Chapter 25 Adapted from Tortora 10th ed.

LECTURE OUTLINE

A. Introduction (p. 764)
   1. Digestion is the breaking down of larger food molecules into molecules that are small enough to enter body cells and absorption is the passage of these small molecules into blood and lymph; the organs that collectively perform these functions comprise the digestive system.
   2. Gastroenterology is the medical specialty that deals with the structure, function, diagnosis, and treatment of diseases of the stomach and intestines; proctology is the medical specialty that deals with the diagnosis and treatment of disorders of the rectum and anus.

B. Overview of the Digestive System (p. 765)
   1. The organs of the digestive system are divided into two groups:
      i. gastrointestinal (GI) tract or alimentary canal, which is a tube that extends from the mouth to the anus through the ventral body cavity; it includes the following organs:
         a. mouth
         b. most of the pharynx
         c. esophagus
         d. stomach
         e. small intestine
         f. large intestine
      ii. accessory digestive organs, which include:
         a. teeth
         b. tongue
         c. salivary glands
         d. liver
         e. gallbladder
         f. pancreas
   2. The digestive system performs six major activities:
      i. ingestion (eating)
      ii. secretion of water, acid, buffers, and digestive enzymes
      iii. mixing of food with secretions and propulsion of food along the GI tract, i.e., motility
      iv. digestion of food by both mechanical and chemical processes
      v. absorption of digested food molecules into the blood and lymph
      vi. defecation of wastes, indigestible substances, and bacteria in the form of feces

3. Mechanical digestion includes:
   i. chewing of food by the teeth before it is swallowed
   ii. churning of food by the smooth muscles of the stomach and small intestine so that it is thoroughly mixed with digestive enzymes
4. **Chemical digestion** is a series of catabolic reactions in which enzymes break down large food molecules, i.e., **carbohydrates**, **lipids**, **protein**, and **nucleic acids**, into smaller molecules that may be absorbed and used by body cells.

C. **Layers of the GI Tract** (p. 765)

1. The wall of the GI tract, from the esophagus to the anal canal, consists of four major layers of tissue which, listed in sequence from innermost to outermost, are:
   
   i. **mucosa**, which is a mucous membrane that surrounds the lumen; it consists of three sublayers:
      
      a. **inner lining layer** of **epithelium**
         - nonkeratinized stratified squamous epithelium in the mouth, pharynx, esophagus, and anal canal provides protection
         - simple columnar epithelium throughout the rest of the GI tract functions in secretion and absorption; included are hormone-secreting enteroendocrine cells
      
      b. **middle layer** of areolar connective tissue called the **lamina propria**
         - contains blood vessels, lymphatic vessels, and scattered lymphatic nodules
         - contains most components of the **mucosa-associated lymphoid tissue** (MALT)
      
      c. **outer layer** of smooth muscle tissue called the **muscularis mucosae**
         - creates small folds in the stomach and intestinal mucosa that increase the surface area for digestion and absorption

   ii. **submucosa**, which consists of areolar connective tissue
      
      a. it is highly vascular
      b. it contains a portion of the **submucosal plexus** (**plexus of Meissner**) which is a component of the enteric nervous system (**ENS**)  
      c. this plexus innervates the mucosa and submucosa and plays an important role in regulating:
         - movements of the mucosa and vasoconstriction of blood vessels
         - secretions by the GI tract
      d. it may also contain glands and lymphatic tissue

   iii. **muscularis**, which consists of muscle tissue
      
      a. in the mouth, pharynx, upper and middle parts of the esophagus, and the external anal sphincter, it consists of **skeletal muscle tissue** which produces voluntary swallowing and voluntary control of defecation
      b. throughout the rest of the GI tract, it consists of **smooth muscle tissue** that is generally divided into two sheets:
         - inner sheet of circular fibers
         - outer sheet of longitudinal fibers
      c. contractions help break down food physically, mix it with digestive secretions, and propel it along the tract
      d. it contains the **myenteric plexus** (**plexus of Auerbach**) which is a component of the enteric nervous system (**ENS**); this plexus primarily controls GI tract motility
iv. **serosa**, which is a serous membrane
   a. it is composed of areolar connective tissue covered by a layer of simple squamous epithelium; the esophagus has a superficial layer called the adventitia
   b. below the diaphragm, it is also called the **visceral peritoneum** and forms a portion of the peritoneum

