

CHAPTER SCOPE

Question: Why do we eat? **Answer:** To survive, right? Yet the answer is more complex than simply survival. As we learned in chapters 2 through 5 we eat primarily for two reasons: 1) to supply our tissue cells with the necessary **carbohydrate, lipid (fat), and protein** nutrients as *fuel* for cell respiration and ATP production; and 2) to provide simple, raw materials for the *biosynthesis* of vital structural and functional molecules of the body. Among the functional molecules are the *neurotransmitter* substances, described in the nervous system (chapters 7 through 10), all of the *hormones* described in chapter 11, and the *digestive enzymes* to be discussed in this chapter. All of these chemicals, and indeed most of your body molecules, are assembled from the basic raw materials that have been digested and absorbed from the foods we eat.

Most activities in the body such as the neuron membrane potential discussed with the nervous system and the membrane pumps along the nephron of the kidneys employ energy (ATP) derived from fuel foods. The energy for activities that hormones demand from their target tissues also is derived from fuel foods. Contractions of skeletal muscle (chapter 12) and cardiac muscle (chapters 13 and 14) also have great demand for metabolic energy as muscle fibers move bones of the skeleton and pump blood around the body. Similarly, our respiratory system (chapter 15) expends energy drafting O₂ gas into the body and blowing CO₂ wastes out into the atmosphere. This ventilation effort enables oxygen-requiring metabolic processes to occur in all cells.

This chapter introduces the digestive system tissues through which carbohydrates, lipids, and protein fuel foods are **digested** by enzymes and **absorbed** into the bloodstream. Notice that we have come a full circle in the book. The enzyme catalyzed *hydrolysis* reactions reviewed here are the reverse of the *dehydration synthesis* steps we traced very early in chapter 2. Digestion and absorption is controlled by the **autonomic nervous system** (especially the *parasympathetic* division), the **endocrine system** and by the local enteric nervous system. The next chapter will expand on the topics that are concerned with the regulation of metabolic processes in the body and their regulation by hormones, most of which are very familiar to us.

I. INTRODUCTION TO THE DIGESTIVE SYSTEM

Within the lumen of the gastrointestinal tract, large food molecules are hydrolyzed into their monomers (subunits). These monomers pass through the inner layer, or mucosa, of the small intestine to enter the blood or lymph in a process called absorption. Digestion and absorption are aided by specializations of the mucosa and by characteristic movements caused by contractions of the muscle layers of the gastrointestinal tract.

A. Multiple Choice

- ___ 1. Which statement about the *digestive system* is *false*?
 - a. Fully active digestive enzymes are limited in their location to the lumen (cavity).
 - b. Indigestible materials never actually enter the body.
 - c. Wavelike muscle contractions and sphincter muscles regulate movement throughout the system.
 - d. Transport is normally in one direction only.
 - e. All of these statements about the *digestive system* are true.
- ___ 2. Which term best describes the process of swallowing food?
 - a. ingestion
 - b. mastication
 - c. deglutition
 - d. absorption
 - e. defecation
- ___ 3. Which is *not* an accessory organ of the digestive system?
 - a. stomach
 - b. salivary glands
 - c. liver
 - d. tongue
 - e. pancreas

- ___ 4. Which is *not* a layer (*tunic*) found along the gastrointestinal (GI) tract?
- mucosa
 - submucosa
 - capsule
 - muscularis
 - serosa
- ___ 5. Which GI layer (*tunic*) features blood and lymphatic vessels, glands, and nerves?
- mucosa
 - submucosa
 - capsule
 - muscularis
 - serosa
- ___ 6. The myenteric (*Auerbach's*) plexus is a major nerve supply that innervates which layer of the gastrointestinal (GI) tract?
- mucosa
 - submucosa
 - capsule
 - muscularis
 - serosa
- ___ 7. Which statement about *parasympathetic* nerves of the gastrointestinal (GI) tract is *false*?
- The vagus nerve stimulates an increase in motility (smooth muscle contractions) and secretions of the GI tract.
 - The lower portion of the large intestine is innervated by spinal nerves emerging from the sacral region.
 - Preganglionic parasympathetic neurons synapse with postganglionic neurons at the submucosal plexus and myenteric plexus.
 - Parasympathetic stimulation decreases peristalsis and reduces GI secretions.
- ___ 8. Which description of the “intrinsic” or local regulation of the gastrointestinal (GI) tract is *false*?
- It works alone in controlling all processes of digestion and absorption.
 - It relies upon intrinsic sensory neurons located within the gut wall.
 - It may be called the enteric nervous system, or the enteric brain.
 - It includes paracrine regulatory molecules acting locally.
 - It includes regulatory control by hormones secreted by the mucosal layer.

B. True or False/Edit

- ___ 9. The primary functions of the digestive system are digestion and absorption.
- ___ 10. The digestive system is open to the environment at both ends, and its epithelial lining is considered an outside surface.
- ___ 11. The esophagus runs along the back wall of the thoracic cavity, behind the lungs, and enters the abdominal cavity at the level of the diaphragm.
- ___ 12. The *submucosa* layer is both an absorptive and major secretory layer composed of simple columnar epithelium and an underlying lamina propria.
- ___ 13. Sympathetic nerve fibers act antagonistically to the effects of parasympathetic fibers, reducing peristalsis and secretions and stimulating the contraction of sphincter muscles.
- ___ 14. The digestive system is regulated intrinsically by the autonomic nervous system and endocrine system, and extrinsically by the enteric nervous system and various paracrine regulators.
- ___ 15. Paracrine molecules are produced locally within the tissues of the GI tract and serve to complement the regulatory actions of the enteric nervous system.

II. FROM MOUTH TO STOMACH

Swallowed food is passed through the esophagus to the stomach by wavelike contractions known as peristalsis. The mucosa of the stomach secretes hydrochloric acid and pepsinogen. Upon entering the lumen of the stomach, pepsinogen is converted into the active protein-digesting enzyme known as pepsin. The stomach partially digests proteins and functions to store its contents, called chyme, for later processing by the small intestine.

