Digestive System

Topics Covered

- Digestive organs and Digestive glands
- Digestion of food
- Absorption of food
- Defecation
- Disorders: Peptic Ulcer, Ulcerative Colitis, Gastro enteritis.

➢ Two groups of organs compose the digestive system: the gastrointestinal (GI) tract and the accessory digestive organs.

The **gastrointestinal (GI) tract**, or *alimentary canal*, is a continuous tube that extends from the mouth to the anus. It includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. Its about 5–7 meters in a living person while, it is longer in a cadaver (7–9 meters). The **accessory digestive organs** include 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. The GI tract contains food from the time it is eaten until it is digested and absorbed or eliminated. 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.

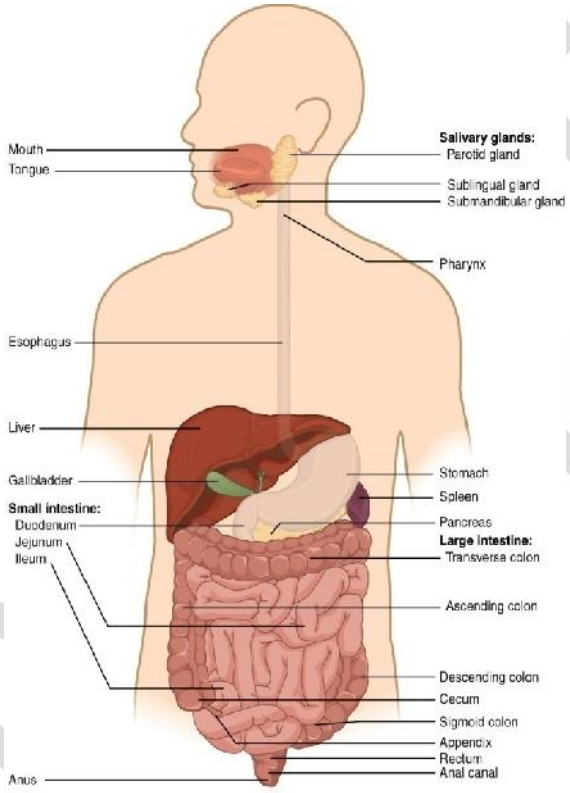
Overall, the digestive system performs **six** basic processes:
1. *Ingestion.* It involves taking foods and liquids into the mouth (eating).
2. *Secretion.* Each day, cells within the walls of the GI tract and accessory digestive organs secrete a total of about 7 liters of water, acid, buffers, and enzymes into the lumen (interior space) of the tract.
3. *Mixing and propulsion.* Alternating contractions and relaxations of smooth muscle in the walls of the GI tract mix food and secretions and move them toward the anus by a process called motility.
4. *Digestion.* Mechanical and chemical processes break down ingested food into small molecules. **mechanical digestion** the teeth cut and grind food before it is swallowed, and then smooth muscles of the stomach and small intestine churn the food to further assist the process. As a result, food molecules become dissolved and thoroughly mixed with digestive enzymes while in **chemical digestion** the large carbohydrate, lipid, protein, and nucleic acid molecules in food are split into smaller molecules by hydrolysis. Enzymes produced by the salivary glands, tongue, stomach, pancreas, and small intestine

catalyze these catabolic reactions. A few substances in food can be absorbed without chemical digestion like vitamins, ions, cholesterol, and water.

5. *Absorption.* The entrance of ingested and secreted fluids, ions, and the products of digestion into the epithelial cells lining the lumen of the GI tract is called **absorption**.

The absorbed substances pass into blood or lymph and circulate to cells throughout the body.

6. *Defecation*. Wastes, indigestible substances, bacteria, cells sloughed from the lining of the GI tract, and digested materials that were not absorbed in their journey through the digestive tract leave the body through the anus in a process called defecation in a form of feces or stool.

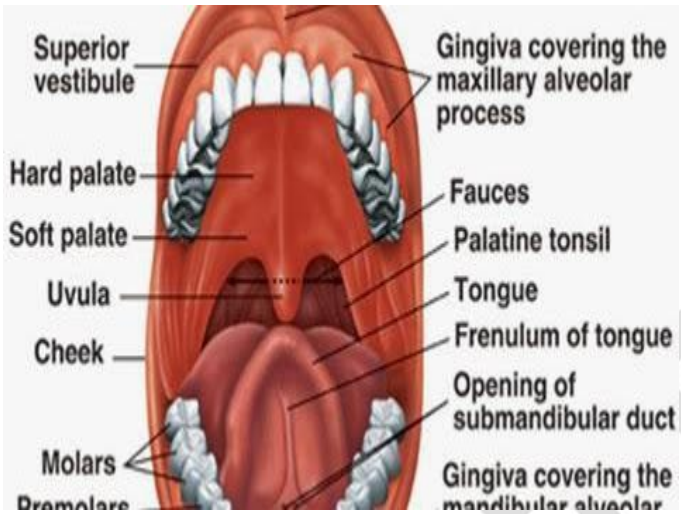


Digestive organs:

Mouth

The **mouth**, also referred to as the **oral** or *buccal* **cavity**, is formed by the cheeks, hard and soft palates, and tongue. The **cheeks** form the lateral walls of the oral cavity. They are covered externally by skin and internally by a mucous membrane. The anterior portions of the cheeks end at the lips. The **lips** or *labia* are fleshy folds surrounding the opening of the mouth. The inner surface of each lip is attached to its corresponding gum by a midline fold of mucous membrane called the **labial frenulum**.

The **oral vestibule** of the oral cavity is the space bounded externally by the cheeks and lips and internally by the gums and teeth. The **oral cavity proper** is the space that extends from the gums and teeth to the **fauces**, the opening between the oral cavity and the oropharynx (throat).



The **palate** is a wall or septum that separates the oral cavity from the nasal cavity, and forms the roof of the mouth. The **hard palate**—the anterior portion of the roof of the mouth; it forms a bony partition between the oral and nasal cavities. The **soft palate**, which forms the posterior portion of the roof of the mouth, is an arch-shaped muscular partition between the oropharynx and nasopharynx that is lined with mucous membrane.

Hanging from the free border of the soft palate is a fingerlike muscular structure called the **uvula**. During swallowing, the soft palate and uvula are drawn superiorly, closing off the nasopharynx and preventing swallowed foods and liquids from entering the nasal cavity. The palatine tonsils are situated between the arches, and the lingual tonsils are situated at the base of the tongue.

Salivary Glands

These are glands, that releases a secretion called saliva. When food enters the mouth, however, secretion of saliva increases and lubricates, dissolves, and begins the chemical breakdown of the food. The mucous membrane of the mouth and tongue contains many small salivary glands that open via short ducts, to the oral cavity. Most saliva is secreted by the **major salivary glands**, which lie beyond the oral mucosa, into ducts that lead to the oral cavity. There are **three** pairs of major salivary glands:

The ***parotid glands*** are located inferior and anterior to the ears. Each secretes saliva into the oral cavity via a **parotid duct** that opens into the vestibule opposite the second maxillary (upper) molar tooth.

The ***submandibular glands*** are found in the floor of the mouth. Their ducts, the **submandibular ducts**, enter the oral cavity proper lateral to the lingual frenulum.

The ***sublingual glands*** are beneath the tongue and superior to the submandibular glands. Their ducts, the **lesser sublingual ducts**, open into the floor of the mouth in the oral cavity proper.

Composition and Functions of Saliva

Chemically, **saliva** is 99.5% water and 0.5% solutes including ions like sodium, potassium, chloride, bicarbonate, and phosphate.

Some dissolved gases and various organic substances, including urea and uric acid, mucus, immunoglobulin A, the bacteriolytic enzyme lysozyme, and salivary amylase are also present. The parotid glands secrete a watery liquid containing salivary amylase. The sublingual glands contain mostly

mucous cells, so they secrete a much thicker fluid that contributes only a small amount of salivary amylase. The water in saliva provides a medium for dissolving foods so that they can be tasted by gustatory receptors and so that digestive reactions can begin. Chloride ions in the saliva activate **salivary amylase,** an enzyme that starts the breakdown of starch in the mouth into maltose, maltotriose, and dextrin. Bicarbonate and phosphate ions buffer acidic foods that enter the mouth, so saliva is only slightly acidic (pH 6.35–6.85). Salivary glands (like the sweat glands of the skin) help remove waste molecules from the body, which accounts for the presence of urea and uric acid in saliva. Mucus lubricates food so it can be moved around easily in the mouth, formed into a ball, and swallowed. Immunoglobulin A (IgA) prevents attachment of microbes so they cannot penetrate the epithelium, and the enzyme lysozyme kills bacteria.