D. **Peritoneum** (p. 768)
   1. Important features of the peritoneum include:
      i. The peritoneum is the largest serous membrane of the body.
      ii. The peritoneum consists of two layers:
         a. **parietal peritoneum** that lines the wall of the abdominopelvic cavity
         b. **visceral peritoneum** that covers some of the abdominal organs and constitutes their serosa
            - between the two layers is a potential space called the **peritoneal cavity** that contains serous fluid; accumulation of serous fluid in certain diseases is a condition called **ascites**
      iii. Some abdominal organs, e.g., kidneys and pancreas, are located on the posterior abdominal wall and are covered by peritoneum on their anterior surfaces only; these organs are said to be **retroperitoneal**.
      iv. The peritoneum contains large **folds** which:
         a. bind organs to each other and to the walls of the abdominal cavity
         b. contain blood vessels, lymphatic vessels, and nerves that supply the abdominal organs
      v. The folds of the peritoneum include:
         a. **greater omentum**
            - it is the largest peritoneal fold and contains large quantities of adipose tissue and many lymph nodes
            - it hangs like a “fatty apron” in front of the abdominal viscera, extending from the stomach and duodenum downward over the small intestine, turning upward, and attaching itself to the transverse colon
         b. **falciform ligament**
            - it attaches the liver to the anterior abdominal wall and diaphragm
         c. **lesser omentum**, which arises as two folds of the stomach and duodenal serosa
            - it suspends the stomach and duodenum from the liver and contains some lymph nodes
         d. **mesentery**, which extends from the posterior abdominal wall to wrap around the small intestine and then returns to its origin
            - it attaches the small intestine to the posterior abdominal wall
         e. **mesocolon**, which is an outward fold of the parietal peritoneum
            - it attaches the large intestine to the posterior abdominal wall
            - it carries blood and lymphatic vessels to the intestines

E. **Mouth (Oral Cavity** or **Buccal Cavity**) (p. 770)
   1. The mouth is formed by the following structures:
      i. **cheeks** that form the lateral walls; they consist of skeletal muscles covered externally by skin and internally by nonkeratinized stratified squamous epithelium
      ii. superior and inferior **lips (labia)** that are formed by the cheeks converging anteriorly
         a. the lips consist of the orbicularis oris muscle covered externally by skin and internally by a mucous membrane; between these two coverings is a
transparent transition zone through which is visible the blood in underlying blood vessels
b. the inner surface of each lip is attached to its corresponding gum by a midline fold of mucous membrane called the labial frenulum
c. the vestibule is the space located between the external cheeks and lips and the internal gums and teeth; the oral cavity proper is a space that extends from the gums and teeth to the fauces that connects the oral cavity to the pharynx

iii. hard palate that forms the anterior portion of the roof of the mouth
   a. it consists of the maxillae and palatine bones covered by mucous membrane
   b. it separates the oral cavity from the nasal cavity

iv. soft palate that forms the posterior portion of the roof of the mouth
   a. it is an arch-shaped muscular partition covered by mucous membrane
   b. it lies between the oropharynx and the nasopharynx
   c. it has a conical process called the uvula that hangs down from its free border
   d. on either side of the base of the uvula are two muscular folds:
      - anteriorly, the palatoglossal arch extends to the side of the base of the tongue
      - posteriorly, the palatopharyngeal arch extends to the side of the pharynx
      - the palatine tonsils are located between the arches; the lingual tonsils are located on the base of the tongue

2. Salivary Glands: (p. 771)
   i. Many small labial, buccal, palatal, and lingual glands in the mucous membrane secrete small amounts of saliva to keep the mouth and pharynx moist.
   ii. Three pairs of major salivary glands secrete major quantities of saliva when food enters the mouth:
      a. parotid glands are located inferior and anterior to the ears between the skin and masseter muscle
         - each gland has a parotid (Stensen’s) duct that pierces the buccinator muscle to open into the vestibule opposite the second maxillary (upper) molar tooth
      b. submandibular glands are located beneath the base of the tongue
         - the submandibular (Wharton’s) ducts travel anteriorly and open into the oral cavity on either side of the lingual frenulum
      c. sublingual glands are located in the floor of the mouth superior to the submandibular glands
         - their lesser sublingual (Rivinus’) ducts open into the floor of the mouth in the oral cavity proper
   iii. The major salivary glands receive their blood supply from branches of the external carotid, facial, and lingual arteries; blood drains into tributaries of the external jugular, facial, sublingual, and submental veins.
   iv. The salivary glands are innervated by both sympathetic (vasoconstrictor) and parasympathetic (vasodilator) fibers which decrease and increase, respectively, saliva production.
   v. Saliva is 99.5% water and 0.5% solutes; notable solutes include:
      a. bacteriolytic lysozyme
      b. salivary amylase which initiates starch digestion
      c. lingual lipase (secreted by lingual glands on the tongue) which initiates triglyceride digestion
vi. Chemical stimulation (by food molecules) of receptors in the taste buds results in nerve impulses being transmitted to the superior and inferior salivatory nuclei in the brain stem; returning parasympathetic impulses in the facial (VII) and glossopharyngeal (IX) nerves stimulate secretion of saliva; the sight, smell, sound, or thought of food may also stimulate increased saliva secretion.