A. Multiple Choice

- ___ 16. Which of the following is *not* one of the three phases of swallowing?
- nasal
 - oral
 - pharyngeal
 - esophageal
- ___ 17. Which part of the brain functions as a swallowing center, coordinating the neurons that establish the pattern of muscle contractions in swallowing?
- cerebral cortex
 - basal nucleus
 - hypothalamus
 - medulla oblongata
 - cerebellum
- ___ 18. The *pyloric* sphincter is located at the end of the
- esophagus leading into the stomach.
 - stomach leading into the small intestine.
 - pancreatic duct leading into the small intestine.
 - common bile duct leading into the small intestine.
- ___ 19. Which statement about the *esophagus* is *false*?
- The esophagus passes through the thoracic cavity and through the diaphragm.
 - The esophagus is lined with nonkeratinized, stratified squamous epithelium.
 - The upper one-third contains smooth muscle and the bottom one-third contains skeletal muscle.
 - Constriction of the lower esophageal (gastroesophageal) sphincter normally prevents stomach contents from regurgitating into the esophagus.
 - All of these statements regarding the esophagus are true.
- ___ 20. The *antrum* region of the stomach is most associated with which other region of the stomach?
- cardiac
 - fundus
 - body
 - pyloric
 - None of these terms is associated with the antrum.
- ___ 21. Which of the following is a true *endocrine* cell within the gastric glands of the stomach?
- goblet cell
 - G cell
 - parietal cell
 - chief cell
 - enterochromaffin-like cell (ECL)
- ___ 22. The gastric gland cells that secrete histamine and serotonin as paracrine regulators of the GI tract, are the
- parietal cells.
 - chief (or zymogenic) cells.
 - enterochromaffin-like cells.
 - G cells.
 - D cells.
- ___ 23. The _____ cells of the gastric glands secrete the hormone gastrin; whereas the _____ cells secrete the hormone somatostatin.
- parietal; chief
 - enterochromaffin-like; D
 - chief; G
 - G; D
 - D; enterochromaffin-like

- ___ 24. Which function is *not* served by the presence of *hydrochloric acid* in the stomach (gastric) juices?
- Hydrochloric acid denatures the tertiary structure of ingested proteins making them more digestible.
 - Hydrochloric acid alters the structure of pepsinogen, resulting in activation of the enzyme, pepsin.
 - Hydrochloric acid partially digests carbohydrate and fat molecules as well as protein molecules in chyme.
 - Hydrochloric acid is the ideal (optimum) pH for maximum pepsin activity.
 - All of these functions are served by the acidic gastric juice.
- ___ 25. Which mechanism does *not* explain how the *stomach mucosa* resists self-digestion and the formation of ulcers?
- A thin layer of alkaline mucus containing bicarbonate buffer lines the stomach mucosa.
 - The gastric mucosa cells are very impermeable to the acid in the stomach lumen.
 - The entire epithelial lining is replaced every three days.
 - Buffers are released from Brunner's glands and the pancreas to neutralize the stomach acids.
 - All of these mechanisms help resist self-digestion and ulcer formation in the stomach.

B. True or False/Edit

- ___ 26. Forming a bolus while chewing is under voluntary control, while the pharyngeal and esophageal phases are involuntary and cannot be stopped once they have begun.
- ___ 27. Peristaltic contractions are wavelike, due first to the squeezing action of circular muscles, followed by the shortening action of longitudinal muscles.
- ___ 28. The esophagus empties its contents into the *cardiac* region of the stomach.
- ___ 29. Hydrochloric acid (HCl) present in the stomach does not directly digest protein ingested with foods, but rather facilitates the activation of the enzyme, pepsin.
- ___ 30. Ingested proteins are completely digested in the stomach by the combined action of the enzyme, pepsin and the presence of HCl.
- ___ 31. Ingested carbohydrates and fats are not digested in the stomach at all.
- ___ 32. The only substances absorbed by stomach epithelium are alcohol and aspirin, which are soluble in the lipid component of the membranes.
- ___ 33. Ulcers of the stomach and duodenum that are produced by the action of HCl are known collectively as gastric ulcers.
- ___ 34. The duodenum is normally protected against gastric acid erosion by the buffering action of bicarbonate found both in alkaline pancreatic juice and in secretions from Brunner's glands.
- ___ 35. The only function of the stomach that appears to be essential for life is the secretion of the intrinsic factor, a molecule necessary for vitamin B12 absorption.
- ___ 36. Antihistamine drugs such as those used to treat head cold and allergy symptoms are found to be effective in blocking the histamine-stimulated secretion of stomach acid.
- ___ 37. The treatment for many people who have peptic ulcers is an antibiotic because most peptic ulcers are caused by a bacterium known as *Helicobacter pylori*.

C. Label the Figure — The Stomach

Knowledge of the stomach anatomy is crucial to understanding how it works, or its physiology. Study the following figure of the stomach. Label the structures of the stomach by writing each term on the appropriate line provided. Some terms have been provided to help you. When you are finished check your work with figure 18.5 in the text. Then, erase your work and set-aside until its time to review for the next examination!

