Chapter 25

Digestive System

The Digestive System

- most **nutrients** we eat cannot be used in their existing form
  - must be broken down into smaller components before our body can make use of them
- the digestive system is essentially a **"disassembly line"**
  - to break down nutrients into a form that can be used by the body
  - to absorb them so they can be distributed to the tissues
- **gastroenterology** – the study of the digestive tract and the diagnosis and treatment of its disorders

Digestive Function

- **digestive system** – the organ system that processes food, extracts nutrients from it, and eliminates the residue
- **five stages of digestion**
  - **ingestion** - selective intake of food
  - **digestion** – mechanical and chemical breakdown of food into a form usable by the body
  - **absorption** - uptake of nutrient molecules into the epithelial cells of the digestive tract and then into the blood and lymph
  - **compaction** - absorbing water and consolidating the indigestible residue into feces
  - **defecation** - elimination of feces

Facets of Digestion

- **mechanical digestion** – the physical breakdown of food into smaller particles
  - cutting and grinding action of the teeth
  - churning action of stomach and small intestines
  - exposes more food surface to the action of digestive enzymes

- **chemical digestion –** a series of hydrolysis reactions that breaks dietary macromolecules into their monomers (residues)
  - carried out by **digestive enzymes** produced by salivary glands, stomach, pancreas and small intestine
  - results:
    - polysaccharides into **monosaccharides**
    - proteins into **amino acids**
    - fats into **monoglycerides and fatty acids**
    - nucleic acids into nucleotides

- some nutrients are present in a usable form in ingested food
  - absorbed without being digested
  - vitamins, free amino acids, minerals, cholesterol, and water

General Anatomy

- digestive system has **two anatomical subdivisions**
- **digestive tract** (alimentary canal)
  - 30 foot long muscular tube extending from mouth to anus
  - mouth, pharynx, esophagus, stomach, small intestine, and large intestine
  - **gastrointestinal (GI) tract** is the stomach and intestines
- **accessory organs**
  - teeth, tongue, salivary glands, liver, gallbladder, and pancreas

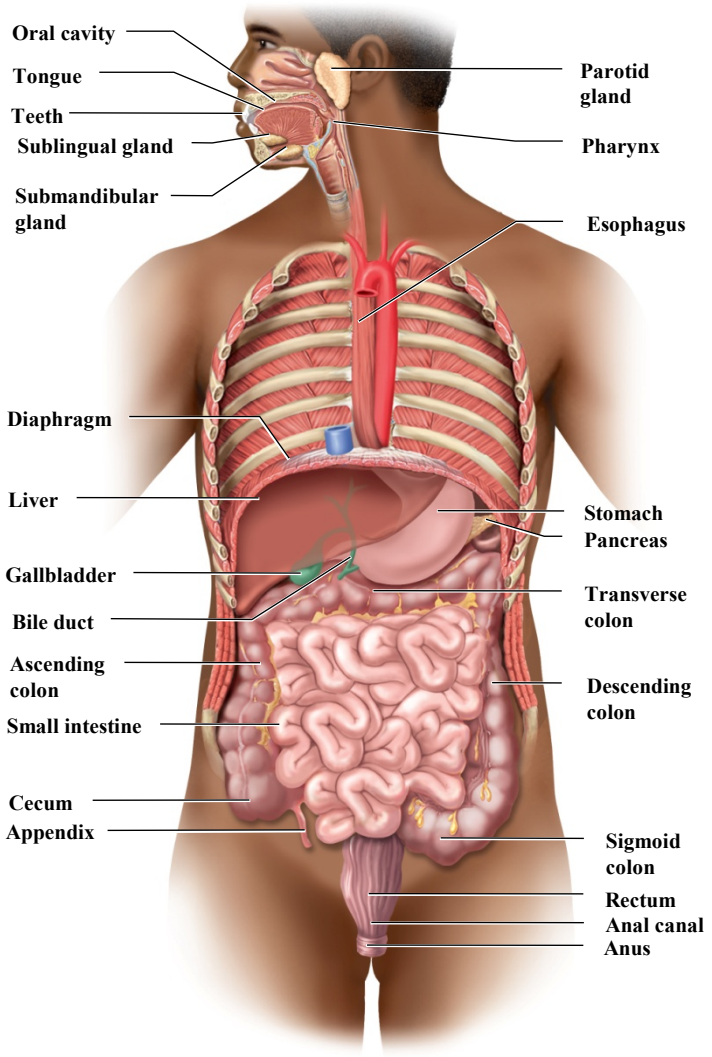


Figure 25.1

General Anatomy

- digestive tract is open to the environment at both ends
- most material in it has not entered the body tissues
  - is considered to be external to the body until it is absorbed by the epithelial cells of the alimentary canal
- in a strict sense, defecated food residue was never in the body

General Anatomy

- **mucosa**
  - epithelium
  - lamina propria
  - muscularis mucosae
- **submucosa**
- **muscularis externa**
  - inner circular layer
  - outer longitudinal layer
- **serosa**
  - areolar tissue
  - mesothelium

Variations in Layers of GI Tract

- **mucosa (mucous membrane)** – lines the lumen and consists of:
  - **inner epithelium**
    - simple columnar in most of digestive tract
    - stratified squamous from mouth through esophagus, and in lower anal canal
  - **lamina propria** – loose connective tissue layer
  - **muscularis mucosa** – thin layer of smooth muscle
    - tenses mucosa creating grooves and ridges that enhance surface area and contact with food
    - improves efficiency of digestion and nutrient absorption
  - **mucosa-associated lymphatic tissue (MALT)** – the mucosa exhibits an abundance of lymphocytes and lymphatic nodules

- **submucosa** – thicker layer of loose connective tissue
  - contains blood vessels, lymphatic vessels, a nerve plexus, and in some places mucus secreting glands that dump lubricating mucus into the lumen
  - MALT extends into the submucosa in some parts of the GI tract

Variations in Layers of GI Tract

- **muscularis externa** – consists of usually two layers of muscle near the outer surface
  - **inner circular layer**
    - in some places, this layer thickens to form **valves (sphincters)** that regulate the passage of material through the tract
  - **outer longitudinal layer**
    - responsible for the **motility** that propels food and residue through the tract
- **serosa** – composed of a thin layer of areolar tissue topped by simple squamous mesothelium

Tissue Layers of GI Tract

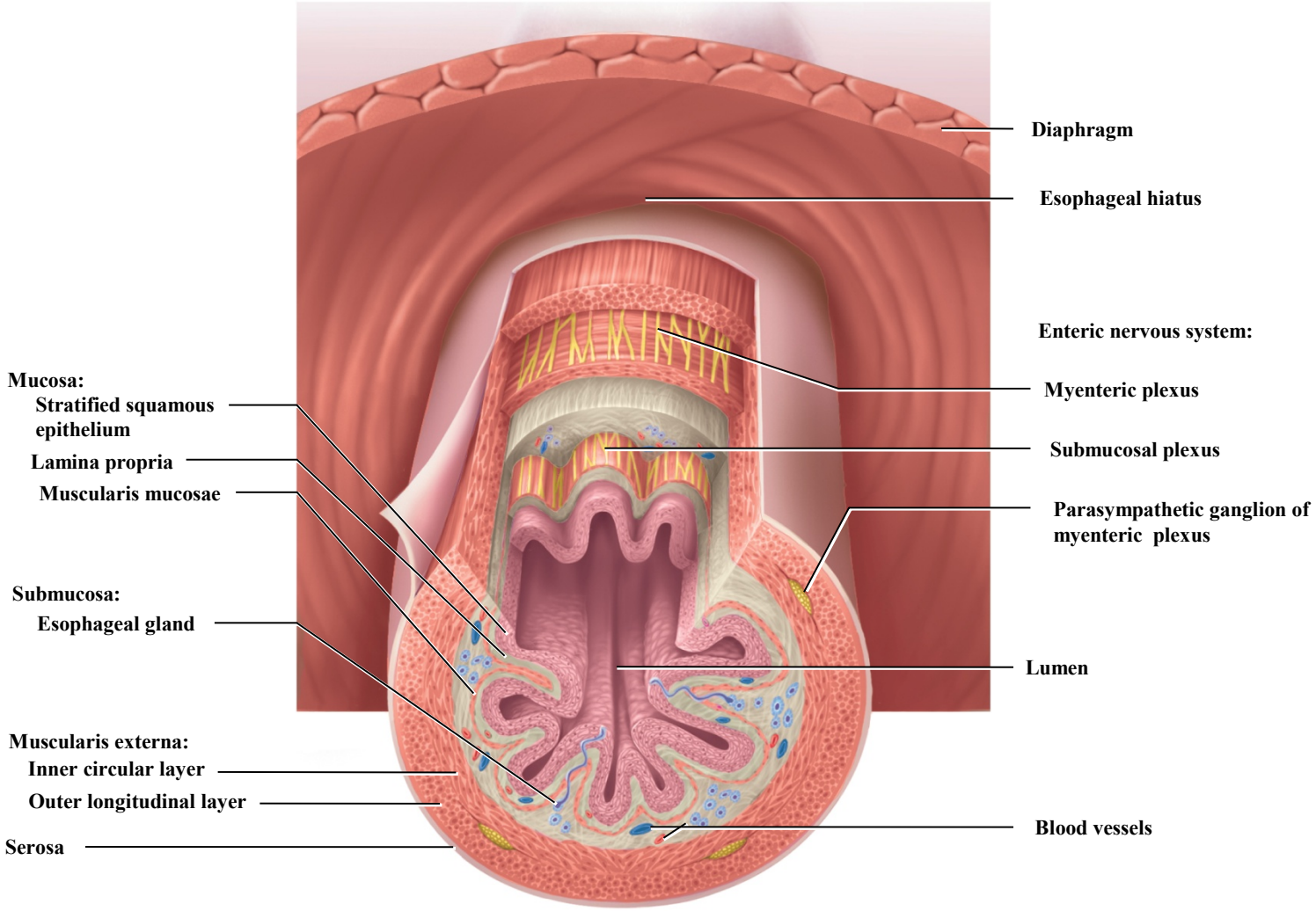


Figure 25.2

Enteric Nervous System

- **enteric nervous system** – a nervous network in the esophagus, stomach, and intestines that regulated digestive tract motility, secretion, and blood flow
  - functions completely independently of the central nervous system
    - CNS exerts a significant influence on its action
- composed of **two networks of neurons**
  - **submucosal plexus** – in submucosa
    - controls glandular secretion of mucosa
    - controls movements of muscularis mucosae
  - **myenteric plexus** – in muscularis externa
    - controls peristalsis and other contractions of muscularis externa
- enteric nervous system contains sensory neurons that monitor tension in gut wall and conditions in lumen

Relationship to Peritoneum

- **mesenteries** – connective tissue sheets that loosely suspend the stomach and intestines from the abdominal wall

Relationship to Peritoneum

- **parietal peritoneum** – a serous membrane that lines the wall of the abdominal cavity
  - forms **dorsal mesentery** – a translucent two-layered membrane extending to the digestive tract
  - the two layers of the mesentery separate and pass around opposite sides of the organ forming the **serosa**
  - come together on the far side of the organ and continue as another sheet of tissue – the **ventral mesentery**
    - may hang freely in the abdominal cavity
    - may attach to the anterior abdominal wall or other organs

- **lesser omentum** – a ventral mesentery that extends from the **lesser curvature of the stomach** to the **liver**

