I. INTRODUCTION
   A. Food contains substances and energy the body needs to construct all cell components. The food must be broken down through digestion to molecular size before it can be absorbed by the digestive system and used by the cells.
   B. The organs that collectively perform these functions compose the digestive system.

II. OVERVIEW OF THE DIGESTIVE SYSTEM
   A. Organs of the digestive system are shown in figure 24.1
   B. The gastrointestinal tract is the tube open at both ends for the transit of food during processing. The functional segments of the GI tract include the mouth, esophagus, stomach, small intestine, and large intestine.
   C. The accessory structures that contribute to the food processing include the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.
   D. Digestion includes six basic processes.
      a. Ingestion
      b. Secretion
      c. Mixing
      d. Digestion
         1. Mechanical digestion consists of movements of the GI tract that aid chemical digestion.
         2. Chemical digestion is a series of catabolic (hydrolysis)
      e. Absorption
      f. Defecation

III. LAYERS OF THE GI TRACT
   A. The basic arrangement of layers in the gastrointestinal tract from the inside outward includes the mucosa, submucosa, muscularis, and serosa (visceral peritoneum) (Figure 24.2).
   B. The mucosa consists of an epithelium, lamina propria, and muscularis mucosa.
1. The epithelium consists of a protective layer of non-keratinized stratified squamous cells in the mouth, pharynx and esophagus and simple columnar cells for secretion and absorption in the stomach and intestines.

2. The lamina propria consists of three components, including loose connective tissue that adheres the epithelium to the lower layers, the system of blood and lymph vessels through which absorbed food is transported, and nerves and sensors.
   a. The lymph system is part of the mucosa-associated lymph tissues (MALT) that monitor and produce an immune response to pathogens passing with food through the GI tract.

3. The muscularis mucosa causes local folding of the mucosal layer to increase surface area for digestion and absorption.

4. The submucosa consists of aerolar connective tissue. It is highly vascular, contains a part of the submucosal plexus (plexus of Meissner), and contains glands and lymphatic tissue.

C. Muscularis

1. The muscularis of the mouth, pharynx, and superior part of the esophagus contains skeletal muscle that produces voluntary swallowing. Skeletal muscle also forms the external anal sphincter.

2. Through the rest of the tract, the muscularis consists of smooth muscle in an inner sheet of circular fibers and an outer sheet of longitudinal fibers.

3. The serosa is the superficial layer of those portions of the GI tract that are suspended in the abdominopelvic cavity.

D. Serosa

1. Inferior to the diaphragm, the serosa is also called the visceral peritoneum.

IV. NEURAL INNERVATION OF THE GI TRACT

A. The Enteric Nervous system

1. The submucosal plexus (plexus of Meissner) is one network of neurons (Figure 24.3)
   a. It regulates movements of the mucosa, vasoconstriction of blood vessels, and innervates secretory cells of mucosal glands.

2. The myenteric plexus (plexus of Auerbach) consists of fibers from both divisions of the ANS.
a. This plexus mostly controls GI tract motility.

B. **Autonomic Nervous System**
   1. In general, 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. In general, the sympathetic nerves that supply the GI tract cause a decrease in GI secretion and motility by inhibiting the neurons of the ENS.

V. **PERITONEUM**
   A. The peritoneum is the largest serous membrane of the body.
      1. The parietal peritoneum lines the wall of the abdominal cavity.
      2. The visceral peritoneum covers some of the organs and constitutes their serosa.
      3. The potential space between the parietal and visceral portions of the peritoneum is called the peritoneal cavity and contains serous fluid (Figure 24.4).
   B. Some organs, such as the kidneys and pancreas, lie on the posterior abdominal wall behind the peritoneum and are called retroperitoneal.
   C. The peritoneum contains large folds that weave between the viscera, functioning to support organs and to contain blood vessels, lymphatic vessels, and nerves of the abdominal organs.
   D. Extensions of the peritoneum include the mesentery, mesocolon, falciform ligament, lesser omentum, and greater omentum (Figure 24.4).
      1. Peritonitis is an acute inflammation of the peritoneum. (Clinical Connection)

VI. **MOUTH**
   A. **Introduction**
      The oral cavity proper is a space that extends from the gums and teeth to the fauces, the opening between the oral cavity and the pharynx or throat.
   B. **Salivary Glands**
      1. The major portion of saliva is secreted by the salivary glands, which lie outside the mouth and pour their contents into ducts that empty into the oral cavity; the remainder of saliva comes from buccal glands in the mucous membrane that lines the mouth.
2. There are three pairs of salivary glands: parotid, submandibular (submaxillary), and sublingual glands (Figure 24.6).

