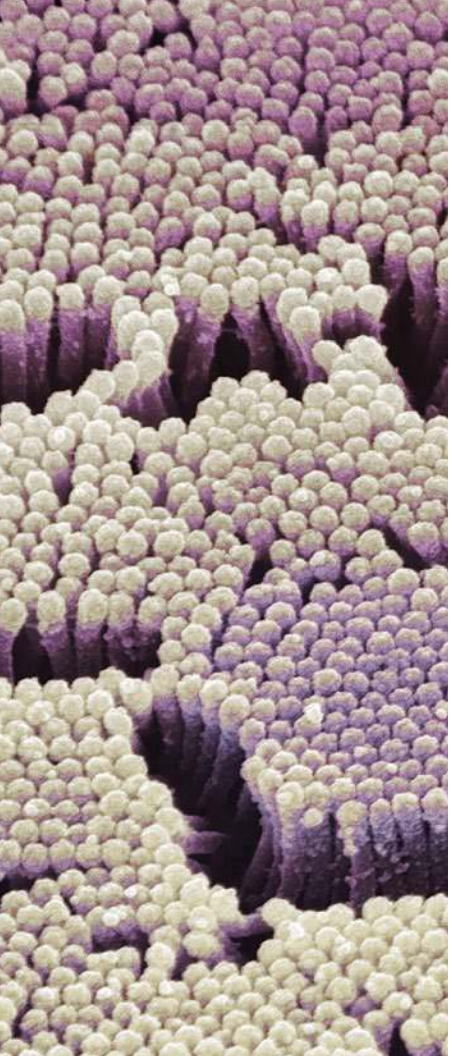

Digestive System 24

This unit explores both the anatomy and physiology of the digestive system. Although much of the emphasis of this unit is on anatomy and histology, physiology activities such as emulsification and digestive enzymes are included as well. The unit concludes with a tracing exercise to help students combine the anatomy and physiology that they have learned.

Estimated Total Lab Completion Time
(without Pre-Lab Exercises):
135–165 minutes
(Note that this lab is intended to span over 1.5–2 lab periods.)

Estimated Total Lab Completion Time
(including Pre-Lab Exercises):
200–230 minutes

Pre-Lab Exercises

Estimated **Total** Completion Time: **65 min.**

Pre-Lab Exercise 24-1 Key Terms

Estimated Completion Time: **20 min.**

Digestive System Structures

Alimentary canal (gastrointestinal tract) A passage extending from the mouth to the anus through which food travels as it is digested; it includes the pharynx, esophagus, stomach, and intestines

Accessory organ Organs that assist in mechanical or chemical digestion, including the teeth, tongue, salivary glands, pancreas, and liver

Peritoneal cavity A cavity located between a double-layered serous membrane that secretes serous fluid, allowing organs to slide over each other without friction; much of the alimentary canal and many accessory organs reside here

Gastroesophageal sphincter Ring of smooth muscle located at the inferior end of the esophagus that prevents contents of the stomach from regurgitating up into the esophagus

Pyloric sphincter Ring of smooth muscle located between the pylorus of the stomach and the duodenum that controls passage of chyme into the small intestine

Duodenum First part of the small intestine

Jejunum Middle part of the small intestine; between the duodenum and the ileum

Ileum Last part of the small intestine; between the jejunum of the small intestine and the cecum of the large intestine

Colon Section of the large intestine that contains four divisions (ascending, transverse, descending, and sigmoid colon)

Salivary glands Accessory organs around the mouth that secrete saliva, which contains substances such as water, salivary amylase, antibodies, and lysozyme

Pancreas Exocrine and endocrine gland that sits posterior and inferior to the stomach; its exocrine functions are digestive whereas its endocrine functions are metabolic

Liver Organ located on the right side of the abdominal cavity consisting of four lobes; produces bile for digestion; detoxifies, processes, and eliminates toxins in blood before the blood enters the general circulation in the body

Gallbladder Sac-like organ located under the liver's right lobe that stores the liver's bile; when stimulated by certain hormones, it will contract and eject bile into the cystic duct to aid in digestion

Digestive Histology

Mucosa The inner epithelial tissue lining of the alimentary canal that is composed of simple columnar epithelium overlying the lamina propria and a layer of muscularis mucosa

Submucosa Layer of connective tissue deep to the mucosa that houses blood vessels, nerves, lymphatics, and elastic fibers

Muscularis externa Contains two layers of smooth muscle (inner circular and outer longitudinal) that contract alternately producing rhythmic contractions of peristalsis

Serosa Outer layer of organs of the alimentary canal that is partially composed of the visceral peritoneum found throughout much of the alimentary canal

Acinar cells Exocrine cells of the pancreas that produce and secrete pancreatic juice (i.e., digestive enzymes, bicarbonate ions, and water) into ducts

Pancreatic islet Endocrine cells of the pancreas that secrete hormones such as insulin into the bloodstream

Liver lobule Hexagonal plates of cells that have a vein in the center of each lobule that eventually drains into hepatic veins; at each lobule's six corners, there are three vessels called portal triads

Digestive Physiology

Digestive enzyme Enzymes produced by organs of the digestive system that catalyze reactions that break food down chemically into smaller molecules

Chemical digestion Process by which the chemical bonds between food molecules are broken in chemical reactions

Emulsification The first step in the process of lipid digestion, it breaks up the fat globules into smaller pieces with the help of bile salts

Bile Fluid produced by the liver and stored in the gallbladder that contains bile salts, which are amphipathic molecules that emulsify fats in the small intestine and aid in their digestion