Tongue

It is an accessory digestive organ composed of skeletal muscle covered with mucous membrane, forms the floor of the oral cavity. The dorsum and lateral surfaces of the tongue are covered with **papillae** projections of the lamina propria. Many papillae contain taste buds, the receptors for gustation. Some papillae lack taste buds, but they contain receptors for touch and increase friction between the tongue and food, making it easier for the tongue to move food in the oral cavity. **Lingual glands** of the tongue secrete both mucus and a watery serous fluid that contains the enzyme **lingual lipase,** which acts on triglycerides and converts them to simpler fatty acids and diglycerides.

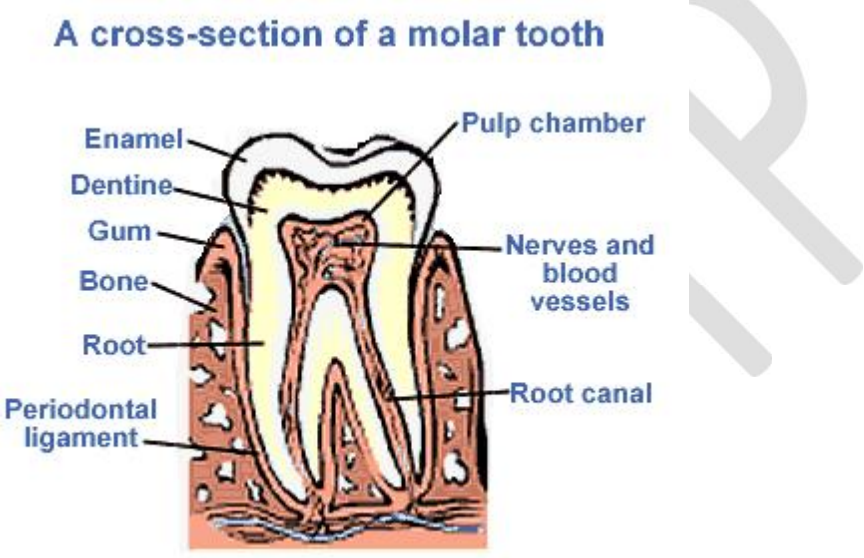
Teeth

The **teeth**, are accessory digestive organs located in sockets of the alveolar processes of the mandible and maxillae. The alveolar processes are covered by the **gingivae,** or gums. The sockets are lined by the **periodontal ligament** which consists of dense fibrous connective tissue that anchors the teeth to the socket walls and acts as a shock absorber during chewing.

It has **three** major external regions: **the crown, root, and neck.**

The **crown** is the visible portion above, embedded in the socket are one to three **roots**. The **neck** is the constricted junction of the crown and root near the gum line. Internally, **dentin** forms the majority of the tooth that consists of a calcified connective tissue that gives the tooth its basic shape and rigidity. It is harder than bone due to hydroxyapatite and covered by **enamel**, which consists of calcium phosphate and calcium carbonate. It serves to protect the tooth from the wear and tear of chewing. It also protects against acids that can easily dissolve dentin. The dentin of the root is covered by **cementum**, which attaches the root to the periodontal ligament. The enlarged part of the space, the **pulp cavity**, lies within the crown and is filled with **pulp**, a connective tissue containing blood vessels, nerves, and lymphatic vessels. Narrow extensions of the pulp cavity, called **root canals**, run through the root of the tooth. The blood vessels bring nourishment, the lymphatic vessels offer protection, and the nerves provide sensation. Humans have two **dentitions**, or sets of teeth: deciduous and permanent. The first, **deciduous teeth,** also called *primary teeth*, *milk teeth*, or *baby teeth* that begin to erupt at about 6 months of age, and approximately two teeth appear each month thereafter, until all 20 are present. The **incisors**, which are closest to the midline, are chisel-shaped and adapted for cutting into food. They are referred to as either **central** or **lateral incisors** based on their position. Next to the incisors, moving posteriorly, are the **canines**, which have a pointed surface called a *cusp.* Canines are used to tear and shred food. Incisors and Canines have only one root apiece. Posterior to the canines lie the **first** and **second deciduous molars**, which have four cusps. Maxillary (upper) molars have three roots; mandibular (lower) molars have two roots. The molars crush and grind food to prepare it for swallowing. All of the deciduous teeth are lost—generally between ages 6 and 12 years—and are replaced by the **permanent** (*secondary*) **teeth**. The

permanent dentition contains 32 teeth the deciduous dentition, with the following exceptions. The deciduous molars are replaced by the **first** and **second premolars**, which have two cusps and one root and are used for crushing and grinding. The permanent molars, which erupt into the mouth posterior to the premolars, do not replace any deciduous teeth and erupt as the jaw grows to accommodate them—the **first permanent molars** at age 6, the **second permanent molars** at age 12, and the **third permanent molars** (*wisdom teeth*) after age 17 or not at all. Often the human jaw does not have enough room posterior to the second molars to accommodate the eruption of the third molars. In this case, the third molars remain embedded in the alveolar bone and are said to be *impacted*. They often cause pressure and pain and must be removed surgically.



Pharynx

When food is first swallowed, it passes from the mouth into the **pharynx** (throat), a funnel-shaped tube that extends from the internal nares to the esophagus posteriorly and to the larynx anteriorly. The pharynx is composed of skeletal muscle and lined by mucous membrane, and is divided into three parts: the nasopharynx, the oropharynx, and the laryngopharynx. The nasopharynx functions only in respiration, but both the oropharynx and laryngopharynx have digestive as well as respiratory functions. Swallowed food passes from the mouth into the oropharynx and laryngopharynx; the muscular contractions of these areas help propel food into the esophagus and then into the stomach.

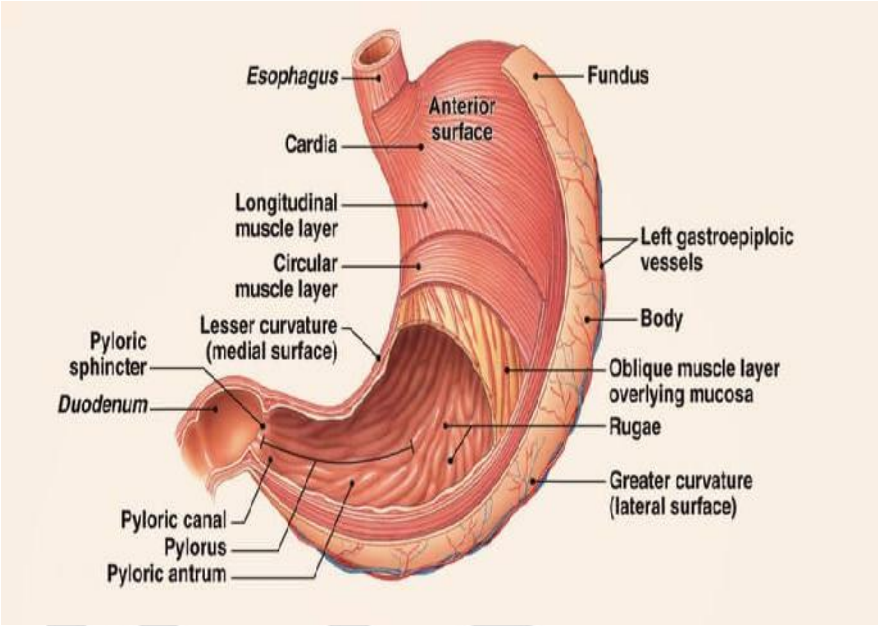
Esophagus

It is a collapsible muscular tube, about 25 cm long, lies posterior to the trachea. It begins at the inferior end of the laryngopharynx, passes through the inferior aspect of the neck, and enters the mediastinum anterior to the vertebral column. Then it pierces the diaphragm through an opening called the **esophageal hiatus,** and ends in the superior portion of the stomach. Sometimes, part of the stomach protrudes above the diaphragm through the esophageal hiatus. This condition, termed a **hiatus hernia.**

Stomach

It is a J-shaped enlargement of the GI tract directly inferior to the diaphragm in the abdomen and connects the esophagus to the duodenum. Because a meal can be eaten much more quickly than the intestines can digest and absorb it, one of the functions of the stomach is to serve as a mixing chamber

and holding reservoir. At appropriate intervals after food is ingested, the stomach forces a small quantity of material into the first portion of the small intestine. The position and size of the stomach vary continually; the diaphragm pushes it inferiorly with each inhalation and pulls it superiorly with each exhalation. Empty, 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.



Anatomy of the Stomach

The stomach has **four** main regions: **cardia, fundus, body, and pylorus**. The **cardia** surrounds the opening of the esophagus into the stomach. The rounded portion superior to and to the left of the cardia is the **fundus**. Inferior to the fundus is the large central portion of the stomach, the **body**. The **pyloric part** is divisible into three regions. The first region, the **pyloric antrum**, connects to the body of the stomach. The second region, the **pyloric canal**, leads to the third region, the **pylorus**, which in turn connects to the duodenum. When the stomach is empty, the mucosa lies in large folds, or **rugae**, that can be seen with the unaided eye. The pylorus communicates with the duodenum of the small intestine via a smooth muscle sphincter called the **pyloric sphincter**. The concave medial border of the stomach is called the **lesser curvature;** the convex lateral border is called the **greater curvature**.