3. Saliva lubricates and dissolves food and starts the chemical digestion of carbohydrates. It also functions to keep the mucous membranes of the mouth and throat moist.

4. Chemically, saliva is 99.5% water and 0.5% solutes such as salts, dissolved gases, various organic substances, and enzymes.

5. Salivation is entirely under nervous control.

6. Mumps is an inflammation and enlargement of the parotid salivary glands caused by infection with the mumps virus (myxovirus). Symptoms include fever, malaise, pain, and swelling of one or both glands. If mumps is contracted by a male past puberty, it is possible to experience inflammation of the testes and, occasionally, sterility. (Clinical Connection)

C. Structure and Function of the Tongue

1. It is composed of skeletal muscle covered with mucous membrane.

2. Participates in food manipulation for chewing and swallowing and in speech.

3. The upper surface and sides of the tongue are covered with papillae. Some papillae contain taste buds.

D. Structure and Function of the Teeth

1. The teeth project into the mouth and are adapted for mechanical digestion (Figure 24.7).

2. A typical tooth consists of three principal portions: crown, root, and neck.

3. Teeth are composed primarily of dentin, a calcified connective tissue that gives the tooth its basic shape and rigidity; the dentin of the crown is covered by enamel, the hardest substance in the body, which protects the tooth from the wear of chewing.

4. The dentin of the root is covered by cementum.

5. There are two dentitions, or sets of teeth, in an individual’s lifetime: deciduous (primary), milk teeth, or baby teeth; and permanent (secondary) teeth (Figure 24.8).

6. There are four different types of teeth based on shape: incisors (used to cut food), cuspids or canines (used to tear or shred food), premolars or bicuspids (absent in the deciduous dentition and used for crushing and grinding food), and molars (also used for crushing and grinding food).
E. **Mechanical and Chemical Digestion in the Mouth**
   1. The enzyme salivary amylase converts polysaccharides (starches) to disaccharides (maltose). This is the only chemical digestion that occurs in the mouth.

VII. **PHARYNX**
   A. The pharynx is a funnel-shaped tube that extends from the internal nares to the esophagus posteriorly and the larynx anteriorly (Figure 23.4).

VIII. **ESOPHAGUS**
   A. The esophagus is a collapsible, muscular tube that lies behind the trachea and connects the pharynx to the stomach (Figure 24.1).
   B. **Histology of the Esophagus**
      1. The wall of the esophagus contains mucosa, submucosa, and muscularis layers.
      2. The outer layer is called the adventitia
   C. **Physiology of the Esophagus**
      1. The esophagus contains an upper and a lower esophageal sphincter.
      2. During the esophageal stage of swallowing (Figure 24.10) progressive contractions of the muscularis push the bolus onward. These propulsive contractions are termed peristalsis.
      3. Gastroesophageal reflux disease occurs when the lower esophageal sphincter fails to close adequately after food has entered the stomach, resulting in stomach contents reflexing into the inferior portion of the esophagus. HCl from the stomach irritates the esophageal wall resulting in heartburn.
         (Clinical Connection)

IX. **STOMACH**
   A. **Introduction**
      1. The stomach is a J-shaped enlargement of the GI tract that begins at the bottom of the esophagus and ends at the pyloric sphincter (Figure 24.11).
      2. It serves as a mixing and holding area for food, begins the digestion of proteins, and continues the digestion of triglycerides, converting a bolus to a liquid called chyme. It can also absorb some substances.
   B. **Anatomy of the Stomach**
1. The gross anatomical subdivisions of the stomach include the cardia, fundus, body, and pyloris (Figure 24.11).