Relationship to Peritoneum

- **greater omentum** – hangs from the **greater curvature of the stomach**
  - covers the small intestines like an apron
  - the inferior margin turns back on itself and passes upward
  - forming a deep pouch between its deep and superficial layers
  - inner superior margin forms serous membranes around the spleen and transverse colon
- **mesocolon** – extension of the mesentery that anchors the colon to the posterior abdominal wall

Fig. A.9

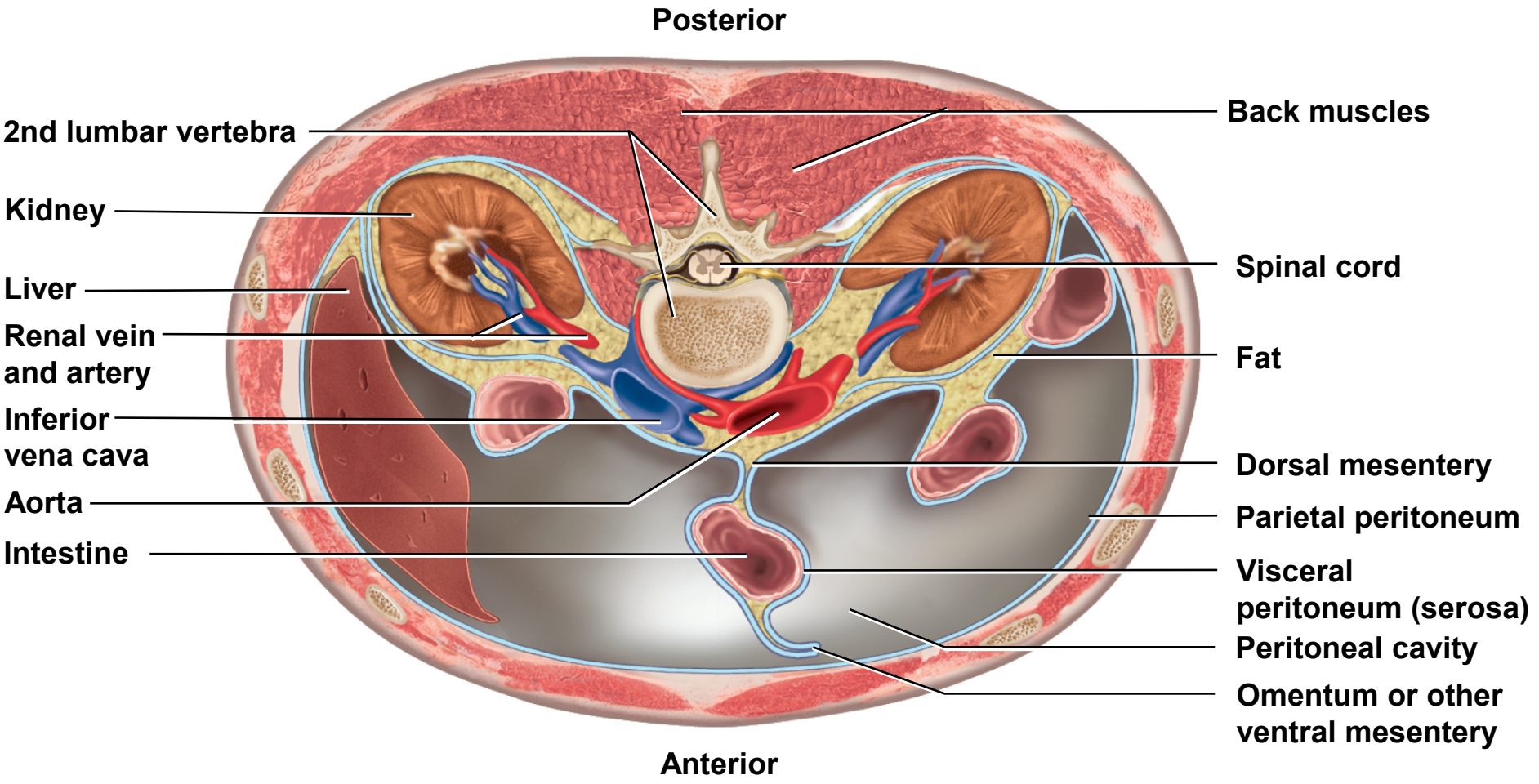
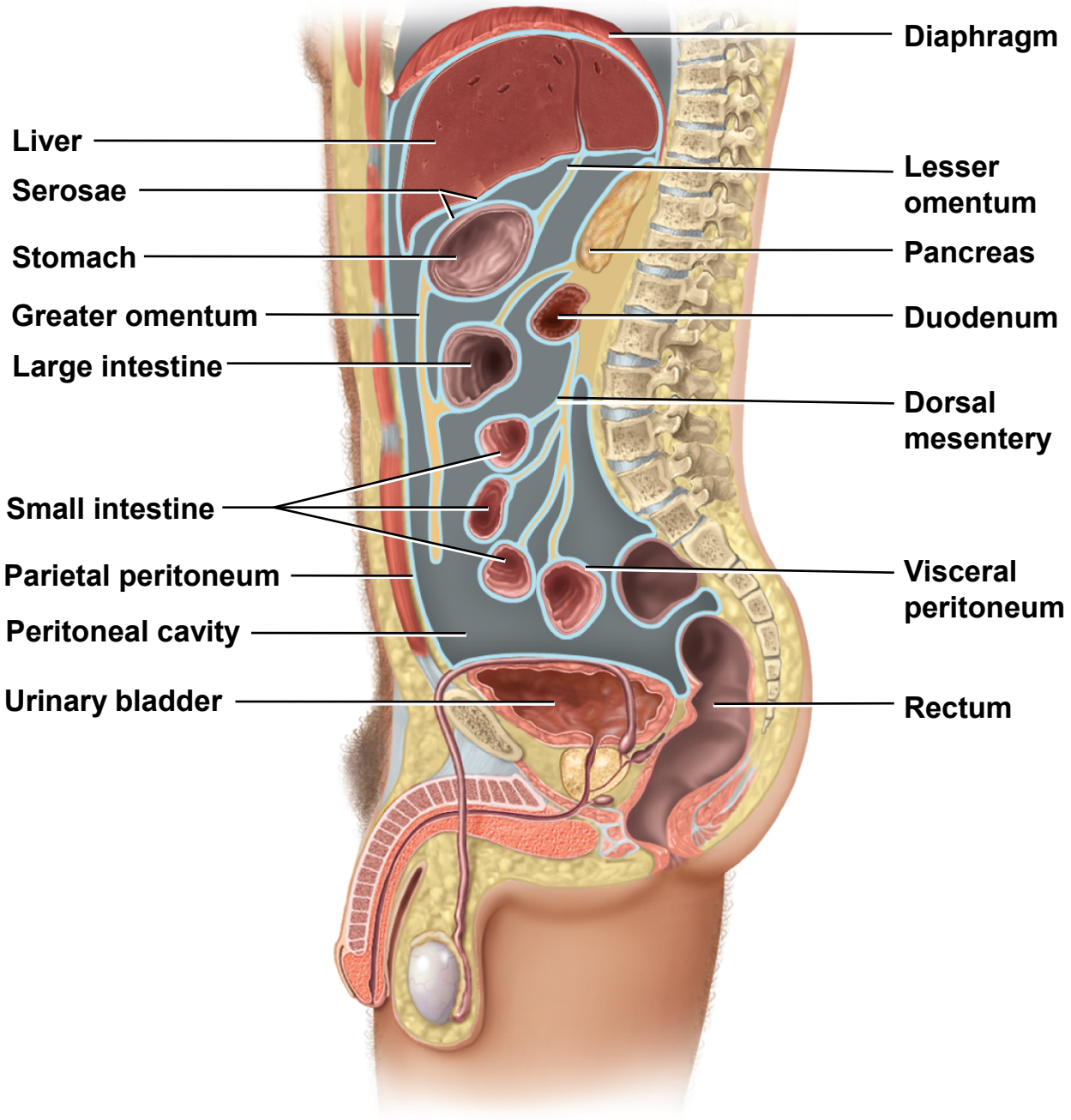
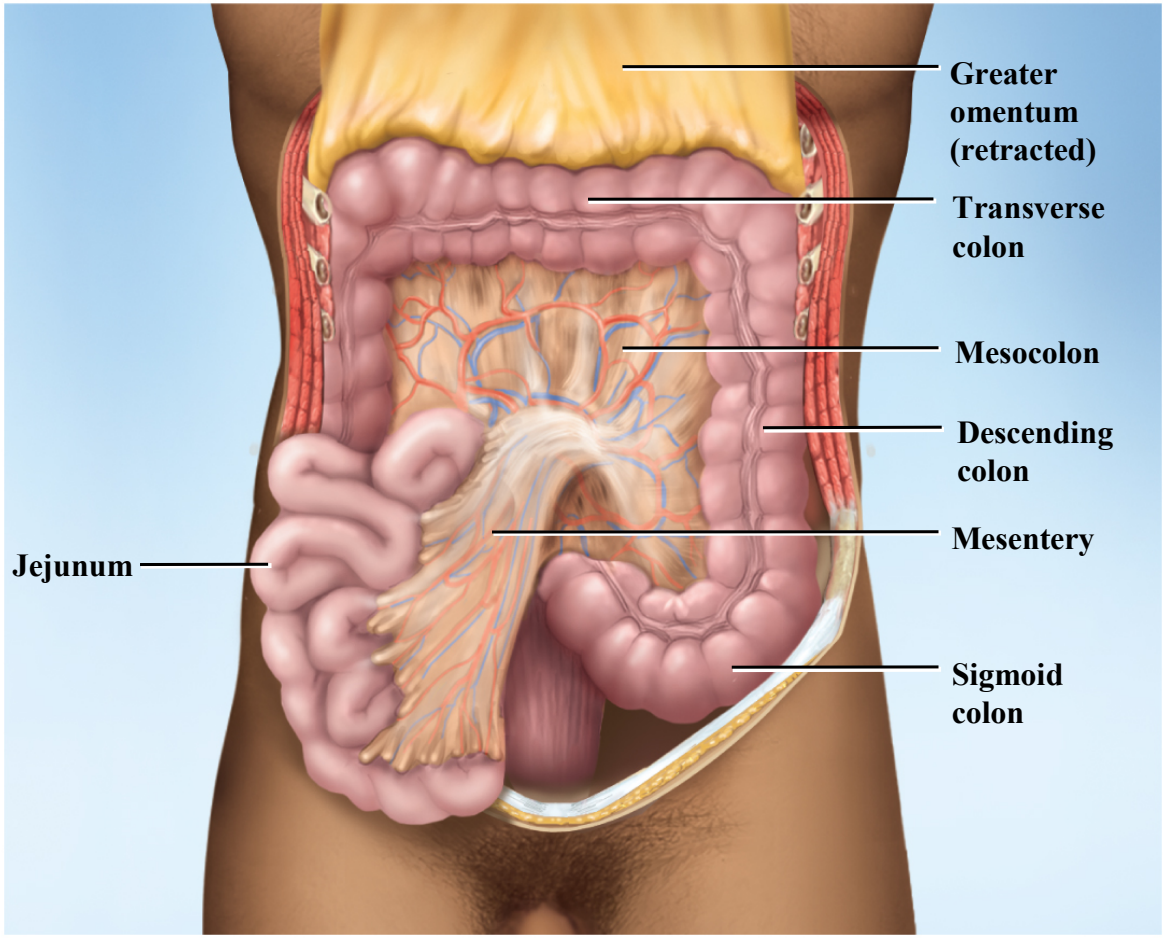