Pancreas

From the stomach, chyme passes into the small intestine. Because chemical digestion in the small intestine depends on activities of the pancreas, liver, and gallbladder, we first consider the activities of these accessory digestive organs and their contributions to digestion in the small intestine.

Anatomy of the Pancreas

A retroperitoneal gland that is about 12–15 cm (5–6 in.) long and 2.5 cm (1 in.) thick, lies posterior to the greater curvature of the stomach. The pancreas consists of a head, a body, and a tail and is usually connected to the duodenum by two ducts. The **head** is the expanded portion of the organ near the curve of the duodenum; superior to and to the left of the head are the central **body** and the tapering **tail**. Pancreatic juices are secreted by exocrine cells into small ducts that ultimately unite to form two larger

ducts, the pancreatic duct and the accessory duct. The **pancreatic duct**, or *duct of Wirsung*, is the larger of the two ducts. In most people, the pancreatic duct joins the common bile duct from the liver and gallbladder and enters the duodenum as a dilated common duct called the **hepatopancreatic ampulla**, or *ampulla of Vater*. The ampulla opens on an elevation of the duodenal mucosa known as the **major duodenal papilla**, which lies about 10 cm inferior to the pyloric sphincter of the stomach. The passage of pancreatic juice and bile through the hepatopancreatic ampulla into the duodenum of the small intestine is regulated by a mass of smooth muscle surrounding the ampulla known as the **sphincter of the hepatopancreatic ampulla**, or *sphincter of Oddi*. The other major duct of the pancreas, the **accessory duct** (*duct of Santorini*), leads from the pancreas and empties into the duodenum about 2.5 cm superior to the hepatopancreatic ampulla.

Composition and Functions of Pancreatic Juice

Each day the pancreas produces 1200–1500 mL of **pancreatic juice**, a clear, colorless liquid consisting of water, salts, sodium bicarbonate and enzymes. The sodium bicarbonate gives slightly alkaline pH (7.1–8.2) that buffers acidic gastric juice in chyme, stops the action of pepsin from the stomach, and creates the proper pH for the action of digestive enzymes in the small intestine. The enzymes in pancreatic juice include a starch-digesting enzyme called **pancreatic amylase;** several enzymes that digest proteins into peptides called **trypsin**, **chymotrypsin**, **carboxypeptidase**, and **elastase**; the principal triglyceride–digesting enzyme in adults, called **pancreatic lipase;** and nucleic acid–digesting enzymes called **ribonuclease** and **deoxyribonuclease** that digest RNA and DNA into nucleotides. Trypsin is secreted in an inactive form called **trypsinogen**. Pancreatic acinar cells also secrete a protein called **trypsin inhibitor** that combines with any trypsin formed accidentally in the pancreas or in pancreatic juice and blocks its enzymatic activity. When trypsinogen reaches the lumen of the small intestine, it encounters an activating brush-border enzyme called **enterokinase**, which splits off part of the trypsinogen molecule to form trypsin. Trypsin acts on **chymotrypsinogen**, **procarboxypeptidase**, and **proelastase** to produce chymotrypsin, carboxypeptidase, and elastase, respectively.

Liver

It is the heaviest gland, about 1.4 kg in an average adult. The liver is inferior to the diaphragm and occupies most of the right hypochondriac part.

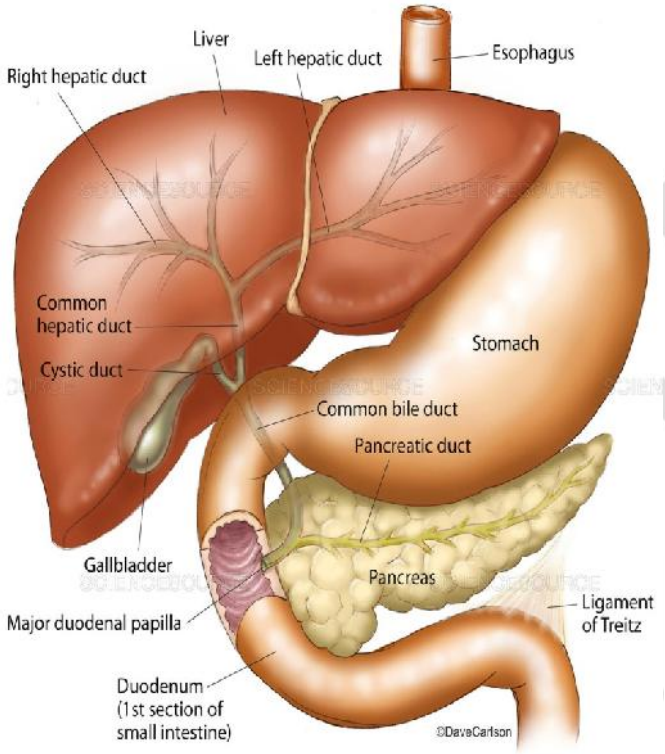
Gallbladder

It is a pear-shaped sac, located in a depression of the posterior surface of the liver. It is 7–10 cm long and typically hangs from the anterior inferior margin of the liver.

Anatomy of the Liver and Gallbladder

It is almost completely covered by visceral peritoneum and is completely covered by a dense irregular connective tissue layer that lies deep to the peritoneum. The liver is divided into two principal lobes—a large **right lobe** and a smaller **left lobe**—by the falciform ligament, a fold of the mesentery. Although the right lobe is considered by many anatomists to include an inferior **quadrate lobe** and a posterior **caudate lobe**, based on internal morphology, the quadrate and caudate lobes more appropriately belong to the left lobe. The falciform ligament extends from the undersurface of the diaphragm between the two principal lobes of the liver to the superior surface of the liver, helping to suspend the liver in the abdominal cavity. In the free border of the falciform ligament is the **ligamentum teres**, a remnant of the umbilical vein of the fetus; this fibrous cord extends from the liver to the umbilicus. The right and left **coronary ligaments**

are narrow extensions of the parietal peritoneum that suspend the liver from the diaphragm. The parts of the gallbladder include the broad **fundus**, which projects inferiorly beyond the inferior border of the liver; the **body**, the central portion; and the **neck**, the tapered portion. The body and neck project superiorly.



Functions of the Liver and Gallbladder

Each day, hepatocytes secrete 800–1000 mL of **bile**, a yellow, brownish, or olive-green liquid, (pH 7.6–8.6) and consists of water, bile salts, cholesterol, a phospholipid called lecithin, bile pigments, and ions. The principal bile pigment is **bilirubin**. The phagocytosis of aged red blood cells liberates iron, globin, and bilirubin. The iron and globin are recycled; the bilirubin is secreted into the bile and is eventually broken down in the intestine. One of its breakdown products—**stercobilin,** gives feces their normal brown color. Bile is partially an excretory product and partially a digestive secretion. Between meals, after most absorption has occurred, bile flows into the gallbladder for storage because the sphincter of the hepatopancreatic ampulla (sphincter of Oddi) closes off the entrance to the duodenum. The sphincter surrounds the hepatopancreatic ampulla. In addition to secreting bile, which is needed for absorption of dietary fats, the liver performs many other vital functions:

• ***Carbohydrate metabolism.*** When blood glucose is low, the liver can break down glycogen to glucose and release the glucose into the bloodstream. The liver can also convert certain amino acids and lactic acid to glucose and it can convert sugars, such as fructose and galactose, into glucose. When blood glucose is high, the liver converts glucose to glycogen and triglycerides for storage.

• ***Lipid metabolism.*** Hepatocytes store some triglycerides; break down fatty acids to generate ATP; synthesize lipoproteins, which transport fatty acids, triglycerides, and cholesterol to and from body cells; synthesize cholesterol; and use cholesterol to make bile salts.