C. Histology of the Stomach

1. The surface of the mucosa is a layer of simple columnar epithelial cells called mucous surface cells (Figure 24.12).
2. The gastric glands consist of three types of exocrine glands: mucous neck cells (secrete mucus), chief or zymogenic cells (secrete pepsinogen and gastric lipase), and parietal or oxyntic cells (secrete HCl).
3. Gastric glands also contain enteroendocrine cells which are hormone producing cells. G cells secrete the hormone gastrin into the bloodstream.
4. The submucosa is composed of areolar connective tissue.
5. The muscularis has three layers of smooth muscle: longitudinal, circular, and an inner oblique layer.

D. Mechanical and Chemical Digestion in the Stomach

1. Mechanical digestion consists of peristaltic movements called mixing waves.
2. Chemical Digestion
   a. Chemical digestion consists mostly of the conversion of proteins into peptides by pepsin, an enzyme that is most effective in the very acidic environment (pH 2) of the stomach. The acid (HCl) is secreted by the stomach’s parietal cells (Figure 24.13).
   b. Gastric lipase splits certain molecules in butterfat of milk into fatty acids and monoglycerides and has a limited role in the adult stomach.
3. The stomach wall is impermeable to most substances; however, some water, electrolytes, certain drugs (especially aspirin), and alcohol can be absorbed through the stomach lining.
4. Gastric emptying is the periodic release of chyme from the stomach into the duodenum.
5. Most food leaves the stomach 2-6 hours after ingestion. Carbohydrates leave earliest, followed by proteins and then fats.

X. PANCREAS

A. The pancreas is divided into a head, body, and tail and is connected to the duodenum via the pancreatic duct and accessory duct (Figure 24.14).

1. Pancreatic islets (islets of Langerhans) secrete hormones and acini secrete a mixture of fluid and digestive enzymes called pancreatic juice.
B. **Pancreatic Juice**
   1. Pancreatic juice contains enzymes that digest starch (pancreatic amylase), proteins (trypsin, chymotrypsin, and carboxypeptidase), fats (pancreatic lipase), and nucleic acids (ribonuclease and deoxyribonuclease).
   2. It also contains sodium bicarbonate which converts the acid stomach contents to a slightly alkaline pH (7.1-8.2), halting stomach pepsin activity and promoting activity of pancreatic enzymes.

XI. **LIVER AND GALLBLADDER**

A. The liver is the heaviest gland in the body and the second largest organ in the body after the skin.

B. **Anatomy of the Liver and Gallbladder**
   1. The liver is divisible into left and right lobes, separated by the falciform ligament.
   2. The gallbladder is a sac located in a depression on the posterior surface of the liver (Figure 24.14).

C. **Histology of the Liver and Gallbladder**
   1. The lobes of the liver are made up of lobules that contain hepatic cells (liver cells or hepatocytes), sinusoids, stellate reticuloendothelial (Kupffer’s) cells, and a central vein (Figure 24.15).
   2. The mucosa of the gallbladder is simple columnar epithelium arranged in rugae. There is no submucosa. The smooth muscle of the muscularis ejects bile into the cystic duct. The outer layer is the visceral peritoneum. Functions of the gallbladder are to store and concentrate bile until it is needed in the small intestine.

D. Jaundice is a yellowish coloration of the sclera, skin, and mucous membranes due to a buildup of bilirubin. The main categories of jaundice are prehepatic, hepatic, and enterohepatic (Clinical Connection).
   1. The liver receives a double supply of blood from the hepatic artery and the hepatic portal vein. All blood eventually leaves the liver via the hepatic vein (Figure 24.16).
   2. Hepatic cells (hepatocytes) produce bile that is transported by a duct system to the gallbladder for concentration and temporary storage.
E. Bile is partially an excretory product (containing components of worn-out red blood cells) and partially a digestive secretion.
   1. Bile’s contribution to digestion is the emulsification of triglycerides.

F. The liver also functions in carbohydrate, lipid, and protein metabolism; removal of drugs and hormones from the blood; excretion of bilirubin; synthesis of bile salts; storage of vitamins and minerals; phagocytosis; and activation of vitamin D.
   1. The fusion of individual crystals of cholesterol is the beginning of 95% of all gallstones. Gallstones can cause obstruction to the outflow of bile in any portion of the duct system. Treatment of gallstones consists of using gallstone-dissolving drugs, lithotripsy, or surgery (Clinical Connection).