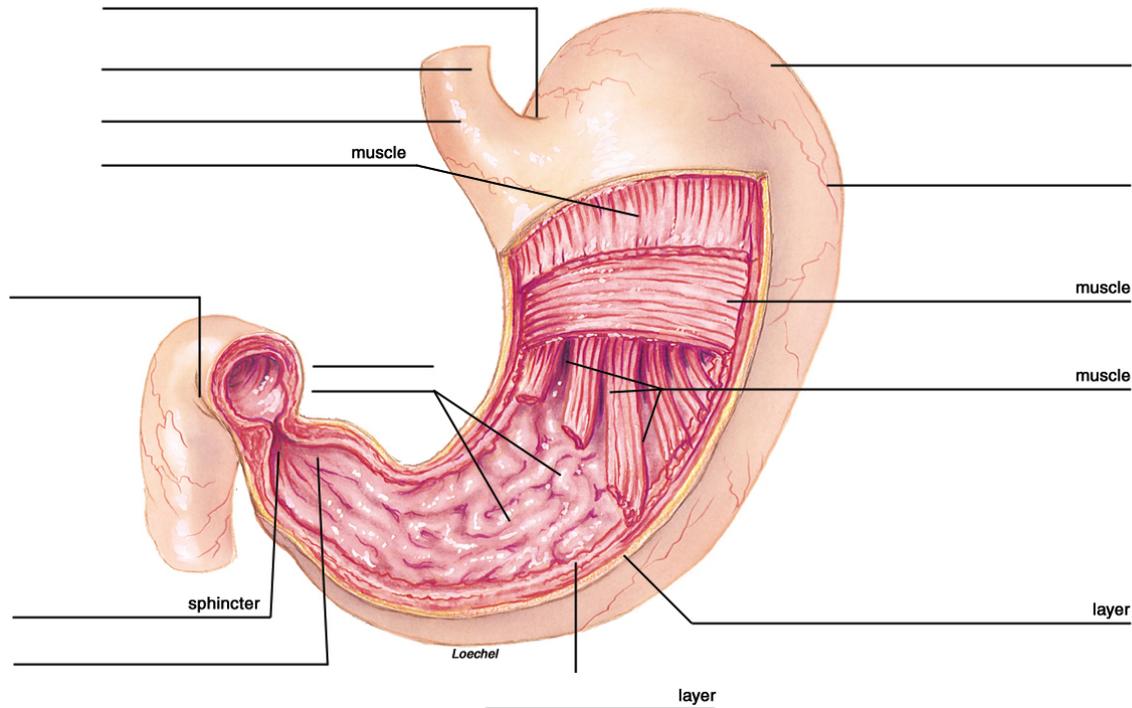


Figure 18.1 The primary regions and structures of the stomach.

III. SMALL INTESTINE

The mucosa of the small intestine is folded into villi that project into the lumen. In addition, the cells that line these villi have foldings of their plasma membrane called microvilli. This arrangement greatly increases the surface area for absorption. It also improves digestion, since the digestive enzymes of the small intestine are embedded within the plasma membrane of the microvilli.

A. Multiple Choice

- ___ 38. The *longest* portion of the small intestine is the
 - a. duodenum.
 - b. ileum.
 - c. jejunum.
- ___ 39. Bile salts, vitamin B₁₂, water, and electrolytes are absorbed primarily by the
 - a. jejunum.
 - b. ileum.
 - c. duodenum.
- ___ 40. Which structure does *not* increase the surface area for absorption in the small intestine?
 - a. rugae
 - b. plicae circularis
 - c. villi
 - d. microvilli
 - e. None of these structures increase the small intestine surface area.
- ___ 41. Absorbed *fat* enters the unique lymphatic vessels in the lamina propria core of each villus known as
 - a. villi capillaries.
 - b. microvilli.
 - c. central lacteals.
 - d. intestinal crypts (crypts of Lieberkühn).
 - e. plicae circularis.

- ___ 42. Which statement about *microvilli* is *false*?
- They are fingerlike projections formed by the foldings of the epithelial plasma membrane itself.
 - Using the light microscope, they appear as a vague “brush border” along the luminal border of the columnar epithelial cells of the intestinal mucosa layer.
 - “Fixed” digestive enzymes attached to the membranes of microvilli face the lumen and hydrolyze various substrates in chyme.
 - They may activate pancreatic juice enzymes such as trypsin that flow into the intestine.
 - All of these statements regarding microvilli are true.
- ___ 43. Which statement about *intestinal motility* in the small intestine is *false*?
- Smooth muscle cells are connected to each other by electrical synapses known as a *nexuses*.
 - Pacesetter potentials, or *slow waves*, are spontaneous depolarizations that are produced by interstitial cells of Cajal
 - When slow waves depolarize interstitial cells of Cajal to a threshold, voltage-gated Ca^{2+} channels are opened causing depolarization of the interconnected smooth muscle cells and firing of action potentials that result in contraction.
 - The frequency and strength of smooth muscle contractions (motility) are increased by stimulation of autonomic sympathetic nerves and the release of norepinephrine.
 - All of these statements regarding intestinal motility are true.

B. True or False/Edit

- ___ 44. The absorption of carbohydrates, lipids, amino acids, calcium, and iron occurs primarily in the duodenum and jejunum of the small intestine.
- ___ 45. Electron microscopic foldings of the apical plasma membrane of epithelial cells lining the small intestine are called villi.
- ___ 46. At the base of each intestinal villus, intestinal crypts or crypts of Lieberkühn form narrow pouches, producing new epithelial cells by mitosis to replace those cells that are continuously exfoliated (shed) from the tips.
- ___ 47. Milk sugar, or lactose is digested by the brush border enzyme, lactase; and whose absence in adults causes the unpleasant symptoms known as lactose intolerance.
- ___ 48. The small intestine has two major types of smooth muscle contractions: peristalsis and pendular action.
- ___ 49. Like cardiac muscle, intestinal smooth muscle is capable of spontaneous electrical activity and automatic rhythmic contractions.
- ___ 50. Stimulation of the vagus (parasympathetic) nerve releases the neurotransmitter, acetylcholine that increases the excitability and contractility of intestinal smooth muscle.
- ___ 51. The major smooth muscle contractile activity of the small intestine is called peristalsis.
- ___ 52. The rhythm of contractions that occurs in the intestinal smooth muscle is paced by graded depolarizations or slow waves that are produced and conducted by unique cells known as the interstitial cells of Cajal.
- ___ 53. When a slow wave depolarization rises above threshold, voltage-gated sodium (Na^+) channels are opened triggering action potentials in a smooth muscle cell.

IV. LARGE INTESTINE

The large intestine absorbs water, electrolytes, and certain vitamins from the chyme it receives from the small intestine. In a process regulated by the action of sphincter muscles, the large intestine passes waste products out of the body through the rectum and anal canal.