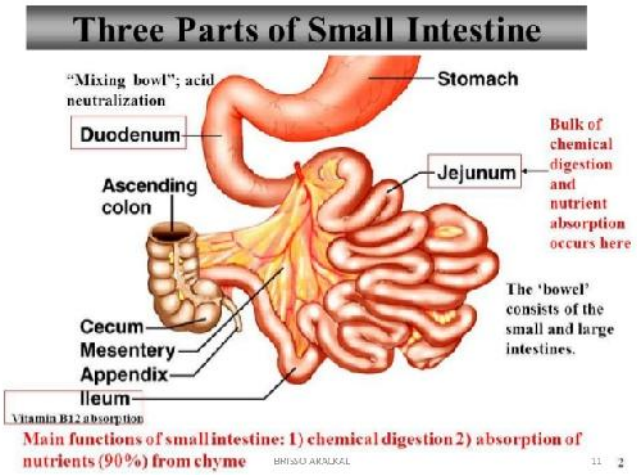
• ***Protein metabolism.*** Hepatocytes *deaminate* amino acids so that the amino acids can be used for ATP production or converted to carbohydrates or fats. The resulting toxic NH3 is then converted into the much less toxic urea, which is excreted in urine. Hepatocytes also synthesize most plasma proteins, such as alpha and beta globulins, albumin, prothrombin, and fibrinogen.
• ***Processing of drugs and hormones.*** The liver detoxifies substances such as alcohol and excretes drugs such as penicillin, erythromycin, and sulfonamides into bile. It can also chemically alter or excrete thyroid hormones and steroid hormones such as estrogens and aldosterone.
• ***Excretion of bilirubin. B***ilirubin, derived from the heme of aged red blood cells, is absorbed by the liver from the blood and secreted into bile. Most of the bilirubin in bile is metabolized in the small intestine by bacteria and eliminated in feces.
• ***Synthesis of bile salts.*** Bile salts are used in the small intestine for the emulsification and absorption of lipids.
• ***Storage. T***he liver is a prime storage site for certain vitamins (A, B12, D, E, and K) and minerals (iron and copper), which are released from the liver when needed elsewhere in the body.
• ***Phagocytosis.*** The stellate reticuloendothelial (Kupffer) cells of the liver phagocytize aged red blood cells, white blood cells, and some bacteria.
• ***Activation of vitamin D.*** It participates in synthesizing the active form of vitamin D.

Small Intestine

Most digestion and absorption of nutrients occur in a long tube called the **small intestine**. Its length provides a large surface area for digestion and absorption, and that area is further increased by circular folds, villi, and microvilli. The small intestine begins at the pyloric sphincter of the stomach, coils through the central and inferior part of the abdominal cavity, and eventually opens into the large intestine. It averages 2.5 cm (1 in.) in diameter; its length is about 3 m (10 ft) in a living person and about 6.5 m (21 ft) in a cadaver.

Anatomy of the Small Intestine

It is divided into three regions. The first part is the **duodenum**, the shortest region, and is retroperitoneal. It starts at the pyloric sphincter and is in the form of a C-shaped tube that extends about 25 cm until it merges with the jejunum. The **jejunum** is about 1 m long and extends to the ileum. The final and longest region, the **ileum**, measures about 2 m and joins the large intestine at a smooth muscle sphincter called the **ileocecal sphincter (valve)**.



Histology of the Small Intestine

The wall of the small intestine is composed of the same **four** layers that make up most of the GI tract: mucosa, submucosa, muscularis, and serosa. The mucosa is composed of a layer of epithelium, lamina propria, and muscularis mucosae. The epithelial layer of the small intestinal mucosa consists of simple columnar epithelium that contains many types of cells. **Absorptive cells** of the epithelium release enzymes that digest food and contain microvilli that absorb nutrients in small intestinal chime and **goblet cells**, which secrete mucus. Cells lining the crevices form the **intestinal glands**, or *crypts of Lieberkühn*, and secrete intestinal juice. The intestinal glands also contain paneth cells and enteroendocrine cells. **Paneth cells** secrete lysozyme, a bactericidal enzyme, capable of phagocytosis and regulates the microbial population in the small intestine. Three types of enteroendocrine cells are found in the intestinal glands: **S cells**, **CCK cells**, and **K cells**, which secrete the hormones **secretin**, **cholecystokinin (CCK)**, and **glucose-dependent insulinotropic peptide** (**GIP)**, respectively. **Solitary lymphatic nodules** are most numerous in the distal part of the ileum. Groups of lymphatic nodules referred to as **aggregated lymphatic follicles**, or *Peyer's patches*, are also present in the ileum. The **submucosa** of the duodenum contains **duodenal glands**, also called *Brunner's glands*, which secrete an alkaline mucus that helps neutralize gastric acid in the chyme. **Circular folds** or *plicae circulares* are folds of the mucosa and submucosa. These permanent ridges, which are about 10 mm long, begin near the proximal portion of the duodenum and end at about the midportion of the ileum. Some extend all the way around the circumference of the intestine; others extend only part of the way around. Circular folds 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. Also present in the small intestine are **villi**, which are fingerlike projections of the mucosa that are 0.5–1 mm long. The large number of villi increases the surface area of the epithelium available for absorption and digestion and gives the intestinal mucosa a velvety appearance. Each villus is covered by epithelium and has 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. Nutrients absorbed by the epithelial cells covering the villus pass through the wall of a capillary or a lacteal to enter blood or lymph, respectively.The small intestine also has **microvilli**, which are projections of the apical membrane of the absorptive cells. Each microvillus is a 1m long cylindrical, membrane-covered projection that contains a bundle of 20–30 actin filaments. The microvilli are too small to be seen individually and form a fuzzy line, called the **brush border**, extending into the lumen of the small intestine. There are an estimated 200 million microvilli per square millimeter of small intestine. Because the microvilli greatly increase the surface area of the plasma membrane, larger amounts of digested nutrients can diffuse into absorptive cells in a given period. The brush border also contains several brush-border enzymes that have digestive functions.

Brush-Border Enzymes

About 1–2 liters of **intestinal juice**, a clear yellow fluid, is secreted each day. Intestinal juice contains water and mucus and is slightly alkaline (pH 7.6). The alkaline pH of intestinal juice is due to its high concentration of bicarbonate ions (HCO_3). Together, pancreatic and intestinal juices provide a liquid medium that aids the absorption of substances from chyme in the small intestine. The absorptive cells of the small intestine synthesize several digestive enzymes, called **brush-border enzymes**, and insert them in the plasma membrane of the microvilli. Thus, some enzymatic digestion occurs at the surface of the absorptive cells that line the villi, rather than in the lumen exclusively, as occurs in other parts of the GI tract. Among the brush-border enzymes are four carbohydrate-digesting enzymes called dextrinase, maltase, sucrase, and lactase; protein-digesting enzymes called peptidases (aminopeptidase and dipeptidase); and two types of nucleotide-digesting enzymes, nucleosidases and phosphatases. Also, as

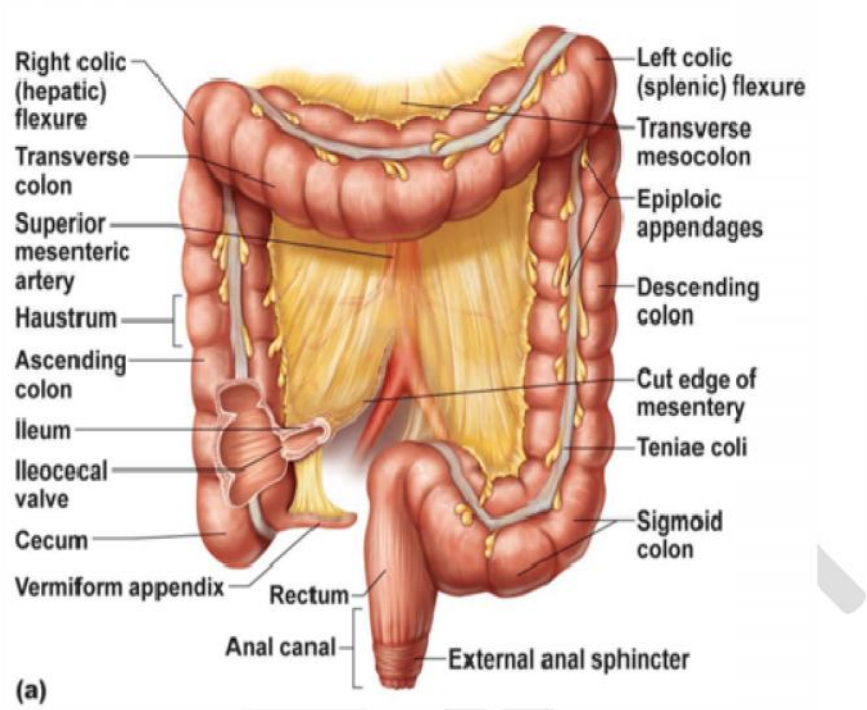
absorptive cells slough off into the lumen of the small intestine, they break apart and release enzymes that help digest nutrients in the chyme.

Large Intestine

It is the terminal portion of the GI tract. The overall functions of the large intestine are the completion of absorption, the production of certain vitamins, the formation of feces, and the expulsion of feces from the body.