Fig. A.10



Mesentery and Mesocolon



(b)

Figure 25.3b

- mesentery of small intestines holds many blood vessels
- mesocolon anchors colon to posterior body wall

Lesser and Greater Omentum

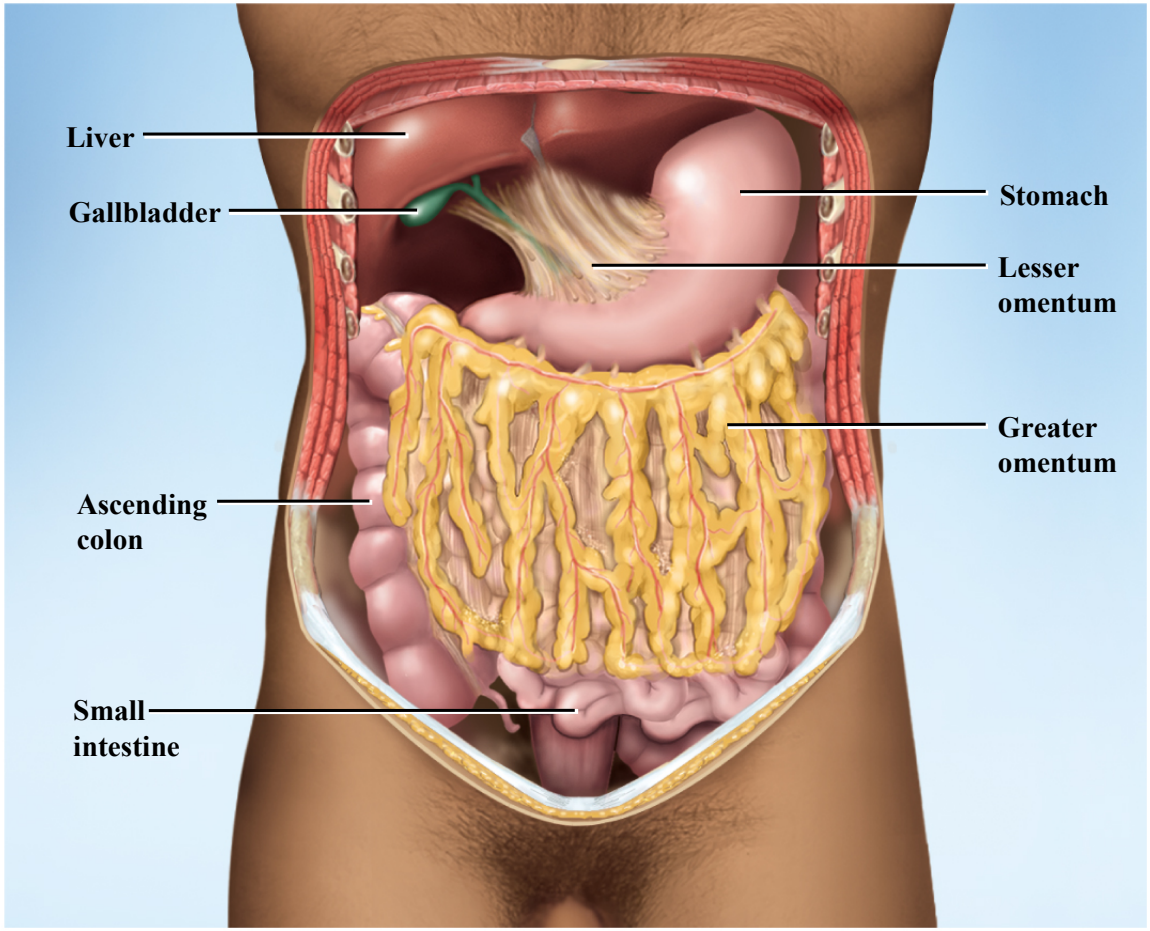


Figure 25.3a

- lesser omentum- attaches stomach to liver
- greater omentum- covers small intestines like an apron

Regulation of Digestive Tract

- **motility** and **secretion** of the digestive tract are controlled by neural, hormonal, and paracrine mechanisms

- **neural control**
  - **short (myenteric) reflexes** – stretch or chemical stimulation acts through myenteric plexus
    - stimulates parastaltic contractions of **swallowing**
  - **long (vagovagal) reflexes** - parasympathetic stimulation of digestive **motility** and **secretion**

- **hormones**
  - chemical messengers secreted into bloodstream, and stimulate distant parts of the digestive tract
  - gastrin and secretin

Mouth or Oral Cavity

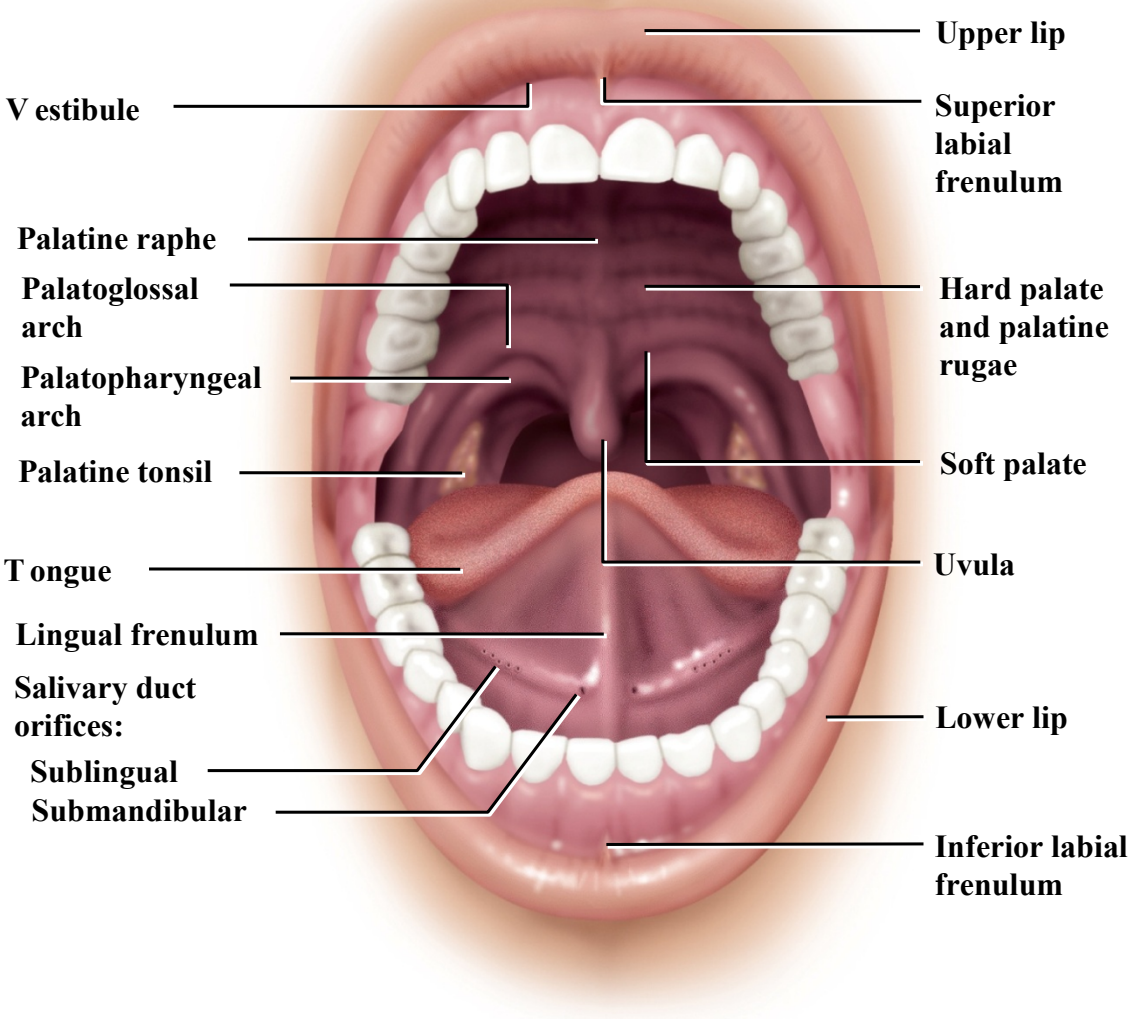


Figure 25.4

The Mouth

- the **mouth** is known as the **oral**, or **buccal cavity**
- **stratified squamous epithelium** lines mouth
  - **keratinized** in areas subject to food abrasion – gums and hard palate
  - **nonkeratinized** in other areas – floor of mouth, soft palate, and inside of cheek and lips

The Tongue

nonkeratinized stratified squamous epithelium covers its surface

lingual papillae – bumps and projections on the tongue that are the sites of the taste buds

intrinsic muscles are contained entirely within the tongue

produce the subtle tongue movements of speech

extrinsic muscles – with origins elsewhere and insertions in the tongue

produce stronger movements of food manipulation

genioglossus, hyoglossus, palatoglossus, and styloglossus

lingual tonsils – contained in the root

Tongue

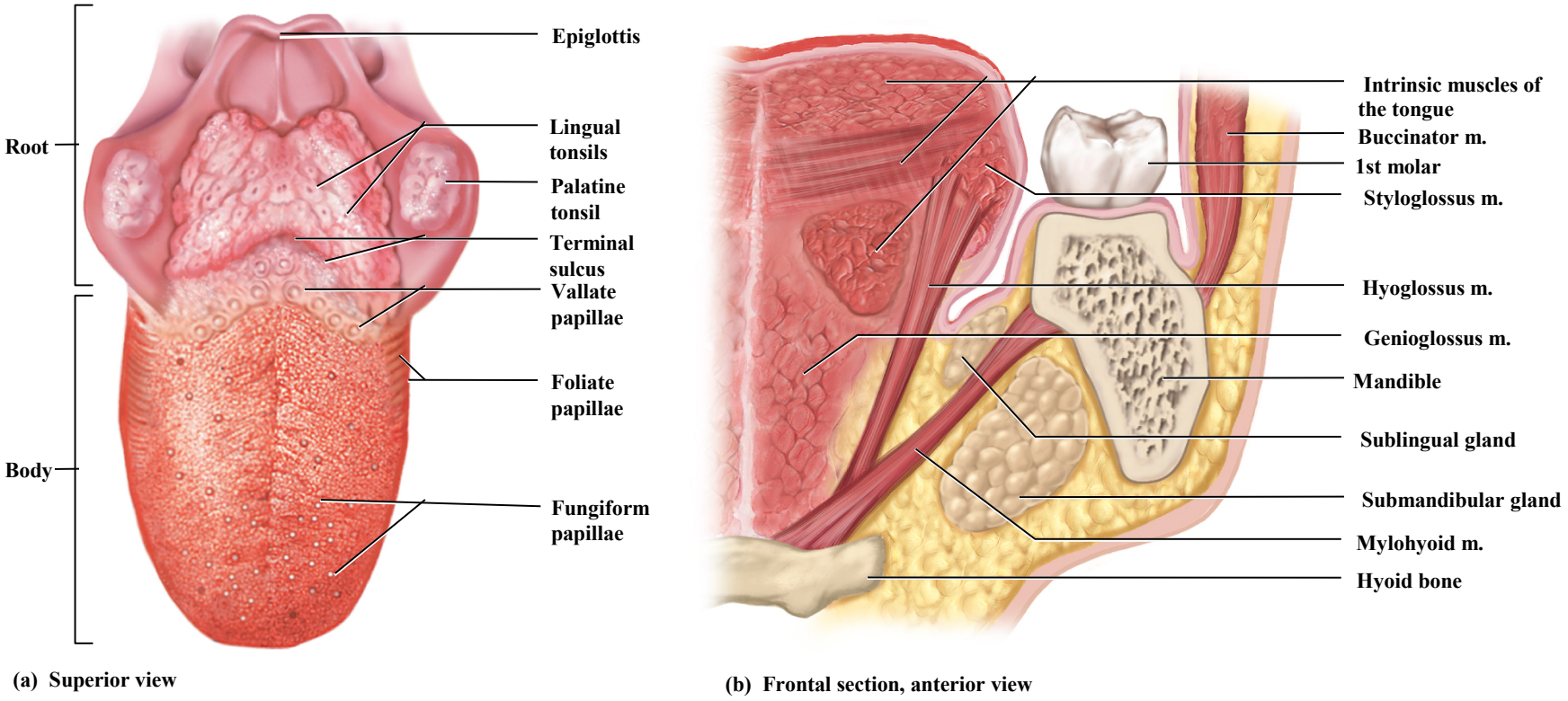
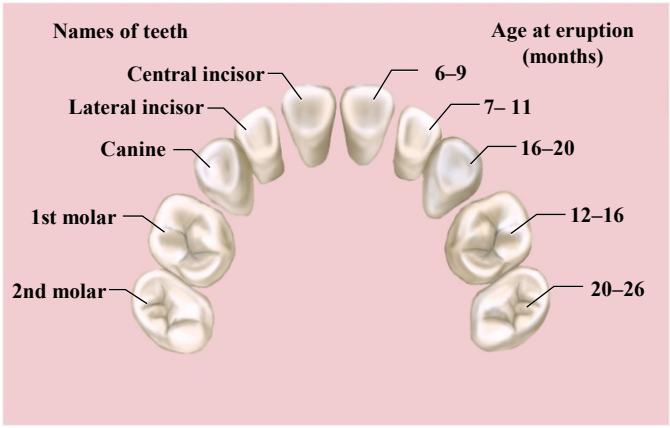