A. Multiple Choice

- ___ 54. Chyme from the ileum passes into the _____ of the large intestine; leading to an increase in pressure in the final section, or _____ before exiting through the anus.
- colon; cecum
 - sigmoid colon; cecum
 - cecum; rectum
 - ascending colon; sigmoid colon
 - sigmoid colon; rectum

- ___ 55. Which statement about the large intestine, or *colon*, is *false*?
- The colon columnar epithelium are interspersed with mucus-secreting goblet cells.
 - Like the small intestine, the epithelium of the large intestine also forms crypts of Lieberkühn.
 - There are no villi present in the large intestine.
 - Bulges or pouches of the outer surface form pouches, called haustra.
 - All of these statements about the colon are true.
- ___ 56. The *vermiform appendix* is a thin outpouching of the
- cecum.
 - ascending colon.
 - transverse colon.
 - sigmoid colon.
 - rectum.
- ___ 57. The total volume of water excreted in the feces each day is about
- 200 ml.
 - 500 ml.
 - 1.0 L.
 - 1.5 L.
 - 2.0 L.
- ___ 58. Which analogy between the intestine and the kidney is *false*?
- Both areas contain tight junctions between adjacent epithelial cells.
 - Both areas have Na^+/K^+ active transport pumps in the basolateral membranes.
 - Both areas can both secrete water into the lumen as well as absorb (or conserve) water.
 - Both areas have receptors for the hormone *aldosterone*, which stimulates salt and water reabsorption.
 - Both areas contribute to the loss of water from the body as a way of excreting other waste materials.
- ___ 59. Which of the following is *not* a direct cause of *diarrhea*?
- cholera
 - celiac sprue
 - appendicitis
 - lactose intolerance

B. True or False/Edit

- ___ 60. A *diverticulum* is a pouch larger than a *haustrum* that forms when the wall of the muscularis externa weakens and stretches lengthwise.
- ___ 61. The *vermiform appendix* is a short, thin outpouching of the cecum that has no true digestive function.
- ___ 62. Resident bacteria in the intestine, collectively referred to the intestinal microbiota or microflora, produce significant amounts of vitamin A and folic acid, which are absorbed by the large intestine.
- ___ 63. Short-chain fatty acids are used as fuel by the epithelial cells of the colon to help absorb sodium, bicarbonate, calcium, magnesium, and iron.
- ___ 64. Most of the fluid and electrolytes in the lumen of the gastrointestinal tract are absorbed by the large intestine.
- ___ 65. Water absorption in the large intestine occurs by osmosis down a water concentration gradient set up by Na^+/K^+ active transport pumps similar to that found in the kidney nephron.
- ___ 66. *Aldosterone*, the hormone that stimulates salt and water reabsorption along the renal tubules, also appears to stimulate salt and water absorption from the *ileum* of the small intestine.
- ___ 67. The defecation reflex is regulated to a large degree by habit.

V. LIVER, GALLBLADDER, AND PANCREAS

The liver regulates the chemical composition of the blood in numerous ways. In addition, the liver produces and secretes bile, which is stored and concentrated in the gallbladder prior to its discharge into the duodenum. The pancreas produces pancreatic juice, an exocrine secretion containing bicarbonate and important digestive enzymes, which is passed into the duodenum via the pancreatic duct.

A. Multiple Choice

- ___ 68. As part of the *reticuloendothelial system*, the *Kupffer cells* in the liver are responsible for the
- synthesis and secretion of bile.
 - phagocytosis of blood swirling within the sinusoids.
 - metabolism of carbohydrates and lipids.
 - synthesis of large plasma proteins.
 - storage of particular vitamins.
- ___ 69. Which statement about the functional unit of the liver, known as the *liver lobules*, is *false*?
- A central vein collects mixed blood from the sinusoids to help form the hepatic vein.
 - Incoming blood from the hepatic artery and from the portal vein mixes in the sinusoids.
 - Bile is made and released into the central vein of each lobule.
 - Liver lobules are destroyed by certain diseases such as cirrhosis.
 - All of these statements regarding liver lobules are true.
- ___ 70. The *enterohepatic circulation* refers to the specific pathway of many compounds, that are
- absorbed from the intestine; and then travel to the liver.
 - carbohydrate and lipid metabolism.
 - synthesis of proteins.
 - synthesis and secretion of bile.
 - All of these are major liver functions.
- ___ 71. Which of the following is not a major function of the liver?
- detoxication of blood
 - carbohydrate and lipid metabolism
 - synthesis of proteins
 - synthesis and secretion of bile
 - All of these are major liver functions.
- ___ 72. Which statement about substance called *bilirubin* is *false*?
- Bilirubin is a pigment secreted from the liver in bile.
 - Bilirubin is derived from liver cholesterol molecules.
 - Bilirubin is bound to albumin in the bloodstream since it is not very water-soluble.
 - In the intestine, bacteria convert bilirubin into another pigment called urobilinogen.
 - Bilirubin can be conjugated (combined) with glucuronic acid to change its solubility properties.
- ___ 73. As part of bile secretions, the bile acids are compounds derived from
- sodium and potassium compounds.
 - cholesterol.
 - bilirubin.
 - lecithin.
 - None of these form bile acids.
- ___ 74. Which statement about *jaundice* is *false*?
- Jaundice is due to high levels of either free or conjugated bilirubin in the blood.
 - Jaundice may be due to the excessive destruction of white blood cells in newborn babies.
 - Jaundice may be seen in premature infants with inadequate amounts of liver enzymes.
 - Jaundice may be seen in adults whose bile ducts are blocked by gallstones.
 - Jaundice is seen in newborn babies who suffer from erythroblastosis fetalis.
- ___ 75. Which route of elimination is *not* used primarily by the liver?
- excretion of compounds in the bile
 - excretion of compounds in the urine
 - phagocytosis by Kupffer cells lining the sinusoids
 - chemical alteration (detoxication) within the hepatocytes
 - All of these routes are used by the liver.
- ___ 76. Which detoxication reaction does the liver *not* use?
- Toxic ammonia molecules are converted into less toxic urea molecules.
 - Toxic porphyrins are converted into the yellow pigment, bilirubin.
 - Toxic organic acids are converted to pH stabilizing bases.
 - Toxic steroid hormones and other nonpolar compounds (drugs) are converted to polar (more water-soluble) ones.
 - All of these reactions occur in the liver.