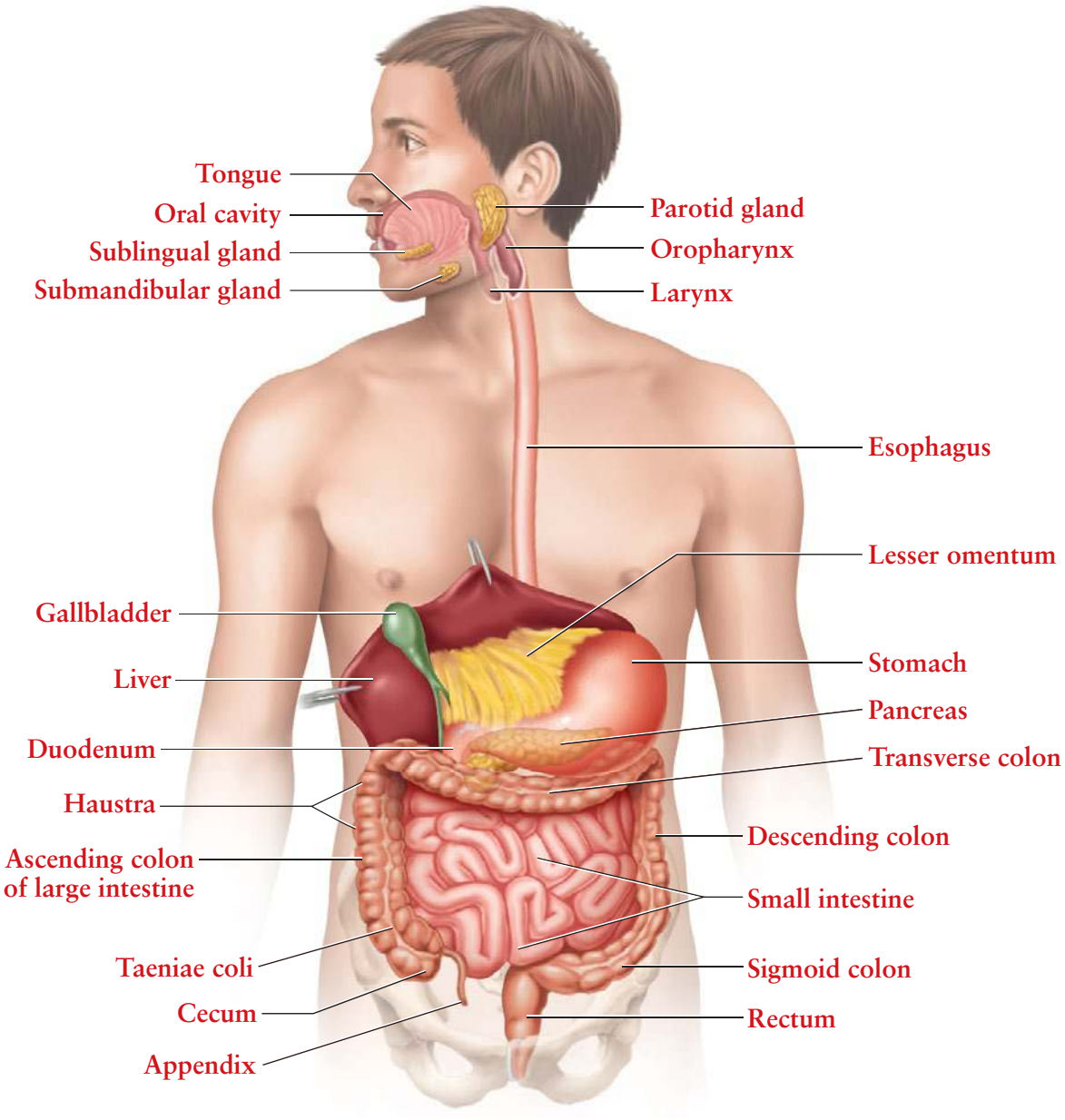

FIGURE 24.1 Anatomy of the digestive system.

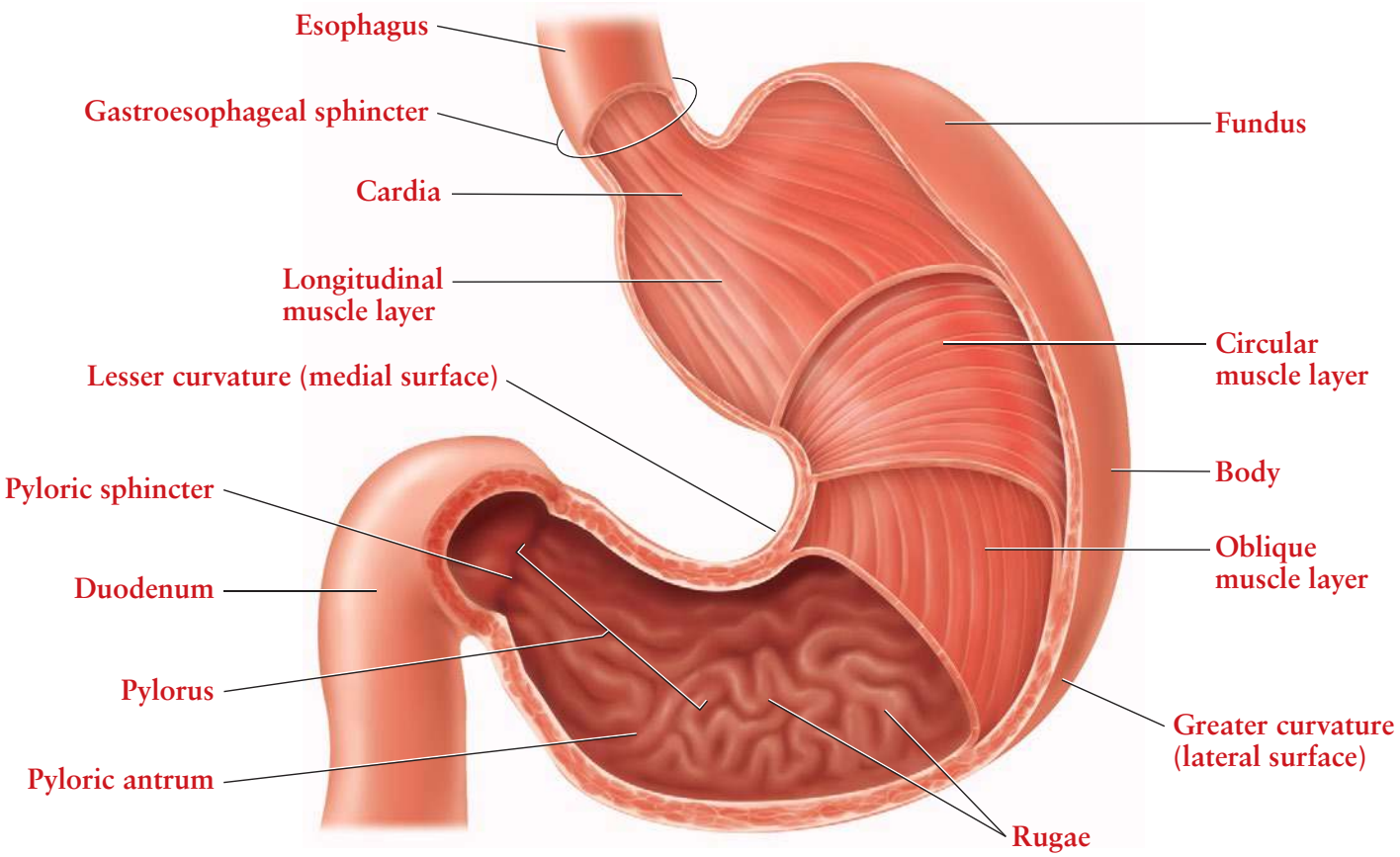

FIGURE **24.2** Structure of the stomach.