Figure 25.5 a-b

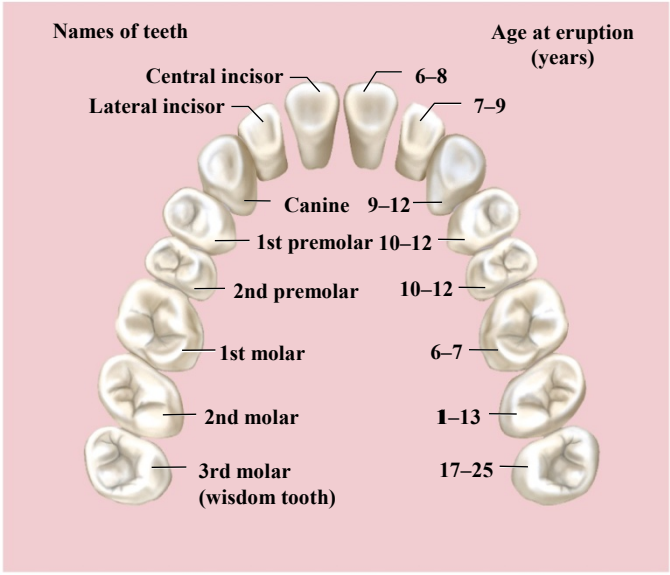
The Teeth

- **dentition** – the teeth
- **masticate** food into smaller pieces
- **32 adult teeth – 20 deciduous (baby) teeth**
  - 16 in mandible
  - 16 in maxilla
  - **from midline to the rear of each jaw**
    - 2 **incisors** – chisel-like cutting teeth used to bite off a piece of food
    - 1 **canine** – pointed and act to puncture and shred food
    - 2 **premolars** – broad surface for crushing and grinding
    - 3 **molars** – even broader surface for crushing and grinding

The Teeth



(a) Deciduous (baby) teeth



(b) Permanent teeth

Figure 25.6

Tooth Structure

- **dentin** – hard yellowish tissue that makes up most of the tooth
- **enamel** – covers crown and neck
- **cementum** – covers root
- cementum and dentin are living tissue and can regenerate
- enamel is noncellular secretion formed during development
- **root canal** in the roots leading to **pulp cavity** in the crown
  - nerves and blood vessels
  - **apical foramen** – pore at the basal end of each root canal

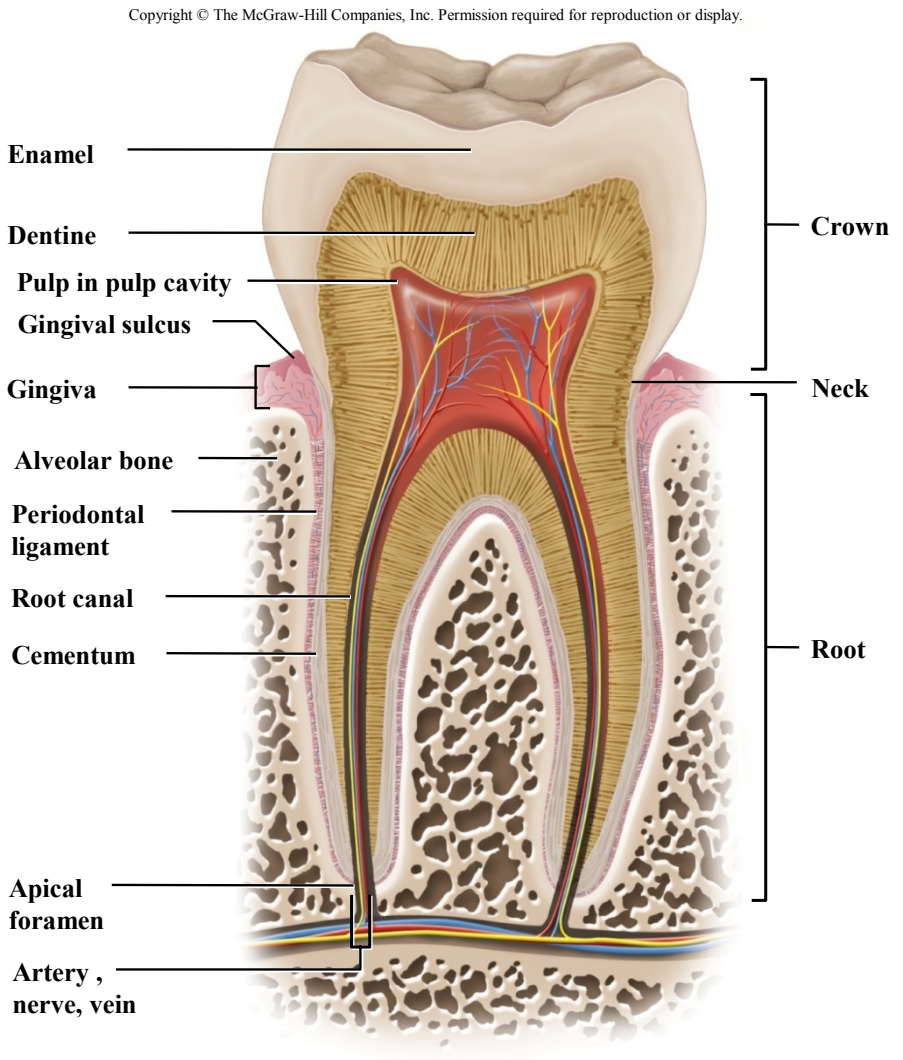


Figure 25.7

Permanent and Deciduous Teeth

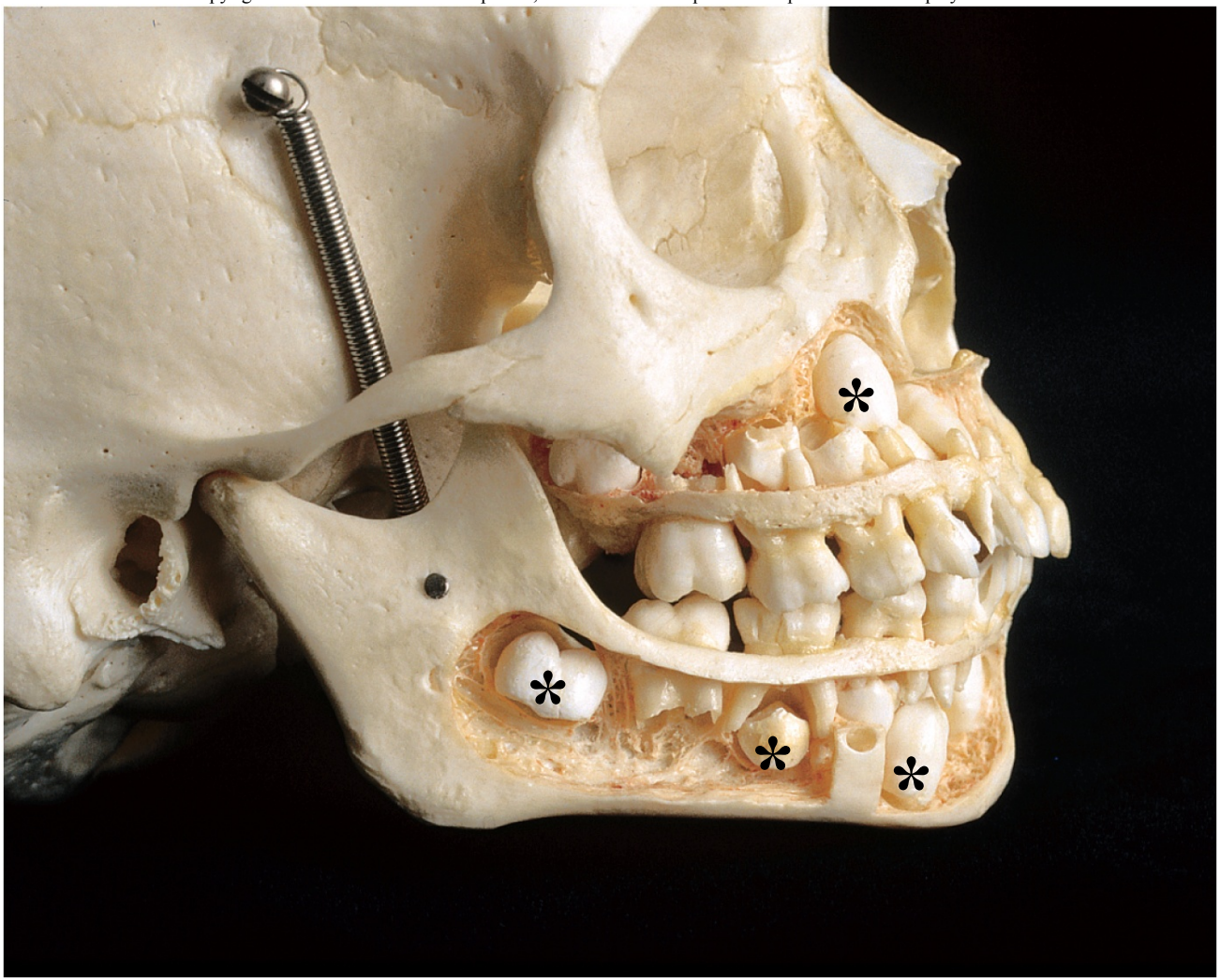


Figure 25.8

Deciduous Teeth

- **20 deciduous teeth** (milk teeth or baby teeth)
- teeth develop beneath the gums and erupt in a predictable order
  - erupt from 6 to 30 months
  - beginning with incisors
  - between 6 and 32 years of age, are replaced by 32 permanent teeth
- third molars (**wisdom teeth**) erupt from 17 – 25
  - may be **impacted** – crowded against neighboring teeth and bone so the cannot erupt