- ___ 77. The metabolism of _____ in the liver requires the binding and activation of nuclear SXR receptors that, in turn, activate specific genes to produce cytochrome P450 enzymes.
- lipophilic (fat soluble) compounds, such as steroid hormones and drugs
 - alcohol
 - hydrophilic (water soluble) compounds, such as urea and sugars
 - bile acids and bile salts
 - ammonia
- ___ 78. The plasma protein that is most common (70% of all plasma protein) and is responsible for much of the colloid osmotic (oncotic) pressure of blood, is
- albumin.
 - K-globulin.
 - fibrinogen.
 - prothrombin.
 - angiotensinogen.
- ___ 79. Which statement about the gallbladder is *false*?
- The gallbladder's major function is to store and concentrate bile.
 - The gallbladder's storage capacity is about 35-100 ml of bile.
 - Bile accumulates in the gallbladder only when the sphincter of Oddi is closed.
 - When full, the gallbladder is the shape of a small pear.
 - Contraction of the muscular gallbladder ejects bile through the common bile duct and into the stomach.
- ___ 80. Which statement about the digestive enzymes secreted by the acini of the pancreas, is *false*?
- These enzymes digest ingested carbohydrates, proteins, and triglycerides.
 - These enzymes are mostly produced as inactive molecules (zymogens) that become active in the small intestine.
 - Enterokinase is one of the more important pancreatic enzymes.
 - Activated trypsin activates many of the other pancreatic zymogens.
 - All of these statements regarding pancreatic enzymes are true.

B. True or False/Edit

- ___ 81. The *liver*, located immediately beneath the diaphragm in the abdominal cavity, is the largest internal organ.
- ___ 82. Liver cells or *hepatocytes* form plates that are one or two cells thick and are separated by highly permeable capillary spaces called *sinusoids*.
- ___ 83. All digestion products (except lipids) that are absorbed into the blood are delivered to the liver first, and then released into the general circulation.
- ___ 84. The *hepatic portal vein* connects the liver to the inferior vena cava that returns blood to the heart.
- ___ 85. Blood and bile travel in separate vessels and therefore do not mix in the liver lobules.
- ___ 86. The liver has the widest variety of functions of any organ in the body.
- ___ 87. *Bilirubin* is the pigment in the blood that is filtered by the kidney and thus gives urine its yellow color.
- ___ 88. *Urobilinogen*, formed by bacteria in the intestine, can return to the blood via the *enterohepatic circulation*, where kidneys may filter it, adding yellow color to the urine.
- ___ 89. Although the major pathway of cholesterol breakdown results in the liver's production of bile acids that are released into the duodenum, almost 95% of these bile acids are absorbed and recycled in the ileum by enterohepatic circulation.
- ___ 90. Liver cells use multispecific organic anion transport carriers to eliminate potentially toxic xenobiotic (foreign) molecules by transporting these conjugated compounds into the bile where they can be excreted.
- ___ 91. The liver *cytochrome P450 enzymes* that metabolize thousands of toxic compounds, such as benzopyrene (a carcinogen from tobacco smoke and charbroiled meat) and dioxin, are *not* related to the cytochromes of cell respiration fame located in the mitochondrion.
- ___ 92. The binding of molecular ligands to SXR nuclear receptors in liver cells is required to stimulate the production of cytochrome P450 enzymes that metabolize hydrophilic compounds.
- ___ 93. After a carbohydrate-rich meal, the liver removes blood glucose and converts this glucose into glycogen (*glycogenesis*) and triglycerides (*lipogenesis*).
- ___ 94. During fasting (or starvation), stored liver glycogen molecules are broken down into free glucose molecules (*gluconeogenesis*) that are subsequently released into the blood.

- ___ 95. When the small intestine is empty of food, the sphincter of Oddi at the end of the common bile duct closes so that bile backs up and fills the gallbladder.
- ___ 96. The pancreas has both endocrine and exocrine functions.
- ___ 97. The *endocrine* cells of the pancreas are clustered into secretory units known as *acini*.
- ___ 98. The complete digestion of food molecules in the small intestine requires the activity of both pancreatic enzymes and fixed brush border intestinal enzymes.
- ___ 99. Bicarbonate seems to be secreted into the pancreatic juice by the cells that line the ductules, rather than by the acinar cells.
- ___ 100. The secretion of H^+ into the blood as bicarbonate is secreted into the pancreatic juice is similar to the acid secretion by parietal cells of the stomach, but with a reversed direction.
- ___ 101. The secretion of bicarbonate from the ductule cells into the lumen is neutralized by the uptake of Cl^- in the opposite direction.
- ___ 102. The cystic fibrosis transmembrane conductance regulator (CFTR) channel seems to promote the influx diffusion of Cl^- from the lumen and into the ductule cells in exchange for bicarbonate efflux.

VI. NEURAL AND ENDOCRINE REGULATION OF THE DIGESTIVE SYSTEM

The activities of different regions of the GI tract are coordinated by the actions of the vagus nerve and by various hormones. The stomach begins to increase its secretion in anticipation of a meal, and further increases its activities in response to the arrival of food. The entry of chyme into the duodenum stimulates the secretion of hormones that promote contractions of the gallbladder, the secretion of pancreatic juice, and the inhibition of gastric activity.

A. Multiple Choice

- ___ 103. During the *cephalic* phase of gastric regulation,
 - a. the brain exerts its control via the vagus nerve.
 - b. HCl is secreted from chief cells.
 - c. the enzyme, pepsinogen, is secreted from parietal cells.
 - d. the hormone, gastrin, is secreted from enterochromaffin-like cells.
- ___ 104. Which statement about the *gastric* phase is *false*?
 - a. The gastric phase exhibits both positive and negative feedback mechanisms that occur as protein arrives in the stomach.
 - b. The presence of fat in the stomach chyme, but not glucose, stimulates gastric acid secretion.
 - c. When the pH of the gastric juice drops (acid levels rise), the secretion of gastrin hormones also drops, correspondingly.
 - d. The amount of HCl and pepsinogen secreted by the stomach is directly proportional to the amount of short polypeptides and amino acids present in the chyme.
 - e. The amount of acid secreted by the parietal cells of the stomach is closely matched to the amount of protein ingested.
- ___ 105. Which statement about the *intestinal* phase is *false*?
 - a. The increased osmolality of chyme in the duodenum may inhibit gastric activity and secretion via nerve reflexes.
 - b. Stretch (distension) caused by chyme entering the duodenum may inhibit gastric activity.
 - c. The presence of protein polypeptides in intestinal chyme may stimulate the release of a hormone (enterogastrone) that inhibits gastric function.
 - d. Somatostatin, cholecystokinin (CCK) and glucagon-like peptide-1 (GLP-1) are polypeptide hormones that collectively serve to inhibit gastric activity.
 - e. The presence of glucose in the intestinal chyme may cause GIP release, which, in turn stimulates the secretion of insulin from the islets of Langerhans.
- ___ 106. Which statement about the enteric nervous system is *false*?
 - a. Because it contains about as many neurons as are found in the spinal cord, it is also known as the enteric brain.
 - b. It contains afferent (sensory) neurons, and both sympathetic and parasympathetic neurons.
 - c. Like the CNS, it contains many short, connecting interneurons.
 - d. Like the CNS, it contains many glial (supporting) cells than neurons.
 - e. All of these statements about the enteric nervous system are true.