XII. SMALL INTESTINE
A. Introduction
   1. The major events of digestion and absorption occur in the small intestine.
   2. The small intestine extends from the pyloric sphincter to the ileocecal sphincter.

B. Anatomy of the Small Intestine
   1. The small intestine is divided into the duodenum, jejunum, and ileum (Figure 24.17).

C. Histology of the Small Intestine
   1. The mucosa forms fingerlike villi which increase the surface area of the epithelium available for absorption and digestion (Figure 24.18).
      a. Embedded in the villus is a lacteal (lymphatic capillary) for fat absorption.
   2. The submucosa of the duodenum contains duodenal (Brunner’s) glands which secrete an alkaline mucus that helps neutralize gastric acid in chyme. The submucosa of the ileum contains aggregated lymphatic nodules (Peyer’s patches) (Figure 24.19).

D. Mechanical Digestion in the Small Intestine
   1. Segmentation, the major movement of the small intestine, is a localized contraction in areas containing food.
   2. Peristalsis propels the chyme onward through the intestinal tract.

E. Chemical Digestion in the Small Intestine
   1. Carbohydrates are broken down into monosaccharides for absorption.
2. **Protein digestion starts in the stomach.**
   a. Proteins are converted to peptides by trypsin and chymotrypsin.

3. Most lipid digestion, in an adult, occurs in the small intestine.
   a. Bile salts break the globules of triglycerides (fats) into droplets
   b. Pancreatic lipase, can hydrolyze more triglycerides into fatty acids and monoglycerides.

4. Nucleic acids are broken down into nucleotides for absorption.

F. **Absorption in the Small Intestine**

1. Absorption is the passage of the end products of digestion from the GI tract into blood or lymph and occurs by diffusion, facilitated diffusion, osmosis, and active transport.

2. Absorption of Monosaccharides


4. Absorption of Lipids
   a. Dietary lipids are all absorbed by simple diffusion.
   b. Triglycerides are formed into protein-coated spherical masses called chylomicrons.
      1. Chylomicrons are taken up by the lacteal of a villus.
      2. From the lacteal they enter the lymphatic system and then pass into the cardiovascular system, finally reaching the liver or adipose tissue (Figure 24.20).
   c. The plasma lipids - fatty acids, triglycerides, cholesterol - are insoluble in water and body fluids.
      1. In order to be transported in blood and utilized by body cells, the lipids must be combined with protein transporters called lipoproteins to make them soluble.
      2. The combination of lipid and protein is referred to as a lipoprotein.

5. **Absorption of Electrolytes**

6. **Absorption of Vitamins**
   a. Fat-soluble vitamins (A, D, E, and K) are included along with ingested dietary lipids in micelles and are absorbed by simple diffusion.
   b. Water-soluble vitamins (B and C) are absorbed by simple diffusion.

7. **Absorption of Water**
All water absorption in the GI tract occurs by osmosis from the lumen of the intestines through epithelial cells and into blood capillaries.

a. The absorption of water depends on the absorption of electrolytes and nutrients to maintain an osmotic balance with the blood.

b. Alcohol begins to be absorbed in the stomach. The longer alcohol remains in the stomach, the slower it is absorbed. Blood alcohol levels rise more slowly when fat rich foods are consumed with alcohol (Clinical Connection).

XIII. LARGE INTESTINE

A. Anatomy of the Large Intestine
   1. The large intestine (colon) extends from the ileocecal sphincter to the anus.
   2. Its subdivisions include the cecum, colon, rectum, and anal canal (Figure 24.22).
   3. Hanging inferior to the cecum is the appendix.
   4. The colon is divided into the ascending, transverse, descending, and sigmoid portions.

B. Histology of the Large Intestine
   1. The mucosa of the large intestine has no villi or permanent circular folds. It does have a simple columnar epithelium with numerous goblet cells (Figure 24.23).