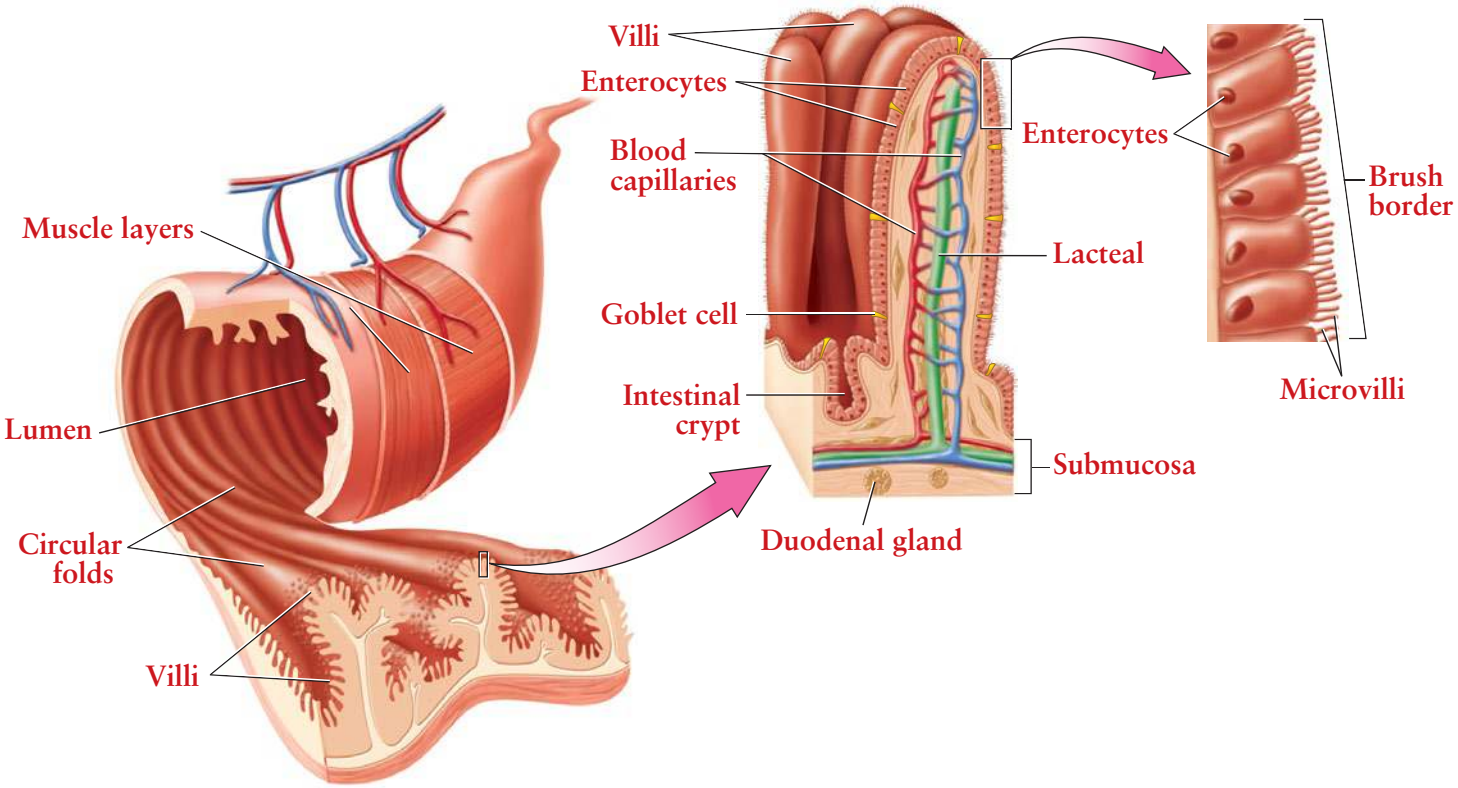

FIGURE **24.3** Gross and microscopic anatomy of the small intestine.