3. Tongue: (p. 773)
   i. The tongue and its associated muscles form the floor of the oral cavity
      a. it is composed of skeletal muscles covered by mucous membrane
      b. it is divided into symmetrical lateral halves by a median septum that is attached inferiorly to the hyoid bone, styloid process of the temporal bone, and mandible
      c. it consists of extrinsic and intrinsic muscles
      d. the extrinsic muscles originate outside the tongue and insert into it
         - they move the tongue for food manipulation during chewing and swallowing
         - they also form the floor of the mouth and hold the tongue in position
      e. the intrinsic muscles originate and insert within the tongue
         - they alter the shape and size of the tongue for speech and swallowing
      f. the lingual frenulum is a fold of mucous membrane that attaches the midline of the inferior surface of the tongue to the floor of the mouth
         - it limits movement of the tongue posteriorly
         - if the lingual frenulum is too short or rigid, ankyloglossia occurs (being “tongue-tied”)
      g. the superior and lateral surfaces of the tongue are covered with papillae, which are projections of the lamina propria covered with epithelium
         - fungiform papillae are mushroom-like projections distributed among the filiform papillae and are more numerous near the tip of the tongue
         - they appear red and most of them contain taste buds
         - vallate (circumvallate) papillae are arranged in the form of an inverted V on the posterior surface of the tongue
         - all of them contain taste buds
         - foliate papillae, on a tongue’s lateral margins, have few taste buds in adults
         - filiform papillae are cone-shaped projections distributed in parallel rows over the anterior two-thirds of the tongue
         - they appear whitish and they lack taste buds
         - they increase friction between the tongue and food, making it easier for the tongue to move food

4. Teeth (Dentes): (p. 773)
   i. The teeth are located in sockets of the alveolar processes of the mandible and maxillae; the alveolar processes are covered by the gingivae or gums, which extend slightly into each socket to form the gingival sulcus
   ii. The sockets are lined by the periodontal ligament or membrane which anchors the teeth in position and acts as a shock absorber during chewing.
   iii. A typical tooth consists of three major regions:
      a. crown is the visible portion located above the level of the gums
      b. one to three roots are embedded in the socket
      c. neck is the narrow junction line of the crown and root near the gum line
   iv. A tooth is composed of several substances:
      a. dentin forms most of the mass of a tooth
         - it consists of calcified connective tissue that is harder than bone tissue
b. the dentin of the crown encloses a **pulp cavity** that is filled with **pulp**, which consists of connective tissue containing blood vessels, lymphatic vessels, and nerves
   - **root canals** are narrow extensions of the pulp cavity that travel through the root; at the end of each root canal is an opening called the **apical foramen** through which blood vessels, lymphatic vessels, and nerves enter the tooth

c. the dentin of the crown is covered by **enamel**
   - it is composed of calcium salts and it is the hardest substance in the body
   - it protects the tooth against the wear of chewing and it is a barrier against acids that may easily dissolve the dentin

d. the dentin of the root is covered by **cementum**
   - it is a bonelike substance that attaches the root to the periodontal ligament

v. Blood supply to the teeth is provided by the anterior and posterior superior alveolar branches of the maxillary arteries and by the incisive and dental branches of the inferior alveolar arteries.

vi. The teeth receive sensory fibers from branches of the maxillary and mandibular divisions of the trigeminal (V) nerves.

vii. **Endodontics** is the branch of dentistry concerned with the prevention, diagnosis, and treatment of diseases that affect the pulp, root, periodontal ligament, and alveolar bone; **orthodontics** is the branch of dentistry concerned with the prevention and correction of abnormally aligned teeth; **periodontics** is the branch of dentistry concerned with the treatment of abnormal conditions of tissues immediately surrounding the teeth (e.g., gums)

viii. Humans have two sets of teeth or dentitions:
   a. **deciduous teeth, primary teeth, milk teeth, or baby teeth**
      - begin to erupt at about 6 months of age, and one pair appears at about each month thereafter until all 20 teeth are present
      - each row contains:
        - 2 **central incisors** which are adapted to cut into food
        - each has one root
        - 2 **lateral incisors** which are also adapted to cut into food
        - each has one root
        - 2 **cuspids (canines)** which are adapted to tear and shred food
        - each has one root
        - 2 **first molars** which are adapted to crush and grind food
        - each has 4 cusps
        - upper ones have 3 roots; lower ones have 2 roots
        - 2 **second molars** which also crush and grind food
        - each has 4 cusps
        - upper ones have 3 roots; lower ones have 2 roots
   b. **deciduous teeth are gradually lost between 6 and 12 years of age and are replaced by the permanent (secondary) teeth**
      - the 32 **permanent teeth** appear between age 6 and adulthood
      - each row contains:
        - 2 central incisors
        - 2 lateral incisors
        - 2 canines
        - 2 **first premolars (bicuspids)**
- replace the deciduous first molars
  - each has 2 cusps
  - upper ones have 2 roots; lower ones have 1 root
- 2 second premolars (bicuspids)
  - replace the deciduous second molars
  - each has 2 cusps
  - each has 1 root
- 2 first molars
- 2 second molars
- 2 third molars (wisdom teeth)

