Absorption

→ Occurs via diffusion, facilitated diffusion, osmosis, and active transport; most absorption occurs in the small intestine.

➢ Monosaccharides, amino acids, and short-chain fatty acids pass into the blood capillaries.

➢ Long-chain fatty acids and monoglycerides are absorbed from micelles, resynthesized to triglycerides, and formed into chylomicrons. Chylomicrons move into lymph in the lacteal of a villus.

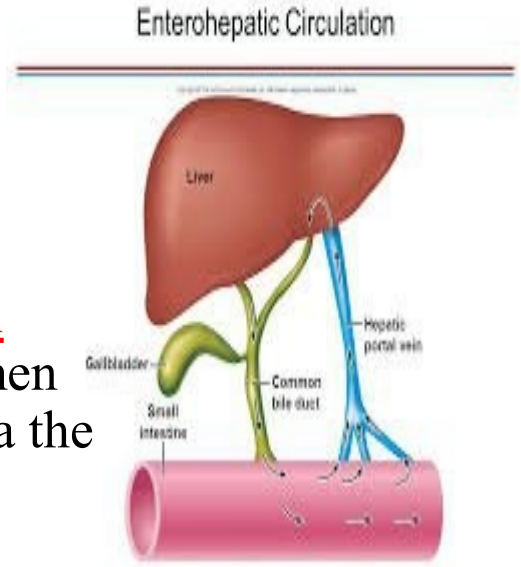
➢ The small intestine also absorbs electrolytes, vitamins, and water.

TABLE 24.4

Summary of Digestive Activities in the Pancreas, Liver, Gallbladder, and Small Intestine

STRUCTURE	ACTIVITY
Pancreas	Delivers pancreatic juice into duodenum via pancreatic duct to assist absorption (see Table 24.5 for pancreatic enzymes and their functions).
Liver	Produces bile (bile salts) necessary for emulsification and absorption of lipids.
Gallbladder	Stores, concentrates, and delivers bile into duodenum via common bile duct.
Small intestine	Major site of digestion and absorption of nutrients and water in gastrointestinal tract.
Mucosa/submucosa	
Intestinal glands	Secrete intestinal juice to assist absorption.
Absorptive cells	Digest and absorb nutrients.
Goblet cells	Secrete mucus.
Enteroendocrine cells (S, CCK, K)	Secrete secretin, cholecystokinin, and glucose-dependent insulinotropic peptide.
Paneth cells	Secrete lysozyme (bactericidal enzyme) and phagocytosis.
Duodenal (Brunner's) glands	Secrete alkaline fluid to buffer stomach acids, and mucus for protection and lubrication.
Circular folds	Folds of mucosa and submucosa that increase surface area for digestion and absorption.
Villi	Fingerlike projections of mucosa that are sites of absorption of digested food and increase surface area for digestion and absorption.
Microvilli	Microscopic, membrane-covered projections of absorptive epithelial cells that contain brush-border enzymes (listed in Table 24.5) and that increase surface area for digestion and absorption.
Muscularis	
Segmentation	Type of peristalsis: alternating contractions of circular smooth muscle fibers that produce segmentation and resegmentation of sections of small intestine; mixes chyme with digestive juices and brings food into contact with mucosa for absorption.
Migrating motility complex (MMC)	Type of peristalsis: waves of contraction and relaxation of circular and longitudinal smooth muscle fibers passing the length of the small intestine; moves chyme toward ileocecal sphincter.