Anatomy of the Large Intestine

It is about 1.5 m long and 6.5 cm in diameter in living humans and extends from the ileum to the anus. It is attached to the posterior abdominal wall by its mesocolon, which is a double layer of peritoneum. Structurally, the **four** major regions of the large intestine are the **cecum, colon, rectum, and anal canal.** The opening from the ileum into the large intestine is guarded by a fold of mucous membrane called the ileocecal sphincter (valve), which allows materials from the small intestine to pass into the large intestine. Hanging inferior to the ileocecal valve is the **cecum**, a small pouch about 6 cm long. Attached to the cecum is a twisted, coiled tube, measuring about 8 cm in length, called the **appendix** or *vermiform appendix*. The open end of the cecum merges with a long tube called the **colon**, which is divided into ascending, transverse, descending, and sigmoid portions. Both the ascending and descending colon are retroperitoneal; the transverse and sigmoid colon are not. True to its name, the **ascending colon** ascends on the right side of the abdomen, reaches the inferior surface of the liver, and turns abruptly to the left to form the **right colic flexure**. The colon continues across the abdomen to the left side as the **transverse colon**. It curves beneath the inferior end of the spleen on the left side as the **left colic** (*splenic*) **flexure** and passes inferiorly to the level of the iliac crest as the **descending colon**. The **sigmoid colon** begins near the left iliac crest, projects medially to the midline, and terminates as the rectum at about the level of the third sacral vertebra. The **rectum** is about 15 cm in length. The terminal 2–3 cm of the large intestine is called the **anal canal.** The mucous membrane of the anal canal is arranged in longitudinal folds called **anal columns** that contain a network of arteries and veins. The opening of the anal canal to the exterior, called the **anus**, is guarded by an **internal anal sphincter** of smooth muscle and an **external anal sphincter** of skeletal muscle.



Histology of the Large Intestine

The wall of the large intestine contains the typical **four** layers found in the rest of the GI tract:

The **mucosa** consists of simple columnar epithelium, lamina propria, and muscularis mucosa. The epithelium contains absorptive and goblet cells. The absorptive cells function primarily in water absorption; the goblet cells secrete mucus that lubricates the passage of the colonic contents. Both absorptive and goblet cells are located in long, straight, tubular intestinal glands (crypts of Lieberkühn) that extend the full thickness of the mucosa. Solitary lymphatic nodules are also found in the lamina propria of the mucosa and may extend through the muscularis mucosa into the submucosa. Compared to the small intestine, the mucosa of the large intestine does not have as many structural adaptations that increase surface area. There are no circular folds or villi; however, microvilli are present on the absorptive cells. Consequently, much more absorption occurs in the small intestine than in the large intestine.

The **submucosa** of the large intestine consists of areolar connective tissue.

The **muscularis** consists of an external layer of longitudinal smooth muscle and an internal layer of circular smooth muscle. Unlike other parts of the GI tract, portions of the longitudinal muscles are thickened, forming three conspicuous bands called the **teniae coli** that run most of the length of the large intestine. The teniae coli are separated by portions of the wall with less or no longitudinal muscle. Tonic contractions of the bands gather the colon into a series of pouches called, which give the colon a puckered appearance. A single layer of circular smooth muscle lies between teniae coli.

The **serosa** of the large intestine is part of the visceral peritoneum. Small pouches of visceral peritoneum filled with fat are attached to teniae coli and are called **omental appendices.**

Mechanical and Chemical Digestion in the Stomach

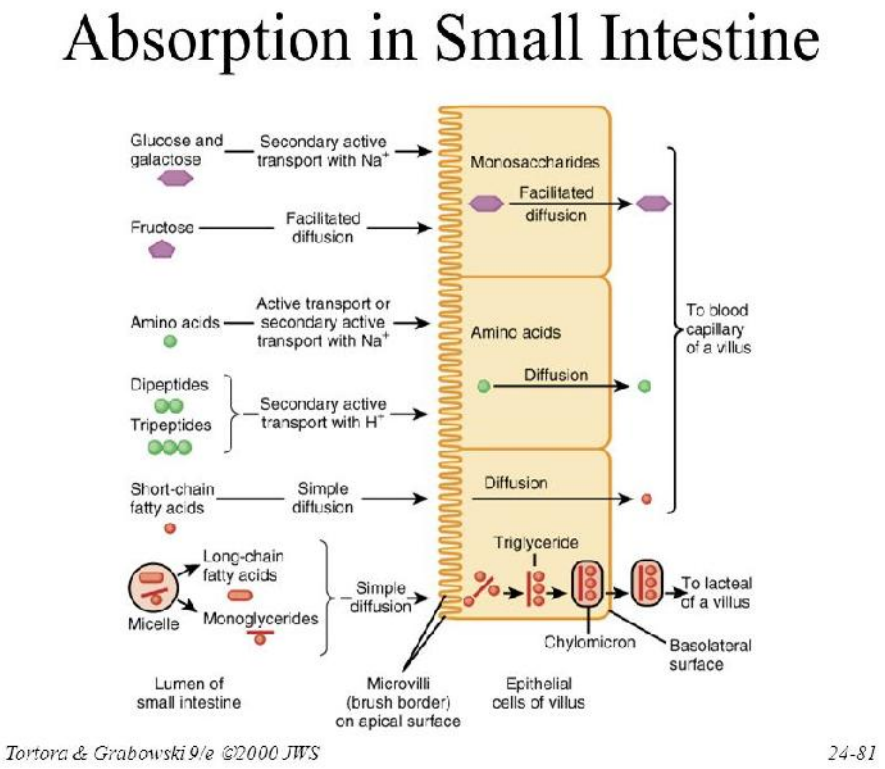
Once food enters the stomach, waves of peristalsis pass over the stomach every 15 to 25 seconds. Few peristaltic waves are observed in the fundus, which primarily has a storage function. Each peristaltic

wave moves gastric contents from the body of the stomach down into the antrum, a process known as **propulsion**. The pyloric sphincter remains almost, but not completely, closed. Because most food particles in the stomach initially are too large to fit through the narrow pyloric sphincter, they are forced back into the body of the stomach, a process referred to as **retropulsion**. Another round of propulsion then occurs, moving the food particles back down into the antrum. The net result of these movements is that gastric contents are mixed with gastric juice, eventually becoming reduced to a soupy liquid called **chyme**. Once the food particles in chyme are small enough, they can pass through the pyloric sphincter, a phenomenon known as **gastric emptying**. Gastric emptying is a slow process: only about 3 mL of chyme moves through the pyloric sphincter at a time. Foods may remain in the fundus for about an hour without becoming mixed with gastric juice. During this time, digestion by salivary amylase from the salivary glands continues. Soon, however, the churning action mixes chyme with acidic gastric juice, inactivating salivary amylase and activating lingual lipase produced by the tongue, which starts to digest triglycerides into fatty acids and diglycerides. Although parietal cells secrete hydrogen ions and chloride ions separately into the stomach lumen, the net effect is secretion of hydrochloric acid (HCl). **Proton pumps** powered by H+k+ATPases actively transport H into the lumen while bringing potassium ions (K) into the cell. At the same time, Cl and K diffuse out into the lumen through Cl and K channels in the apical membrane. The enzyme *carbonic anhydrase*, which is especially plentiful in parietal cells, catalyzes the formation of carbonic acid (H2CO3) from water (H2O) and carbon dioxide (CO2). HCl secretion by parietal cells can be stimulated by several sources: acetylcholine released by parasympathetic neurons, gastrin secreted by G cells, and histamine, which is a paracrine substance released by mast cells in the nearby lamina propria. Acetylcholine and gastrin stimulate parietal cells to secrete more HCl in the presence of histamine. The only proteolytic enzyme in the stomach is **pepsin**, which is secreted by chief cells. Pepsin severs certain peptide bonds between amino acids, breaking down a protein chain of many amino acids into smaller peptide fragments. Pepsin is most effective in the very acidic environment of the stomach (pH 2); it becomes inactive at a higher pH. What keeps pepsin from digesting the protein in stomach cells along with the food? First, pepsin is secreted in an inactive form called *pepsinogen;* in this form, it cannot digest the proteins in the chief cells that produce it. Pepsinogen is not converted into active pepsin until it comes in contact with hydrochloric acid secreted by parietal cells or active pepsin molecules. Second, the stomach epithelial cells are protected from gastric juices by a layer 1–3 mm thick of alkaline mucus secreted by surface mucous cells and mucous neck cells. Another enzyme of the stomach is **gastric lipase**, which splits triglycerides in fat molecules into fatty acids and monoglycerides. A monoglyceride consists of a glycerol molecule that is attached to one fatty acid molecule. This enzyme, which has a limited role in the adult stomach, operates best at a pH of 5–6. More important than either lingual lipase or gastric lipase is pancreatic lipase, an enzyme secreted by the pancreas into the small intestine. 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 and alcohol. Within 2 to 4 hours after eating a meal, the stomach has emptied its contents into the duodenum.