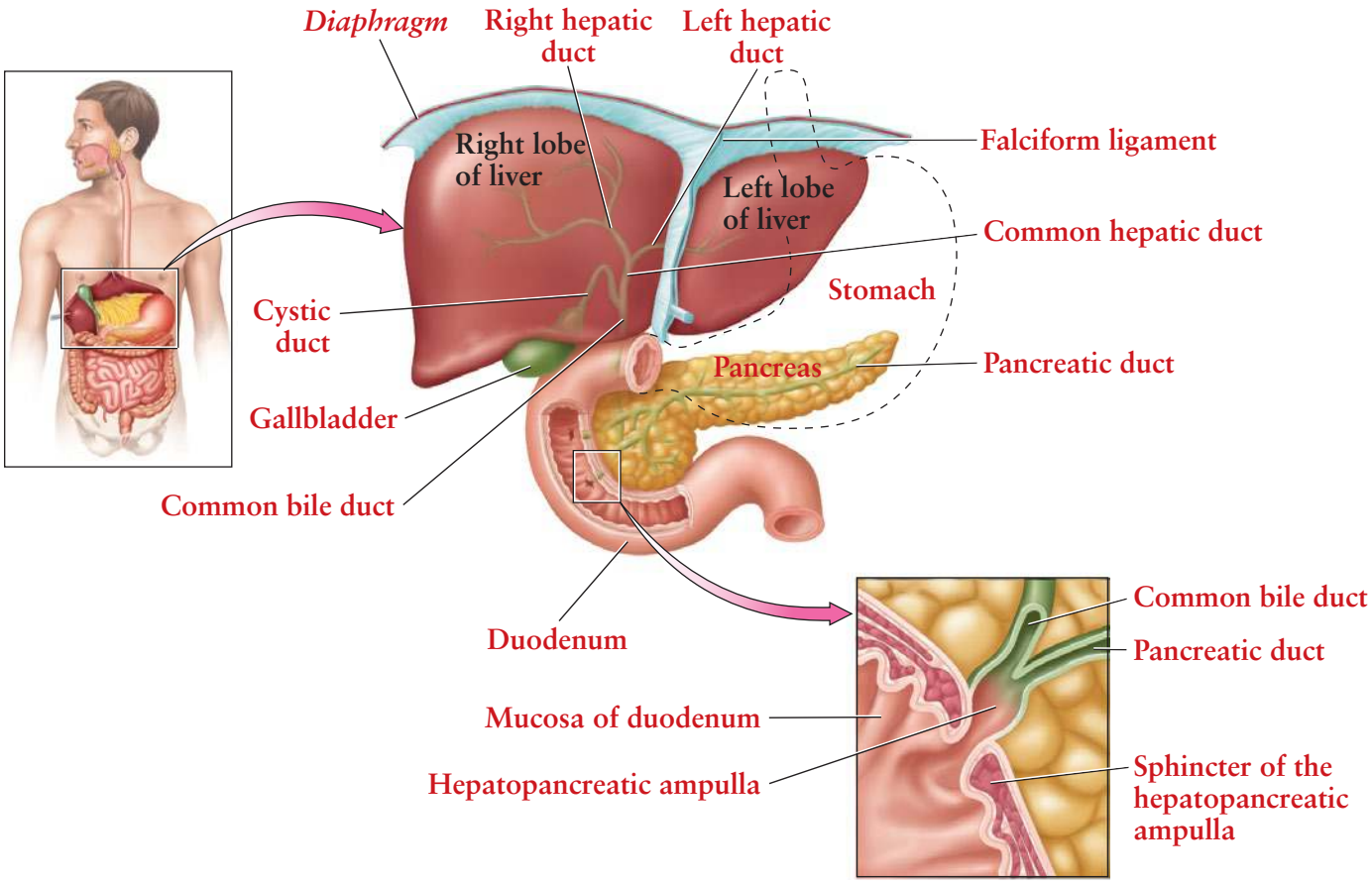

FIGURE **24.4** Structure of the liver, gallbladder, pancreas, and duodenum.

Pre-Lab Exercise 24-3 Digestive Enzymes

Estimated Completion Time: **10 min.**

TABLE **24.1** Digestive Enzymes

Enzyme	Source	Function
Salivary amylase	Salivary glands	Catalyzes reactions that break starch into oligosaccharides
Pepsin	Chief cells of the stomach	Catalyzes reactions that break proteins into polypeptides
Trypsin	Pancreas	Catalyzes reactions that break polypeptides into small polypeptides and peptides
Pancreatic lipase	Pancreas	Catalyzes reactions that break triglycerides into free fatty acids and monoglycerides
Brush border enzymes	Enterocytes of the small intestine mucosa	Catalyze reactions that break disaccharides into monosaccharides

Materials and Prep Notes

Exercise 24-1 Digestive System Anatomy

Estimated **Total** Completion Time: **50–60 min.**

In this exercise, your students learn about the structures of the digestive system. There is a lot of anatomy here, and it is spread out over a lot of models. In our lab, we use human torso models, half-head models, and models specific for the digestive system (digestive plates, the pancreas/spleen/duodenum model, the intestinal villus, etc.). My students typically run straight to the smaller models, but I ask them to start with a more global model, such as the human torso, to get oriented to the basic layout and organization first. This helps to make the more specific and often more abstract models easier to understand.

Procedure 1 Model Inventory for the Digestive System

Estimated Completion Time: **40–50 min.**

MATERIALS

- ❑ Anatomical models of the digestive system, including human torsos; digestive system plates; pancreas, spleen, and duodenum model; and head and neck models

Procedure 2 Time to Draw

Estimated Completion Time: **10 min.**

MATERIALS

- ❑ An anatomical model of the digestive system showing the arrangement of the liver, duodenum, and pancreas for students to draw
- ❑ Colored pencils

Exercise 24-2 Digestive System Histology

Estimated **Total** Completion Time: **30 min.**

In this exercise, students examine the microscopic structure of several digestive organs. Students start with models, as there are generally models that show digestive histology, after which they turn to slides. Some of the slides your students will examine might be included in the tissue types microscope slide set (for example, the esophagus is sometimes used for the stratified squamous epithelium), so you may want to check the slide set before you order the slides for this unit (Carolina Biological #312148).

Procedure 1 Model Inventory for the Histologic Structures of the Digestive System

MATERIALS

Estimated Completion Time: **10 min.**

- ❑ Models showing the tissue layers of the alimentary canal, intestinal villus model

Procedure 2 Microscopy of Digestive Organs

Estimated Completion Time: **20 min.**

MATERIALS

- ❑ Microscope slides of a tooth (Ward's Science #934454), esophagus (Carolina Biological #314998), stomach—fundus (Carolina Biological #315082), duodenum (Carolina Biological #315160), pancreas (Carolina Biological #315478), and liver (Carolina Biological #315358); one set per group.
- ❑ Light microscope with three objectives
- ❑ Colored pencils

Exercise 24-3 Digestion

Estimated **Total** Completion Time: **35–55 min.**

This exercise allows students to examine the processes of digestion of proteins, carbohydrates, and lipids. Three of the procedures require a hot-water bath. There are many options available for purchasing a hotplate, ranging from a simple hotplate from a big-box store to more expensive digital lab equipment. I've found that both work equally well for procedures such as this, so if budget is a concern, the cheaper options might be ideal for you.

Procedure 1 Test Carbohydrate Digestion

Estimated Completion Time: **10–15 min.**
(with a 30-minute wait time during which students may do other activities)

* Note that some professors have reported mixed results with this procedure. If you are not seeing sufficient digestion, try leaving the tubes in the water bath for a longer time period (45 minutes to an hour).

MATERIALS

- ❑ 6 small glass test tubes, one set per group
- ❑ 2% starch solution—add 2.0 g soluble starch (Carolina Biological #892529) to 100 mL of water to make a paste. Pour the paste into 1 L of warm water, and stir until dissolved.
- ❑ Amylase (Ward's Natural Science #9000-90-2)
- ❑ Lugol's iodine (Carolina Biological #872793)
- ❑ Benedict's reagent (Carolina Biological #847121)
- ❑ Warm-water bath set to 37°C
- ❑ Boiling water bath set to 100°C; maintain bath at slow boil
- ❑ Glass stirring rods
- ❑ Sharpie pen

Procedure 2 Test Protein Digestion

Estimated Completion Time: **10–15 min.**
(with a 1-hour wait time during which s tudents may do other activities)

MATERIALS

- ❑ 4 small glass test tubes, one set per group
- ❑ Egg white—you may purchase albumin from a supply company, but egg whites from the grocery store work just as well.
- ❑ Pepsin (Carolina Biological #879377) in 0.1 M NaOH, dissolve 100 mg of powdered pepsin in 100 mL of 0.1M NaOH; ensure that the pH of the resulting solution is above 8
- ❑ Pepsin in 0.5 M HCl (dissolve 33 g of powdered pepsin in 100 mL of 0.5 M HCl); ensure that the pH of the resulting solution is 1–2
- ❑ 0.1M NaOH (Carolina Biological #889551)
- ❑ 0.5 M HCl (Carolina Biological #867821)
- ❑ Biuret reagent (Carolina Biological #848211)
- ❑ Water bath set to 37°C

Procedure 3 Demonstrate Lipid Emulsification

Estimated Completion Time: **5–10 min.**

MATERIALS

- ❑ Vegetable oil (any kind will suffice)
- ❑ Detergent such as liquid dish soap
- ❑ Glass test tube, one per group
- ❑ Sudan red stain (Carolina Biological #892963)
- ❑ Distilled/deionized H_2O

Procedure 4 Test Lipid Digestion

Estimated Completion Time: **10–15 min.**
(with a 30-minute wait time during which students may do other activities)

MATERIALS

- ❑ Vegetable oil
- ❑ Phenol red (Carolina Biological #879875)
- ❑ 0.1M NaOH
- ❑ 5% lipase solution—dissolve 5 g lipase in 100 mL H_2O (Ward's Natural Science #9001-62)
- ❑ Bile salt solution—10 g of bile salts in 100 mL H_2O (Ward's Natural Science #470300-380)
- ❑ 4 glass test tubes, one set per group
- ❑ Distilled H_2O
- ❑ Water bath set to 37°C

Exercise 24-4 Time to Trace!