Tooth and Gum Disease

- the human mouth is home to more than 700 species of microorganisms, especially bacteria
- **plaque** – sticky residue on the teeth made up of bacteria and sugars
  - **calculus –** calcified plaque
  - bacteria metabolize sugars and release acids that dissolve the minerals of enamel and dentin to form **dental caries (cavities)**
- **root canal therapy** is necessary if cavity reaches pulp
- **gingivitis** – inflammation of the gums
  - **periodontal disease** – destruction of the supporting bone around the teeth which may result in tooth loss

Mastication

- **mastication** (chewing) - breaks food into smaller pieces to be swallowed and exposes more surface to the action of digestive enzymes

Saliva

- saliva
  - begin starch and fat digestion
  - inhibit bacterial growth
  - dissolves molecules so they can stimulate the taste buds
  - moistens food and bind it together into bolus to aid in swallowing

- hypotonic solution of 97.0% to 99.5% water and the following solutes:
  - **salivary amylase** – enzyme that begins starch digestion in the mouth
  - **lingual lipase** – enzyme that is activated by stomach acid and digests fat after the food is swallowed
  - **mucus** – binds and lubricates the mass of food and aids in swallowing
  - **lysozyme** – enzyme that kills bacteria
  - **immunoglobulin A (IgA)** – an antibody that inhibits bacterial growth

Salivary Glands

- **intrinsic salivary glands** – small glands dispersed amid other oral tissues

extrinsic salivary glands – three pair connected to oral cavity by ducts

- **parotid** – located beneath the skin anterior to the earlobe
  - mumps is an inflammation and swelling of the parotid gland caused by a virus
- **submandibular gland** – located halfway along the body of the mandible
  - its duct empties at the side of the lingual frenulum, near the lower central incisors
- **sublingual glands** – located in the floor of the mouth
  - has multiple ducts that empty posterior to the papilla of the submandibular duct

Salivary Glands

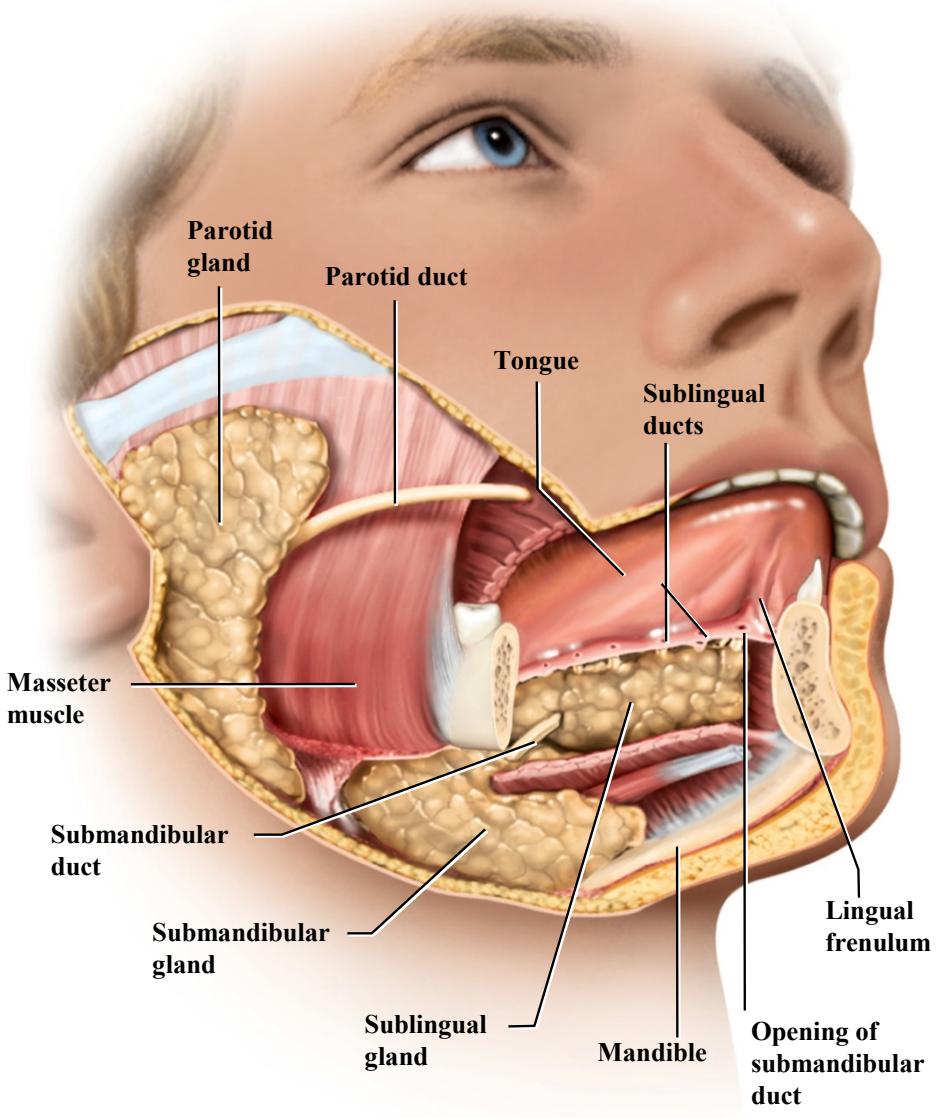


Figure 25.9

Esophagus

- **esophagus** – a straight muscular tube 25-30 cm long
  - extends from **pharynx** to **cardiac orifice** of stomach passing through **esophageal hiatus** in diaphragm
  - **lower esophageal sphincter** – food pauses at this point because of this constriction
    - prevents stomach contents from regurgitating into the esophagus
    - protects esophageal mucosa from erosive effect of the stomach acid
    - **heartburn** – burning sensation produced by acid reflux into the esophagus
  - **nonkeratinized stratified squamous epithelium**
  - **esophageal glands** in submucosa secrete mucus
  - skeletal muscle in upper one-third, mixture in middle one-third, and only smooth muscle in the bottom one-third

Swallowing

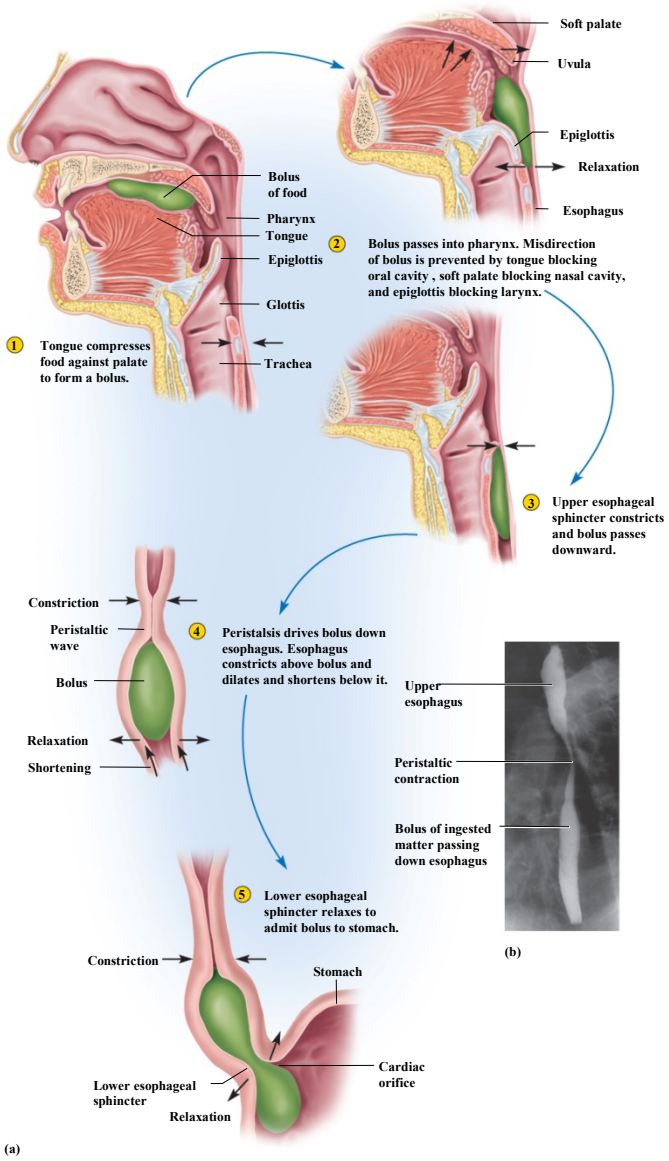


Figure 25.11 a-b

Swallowing

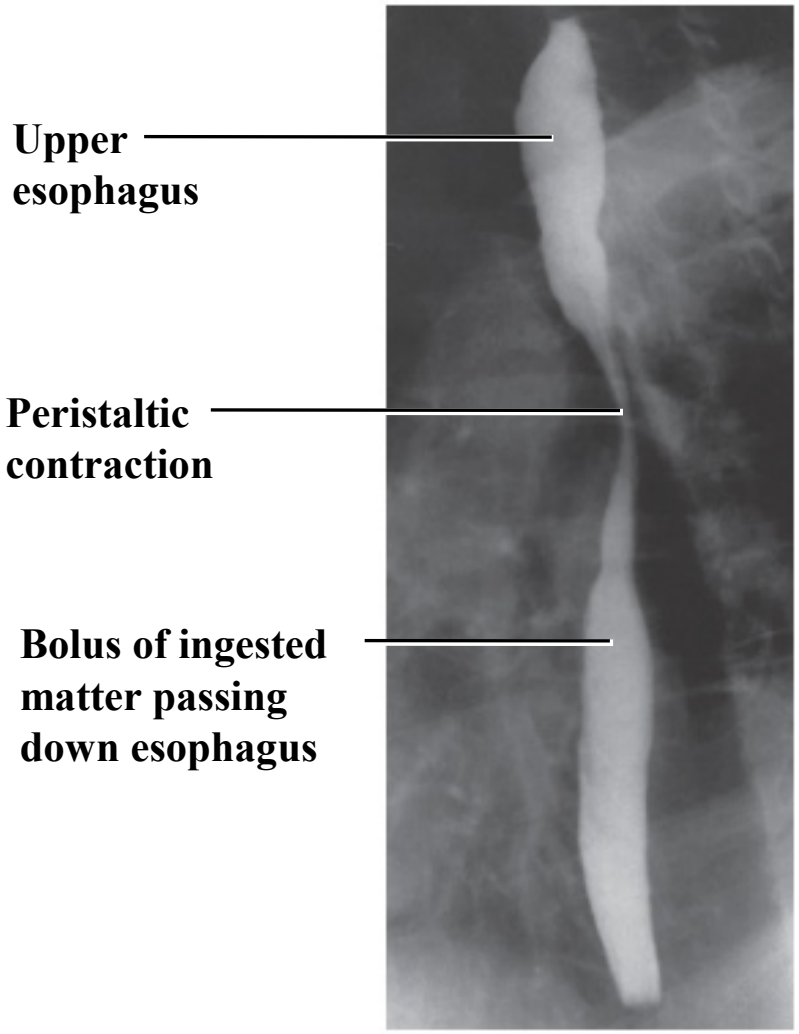
- **swallowing center** – pair of nuclei in medulla oblongata that coordinates swallowing
  - communicates with muscles of the pharynx and esophagus