Mechanical Digestion in the Small Intestine

The two types of movements of the small intestine—segmentations and migrating motility complexes are governed mainly by the myenteric plexus. **Segmentations** are localized, mixing contractions that occur in portions of intestine distended by a large volume of chyme. Segmentations mix chime with the digestive juices and bring the particles of food into contact with the mucosa for absorption. The segmentation starts with the contractions of circular muscle fibers in a portion of the small intestine, an action that constricts the intestine into segments. Next, muscle fibers that encircle the middle of each segment also contract,

dividing each segment again. Finally, the fibers that first contracted relax, and each small segment unites with an adjoining small segment so that large segments are formed again. As this sequence of events repeats, the chyme sloshes back and forth. Segmentations occur most rapidly in the duodenum, about 12 times per minute, and progressively slow to about 8 times per minute in the ileum. This movement is similar to alternately squeezing the middle and then the ends of a capped tube of toothpaste. After most of a meal has been absorbed, which lessens distension of the wall of the small intestine, segmentation stops and peristalsis begins. The type of peristalsis that occurs in the small intestine, termed a **migrating motility complex (MMC)**, begins in the lower portion of the stomach and pushes chyme forward along a short stretch of small intestine before dying out. The MMC slowly migrates down the small intestine, reaching the end of the ileum in 90–120 minutes. Then another MMC begins in the stomach. Altogether, chyme remains in the small intestine for 3–5 hours.



Chemical Digestion in the Small Intestine

The chyme entering the small intestine contains partially digested carbohydrates, proteins, and lipids. The completion of the digestion of carbohydrates, proteins, and lipids is a collective effort of pancreatic juice, bile, and intestinal juice in the small intestine.

Digestion of Carbohydrates

The starches that are not in stomach are now broken down into maltose, maltotriose, and dextrins are cleaved by pancreatic amylase, an enzyme in pancreatic juice that acts in the small intestine. Although pancreatic amylase acts on both glycogen and starches, it has no effect on another polysaccharide called cellulose, an indigestible plant fiber that is commonly referred to as "roughage" as it moves through the digestive system. After amylase has split starch into smaller fragments, a brush-border enzyme called **dextrinase** acts on the resulting dextrins, clipping off one glucose unit at a time. Ingested molecules of

sucrose, lactose, and maltose—three disaccharides—are not acted on until they reach the small intestine. Three brush-border enzymes digest the disaccharides into monosaccharides. **Sucrase** breaks sucrose into a molecule of glucose and a molecule of fructose; **lactase** digests lactose into a molecule of glucose and a molecule of galactose; and **maltase** splits maltose and maltotriose into two or three molecules of glucose, respectively. Digestion of carbohydrates ends with the production of monosaccharides, which the digestive system is able to absorb.

Digestion of Proteins

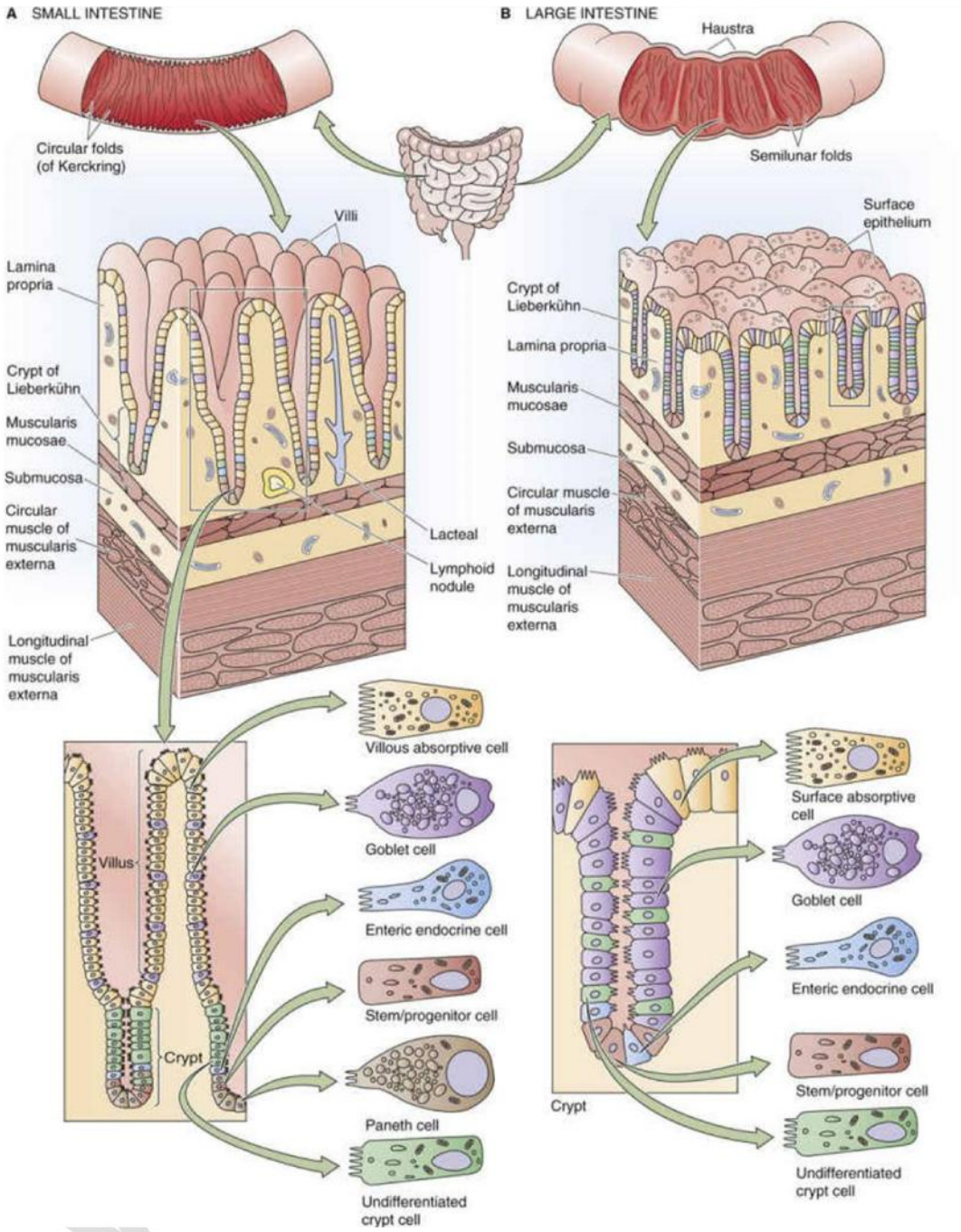
Enzymes in pancreatic juice—trypsin, chymotrypsin, carboxypeptidase, and elastase—continue to break down proteins into peptides. Although all of these enzymes convert whole proteins into peptides, their actions differ somewhat because each splits peptide bonds between different amino acids. Trypsin, chymotrypsin, and elastase all cleave the peptide bond between a specific amino acid and its neighbor; carboxypeptidase splits off the amino acid at the car boxyl end of a peptide. Protein digestion is completed by two **peptidases** in the brush border: aminopeptidase and dipeptidase. A**minopeptidase** cleaves off the amino acid at the amino end of a peptide. **Dipeptidase** splits dipeptides into single amino acids.

Digestion of Lipids

The most abundant lipids in the diet are triglycerides, which consist of a molecule of glycerol bonded to three fatty acid molecules. Enzymes that split triglycerides and phospholipids are called **lipases**. Recall that there are three types of lipases that can participate in lipid digestion: lingual lipase, gastric lipase, and pancreatic lipase. Although some lipid digestion occurs in the stomach through the action of lingual and gastric lipases, most occurs in the small intestine through the action of pancreatic lipase. Triglycerides are broken down by pancreatic lipase into fatty acids and monoglycerides. The liberated fatty acids can be either short-chain fatty acids or long-chain fatty acids. Before a large lipid globule containing triglycerides can be digested in the small intestine, it must first undergo emulsification—a process in which the large lipid globule is broken down into several small lipid globules. Recall that bile contains bile salts, the sodium salts and potassium salts of bile acids. Bile salts are **amphipathic,** which means that each bile salt has a hydrophobic (nonpolar) region and a hydrophilic (polar) region. The amphipathic nature of bile salts allows them to emulsify a large lipid globule: The hydrophobic regions of bile salts interact with the large lipid globule, while the hydrophilic regions of bile salts interact with the watery intestinal chyme. Consequently, the large lipid globule is broken apart into several small lipid globules, each about 1 m in diameter. The small lipid globules formed from emulsification provide a large surface area that allows pancreatic lipase to function more effectively.

Digestion of Nucleic Acids

It contains two nucleases: ribonuclease, which digests RNA, and deoxyribonuclease, which digests DNA. The nucleotides that result from the action of the two nucleases are further digested by brush-border enzymes called **nucleosidases** and **phosphatases** into pentoses, phosphates, and nitrogenous bases. These products are absorbed via active transport.