Estimated **Total** Completion Time: **20 min.**

The final exercise is a tracing exercise in which students trace the digestive pathway of an ingested carbohydrate, protein, and lipid. This is a big-picture-type exercise in which students are asked to combine the anatomy and physiology they have learned and apply it to the digestion of different nutrients. My students find it helpful to have a laminated outline of the human body on which to draw the pathway as they trace, so you may wish to have these available for your students.

MATERIALS

No specific materials are needed for these exercises; however, laminated outlines of the human body may be useful

Answers to Procedural Questions

Exercise 24-3 Digestion

Procedure 1 Test Carbohydrate Digestion

13 Interpret your results:

a In which tube(s) did carbohydrate digestion occur? How do you know?

Carbohydrate digestion occurred in tubes 3 and 5. This is evidenced by the negative reaction with Lugol's iodine and positive reaction with Benedict's reagent.

b In which tube(s) did no carbohydrate digestion occur? How do you know?

Limited to no digestion occurred in tubes 4 and 6, as evidenced by the positive reaction with Lugol's iodine and the negative reaction with Benedict's reagent.

c What conclusions can we draw?

Amylase increases the rate of the reactions that break starch into monosaccharides. With no amylase, little to no starch digestion occurs; however, were the starch to sit in water for several hours, digestion would occur, just much more slowly.

Procedure 2 Test Protein Digestion

9 Interpret your results:

a In which tube(s) did protein digestion occur? How do you know?

Protein digestion occurred in tube 2, as evidenced by the lavender-pink color of the Biuret reagent.

b In which tube(s) did no protein digestion occur? How do you know?

Little to no protein digestion occurred in the other tubes, as evidenced by the purple-blue color of the Biuret reagent.

c What effect does pH have on protein digestion with pepsin? Why?

Pepsin is only active in a solution with an acidic pH. This helps to ensure that pepsin remains inactive (in the form of pepsinogen) until digestion occurs, which prevents the enzyme from catalyzing reactions that would damage stomach cells.

d What other effects does acid have in the stomach?

The acidic pH of the stomach kills or decreases the growth of many microorganisms, which helps prevent infection and/or colonization of the stomach.

Procedure 3 Demonstrate Lipid Emulsification

3 Place a rubber stopper into the tube and shake it vigorously for 15 seconds. Allow it to stand for 2 minutes. What happens to the oil and water?

The oil and water should separate.

4 Add three or four drops of Sudan red stain, and shake the tube again for 15 seconds. What color is the oil? What color is the water?

The oil should be red; the water should remain clear.

5 Add about 1 mL of liquid detergent to the mixture and shake the tube vigorously for 15 seconds. Allow the tube to stand for 2 minutes. What has happened to the solution? Is it still two distinct colors? Explain your results.

The solution should be uniformly red because the lipids are uniformly distributed in the water.

Procedure 4 Test Lipid Digestion

10 Interpret your results:

a In which tube(s) did lipid digestion occur? How do you know?

Lipid digestion occurred in tube 1, as evidenced by the yellow color of the solution.

b In which tube(s) did limited or no lipid digestion occur? How do you know?

Limited to no digestion occurred in the remaining tubes, as evidenced by pink/red-orange color of the solutions.

c What effect does bile have on lipid digestion? Why?

Bile enhances lipid digestion by breaking lipids into smaller droplets and giving lipase greater surface area on which to work.

Exercise 4 Time to Trace

Tracing Steps

1. Cookie: **Start:** mouth → esophagus → stomach (mechanical digestion with churning) → small intestine [chemical digestion with pancreatic amylase (minimal) and sucrase into individual glucose molecules] → absorption across the enterocyte via cotransport into the capillaries of the intestinal villi → intestinal veins → superior mesenteric vein → hepatic portal vein → hepatic portal system → inferior vena cava → heart **End**

2. Egg: **Start:** mouth → esophagus → stomach (mechanical digestion with churning, chemical digestion into polypeptides with pepsin) → small intestine (chemical digestion with pancreatic and brush border enzymes into amino acids) → absorption across the enterocyte via cotransport into the capillaries of the intestinal villi → intestinal veins → superior mesenteric vein → hepatic portal vein → hepatic portal system → inferior vena cava → heart **End**

3. Greasy fried food: **Start:** mouth → esophagus → stomach (mechanical digestion of churning) → small intestine (mechanical digestion of emulsification, chemical digestion from pancreatic lipase) → association with bile salts into micelles → entry of free fatty acids and monoglycerides into the enterocyte → assembly of the free fatty acids and monoglycerides into chylomicrons → entry of chylomicrons into the lacteal in the core of the intestinal villus → intestinal lymphatic trunk → cisterna chyli → thoracic duct → junction of the left internal jugular and left subclavian veins → left subclavian vein → left brachiocephalic vein → superior vena cava → heart **End**

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Check Your Recall

REVIEW

1 Label the following structures on Figure 24.28.

- ❑ Cecum
- ❑ Esophagus
- ❑ Gallbladder
- ❑ Greater omentum
- ❑ Lesser omentum
- ❑ Liver
- ❑ Mesentery
- ❑ Parotid gland
- ❑ Rectum
- ❑ Sigmoid colon
- ❑ Sublingual gland
- ❑ Submandibular gland
- ❑ Transverse colon
- ❑ Vermiform appendix