ix. The following terms are used in dental terminology to describe the surface orientation of teeth (see Table 25.1):
  a. labial
  b. buccal
  c. lingual
  d. palatal
  e. mesial
  f. distal
  g. occlusal

F. Pharynx (p. 776)
1. Mastication or chewing reduces the food to a soft, flexible mass called a bolus that is swallowed.
2. In deglutition or swallowing, the bolus of food first enters the pharynx, the funnel-shaped tube that extends from the internal nares to the esophagus posteriorly and the larynx anteriorly.
3. The pharynx is composed of skeletal muscle covered by mucous membrane.
4. Muscular contractions of the oropharynx and laryngopharynx help propel the bolus of food into the esophagus.

G. Esophagus (p. 776)
1. The esophagus is a muscular, collapsible tube that travels from the laryngopharynx down through the mediastinum anterior to the spine and posterior to the trachea, through the esophageal hiatus in the diaphragm, and ends in the superior portion of the stomach; sometimes, a portion of the stomach protrudes through the esophageal hiatus resulting in a hiatal hernia.
2. Blood is supplied to the esophagus by the inferior thyroid, thoracic aorta, intercostal, phrenic, and left gastric arteries; blood drains into adjacent veins.
3. The esophagus is innervated by the recurrent laryngeal nerves, the cervical sympathetic chain, and the vagus (X) nerves.
4. Histology: The wall of the esophagus consists of the following layers which, listed in sequence from innermost to outermost, are:
   i. mucosa
      a. in addition to standard features of mucosa, it also contains mucous glands near the stomach
   ii. submucosa
      a. in addition to standard features of submucosa, it also contains mucous glands
   iii. muscularis
      a. upper third is skeletal muscle tissue
      b. middle third is skeletal and smooth muscle tissue
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c. lower third is smooth muscle tissue
iv. **adventitia**, rather than serosa; so-named because:
   a. areolar connective tissue is not covered by epithelium
   b. connective tissue merges with the connective tissue of surrounding structures

5. The esophagus performs two functions:
   i. secretes mucus
   ii. transports food to the stomach
      a. entry of food into the esophagus is regulated by the **upper esophageal sphincter**
      b. food is pushed through the esophagus by involuntary waves of muscular contraction called **peristalsis**, which is a function of the muscularis
      c. passage of the bolus is facilitated by mucus secreted by esophageal glands
      d. just above the diaphragm is the **lower esophageal (gastroesophageal or cardiac) sphincter** which briefly relaxes to permit passage of the bolus from the esophagus into the stomach

H. Stomach (p. 778)

1. The stomach is a typically J-shaped organ located directly under the diaphragm in the upper left portion of the abdominal cavity; its precise position and size vary continually.

2. The stomach consists of four major areas:
   i. **cardia**, which surrounds the superior opening of the stomach
   ii. **fundus**, which is the rounded portion above and to the left of the cardia
   iii. **body**, which is the large central portion
   iv. **pylorus**, which is the inferior portion that connects to the **duodenum**; it has two regions:
      a. **pyloric antrum**, which connects to the stomach’s body
      b. **pyloric canal**, which leads into the duodenum

3. When the stomach is empty, its mucosa lies in large folds called **rugae**.

4. The pylorus communicates with the duodenum via the **pyloric sphincter**.

5. The concave medial border is called the **lesser curvature**; the convex lateral border is called the **greater curvature**.

6. The stomach receives its blood supply from branches of the celiac artery, i.e., gastric, gastroepiploic, and short gastric arteries; blood drains into veins of the same name and eventually into the hepatic portal vein.

7. The vagus (X) nerves convey parasympathetic fibers which form synapses within the submucosal plexus and the myenteric plexus of the stomach; the sympathetic innervation of the stomach arises from the celiac ganglia.