- ___ 107. Which of the following substances is a hormone that is produced not only by cells of the intestine, but by the brain and stomach as well?
- somatostatin
 - enterogastrone
 - cholecystokinin (CCK)
 - glucagon-like peptide-1 (GLP-1)
 - guanylin
- ___ 108. Which locally controlled intestinal reflex results in the decrease in gastric motility in response to distension of the ileum with chyme?
- gastroileal reflex
 - ileogastric reflex
 - intestino-intestinal reflex
 - knee jerk reflex
- ___ 109. The arrival of chyme causes the reflex secretion of pancreatic juice and bile during the
- cephalic phase.
 - gastric phase.
 - intestinal phase.
 - progress through all of these phases.
- ___ 110. The presence of _____ in chyme stimulates *secretin* release, while the presence of _____ in chyme stimulates *cholecystokinin (CCK)* release.
- acid; alkaline
 - acid; fat and protein
 - fat; protein and glucose
 - protein and fat; acid
 - alkaline; protein and glucose
- ___ 111. As chyme enters the duodenum, bile secretion is enhanced by
- secretin secretion.
 - enterogastrone secretion.
 - CCK secretion.
 - Both a and b are correct.
 - Both a and c are correct.

B. True or False/Edit

- ___ 112. Autonomic nerve activity and various hormones modify the existing gastric motility and glandular secretions due to the presence of food.
- ___ 113. One action of vagus nerve excitation is to stimulate stomach chief cells to secrete the enzyme precursor, pepsinogen.
- ___ 114. Another action of vagus nerve excitation is the powerful release of HCl both by direct effects (muscarinic) on the stomach parietal cells and by indirect action on ECL cells to release histamine, which then stimulates parietal cells.
- ___ 115. Just talking about yummy food is sometimes a more potent stimulus for gastric acid secretion than the actual sight and smell of food.
- ___ 116. Distension of the stomach by the presence of large amount of chyme will cause a reduction in gastric secretions.
- ___ 117. The amino acids *tryptophan* and *phenylalanine* have been shown to be potent stimulators of both *pepsinogen* secretion from chief cells and *gastrin* secretion from G cells of the stomach.
- ___ 118. A breakfast of pancakes and syrup takes longer to digest and pass through the stomach than a breakfast of bacon and eggs, due partly to the inhibitory action of *enterogastrone*.
- ___ 119. Ultimately regulated by the enteric nervous system, peristalsis occurs when extrinsic afferents with cell bodies located in the myenteric plexus activate motor neurons controlling smooth muscle contractions.
- ___ 120. During peristalsis, intestinal smooth muscles are stimulated to contract above the bolus of chyme by neurotransmitters ACh and substance P whereas smooth muscle below the bolus is relaxed by nitric oxide, vasoactive intestinal peptide (VIP), and ATP.
- ___ 121. The enterochromaffin-like (ECL) cells of the mucosal layer of the intestine respond to pressure and various chemicals in the chyme by secreting the locally active paracrine regulator molecules such as serotonin (5-hydroxytryptamine) and motilin.

- ___ 122. Guanylin is a paracrine regulator molecule produced by the ileum and colon that stimulates the intestinal epithelial cells (via cGMP production) to secrete Cl^- and water into the lumen while inhibiting their absorption of Na^+ from the chyme, thereby increasing fecal loss of salt and water.
- ___ 123. *Secretin* promotes the synthesis and release of bicarbonate by the pancreas while *cholecystokinin* (CCK) increases the digestive enzyme content of pancreatic juice.
- ___ 124. In the acinar cells of the pancreas, the cytoplasmic second messenger responding to the hormone secretin, is Ca^{2+} , whereas the second messenger for the hormone CCK, is cyclic AMP.
- ___ 125. Since nerve reflexes can help regulate digestion, it seems the role of GI hormones may be primarily *trophic*, or supportive.
- ___ 126. The structure of the gastric mucosa is dependent upon the supportive, or *trophic*, effects of the hormone, *secretin*.
- ___ 127. The structure of the acinar (exocrine) cells of the pancreas is dependent upon the *trophic* effects of *cholecystokinin* (CCK).

VII. DIGESTION AND ABSORPTION OF CARBOHYDRATES, LIPIDS, AND PROTEINS

Polysaccharides and polypeptides are hydrolyzed into their subunits. These subunits enter the epithelial cells of the intestinal villi and are secreted into blood capillaries. Fat is emulsified by the action of bile salts, hydrolyzed into fatty acids and monoglycerides, and absorbed into the intestinal epithelial cells. Once inside the cells, triglycerides are resynthesized and combined with proteins to form particles that are secreted into the lymphatic fluid.