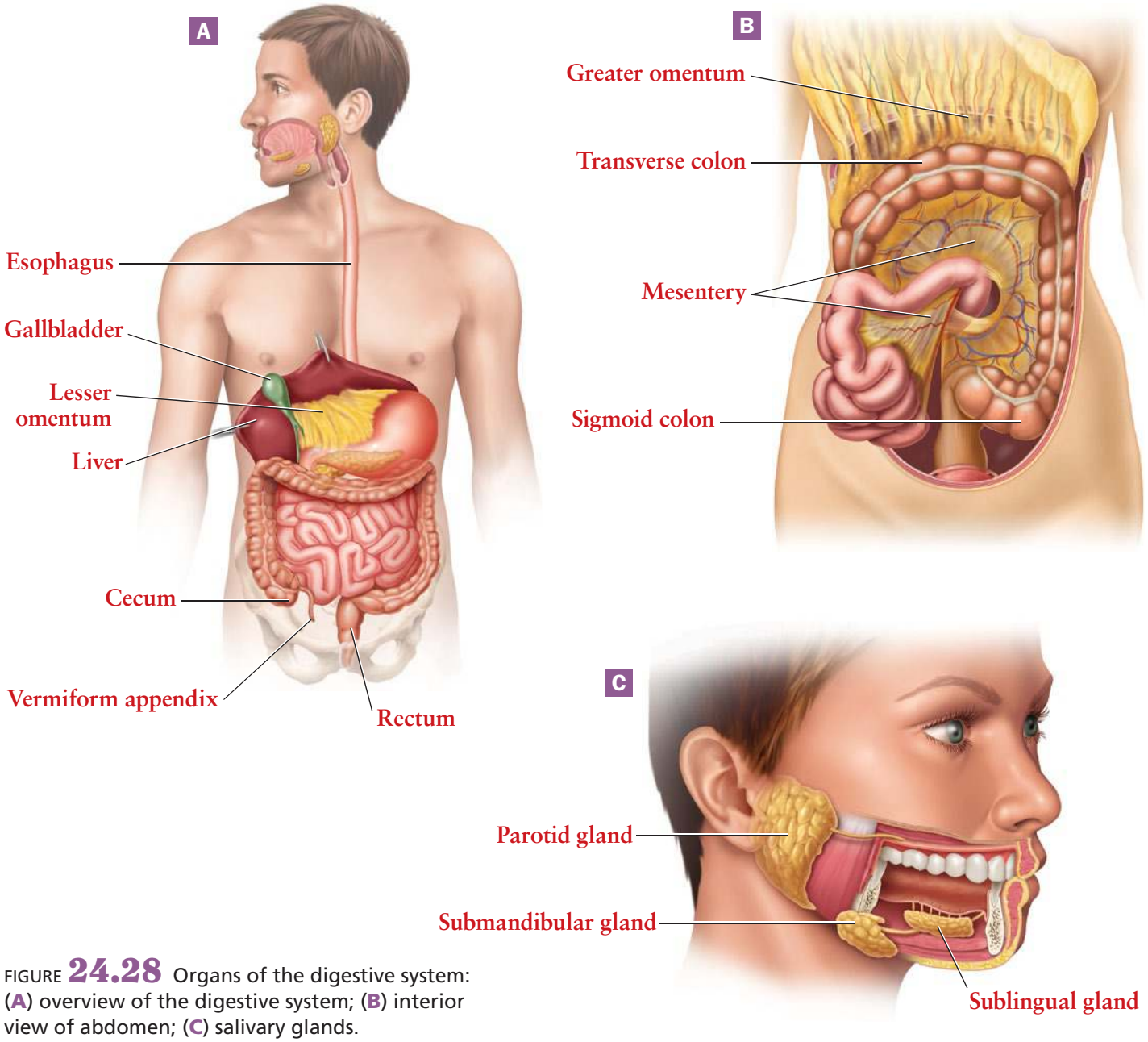

FIGURE **24.28** Organs of the digestive system: (**A**) overview of the digestive system; (**B**) interior view of abdomen; (**C**) salivary glands.

2 Label the following structures on Figure 24.29.

- ❑ Body
- ❑ Cardia
- ❑ Circular muscle layer
- ❑ Duodenum
- ❑ Fundus
- ❑ Gastroesophageal sphincter
- ❑ Pyloric sphincter
- ❑ Pylorus
- ❑ Rugae

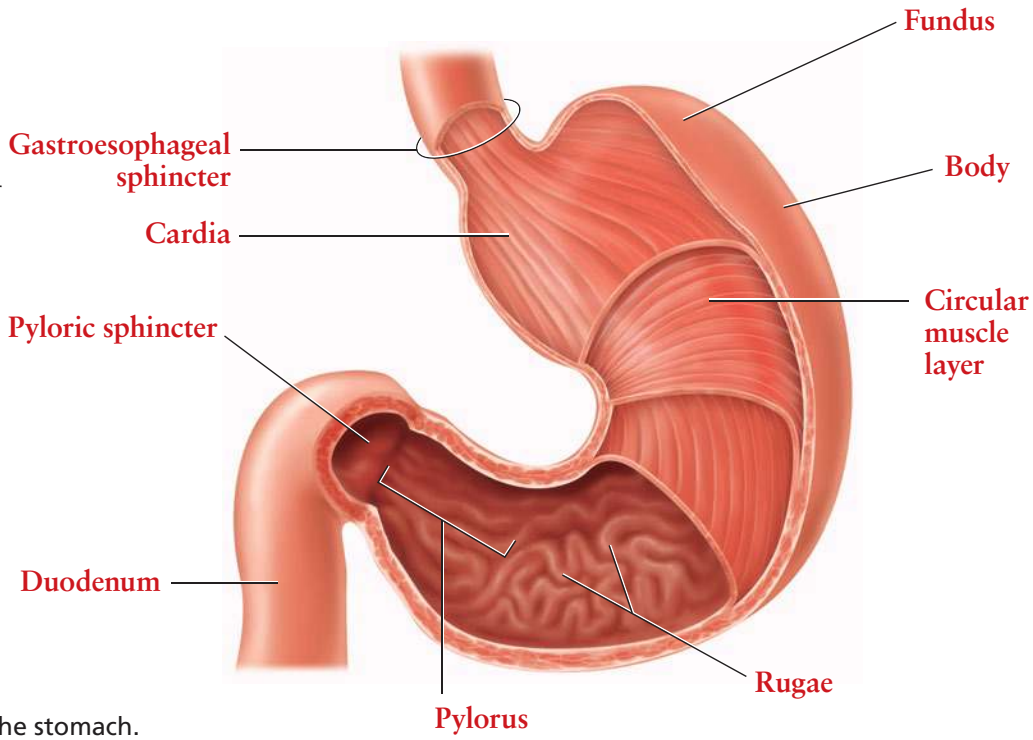

FIGURE **24.29** Anatomy of the stomach.

3 Which of the following organs is not an accessory organ of digestion?

a. Salivary glands.
b. Gallbladder.
c. Cecum.
d. Pancreas.