8. **Histology**: The wall of the stomach consists of the four standard layers found throughout the GI tract, as well as the following modifications:
   i. the **mucosa** has **surface mucous cells** that secrete mucus
      a. these cells extend inward and form many narrow channels called **gastric pits** which extend down into the lamina propria
      b. at the bottoms of the pits are openings of the **gastric glands** whose secretions flow into the gastric pits
   c. the gastric glands contain four types of secretory cells:
      1. **mucous neck cells**, which secrete mucus
      2. **chief (zymogenic) cells**, which secrete **pepsinogen** and **gastric lipase**
      3. **parietal (oxyntic) cells**, which secrete **hydrochloric acid** (that converts pepsinogen into the active pepsin and kills microbes in...
food) and intrinsic factor (that is essential for absorption of vitamin B₁₂)
- the secretions of the above three types of cells collectively form gastric juice, which is secreted into the stomach lumen

4. **G cells**, which are located primarily in the pyloric antrum and secrete the hormone gastrin into the blood
   - **submucosa**
   - **muscularis** has three layers of smooth muscle tissue:
     a. outer longitudinal layer
     b. middle circular layer
     c. inner oblique layer, found primarily in the body of the stomach
     - this three-layered arrangement permits contractions in a variety of directions to effectively churn and break apart the food, mix it with gastric juice, and pass it into the duodenum
   - **serosa** is part of the visceral peritoneum
     a. at the lesser curvature, it extends upward to the liver as the lesser omentum
     b. at the greater curvature, it continues downward as the greater omentum

9. The functions of the stomach include:
   i. **mixing waves** that macerate food, mix it with gastric juice, and reduce it to a soupy liquid called **chyme**
   ii. propelling small quantities of chyme through the slightly open pyloric sphincter into the duodenum
   iii. digestion of proteins by **pepsin** into **peptides**; pepsin is secreted as inactive pepsinogen by chief cells and is subsequently converted into its active form by hydrochloric acid
   iv. limited digestion of triglycerides by **gastric lipase**
   v. depending upon the chemical composition of a meal, the stomach usually empties all its contents into the duodenum about 2 to 4 hours after ingestion
   vi. the only substances absorbed into the stomach wall are:
     a. some water
     b. electrolytes
     c. certain drugs (notably aspirin)
     d. alcohol

I. **Pancreas** (p. 782)
   1. The pancreas is retroperitoneal and is located posterior to the greater curvature of the stomach.
   2. The pancreas consists of three major regions:
     i. **medial head** located near the curve of the duodenum
     ii. **central body** located superior and to the left of the head
     iii. lateral, tapering **tail**
   3. Pancreatic exocrine secretions pass from secretory cells into small ducts that unite to form two larger ducts:
     i. **pancreatic duct (duct of Wirsung)**
        a. in most people, it joins the **common bile duct** from the liver and gallbladder to form the **hepatopancreatic ampulla (ampulla of Vater)** which enters the duodenum at an elevation called the **major duodenal papilla** that is located about 10 cm below the pyloric sphincter
        ii. smaller **accessory duct (duct of Santorini)** that empties into the duodenum about 2.5 cm above the hepatopancreatic ampulla
4. The pancreas receives its blood supply from the superior and inferior pancreaticoduodenal arteries and the splenic and superior mesenteric arteries; blood drains into veins of the same name and eventually into the hepatic portal vein.

5. The nerves to the pancreas are autonomic nerves derived from the celiac and superior mesenteric plexuses; included are preganglionic vagal, postganglionic sympathetic, and sensory fibers.

6. **Histology:**
   i. about 1% of the glandular epithelial cells are organized into clusters called **pancreatic islets (islets of Langerhans)**
      a. they form the endocrine portion of the pancreas and secrete the following hormones which were studied in Chapter 23:
         - glucagon
         - insulin
         - somatostatin
         - pancreatic polypeptide
   ii. the remaining 99% of the glandular epithelial cells are arranged in clusters called **acini**
      a. they form the exocrine portion of the pancreas and secrete a mixture of fluid and digestive enzymes called **pancreatic juice**

7. The major exocrine function of the pancreas is to secrete pancreatic juice which includes the following components:
   i. water
   ii. some salts
   iii. sodium bicarbonate, which buffers acidic gastric juice in chyme, stops the action of pepsin, and provides the proper pH for the action of digestive enzymes in the small intestine
   iv. several digestive enzymes:
      a. **pancreatic amylase**, which digests carbohydrates
      b. **trypsin**, which digests proteins
      c. **chymotrypsin**, which also digests proteins
      d. **carboxypeptidase**, which also digests proteins
      e. **elastase**, which also digests protein
      f. **pancreatic lipase**, which digests triglycerides
      g. **ribonuclease**, which digests RNA
      h. **deoxyribonuclease**, which digests DNA
J. Liver (p. 784)

1. The liver is the heaviest gland of the body and, after the skin, the second largest organ of the body; it is located under the diaphragm in the upper right portion of the abdominal cavity.