- **swallowing occurs in two phases:**
  - **buccal phase** – under voluntary control
    - tongue collects food, presses it against the palate forming a bolus, and pushes it posteriorly
    - food accumulates in oropharynx in front of the ‘blade’ of the epiglottis
    - epiglottis tips posteriorly and food bolus slides around it through the laryngeal opening
    - bolus enters laryngopharynx and stimulates tactile receptors and activates next phase

Swallowing

- **pharyngoesophageal phase** – is involuntary
  - three actions prevent food and drink from reentering the mouth or entering the nasal cavity or larynx
    - the root of the tongue blocks the oral cavity
    - the soft palate rises and blocks the nasopharynx
    - the infrahyoid muscles pull the larynx up to meet the epiglottis while laryngeal folds close the airway
  - bolus enters esophagus, stretches it, and stimulates peristalsis
  - **peristalsis** – wave of muscular contraction that pushes the bolus ahead of it
    - an entirely involuntary reflex

X-ray: Swallowing in Esophagus



(b)

Figure 25.11b

Stomach

- **stomach** – a muscular sac in upper left abdominal cavity immediately inferior to the diaphragm
  - internal volume of about **50 mL when empty**
  - **1.0 – 1.5 L after a typical meal**
  - up to **4 L on Thanksgiving!**
- mechanically breaks up food particles, liquefies the food, and begins chemical digestion of protein and fat
  - **chyme** – soupy or pasty mixture of semi-digested food in the stomach
- most digestion occurs after the chyme passes on to the small intestine

Gross Anatomy of Stomach

- **divided into four regions**
  - **cardiac region** – small area within about 3 cm of the cardiac orifice
  - **fundic region** – dome-shaped portion superior to esophageal attachment
  - **body** – makes up the greatest part of the stomach
  - **pyloric region** – narrower pouch at the inferior end
  - **pylorus** – narrow passage to duodenum
- **pyloric sphincter** – regulates the passage of chyme into the duodenum

Innervation and Circulation

- stomach receives:
  - **parasympathetic fibers** from vagus
  - **sympathetic fibers** from celiac ganglia
- all blood drained from stomach and intestines enters **hepatic portal circulation** and is filtered through liver before returning to heart

Gross Anatomy of Stomach

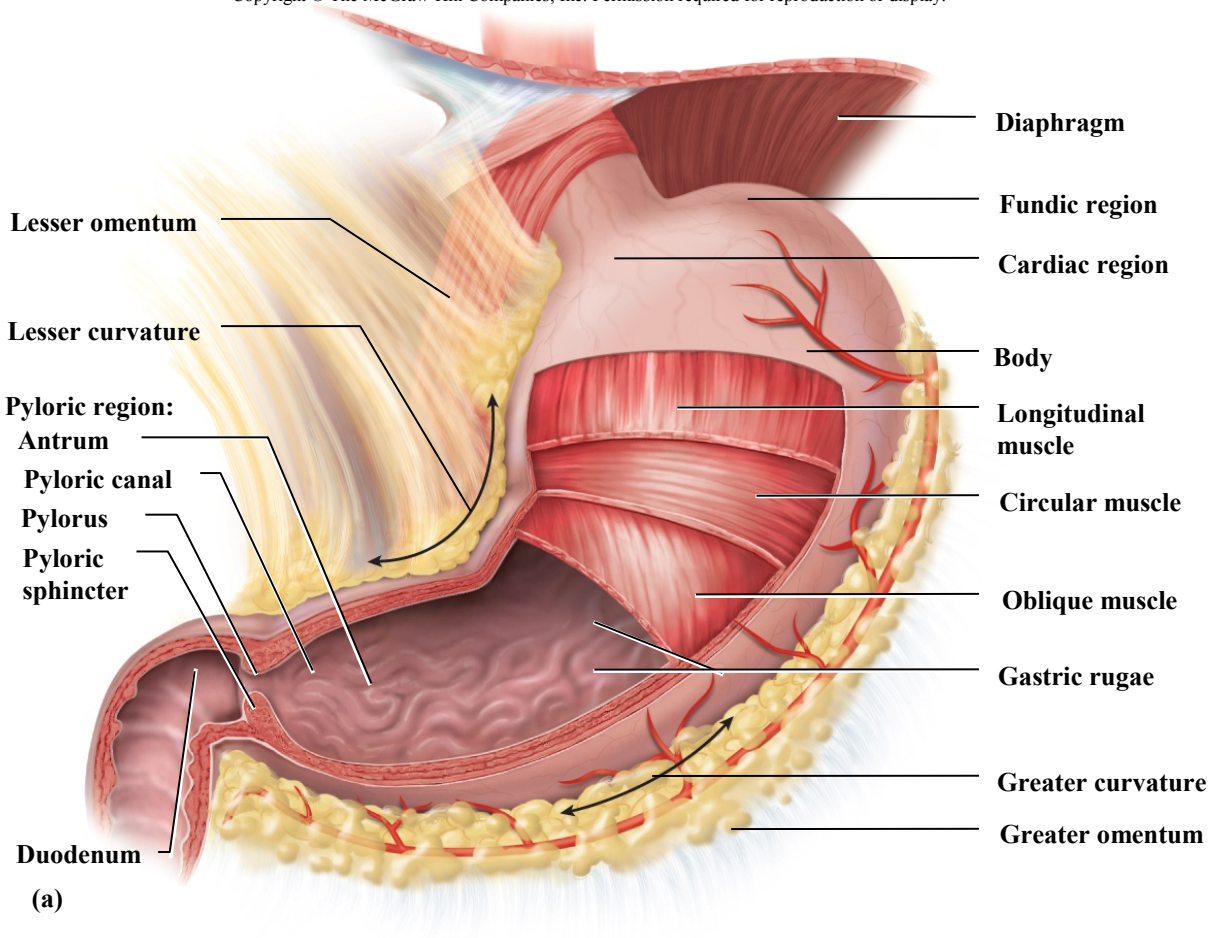


Figure 25.12a

Gross Anatomy of Stomach

Figure 25.12b

longitudinal wrinkles called **rugae** can be seen in empty stomach wall.

Microscopic Anatomy

- **simple columnar epithelium** covers mucosa
  - Gastric pits
- mucosa and submucosa flat when stomach is full, but form longitudinal wrinkles called **gastric rugae** when empty
- **muscularis externa** has three layers instead of two
  - outer longitudinal, middle circular and inner oblique layers

Microscopic Anatomy

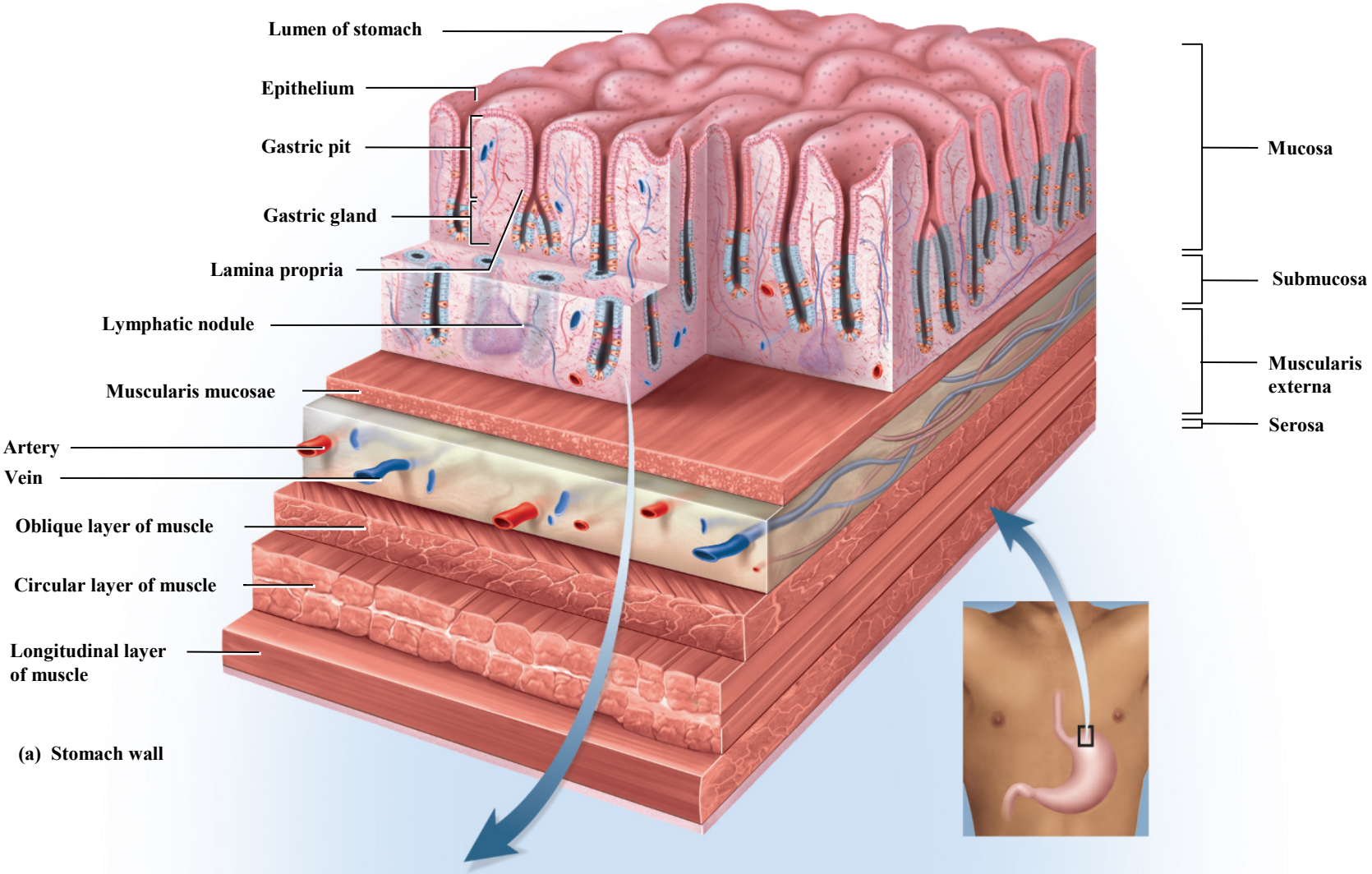


Figure 25.13a

Gastric Pits

- **depressions in gastric mucosa**
  - lined with simple columnar epithelium
  - two or three tubular glands open into the bottom of each gastric pit
  - **cardiac glands** in cardiac region
  - **pyloric glands** in pyloric regions
  - **gastric glands** in the rest of the stomach