4 *True/False:* Mark the following statements as true (T) or false (F). If the statement is false, correct it so it becomes a true statement.

__F__ a. The peritoneal cavity is located between the visceral peritoneum and the ~~mesentery~~ parietal peritoneum.

__T__ b. The shortest segment of the small intestine is the duodenum.

__T__ c. Filiform papillae are keratinized projections from the tongue that help physically break down food.

__F__ d. ~~Pancreatic islets~~ Acinar cells are the exocrine portion of the pancreas.

__F__ e. The ~~ileocecal valve~~ pyloric sphincter regulates flow from the stomach to the duodenum.

__T__ f. The vermiform appendix is a blind-ended sac that contains lymphoid follicles.

5 *Fill in the blanks:* Bile is produced by the liver and stored and concentrated in the gallbladder .

6 Label the following structures on Figure 24.30.

- ❑ Caudate lobe of liver
- ❑ Common bile duct
- ❑ Common hepatic duct
- ❑ Cystic duct
- ❑ Falciform ligament
- ❑ Gallbladder
- ❑ Hepatopancreatic ampulla
- ❑ Left lobe of liver
- ❑ Pancreas
- ❑ Pancreatic duct
- ❑ Porta hepatis
- ❑ Right lobe of liver
- ❑ Round ligament

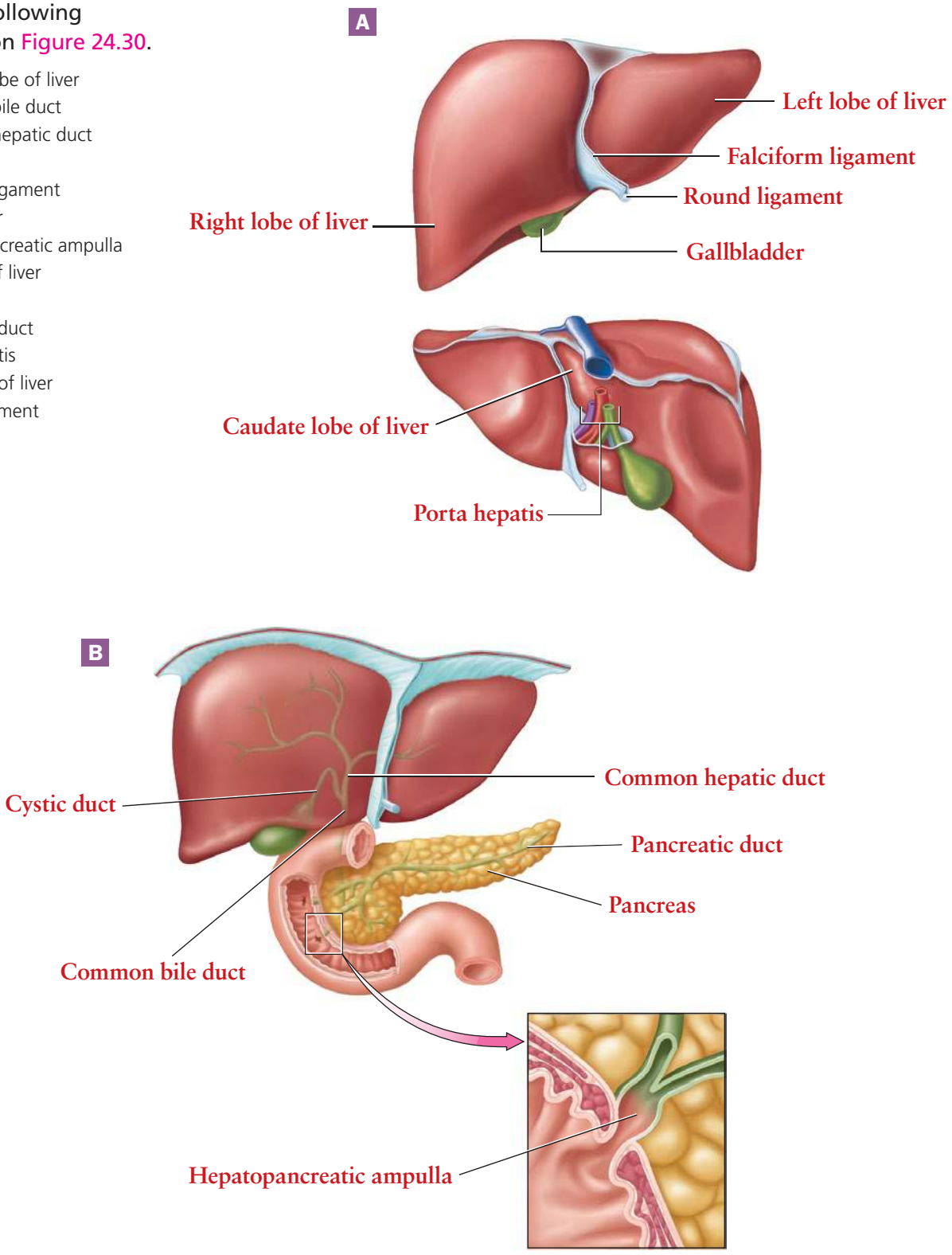

FIGURE **24.30** Accessory organs of the digestive system: (**A**) anterior and posterior views of the liver; (**B**) liver and associated accessory organs.

7 Label the following structures on Figure 24.31.

- ❑ Circular layer of smooth muscle
- ❑ Longitudinal layer of smooth muscle
- ❑ Lumen
- ❑ Mucosa
- ❑ Muscularis mucosae
- ❑ Serosa
- ❑ Submucosa