2. It is completely covered by a layer of dense irregular connective tissue that is, in turn, almost completely covered by visceral peritoneum.

3. The liver consists of two major lobes:
   i. large right lobe
   ii. smaller left lobe; associated with the left lobe are two smaller lobes:
      a. inferior quadrate lobe
      b. posterior caudate lobe

4. Histology:
   i. the lobes consist of functional units called lobules that are composed of specialized epithelial cells called hepatocytes
   ii. the hepatocytes are arranged in irregular, branching, interconnected plates around a central vein that receives blood from sinusoids
   iii. the sinusoids are lined by endothelium and partly by phagocytic cells called stellate reticuloendothelial (Kupffer’s) cells which destroy worn-out leukocytes, erythrocytes, bacteria, and other foreign matter
   iv. hepatocytes secrete bile, which is partially an excretory product and partially a digestive secretion; bile has several important components including:
      a. bile salts play a role in emulsification of fats and absorption of the products of fat digestion
      b. cholesterol
      c. bile pigments, notably bilirubin that is derived from heme; one of the breakdown products of bilirubin gives feces their normal brown color
   v. bile is secreted into bile canaliculi that empty into small bile ductules which in turn pass bile into bile ducts
   vi. these small ducts merge to eventually form the larger right and left hepatic ducts, which unite to form the common hepatic duct that exits the liver
   vii. the common hepatic duct merges with the cystic duct from the gallbladder to form the common bile duct; bile enters the cystic duct and is temporarily stored in the gallbladder

5. The liver receives blood from two sources, and its blood drains into one set of veins:
   i. the hepatic artery provides oxygenated blood
   ii. the hepatic portal vein delivers deoxygenated blood containing newly absorbed nutrients from the GI tract
   - branches of these two blood vessels carry blood to the sinusoids, where oxygen, most nutrients and certain toxins are absorbed by the hepatocytes
   - products manufactured by hepatocytes and nutrients needed by other cells are secreted back into the blood, which then drains into the central vein and eventually into a hepatic vein
   - branches of the hepatic portal vein, hepatic artery, and bile duct typically accompany each other and collectively form a portal triad
6. The nerve supply to the liver consists of parasympathetic innervation from the vagus (X) nerves and sympathetic innervation from the greater splanchnic nerves through the celiac ganglia.

7. The functions of the liver include:
   i. carbohydrate metabolism
   ii. lipid metabolism
   iii. protein metabolism
   iv. processing of drugs and hormones
   v. excretion of bilirubin
   vi. synthesis of bile salts
   vii. storage of numerous substances including glycogen, certain vitamins, and some minerals
   viii. phagocytosis
   ix. activation of vitamin D

K. Gallbladder (p. 784)
1. The gallbladder is a pear-shaped sac that is located in a depression of the posterior surface of the right lobe of the liver; it consists of a broad fundus, a central body, and a tapering neck.
2. Histology:
   i. the mucosa consists of simple columnar epithelium arranged in rugae
   ii. it lacks a submucosa
   iii. the muscularis, composed of smooth muscle tissue, contracts upon hormonal stimulation to eject stored bile into the cystic duct
   iv. the outer layer is the visceral peritoneum
3. The functions of the gallbladder are to store and concentrate bile until it is needed in the small intestine.
4. When the small intestine is empty, the sphincter of the hepatopancreatic ampulla or sphincter of Oddi closes; this causes bile to accumulate in the common bile duct and enter the cystic duct and the gallbladder where it is stored.
5. When food enters the duodenum, the hormone cholecystokinin (CCK) stimulates contraction of the wall of the gallbladder and relaxation of the sphincter of the hepatopancreatic ampulla; this causes bile to flow into the duodenum.
6. The gallbladder receives its blood supply from the cystic artery, which usually arises from the right hepatic artery; blood drains into cystic veins.
7. The gallbladder is innervated by branches from the celiac plexus and the vagus (X) nerves.

L. Small Intestine (p. 788)
1. The small intestine extends from the pyloric sphincter to the large intestine; it averages 2.5 cm in diameter and about 3 m in length in a living person, but is about 6.5 m long in a cadaver.
2. It consists of three regions:
   i. duodenum
      a. is about 25 cm long
      b. is retroperitoneal
   ii. jejunum
      a. is about 1 m long
   iii. ileum
      a. is about 2 m long
      b. meets the large intestine at the ileocecal sphincter
3. The small intestine receives blood from the superior mesenteric artery and the gastroduodenal artery; blood drains into the superior mesenteric vein.
4. The nerves to the small intestine are supplied by the superior mesenteric plexus; branches of the plexus contain postganglionic sympathetic fibers, preganglionic parasympathetic
fibers, and sensory fibers (which are both vagal and of spinal nerves). The small intestine’s muscularis contains the myenteric plexus and the submucosa contains the submucosal plexus; the nerve fibers are derived primarily from the sympathetic division of the ANS and partly from the vagus (X) nerves.