C. The last stages of chemical digestion occur in the large intestine through bacterial, rather than enzymatic, action. Substances are further broken

D. Absorption and Feces Formation in the Large Intestine
   1. The large intestine absorbs water, electrolytes, and some vitamins.
   2. Feces consist of water, inorganic salts, sloughed-off epithelial cells, bacteria, products of bacterial decomposition, and undigested parts of food.
   3. The main diagnostic value of the occult blood test is to screen for colorectal cancer

E. Defecation Reflex
   1. The elimination of feces from the rectum is called defecation.
   2. Defecation is a reflex action aided by voluntary contractions of the diaphragm and abdominal muscles. The external anal sphincter can be voluntarily controlled (except in infants) to allow or postpone defecation.
3. Diarrhea refers to frequent defecation of liquid feces. It can lead to dehydration and electrolyte imbalances.
4. Constipation refers to infrequent or difficult defecation. It may be alleviated by increasing one’s intake of dietary fiber and fluids.
5. Dietary fiber may be classified as insoluble (does not dissolve in water) and soluble (dissolves in water). There is evidence that insoluble fiber may help protect against colon cancer and that soluble fiber may help lower blood cholesterol level.

XIV. PHASES OF DIGESTION

A. Digestion occurs in three overlapping phases: cephalic (reflex), gastric, and intestinal.

1. Cephalic Phase
   a. The cephalic phase consists of reflexes initiated by sensory receptors in the head that stimulates gastric secretion and motility.

2. Gastric Phase
   a. The gastric phase can be regulated by neural and hormonal mechanisms.
   b. Neural regulation begins when the stomach walls are distended or when pH increases because proteins have entered the stomach and buffered some of the stomach acid, the stretch receptors and chemoreceptors are activated (Figure 24.24) resulting in waves of peristalsis and continual flow of gastric juice.
   c. Hormonal negative feedback also regulates gastric secretions during the gastric phase.
      1. Chemoreceptors and stretch receptors stimulate the ANS to release acetylcholine which stimulates the release of gastrin by G cells.
      2. Gastrin stimulates growth of the gastric glands and secretion of large amounts of gastric juice. It also strengthens contraction of the lower esophageal sphincter, increases motility of the stomach, and relaxes the pyloric and ileocecal sphincters.

3. Intestinal Phase
   a. The intestinal phase begins when partially digested food enters the small intestine.
   b. Neural regulation
      1. Neural regulation is stimulated by distension of the duodenum.
2. Distension triggers the enterogastric reflex which reduces gastric emptying.

c. Hormonal regulation

1. Secretin promotes secretion of bicarbonate ions into pancreatic juice and bile. It inhibits secretion of gastric juice and promotes normal growth and maintenance of the pancreas. It enhances the effects of CCK. Overall, it causes buffering of acid in chyme.

2. CCK stimulates secretion of pancreatic juice rich in digestive enzymes and ejection of bile into the duodenum. It also slows gastric emptying.

d. There are other hormones secreted by and having effects on the GI tract. They include motilin, substance P, bombesin, vasoactive intestinal polypeptide, gastrin-releasing peptide, and somatostatin.

e. Table 24.8 summarizes the activities of the digestive hormones

XV. DISORDERS: HOMEOSTATIC IMBALANCES

A. Dental caries, or tooth decay, is started by acid-producing bacteria that reside in dental plaque, act on sugars, and demineralize tooth enamel and dentin with acid.

B. Peptic ulcers are crater-like lesions that develop in the mucous membrane of the GI tract in areas exposed to gastric juice. The most common complication of peptic ulcers is bleeding, which can lead to anemia if blood loss is serious. The three well-defined causes of peptic ulcer disease (PUD) are the bacterium Helicobacter pylori; nonsteroidal anti-inflammatory drugs, such as aspirin; and hypersecretion of HCl.

C. Diverticula are saclike outpouchings of the wall of the colon in places where the muscularis has become weak. The development of diverticula is called diverticulosis. Inflammation within the diverticula, known as diverticulitis, may cause pain, nausea, vomiting, and either constipation or an increased frequency of defecation. High fiber diets help relieve the symptoms.

D. Tumors, both benign and malignant, may occur in any portion of the GI tract. One of the most common and deadly malignancies is colorectal cancer, second only to lung cancer in males and third after lung and breast cancer in females. Screening for colorectal cancer includes fecal occult blood testing, digital rectal examination, sigmoidoscopy, colonoscopy, and barium enema.