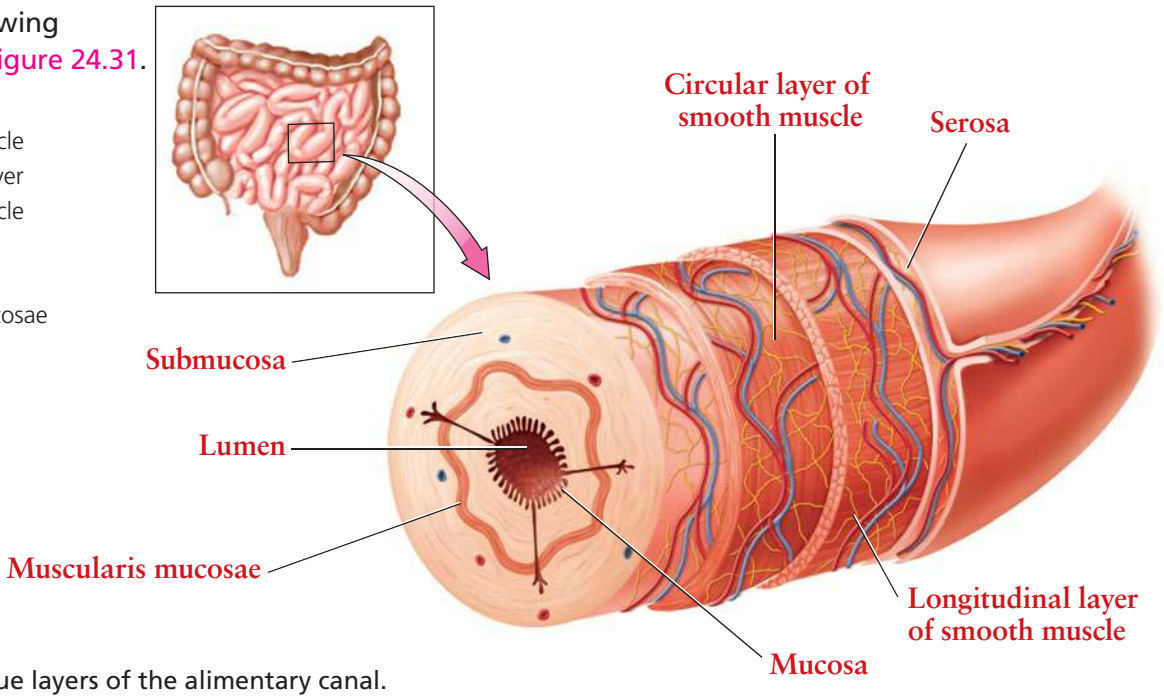

FIGURE **24.31** Tissue layers of the alimentary canal.

8 *Matching:* Match the following with the correct definition.

__F__ Salivary amylase	A. Protein-coated lipid droplets that are absorbed
__C__ Bile salts	B. Protein-digesting enzyme(s) produced by the stomach
__D__ Micelles	C. Emulsifies/emulsify fats
__B__ Pepsin	D. Clusters of bile salts and digested lipids in the small intestine
__A__ Chylomicrons	E. Required to activate pepsinogen
__H__ Pancreatic lipase	F. Begin(s) carbohydrate digestion in the mouth
__E__ Hydrochloric acid	G. Structure(s) into which lipids are absorbed
__G__ Lacteal	H. Enzyme(s) that digest(s) lipids into free fatty acids and monoglycerides

9 Folds of the small intestinal mucosa are known as

a. microvilli.
b. circular folds.
c. intestinal crypts.
d. villi.

10 Explain the importance of emulsification in lipid digestion.

Emulsification physically breaks apart lipids into smaller droplets to give pancreatic lipase a greater surface area on which to work as it catalyzes lipid breakdown.

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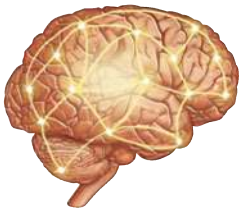

Check Your Understanding

REVIEW

Critical Thinking and Application Questions

1 Eva has been diagnosed with *gallstones*, which are lumps of cholesterol and other components of bile. One of the gallstones is blocking her cystic duct, preventing the release of bile from the gallbladder.

a Will the gallstones prevent bile from being produced and released into the duodenum? Why or why not?

Bile is produced by the liver, not the gallbladder, so it will be produced even if the gallbladder is removed. As long as the common bile duct is intact, bile will continue to be released into the duodenum via the common hepatic duct.

b Predict what might happen if a gallstone were to block Eva's pancreatic duct, preventing the release of pancreatic juice into the duodenum.

This would lead to various digestive issues, as the majority of digestive enzymes and bicarbonate ions are in pancreatic juice. (*Note:* It would also cause some of the enzymes to catalyze digestion of the pancreas itself, leading to *pancreatitis*.)

2 The condition known as *appendicitis* is an acute inflammation of the appendix, usually due to bacterial infection. What anatomical or histological feature does the appendix contain that makes it at risk for this type of condition? How does its location and shape complicate this? Explain.

The appendix contains numerous lymphatic nodules that can trap bacteria, leading to infection and inflammation. Due to the narrow shape and small size of the appendix, when it becomes inflamed, it does not drain. This causes it to be at risk for rupture.

3 If the ileocecal valve fails to close properly, the contents of the cecum can reflux back into the ileum. Why might this cause problems? (***Hint:*** What is found in the large intestine that is not normally found in the small intestine?)

The large intestine houses large numbers of bacteria, but the small intestine is normally sterile. When the bacteria-filled contents of the large intestine reflux into the small intestine, it can cause infection and inflammation of the ileum.

4 If you go into your local grocery store, you are bound to find a host of gluten-free products made with synthetic proteins instead of the natural wheat-based protein gluten. About 1 to 3 percent of the population is sensitive to gluten. The most severe form of gluten intolerance is the autoimmune disease *celiac disease* (note that it is not caused by gluten, and you cannot get it from eating gluten). In individuals with celiac disease, the immune response to gluten antigens causes the flattening of the villi in the small intestine. How would this affect the ability of the small intestine to function? Predict the symptoms you would expect to see from celiac disease.

The villi increase surface area for chemical digestion and absorption in the small intestine. When the villi become flattened, nutrient absorption and chemical digestion of certain nutrients decreases significantly. In addition, absorption of water, electrolytes, vitamins, and minerals decreases. This leads to nutrient deficiencies, dehydration, diarrhea, and vomiting.

5 Sadaf has an ulcer of her large intestine that has *perforated*, meaning that it has developed a hole that has gone through all tissue layers.

a Through which tissue layers would the ulcer have had to pass to perforate completely?

The ulcer would have had to pass through the mucosa, submucosa, muscularis externa (the taenia coli), and the serosa.

b A major concern with large intestine perforation is *peritonitis*, or infection of the peritoneal fluid. Why is this a particular concern with the large intestine?

The high bacterial content of the large intestine creates a very high risk of infection in the peritoneal cavity.

c Why could peritonitis have wide-ranging effects on Sadaf's other organs of the abdomen and digestive system? Are there any organs that would be unlikely to be directly affected by peritonitis? Explain.

Peritonitis could affect any organs within the peritoneal cavity, including the stomach, liver, part of the pancreas, transverse colon, spleen, sigmoid colon, ileum, jejunum, and part of the duodenum. Organs that would not be directly affected include retroperitoneal organs, such as the kidneys, adrenal glands, ascending and descending colon, and ureters.

6 Many dietary supplements contain digestive enzymes the manufacturers claim are necessary to digest food properly. What will happen to these enzymes in the stomach? (***Hint:*** Enzymes are proteins.) Will the enzymes continue to function once they have reached the small intestine? Why or why not?

The enzymes will be destroyed by the pepsin in the stomach, rendering them useless and a fantastic waste of money.