Pyloric and Gastric Glands

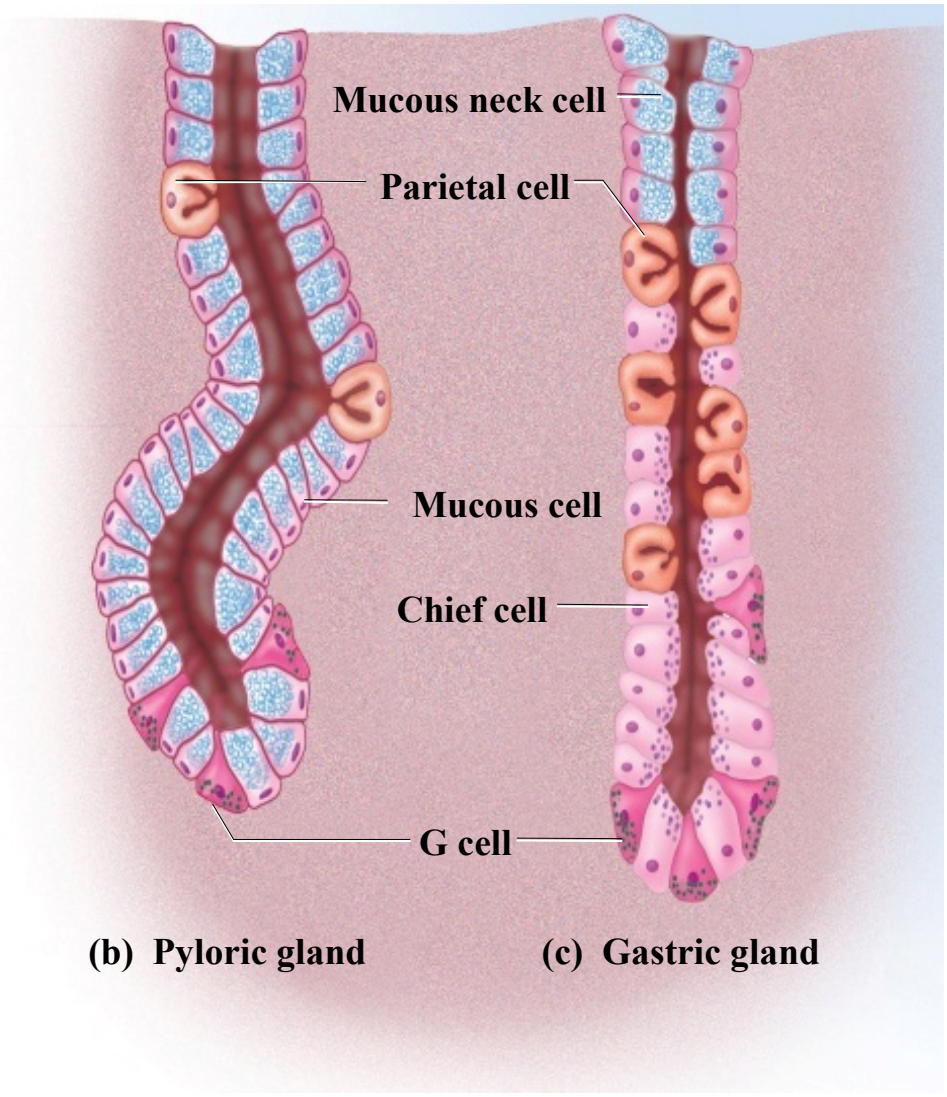


Figure 25.13 b-c

Cells of Gastric Glands

- **mucous cells** – secrete mucus

- **regenerative (stem) cells**
  - divide rapidly and produce a continual supply of new cells to replace cells that die

- **parietal cells**
  - secrete **hydrochloric acid (HCl), intrinsic factor**, and a hunger hormone **ghrelin**

- **chief cells** – most numerous
  - secrete **gastric lipase** and **pepsinogen**

- **enteroendocrine cells**
  - secrete **hormones** and **paracrine messengers** that regulate digestion

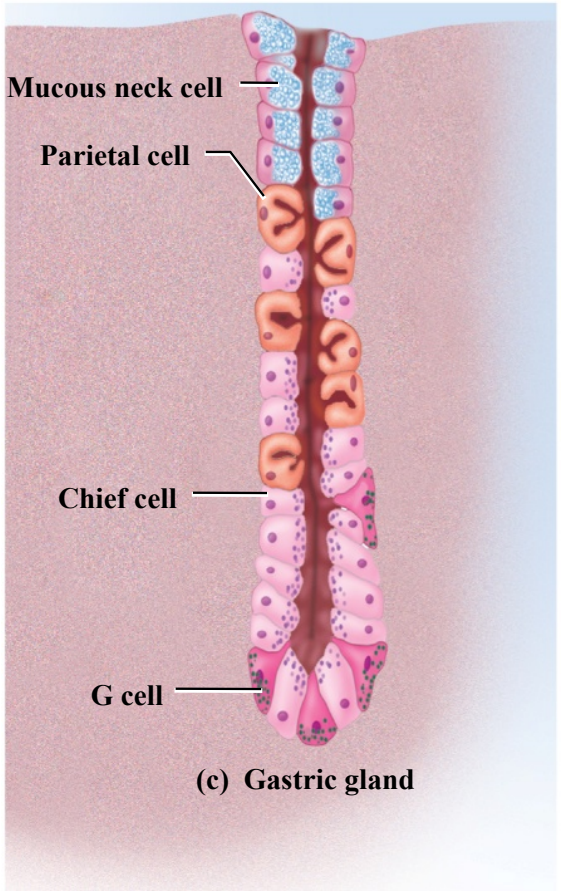


Figure 25.13c

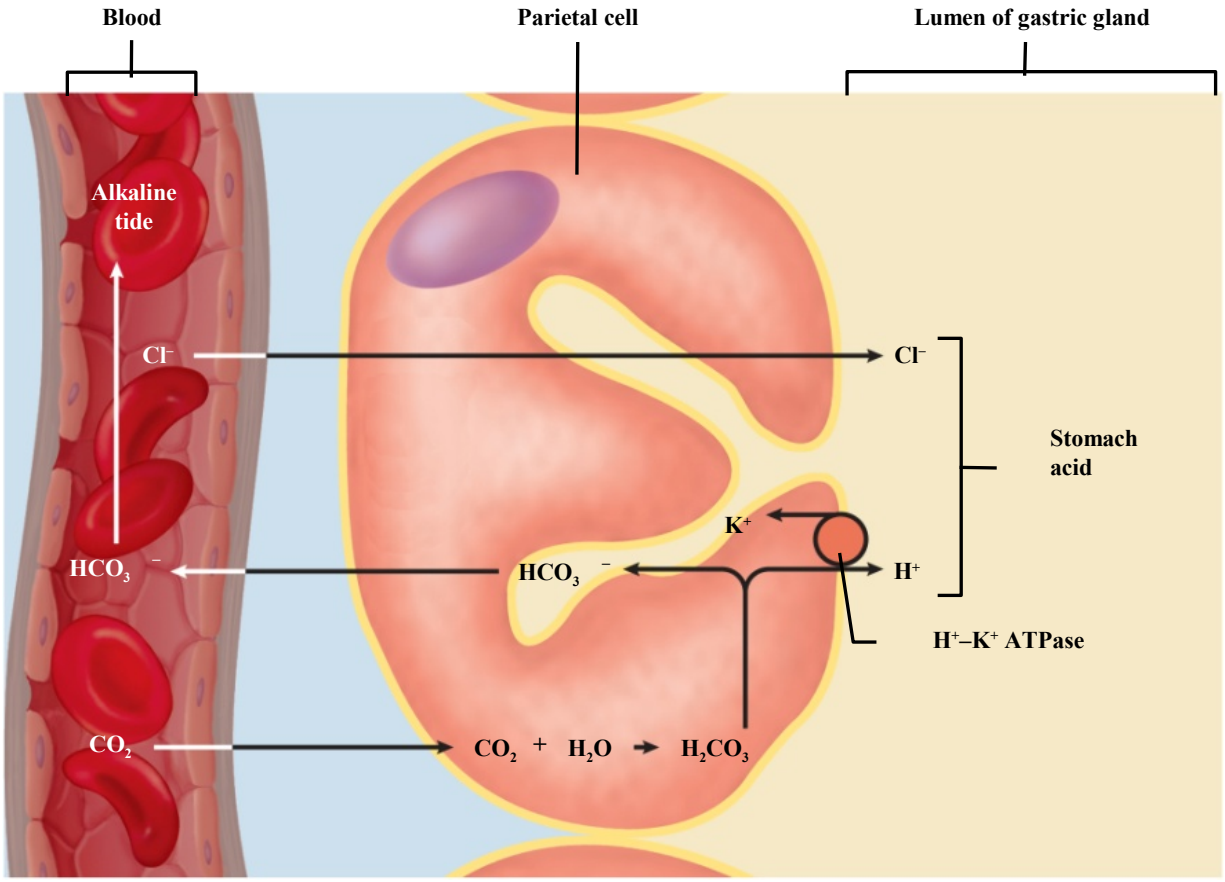
Gastric Secretions

- **gastric juice –** 2 – 3 liters per day produced by the gastric glands

- mainly a mixture of water, hydrochloric acid, and pepsin

Hydrochloric Acid

- **gastric juice** has a high concentration **of hydrochloric acid**
  - pH as low as 0.8
- **parietal cells produce HCl** and contain **carbonic anhydrase** (CAH)



Functions of Hydrochloric Acid

- activates **pepsin** and **lingual/gastric lipase**
- breaks up connective tissues and plant cell walls
  - helps liquefy food to form **chyme**
- converts ingested **ferric ions (Fe^{3+})** to **ferrous ions (Fe^{2+})**
  - Fe^{2+} absorbed and used for hemoglobin synthesis
- contributes to nonspecific disease resistance by destroying most ingested pathogens

Pepsin

- **zymogens –** digestive enzymes secreted as inactive proteins
  - converted to active enzymes by removing some of their amino acids
- **pepsinogen** – zymogen secreted by the **chief cells**
  - **hydrochloric acid** removes some of its amino acids and forms **pepsin** that digests proteins
  - **autocatalytic effect** – as some pepsin is formed, it converts more pepsinogen into more pepsin
- **pepsin** digests dietary proteins into shorter peptide chains
  - protein digestion is completed in the small intestine