Absorption in the Small Intestine

All of the chemical and mechanical phases of digestion from the mouth through the small intestine are directed toward changing food into forms that can pass through the absorptive epithelial cells lining the mucosa and into the underlying blood and lymphatic vessels. These forms are monosaccharides (glucose, fructose, and galactose) from carbohydrates; single amino acids, dipeptides, and tripeptides from proteins; and fatty acids, glycerol, and monoglycerides from triglycerides. Passage of these digested nutrients from the gastrointestinal tract into the blood or lymph is called absorption. Absorption of materials occurs via diffusion, facilitated diffusion, osmosis, and active transport. About 90% of all absorption of nutrients occurs in the small intestine; the other 10% occurs in the stomach and large

intestine. Any undigested or unabsorbed material left in the small intestine passes on to the large intestine.

Absorption of Monosaccharides

All carbohydrates are absorbed as monosaccharides. The capacity of the small intestine to absorb monosaccharides is huge—an estimated 120 grams per hour. As a result, all dietary carbohydrates that are digested normally are absorbed, leaving only indigestible cellulose and fibers in the feces. Monosaccharides pass from the lumen through the apical membrane via *facilitated diffusion* or *active transport*. Fructose, a monosaccharide found in fruits, is transported via *facilitated diffusion*; glucose and galactose are transported into absorptive cells of the villi via *secondary active transport* that is coupled to the active transport of Na. The transporter has binding sites for one glucose molecule and two sodium ions; unless all three sites are filled, neither substance is transported. Galactose competes with glucose to ride the same transporter. (Because both Na_ and glucose or galactose move in the same direction, this is a *symporter*.) Monosaccharides then move out of the absorptive cells through their basolateral surfaces via *facilitated diffusion* and enter the capillaries of the villi.

Absorption of Amino Acids, Dipeptides, and Tripeptides

Most proteins are absorbed as amino acids via *active transport* processes that occur mainly in the duodenum and jejunum. About half of the absorbed amino acids are present in food; the other half come from the body itself as proteins in digestive juices and dead cells that slough off the mucosal surface! Normally, 95–98% of the protein present in the small intestine is digested and absorbed. Different transporters carry different types of amino acids. Some amino acids enter absorptive cells of the villi via Na_- dependent secondary active transport processes that are similar to the glucose transporter; other amino acids are actively transported by themselves. At least one symporter brings in dipeptides and tripeptides together with H_; the peptides then are hydrolyzed to single amino acids inside the absorptive cells. Amino acids move out of the absorptive cells via diffusion and enter capillaries of the villus. Both monosaccharides and amino acids are transported in the blood to the liver by way of the hepatic portal system. If not removed by hepatocytes, they enter the general circulation.

Absorption of Lipids and Bile Salts

All dietary lipids are absorbed via *simple diffusion*. Adults absorb about 95% of the lipids present in the small intestine; due to their lower production of bile, newborn infants absorb only about 85% of lipids. As a result of their emulsification and digestion, triglycerides are mainly broken down into monoglycerides and fatty acids, which can be either short-chain fatty acids or long-chain fatty acids. Small short-chain fatty acids are hydrophobic, contain less than 10–12 carbon atoms, and are more water-soluble. Thus, they can dissolve in the watery intestinal chyme, pass through the absorptive cells via simple diffusion, and follow the same route taken by monosaccharides and amino acids into a blood capillary of a villus. Large short-chain fatty acids, long-chain fatty acids, and monoglycerides are larger and hydrophobic, and since they are not water-soluble, they have difficulty being suspended in the watery environment of the intestinal chyme. Besides their role in emulsification, bile salts also help to make these large short-chain fatty acids, long-chain fatty acids, and monoglycerides more soluble. The bile salts in intestinal chyme surround them, forming tiny spheres called **micelle**, each of which is 2–10 nm in diameter and includes 20–50 bile salt molecules. Micelles are formed due to the amphipathic nature of bile salts: The hydrophobic regions of bile salts interact with the large short-chain fatty acids, long-chain fatty acids, and monoglycerides, and the hydrophilic regions of bile salts interact with the watery intestinal chyme. Once formed, the micelles move from the interior of the small intestinal lumen to the brush border of the absorptive cells. At that point, the large short-chain fatty acids, long-chain fatty acids, and monoglycerides diffuse out of the micelles into the absorptive cells, leaving the micelles behind in the chyme. The micelles continually repeat this ferrying function as they move from the brush border

back through the chime to the interior of the small intestinal lumen to pick up more of the large short-chain fatty acids, long-chain fatty acids, and monoglycerides. Micelles also solubilize other large hydrophobic molecules such as fat-soluble vitamins (A, D, E, and K) and cholesterol that may be present in intestinal chyme, and aid in their absorption. These fat-soluble vitamins and cholesterol molecules are packed in the micelles along with the long-chain fatty acids and monoglycerides. Once inside the absorptive cells, long-chain fatty acids and monoglycerides are recombined to form triglycerides, which aggregate into globules along with phospholipids and cholesterol and become coated with proteins. These large spherical masses, about 80 nm in diameter, are called **chylomicrons** (kı¯-lo¯-MI¯-kronz). Chylomicrons leave the absorptive cell via exocytosis, because they are so large and bulky, chylomicrons cannot enter blood capillaries—the pores in the walls of blood capillaries are too small. Instead, chylomicrons enter lacteals, which have much larger pores than blood capillaries. From lacteals, chylomicrons are transported by way of lymphatic vessels to the thoracic duct and enter the blood at the junction of the left internal jugular and left subclavian veins. The hydrophilic protein coat that surrounds each chylomicron keeps the chylomicrons suspended in blood and prevents them from sticking to each other. Within 10 minutes after absorption, about half of the chylomicrons have already been removed from the blood as they pass through blood capillaries in the liver and adipose tissue. This removal is accomplished by an enzyme attached to the apical surface of capillary endothelial cells, called **lipoprotein lipase**, that breaks down triglycerides in chylomicrons and other lipoproteins into fatty acids and glycerol. The fatty acids diffuse into hepatocytes and adipose cells and combine with glycerol during resynthesis of triglycerides. Two or three hours after a meal, few chylomicrons remain in the blood. After participating in the emulsification and absorption of lipids, most of the bile salts are reabsorbed by active transport in the final segment of the small intestine (ileum) and returned by the blood to the liver through the hepatic portal system for recycling. This cycle of bile salt secretion by hepatocytes into bile, reabsorption by the ileum, and resecretion into bile is called the **enterohepatic circulation**.

Absorption of Electrolytes

Sodium ions are actively transported out of absorptive cells by basolateral sodium–potassium pumps (Na/K ATPases) after they have moved into absorptive cells via diffusion and secondaryactive transport. Thus, most of the sodium ions in gastrointestinal secretions are reclaimed and not lost in the feces. Negatively charged bicarbonate, chloride, iodide, and nitrate ions can passively follow Na or be actively transported. Calcium ions also are absorbed actively in a process stimulated by calcitriol. Other electrolytes such as iron, potassium, magnesium, and phosphate ions also are absorbed via active transport mechanisms.

Absorption of Vitamins

As you have just learned, the fat-soluble vitamins A, D, E, and K are included with ingested dietary lipids in micelles and are absorbed via simple diffusion. Most water-soluble vitamins, such as most B vitamins and vitamin C, also are absorbed via simple diffusion. Vitamin B12, however, combines with intrinsic factor produced by the stomach, and the combination is absorbed in the ileum via an active transport mechanism.

Absorption of Water

The total volume of fluid that enters the small intestine each day—about 9.3 liters (9.8 qt)—comes from ingestion of liquids (about 2.3 liters) and from various gastrointestinal secretions (about 7.0 liters). The small intestine absorbs about 8.3 liters of the fluid; the remainder passes into the large intestine, where about 0.9 liter is also absorbed. Only 0.1 liter (100 mL) of water is excreted in the feces each day. All water absorption in the GI tract occurs via *osmosis* from the lumen of the intestines through absorptive cells and into blood capillaries. Because water can move across the intestinal mucosa in both directions,

the absorption of water from the small intestine depends on the absorption of electrolytes and nutrients to maintain an osmotic balance with the blood.