A. Multiple Choice

- ___ 128. The nutrients in foods that serve predominantly as “fuel food,” providing energy for metabolism are
 - a. vitamins, minerals, and carbohydrates.
 - b. carbohydrates, lipids (fats), and vitamins.
 - c. protein, lipids (fats), and water.
 - d. carbohydrates, proteins, and lipids (fats).
 - e. protein, vitamins, and carbohydrates.
- ___ 129. Which statement about the digestion of *protein* in ingested food is *false*?
 - a. Protein digestion begins in the mouth with enzymes in saliva.
 - b. The stomach enzyme, pepsin, only partially digests proteins.
 - c. Most protein digestion occurs in the duodenum and jejunum.
 - d. Peptide bonds between amino acids are broken by both endopeptidases and exopeptidases, depending upon their location along the protein chain.
 - e. Microvilli brush border peptidase enzymes are also involved in protein digestion.
- ___ 130. Which statement about the digestion of *lipid* in ingested food is *false*?
 - a. Lipid digestion begins in the duodenum with the digestion of large lipid globules into smaller globules.
 - b. The emulsification process requires the mixture of lipids with bile salts.
 - c. Emulsification means to digest lipids, forming free fatty acids and glycerol.
 - d. Pancreatic enzymes lipase and colipase, aid the hydrolysis of lipids.
 - e. Mixed micelles of digested lipids are absorbed primarily by diffusion.
- ___ 131. Which statement about the intestinal absorption or the transport of lipids in the blood is *false*?
 - a. Chylomicrons are lipid-protein particles formed within the intestinal epithelial cells during lipid absorption.
 - b. Chylomicrons enter the central lacteals of the intestinal villi for transport through lymphatic vessels.
 - c. Absorbed lipids do not normally travel through the hepatic portal vein.
 - d. Chylomicrons ultimately travel via the thoracic duct where they enter the venous blood of the subclavian vein.
 - e. All of these statements regarding the intestinal absorption or the transport of lipids in the blood are true.

B. True or False/Edit

- ___ 132. The enzyme *amylase*, or ptyalin, is secreted with the saliva and is responsible for most of the digestion of starch molecules into maltose, maltotriose, and oligosaccharides.
- ___ 133. The digestive enzymes “fixed” to the brush border of epithelial cells in the duodenum complete the digestion of starch, forming monosaccharides for absorption.
- ___ 134. Absorption of digested carbohydrates such as glucose or fructose in the intestine occurs primarily by coupled transport (cotransport, or secondary active transport coupled to Na^+ diffusion).

- ___ 135. Like most glucose absorption, the absorption of free amino acid from the intestine requires coupled transport (cotransport, or secondary active transport coupled to Na⁺ diffusion).
- ___ 136. Bile emulsification of fat is the process by which droplets of fat are formed with less surface area for the hydrolytic action of *lipase* and *colipase* enzymes.
- ___ 137. Once inside the epithelial cells, digested free fatty acids and monoglycerides are reassembled to form triglycerides and phospholipids.
- ___ 138. Cholesterol molecules in the blood come from two sources: synthesis of new cholesterol by the liver and absorption of dietary cholesterol from the intestine.
- ___ 139. Plant sterols or phytosterols that are normally found in such plants as rice bran, corn, soybeans, and sesame oils, as well as many fruits and vegetables work to promote cholesterol absorption from the intestine.
- ___ 140. Stanols are plant sterols (phytosterols) that have been altered chemically to inhibit cholesterol more effectively and yet are not themselves significantly absorbed.
- ___ 141. *Lipoprotein lipase* enzymes are attached to the endothelium of blood vessels, hydrolyzing triglycerides and releasing fatty acids and glycerol for use by the tissues.

CHAPTER REVIEW

A. Sequencer — The Cheeseburger

142. Lipid digestion, absorption, and transport in the blood follow a particularly intricate sequence of events. After consuming a large high-fat cheeseburger, let's trace the lipid digestion-absorption-transport sequence starting with the movement of lipid-loaded chyme out of the stomach and into the duodenum of the small intestine. From one through fourteen, number the following events in their proper order—the last one has been done for you. As always, use your text to redirect your thinking if you go astray!
- ___ Mixed micelles of bile salts, lecithin, and cholesterol are secreted from the liver into the duodenum.
 - ___ Triglycerides and phospholipids are reassembled in the intestinal epithelial cells.
 - ___ Cholecystokinin (CCK) hormones are released into the blood in response to the presence of fat in the intestinal chyme.
 - ___ Remnant particles (mostly cholesterol) are removed from the blood by receptor-mediated endocytosis in the liver.
 - ___ Fat hydrolysis occurs due to the presence of pancreatic lipase, colipase, and phospholipase A enzymes.
 - 14 Lipoproteins secreted by the liver provide tissue cells with triglycerides, forming low-density lipoproteins (LDL), which transport cholesterol to various organs, including blood vessels.
 - ___ Lipoprotein lipase enzymes attached to the endothelium of blood vessels release free fatty acids and glycerol from chylomicrons for use by tissue cells.
 - ___ Large fat globules flow into the duodenum.
 - ___ Chylomicrons are transported through the lymphatic system and enter the venous blood by way of the thoracic duct.
 - ___ Mixed micelles of bile salts, digested lipids and lecithin move to the brush border of the intestinal epithelium for absorption.
 - ___ Cholecystokinin (CCK) stimulates bile secretion from the liver and contraction of the gallbladder.
 - ___ Liver repackages cholesterol and triglyceride with apoproteins, forming very-low-density lipoproteins (VLDL).
 - ___ Inside the epithelial cells cholesterol and protein are packaged with triglycerides and phospholipids, forming chylomicrons, that migrate into the lymphatic lacteals of the villi.
 - ___ Emulsification results in the formation of tiny droplets of triglycerides in the duodenum.

B. Essay

Essay Tutorial

This essay tutorial will answer the first essay question found in the “**Review Activities**” section of your *Human Physiology* textbook. Please read *Essay Question 1* in the “**Test Your Understanding of Concepts and Principles**” section located at the end of chapter 18 and let me guide you through one possible answer. Watch for key terms in boldface type, helpful tips and general suggestions on writing the essay or short-answer questions. Enjoy!

143. Explain how the gastric secretion of **HCl** and **pepsin** is regulated during the cephalic, gastric, and intestinal phases.

Answer. We have two ways to answer this question. (1) Start with HCl, and follow HCl regulation through these three extrinsic phases; then, in a similar fashion, follow the control of pepsin secretion. (2) First, discuss the three phases of gastric control in their proper sequence, and then compare the control of HCl and pepsin secretion that occurs in each phase.

Let's use the latter method.

Cephalic phase — refers to control by the brain as the vagus nerve carries impulses to the *chief* cells, stimulating *pepsinogen* secretion, and indirectly stimulates the *parietal* cells to secrete HCl. Simultaneously, the vagus nerve directly stimulates *G cells* in the antrum to secrete *gastrin* and the *ECL cells* to secrete *histamine*. The gastrin is circulated back to the stomach, where it also stimulates the ECL cells to release histamine. Histamine, in turn, activates H₂ receptors on the parietal cells to stimulate acid secretion.