Enterohepatic Circulation

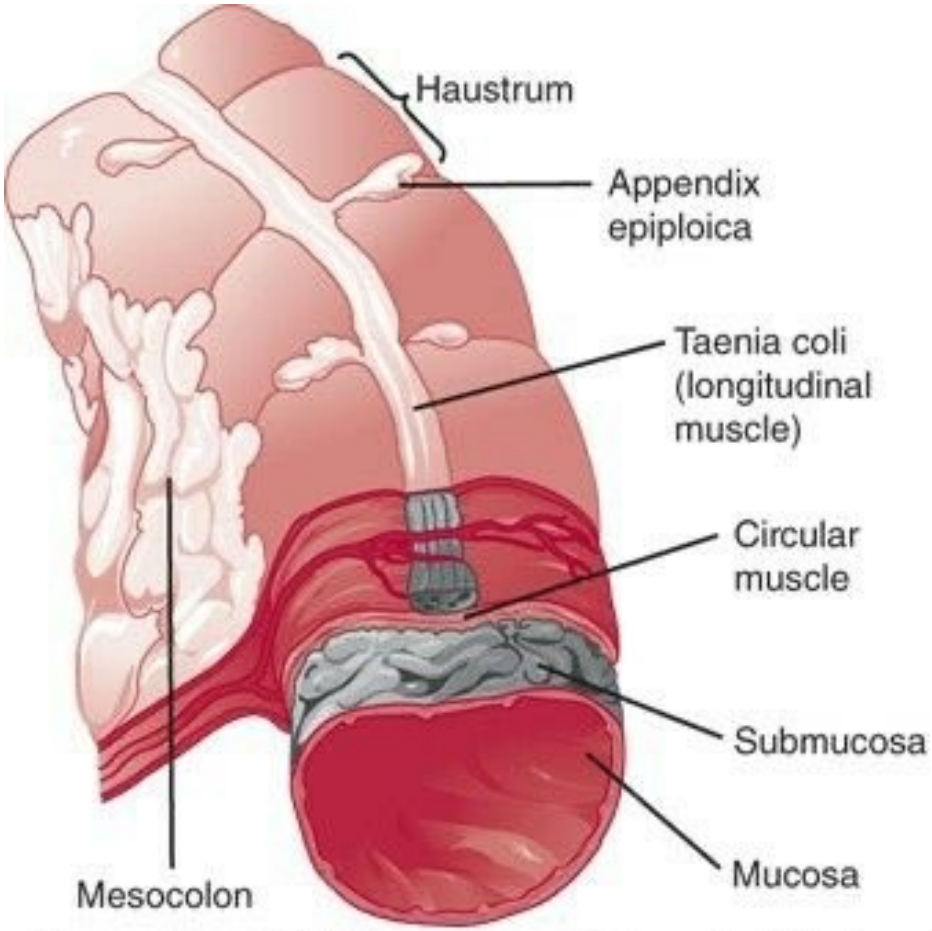


- Substances are said to undergo an **enterohepatic circulation** (EHC) when they are excreted into the bile, pass into the lumen of the intestine, are reabsorbed and then return to the liver via the circulation.
- Many endogenous and exogenous substances can undergo an EHC.
- Among the **endogenous** substances are the bile salts, the biliary lipids and biliary phospholipids; the degree of reabsorbability varies considerably for each of these types of substances. Other endogenous substances include estrone and estriol, folic acid, vitamin B12, and urobilinogen.
- Examples of **exogenous** substances: a number of drugs are secreted by the liver into bile, and are therefore capable of undergoing EHC, include antibiotics, NSAIDS, hormones, opioids, digoxin, and warfarin.