Mechanical Digestion in the Large Intestine

The passage of chyme from the ileum into the cecum is regulated by the action of the ileocecal sphincter. Normally, the valve remains partially closed so that the passage of chime into the cecum usually occurs slowly. Immediately after a meal, a **gastroileal reflex** intensifies peristalsis in the ileum and forces any chyme into the cecum. The hormone gastrin also relaxes the sphincter. Whenever the cecum is distended, the degree of contraction of the ileocecal sphincter intensifies. Movements of the colon begin when substances pass the ileocecal sphincter. Because chyme moves through the small intestine at a fairly constant rate, the time required for a meal to pass into the colon is determined by gastric emptying time. As food passes through the ileocecal sphincter, it fills the cecum and accumulates in the ascending colon. One movement characteristic of the large intestine is **haustral churning**. In this process, the haustra remain relaxed and become distended while they fill up. When the distension reaches a certain point, the walls contract and squeeze the contents into the next haustrum. Peristalsis also occurs, although at a slower rate (3–12 contractions per minute) than in more proximal portions of the tract. A final type of movement is **mass peristalsis**, a strong peristaltic wave that begins at about the middle of the transverse colon and quickly drives the contents of the colon into the rectum. Because food in the stomach initiates this **gastrocolic reflex** in the colon, mass peristalsis usually takes place three or four times a day, during or immediately after a meal.

Chemical Digestion in the Large Intestine

The final stage of digestion occurs in the colon through the activity of bacteria that inhabit the lumen. Mucus is secreted by the glands of the large intestine, but no enzymes are secreted. Chyme is prepared for elimination by the action of bacteria, which ferment any remaining carbohydrates and release hydrogen, carbon dioxide, and methane gases. These gases contribute to flatus (gas) in the colon, termed *flatulence* when it is excessive. Bacteria also convert any remaining proteins to amino acids and break down the amino acids into simpler substances: indole, skatole, hydrogen sulfide, and fatty acids. Some of the indole and skatole is eliminated in the feces and contributes to their odor; the rest is absorbed and transported to the liver, where these compounds are converted to less toxic compounds and excreted in the urine. Bacteria also decompose bilirubin to simpler pigments, including stercobilin, which gives feces their brown color. Bacterial products that are absorbed in the colon include several vitamins needed for normal metabolism, among them some B vitamins and vitamin K.

Absorption and Feces Formation in the Large Intestine

By the time chyme has remained in the large intestine 3–10 hours, it has become solid or semisolid because of water absorption and is now called **feces**. Chemically, feces consist of water, inorganic salts, sloughed-off epithelial cells from the mucosa of the gastrointestinal tract, bacteria, products of bacterial decomposition, unabsorbed digested materials, and indigestible parts of food. Although 90% of all water absorption occurs in the small intestine, the large intestine absorbs enough to make it an important organ in maintaining the body's water balance. Of the 0.5–1.0 liter of water that enters the large intestine, all but about 100–200 mL is normally absorbed via osmosis. The large intestine also absorbs ions, including sodium and chloride, and some vitamins.

The Defecation Reflex

Mass peristaltic movements push fecal material from the sigmoid colon into the rectum. The resulting distension of the rectal wall stimulates stretch receptors, which initiates a **defecation reflex** that results in **defecation**, the elimination of feces from the rectum through the anus. The defecation reflex occurs as follows: In response to distension of the rectal wall, the receptors send sensory nerve impulses to the sacral spinal cord. Motor impulses from the cord travel along parasympathetic nerves back to the descending colon, sigmoid colon, rectum, and anus. The resulting contraction of the longitudinal rectal muscles shortens the rectum, thereby increasing the pressure within it. This pressure, along with voluntary contractions of the diaphragm and abdominal muscles, plus parasympathetic stimulation, opens the internal anal sphincter. The external anal sphincter is voluntarily controlled. If it is voluntarily relaxed, defecation occurs and the feces are expelled through the anus; if it is voluntarily constricted, defecation can be postponed. Voluntary contractions of the diaphragm and abdominal muscles aid defecation by increasing the pressure within the abdomen, which pushes the walls of the sigmoid colon and rectum inward. If defecation does not occur, the feces back up into the sigmoid colon until the next wave of mass peristalsis stimulates the stretch receptors, again creating the urge to defecate. In infants, the defecation reflex causes automatic emptying of the rectum because voluntary control of the external anal sphincter has not yet developed. The normal range of bowel activity varies from two or three bowel movements per day to three or four bowel movements per week.

Disorders

Peptic Ulcer Disease

In the United States, 5–10% of the population develops **peptic ulcer disease (PUD)**. An **ulcer** is a craterlike lesion in a membrane; ulcers that develop in areas of the GI tract exposed to acidic gastric juice are called **peptic ulcers.** The most common complication of peptic ulcers is bleeding, which can lead to anemia if enough blood is lost. In acute cases, peptic ulcers can lead to shock and death. Three distinct causes of PUD are recognized: (1) the bacterium *Helicobacter pylori* ; (2) nonsteroidal anti-inflammatory drugs (NSAIDs) such as aspirin; and (3) hypersecretion of HCl, as occurs in Zollinger– Ellison syndrome, a gastrin-producing tumor, usually of the pancreas. *Helicobacter pylori* (previously named *Campylobacter pylori*) is the most frequent cause of PUD. The bacterium produces an enzyme called urease, which splits urea into ammonia and carbon dioxide. While shielding the bacterium from the acidity of the stomach, the ammonia also damages the protective mucous layer of the stomach and the underlying gastric cells. The microbe also produces catalase, an enzyme that may protect *H. pylori* from phagocytosis by neutrophils, plus several adhesion proteins that allow the bacterium to attach itself to gastric cells. Several therapeutic approaches are helpful in the treatment of PUD. Cigarette smoke, alcohol, caffeine, and NSAIDs should be avoided because they can impair mucosal defensive mechanisms, which increases mucosal susceptibility to the damaging effects of HCl. In cases associated with *H. pylori,* treatment with an antibiotic drug often resolves the problem.

Colorectal Cancer

Colorectal cancer is among the deadliest of malignancies, ranking second to lung cancer in males and third after lung cancer and breast cancer in females. Genetics plays a very important role; an inherited predisposition contributes to more than half of all cases of colorectal cancer. Intake of alcohol and diets high in animal fat and protein are associated with increased risk of colorectal cancer; dietary fiber, retinoids, calcium, and selenium may be protective. Signs and symptoms of colorectal cancer include diarrhea, constipation, cramping, abdominal pain, and rectal bleeding, either visible or occult (hidden in feces). Precancerous growths on the mucosal surface, called **polyps**, also increase the risk of developing

colorectal cancer. Screening for colorectal cancer includes testing for blood in the feces, digital rectal examination, sigmoidoscopy, colonoscopy, and barium enema. Tumors may be removed endoscopically or surgically.

Gastroenteritis
(*gastro-* _ stomach; *-enteron-* _intestine; *-itis* _ inflammation)
There is inflammation of the lining of the stomach and intestine (especially the small intestine). It is usually caused by a viral or bacterial infection that may be acquired by contaminated food or water or by people in close contact. Symptoms include diarrhea, vomiting, fever, loss of appetite, cramps, and abdominal discomfort.

Summary of Organs of the Digestive System and Their Functions

ORGAN	FUNCTION(S)
Tongue	Maneuvers food for mastication, shapes food into a bolus, maneuvers food for deglutition, detects sensations for taste, and initiates digestion of triglycerides.
Salivary glands	Saliva produced by these glands softens, moistens, and dissolves foods; cleanses mouth and teeth; initiates the digestion of starch.
Teeth	Cut, tear, and pulverize food to reduce solids to smaller particles for swallowing.
Pancreas	Pancreatic juice buffers acidic gastric juice in chyme, stops the action of pepsin from the stomach, creates the proper pH for digestion in the small intestine, and participates in the digestion of carbohydrates, proteins, triglycerides, and nucleic acids.
Liver	Produces bile, which is required for the emulsification and absorption of lipids in the small intestine.
Gallbladder	Stores and concentrates bile and releases it into the small intestine.
Mouth	See the functions of the tongue, salivary glands, and teeth, all of which are in the mouth. Additionally, the lips and cheeks keep food between the teeth during mastication, and buccal glands lining the mouth produce saliva.
Pharynx	Receives a bolus from the oral cavity and passes it into the esophagus.
Esophagus	Receives a bolus from the pharynx and moves it into the stomach; this requires relaxation of the upper esophageal sphincter and secretion of mucus.
Stomach	Mixing waves combine saliva, food, and gastric juice, which activates pepsin, initiates protein digestion, kills microbes in food, helps absorb vitamin B12, contracts the lower esophageal sphincter, increases stomach motility, relaxes the pyloric sphincter, and moves chyme into the small intestine.
Small intestine	Segmentation mixes chyme with digestive juices; peristalsis propels chyme toward the ileocecal sphincter; digestive secretions from the small intestine, pancreas, and liver complete the digestion of carbohydrates, proteins, lipids, and nucleic acids; circular folds, villi, and microvilli help absorb about 90% of digested nutrients.
Large intestine	Haustral churning, peristalsis, and mass peristalsis drive the colonic contents into the rectum; bacteria produce some B vitamins and vitamin K; absorption of some water, ions, and vitamins occurs; defecation.