Gastric phase — in the stomach, both the distension of the stomach and the presence of polypeptides in chyme increase gastrin release, increasing pepsinogen and HCl secretion as described above. The activity of pepsin and HCl makes more polypeptides, leading to more secretions — a *positive* feedback mechanism. However, by *negative* feedback, too much acid (lower pH) reduces the secretion of gastrin so that stomach pH is related somewhat to the amount of ingested protein. This inhibition of gastrin secretion from G cells may be mediated by the hormone *somatostatin*, secreted by the *D cells* of the stomach.

Intestinal phase — the presence of chyme in the small intestine inhibits both HCl and pepsinogen secretion from the stomach by two mechanisms: (1) the bulk and osmolality of chyme, together with other stimuli, seem to activate neural reflexes which inhibit gastric motility and secretion, and (2) fat in the chyme stimulates the release of the hormone, *enterogastrone*, (and perhaps others such as gastric inhibitory peptide (GIP), CCK, somatostatin, and glucagon-like peptide-1 (GLP-1)) that inhibits the release of HCl and pepsinogen and gastric activity ceases.

Note: An answer in table form (see table 18.6 in the text) is also acceptable and may be more easily read by your instructor, perhaps leading to a better grade! Now, got time for a few more?

144. Describe the *digestion*, *absorption*, and *transport* of fats from the intestine to the liver for processing. (*Hint:* See the sequencer, part A.)

145. From the lumen to the outside, list the four layers of the GI wall. Include all smooth muscle layers and nerve networks (plexuses) that innervate these muscles.

146. Draw and label one intestinal *villus*—include: simple columnar epithelium, four layers of the intestine, crypts of Lieberkühn, central lacteal, and brush border (microvilli). You can check your drawing against figures 18.3 and 18.13 in the text. State the function of each anatomical feature.

147. Describe the structure and function of the *large* intestine. Include a description of the defecation reflex.

148. Describe the unique architecture of the *liver lobule* and the inflow of blood from both the hepatic portal vein and the hepatic artery. How is bile formed in the lobule and where does it go for elimination from the body?

Let's try something new! Here is a comprehensive essay question that is perhaps typical of an essay question on a large examination. I would like you to answer the following "grand essay question."

149. You have just consumed a large, cold, frothy glass of whole milk containing milk sugar (lactose), milk protein, and milk fat. From the mouth, trace the pathway of each nutrient as it is (1) digested, (2) absorbed, (3) transported in the blood, and finally, (4) processed by the tissue cells for energy.

Answers — Chapter 18

- I. Introduction to the Digestive System
- A. 1. e, 2. c, 3. a, 4. c, 5. b, 6. d, 7. d, 8. a
- B. 9. T, 10. T, 11. T, 12. F—Replace “submucosa” with “mucosa,” 13. T, 14. F—Switch “intrinsically” with “extrinsically,” 15. T
- II. Esophagus and Stomach
- A. 16. a, 17. d, 18. b, 19. c, 20. d, 21. b, 22. c, 23. d, 24. c, 25. d
- B. 26. T, 27. T, 28. T, 29. T, 30. F—Replace “completely” with “partially,” 31. T, 32. T, 33. F—Replace “gastric” with “peptic,” 34. T, 35. T, 36. F—Antihistamines taken to block gastric acid secretion block H₂ histamine receptors; antihistamines for colds block H₁ histamine receptors, 37. T
- C. Label the Figure — The Stomach; See figure 18.5 in the text.
- III. Small Intestine
- A. 38. b, 39. b, 40. a, 41. c, 42. e, 43. d
- B. 44. T, 45. F—Replace “villi” with “microvilli,” 46. T, 47. T, 48. F—Replace “pendular action” with “segmentation,” 49. T, 50. T, 51. F—Replace “peristalsis” with “segmentation,” 52. T, 53. F—Replace “Na⁺” with “Ca²⁺”
- IV. Large Intestine
- A. 54. c, 55. e, 56. a, 57. a, 58. c, 59. c
- B. 60. T, 61. T, 62. F—Replace “A” with “K,” 63. T, 64. F—Replace “large” with “small,” 65. T, 66. T, 67. T
- V. Liver, Gallbladder, and Pancreas
- A. 68. b, 69. c, 70. b, 71. e, 72. b, 73. b, 74. b, 75. b, 76. c, 77. a, 78. a, 79. e, 80. c
- B. 81. T, 82. T, 83. T, 84. F—Delete “portal,” 85. T, 86. T, 87. F—Replace “Bilirubin” with “Urobilinogen,” 88. T, 89. T, 90. T, 91. T, 92. F—Replace “hydrophilic” with “lipophilic,” 93. T, 94. F—Replace “gluconeogenesis” with “glycogenolysis,” 95. T, 96. T, 97. F—Replace “endocrine” with “exocrine,” 98. T, 99. T, 100. T, 101. T, 102. F—CFTR channels promote Cl⁻ diffusion out of the ductule cells and into the lumen.
- VI. Neural and Endocrine Regulation of the Digestive System
- A. 103. a, 104. b, 105. c, 106. e, 107. b, 108. b, 109. c, 110. b, 111. e
- B. 112. T, 113. T, 114. T, 115. T, 116. F—Replace “a reduction” with “an increase,” 117. T, 118. F—Replace “longer” with “shorter,” 119. F—Replace “extrinsic” with “intrinsic,” 120. T, 121. T, 122. T, 123. T, 124. F—Switch “Ca²⁺” and “cyclic AMP,” 125. T, 126. F—Replace “secretin” with “gastrin,” 127. T
- VII. Digestion and Absorption of Carbohydrates, Lipids, and Proteins
- A. 128. d, 129. a, 130. c, 131. e
- B. 132. F—Replace “Salivary amylase, or ptyalin” with “Pancreatic amylase,” 133. T, 134. T, 135. T, 136. F—Replace “less” with “greater,” 137. T, 138. T, 139. F—Replace “promote” with “inhibit,” 140. T, 141. T
- Chapter Review
- A. 142. 4, 8, 2, 12, 6, 14, 11, 1, 10, 7, 3, 13, 9, 5
- B. Essay