5. **Histology**: Since almost all digestion and absorption of nutrients occurs in the small intestine, the standard four major layers that form the wall of the GI tract have special modifications to ensure that these processes are completed in the small intestine:
   
   i. **the mucosa** has numerous villi which greatly increase the surface area available for digestion and absorption
      - each villus has a core of lamina propria in which there are an arteriole, a venule, a capillary network, and a lacteal, i.e., a lymphatic capillary
   
   ii. the mucosal epithelium consists of simple columnar epithelium and contains several types of cells, including:
      - **goblet cells** which secrete mucus
      - **absorptive cells** which absorb digested nutrients
         - the apical plasma membrane has numerous microvilli that form a brush border
         - the microvilli increase the surface area available for absorption
         - the brush border also contains several digestive enzymes
   
   iii. the mucosa also contains deep crevices containing intestinal glands (crypts of Lieberkuhn) which secrete intestinal juice
   
   iv. the mucosal epithelium also contains:
      - **Paneth cells** which secrete lysozyme and are capable of phagocytosis; these cells are located in the deepest parts of the intestinal glands
      - **enteroendocrine cells** which secrete three hormones into the blood
   
   v. there are numerous lymphatic nodules present in the lamina propria, especially in the ileum; these include:
      - **solitary lymphatic nodules**
      - **aggregated lymphatic follicles (Peyer’s patches)**
         - they are components of MALT
   
   vi. the mucosa also has circular folds (or plicae circulares) which are permanent ridges that further increase the surface area available for digestion and absorption; these folds also cause the chyme to spiral as it passes through the small intestine
   
   vii. the submucosa of the duodenum contains duodenal (Brunner’s) glands which secrete an alkaline mucus that helps neutralize gastric acid in the chyme
   
   viii. the muscularis consists of an outer thinner layer of longitudinal smooth muscle tissue and an inner thicker layer of circular muscle tissue
   
   ix. the serosa completely surrounds the small intestine except for a major portion of the duodenum

6. **Functions**:
   
   i. digestion of carbohydrates, proteins, and lipids is completed in the small intestine due to the collective action of pancreatic juice, bile, and intestinal juice
   
   ii. the surfaces of microvilli have brush border enzymes:
      - **α-dextrinase**
      - **maltase**
      - **sucrase**
      - **lactase**
      - the above four enzymes digest specific carbohydrates
      - **aminopeptidase**
      - **dipeptidase**
         - these two peptidases digest proteins
      - **nucleosidases**
Digestion

h. **phosphatases**
   - these two enzymes digest nucleotides

iii. there are two types of movements that occur in the small intestine:
   a. **segmentations** slosh chyme back and forth to thoroughly mix the chyme with digestive juices and bring nutrients into contact with the mucosa for absorption
   b. a type of **peristalsis** called **migrating motility complex (MMC)** propels the chyme through the small intestine

iv. about 90% of **absorption** of nutrients occurs in the small intestine (the other 10% occurs in the stomach and large intestine)
   a. absorbed nutrients pass from the absorptive cells into the capillary network or lacteal within a villus
   b. any undigested or unabsorbed substances pass into the large intestine

M. **Large Intestine** (p. 794)
   1. The functions of the large intestine include:
      i. completion of absorption
      ii. production of certain vitamins
      iii. formation and storage of feces
      iv. expulsion of feces
   2. The large intestine is about 1.5 m long and 6.5 cm in diameter.
   3. It is attached to the posterior abdominal wall by the **mesocolon**.
   4. The large intestine consists of four major regions:
      i. **cecum**, a blind pouch in the lower right portion of the abdominal cavity
         a. chyme from the ileum enters the cecum via the **ileocecal sphincter** or valve
         b. attached to the cecum is the **appendix** or **vermiform appendix**
            - the mesentery of the appendix is the **mesoappendix**, which attaches the appendix to the inferior part of the mesentery of the ileum
      ii. **colon**, which consists of four segments:
         a. retroperitoneal **ascending colon** ascends on the right side of the abdominal cavity to the **right colic (hepatic) flexure**
         b. **transverse colon** travels across to the left side to the **left colic (splenic) flexure**
         c. retroperitoneal **descending colon** descends on the left side of the abdominal cavity to the level of the iliac crest
         d. **sigmoid colon** travels medially from the left iliac crest to the level of the third sacral vertebra
      iii. **rectum**, which descends anterior to the sacrum and coccyx
      iv. **anal canal**, which is the terminal 2 to 3 cm of the rectum
         a. the mucous membrane is arranged in longitudinal folds called **anal columns** which contain blood vessels
         b. the opening to the exterior is called the **anus** which is normally closed by two sphincters:
            - internal sphincter of smooth muscle tissue (involuntary)
            - external sphincter of skeletal muscle tissue (voluntary)
   5. Blood is supplied to the cecum and colon by branches of the superior and inferior mesenteric arteries; this blood drains into the superior and inferior mesenteric veins. Blood is supplied to the rectum and anal canal by the superior, middle, and inferior rectal arteries; this blood drains into the corresponding rectal veins.
   6. The nerves to the large intestine consist of sympathetic, parasympathetic, and sensory components:
i. the sympathetic innervation is derived from the celiac, superior, and inferior mesenteric ganglia and superior and inferior mesenteric plexuses; the fibers reach the viscera via the thoracic and lumbar splanchnic nerves
ii. the parasympathetic innervation is derived from the vagus (X) and pelvic splanchnic nerves