Large Intestine

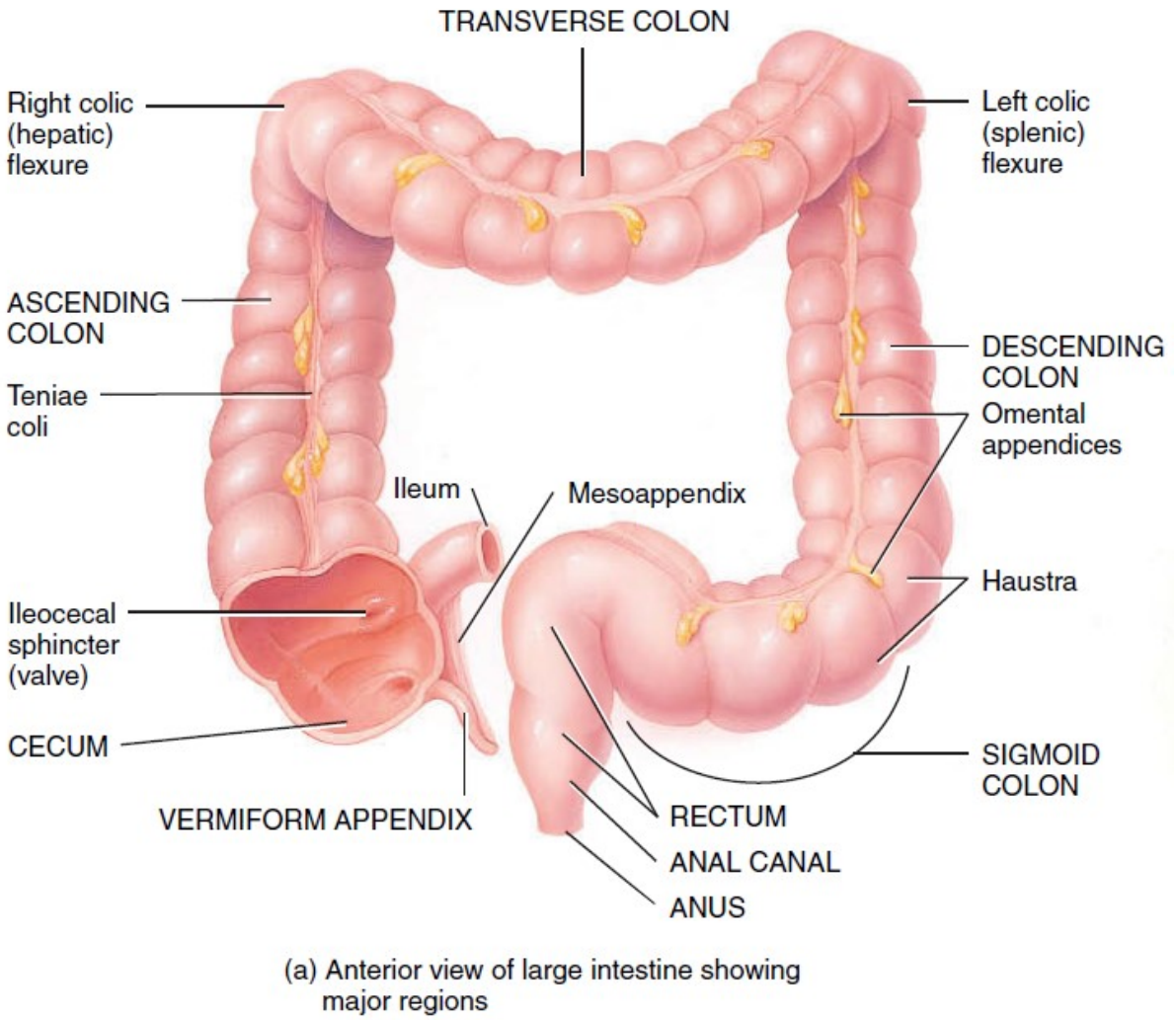
- The large intestine extends from the ileocecal sphincter to the anus.
- Its **regions** include the cecum, colon, rectum, and anal canal.
- The **mucosa** contains many goblet cells, and the **muscularis** consists of teniae coli and haustra.
- **Mechanical movements** of the large intestine include haustral churning, peristalsis, and mass peristalsis.
- The last stages of **chemical digestion** occur in the large intestine through **bacterial action**. Substances are further broken down, and some vitamins are synthesized.
- The large intestine **absorbs** water, ions, and vitamins.
- **Feces** consist of water, inorganic salts, epithelial cells, bacteria, and undigested foods.
- The elimination of feces from the rectum is called **defecation**.
- Defecation is a reflex action aided by voluntary contractions of the diaphragm and abdominal muscles and relaxation of the external anal sphincter.

Muscularis of the large intestine

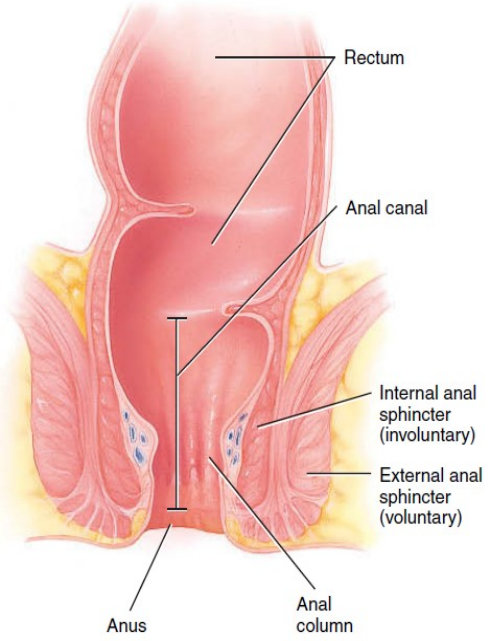


Source: Gerard M. Doherty: Current Diagnosis & Treatment: Surgery, 14th Edition
www.accessmedicine.com

Figure 24.23 Anatomy of the large intestine.
The regions of the large intestine are the cecum, colon, rectum, and anal canal.



(a) Anterior view of large intestine showing major regions



(b) Frontal section of anal canal