7. Histology:
   i. the mucosa contains:
      a. simple columnar epithelium whose main function is water reabsorption
      b. goblet cells which secrete mucus; note that no enzymes are secreted
      c. solitary lymphatic nodules
   ii. the submucosa has no unique features
   iii. the muscularis consists of two layers of smooth muscle tissue
      a. an inner circular layer and an outer longitudinal layer; the latter has 3 thickened longitudinal bands called teniae coli
      b. tonic contractions of these bands create a series of pouches called haustra in the colon
   iii. the serosa has epiploic appendages which are small pouches of visceral peritoneum that are filled with fat and attached to the teniae coli

8. Functions:
   i. ileal peristalsis moves chyme through the ileocecal sphincter into the cecum
   ii. within the large intestine several types of movements occur:
      a. haustral churning
      b. peristalsis
      c. mass peristalsis
   iii. bacteria that live in the lumen perform several activities:
      a. ferment any remaining carbohydrates and release gases that contribute to flatus in the colon
      b. convert remaining proteins into amino acids and simpler substances, some of which contribute to the odor of feces
      c. decompose bilirubin to simpler pigments that give feces their brown color
      d. produce several vitamins including some B vitamins and vitamin K
   iv. due to absorption of water by epithelial cells, the chyme is converted into feces
   v. distension of the rectum by feces initiates a defecation reflex which involves a number of events:
      a. contraction of longitudinal rectal muscles by parasympathetic nerves
      b. opening of the internal anal sphincter by parasympathetic nerves
      c. voluntary relaxation of the external anal sphincter
      d. voluntary contractions of the diaphragm and abdominal muscles
         - diarrhea is an increase in the frequency, volume and fluid content of the feces; constipation refers to infrequent or difficult defecation

Note: Table 25.2 provides a Summary of Organs of the Digestive System and Their Functions.

N. Development of the Digestive System (p. 799)
   1. Cells of the endoderm form the primitive gut; the splanchnic mesoderm becomes associated with this endoderm.
   2. Therefore, the primitive gut has a double-layered wall:
      i. endodermal layer, which develops into the epithelial lining and glands of most of the GI tract
      ii. mesodermal layer, which develops into smooth muscle and connective tissue of the GI tract
3. The primitive gut elongates and differentiates into an anterior **foregut**, an intermediate **midgut**, and a posterior **hindgut**.

4. A depression of the ectoderm called the **stomodeum** develops into the **oral cavity**; the **oropharyngeal membrane** ruptures so that the foregut is continuous with the oral cavity.

5. Another depression of the ectoderm called the **proctodeum** develops into the **anus**; the **cloacal membrane** ruptures so that the hindgut is continuous with the anus.

6. The foregut develops into the following organs:
   i. **pharynx**
   ii. **esophagus**
   iii. **stomach**
   iv. **portion of the duodenum**

7. The midgut develops into:
   i. **remainder of the duodenum**
   ii. **jejunum**
   iii. **ileum**
   iv. **portions of the large intestine**

8. The hindgut develops into:
   i. **remainder of the large intestine**

9. The endoderm of the foregut develops into:
   i. **salivary glands**
   ii. **liver**
   iii. **gallbladder**
   iv. **pancreas**

**O. Aging and the Digestive System** (p. 800)

1. The general effects of aging on the digestive system include:
   i. decreased secretory mechanisms
   ii. decreased motility of the digestive organs
   iii. loss of strength and tone of the muscular tissue and its supporting structures
   iv. changes in neurosensory feedback
   v. diminished response to pain and internal sensations

2. There are numerous specific changes that may occur in the GI tract and associated digestive organs with aging.

**P. Key Medical Terms Associated with the Digestive System** (p. 802)

1. Students should familiarize themselves with the glossary of key medical terms.