Production and Action of Pepsin

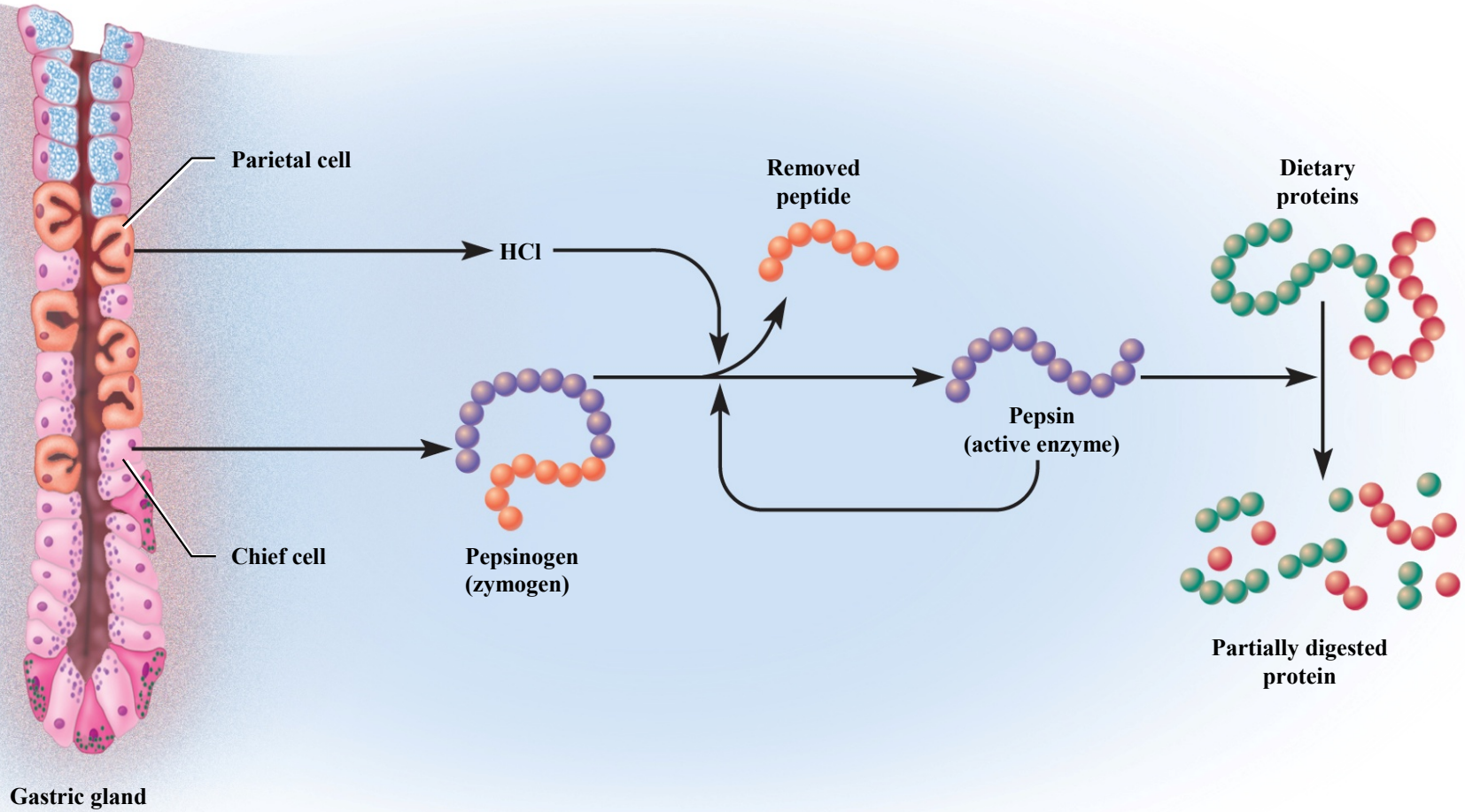


Figure 25.15

Gastric Lipase

- **gastric lipase –** produced by **chief cells**
- **gastric lipase** and **lingual lipase** play a minor role in digesting dietary fats

Intrinsic Factor

- **intrinsic factor** – a glycoprotein secreted by **parietal cells**
- essential to absorption of **vitamin B_{12}** by the small intestine
  - binds vitamin B_{12} and intestinal cells absorb this complex
- vitamin B_{12} is needed to **synthesize hemoglobin**

Gastric Motility

- swallowing center of medulla oblongata signals stomach to relax
- food stretches stomach activating a **receptive-relaxation response**
  - resists stretching briefly, but relaxes to hold more food
- **peristaltic contractions** controlled by **pacemaker cells** in longitudinal layer of muscularis externa

Digestion and Absorption

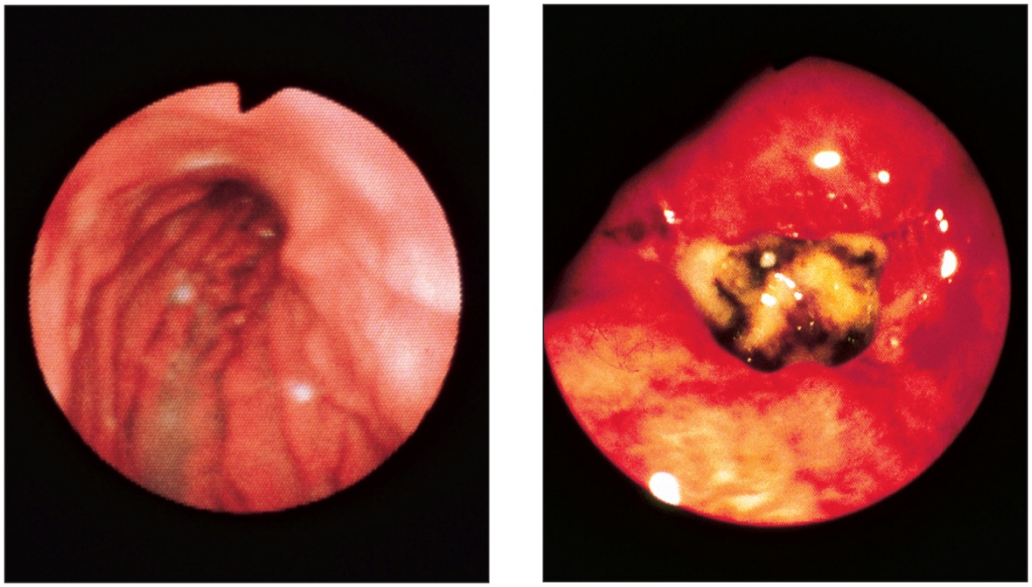
- Digestion incomplete
- Very little absorption in stomach

Protection of the Stomach

- **mucous coat** – highly alkaline mucus
- **tight junctions**
- **epithelial cell replacement** – stomach epithelial cells live only 3 to 6 days

- breakdown of these protective measures can result in **inflammation** and **peptic ulcer**

Healthy Mucosa and Peptic Ulcer



(a) Normal **(b) Peptic ulcer**

CNR/SPL/Photo Researchers, Inc.

Figure 25.16 a-b

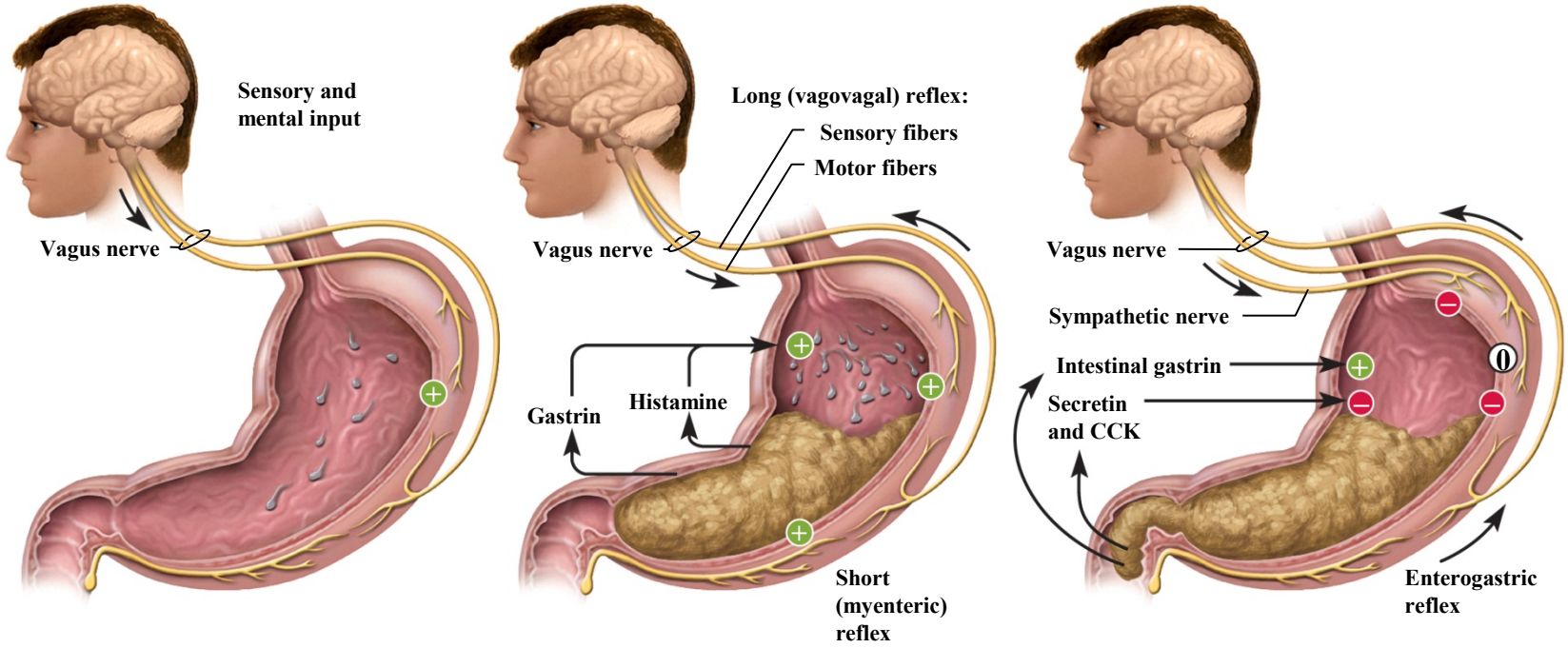
- **gastritis**, inflammation of the stomach can lead to a **peptic ulcer**

- most ulcers are caused by acid-resistant bacteria, ***Helicobacter pylori*** that can be treated with antibiotics and Pepto-Bismol.

Regulation of Gastric Function

- **nervous** and **endocrine systems** collaborate
  - increase gastric secretion and motility when food is eaten
  - suppresses them when the stomach empties
- gastric activity is divided into **three phases**:
  - **cephalic phase** – stomach being controlled by brain
  - **gastric phase –** stomach controlling itself
  - **intestinal phase** – stomach being controlled by small intestine
- phases over lap and can occur simultaneously

Regulation of Gastric Function



1 **Cephalic phase**
Vagus nerve stimulates gastric secretion even before food is swallowed.

2 **Gastric phase**
Food stretches the stomach and activates myenteric and vagovagal reflexes. These reflexes stimulate gastric secretion. Histamine and gastrin also stimulate acid and enzyme

3 **Intestinal phase**
Intestinal gastrin briefly stimulates the stomach, but then secretin, CCK, and the enterogastric reflex inhibit gastric secretion and motility while the duodenum processes the chyme already in it. Sympathetic nerve fibers suppress gastric activity, while vagal (parasympathetic) stimulation of the stomach is now inhibited.

Key
- ⊕ Stimulation
- ⊖ Inhibition
- 0 Reduced or no effect

Figure 25.17

Regulation of Gastric Function

- **cephalic phase**
  - **stomach responds** to site, smell, taste, or thought of food
  - sensory and mental inputs - **hypothalamus**
    - relays signals to **medulla oblongata**
  - **vagus nerve** fibers from medulla oblongata stimulate the **enteric nervous system** of stomach
    - stimulates gastric secretion

Regulation of Gastric Function

- **gastric phase**
  - period in which swallowed food and semi-digested protein activates gastric activity
    - **two-thirds of gastric secretion** occurs in this phase
  - **ingested food stimulates gastric activity in two ways**:
    - by **stretching the stomach**
      - activates **short reflex** mediated through **myenteric nerve plexus**
      - activates **long reflex** mediated through the **vagus nerves and the brainstem**
    - by **increasing the pH** of its contents
  - **gastric secretion is stimulated by three chemicals**:
    - **acetylcholine (ACh)**
    - **histamine**
    - **gastrin**

Regulation of Gastric Function

- **intestinal phase**
  - stage in which the duodenum responds to arriving chyme and moderates gastric activity through hormones and nervous reflexes
  - duodenum **initially enhances** gastric secretion, but **soon inhibits it**
    - stretching of the duodenum accentuates vagovagal reflex that stimulates the stomach
    - peptides and amino acids in chyme stimulate **G cells** of the duodenum to secrete more **gastrin** which further stimulates the stomach

Regulation of Gastric Function

- **enterogastric reflex** – duodenum sends **inhibitory signals** to the stomach by way of the enteric nervous system and signals to the medulla oblongata - triggered by acid and semi-digested fats in the duodenum

- **chyme** also stimulates **duodenal enteroendocrine cells** to release **secretin** and **cholecystokinin**
  - they stimulate the pancreas and gall bladder
  - also suppress gastric secretion
- **pyloric sphincter** contracts tightly to limit chyme entering duodenum
  - gives duodenum time to work on chyme

Positive Feedback Control- Gastric Secretion

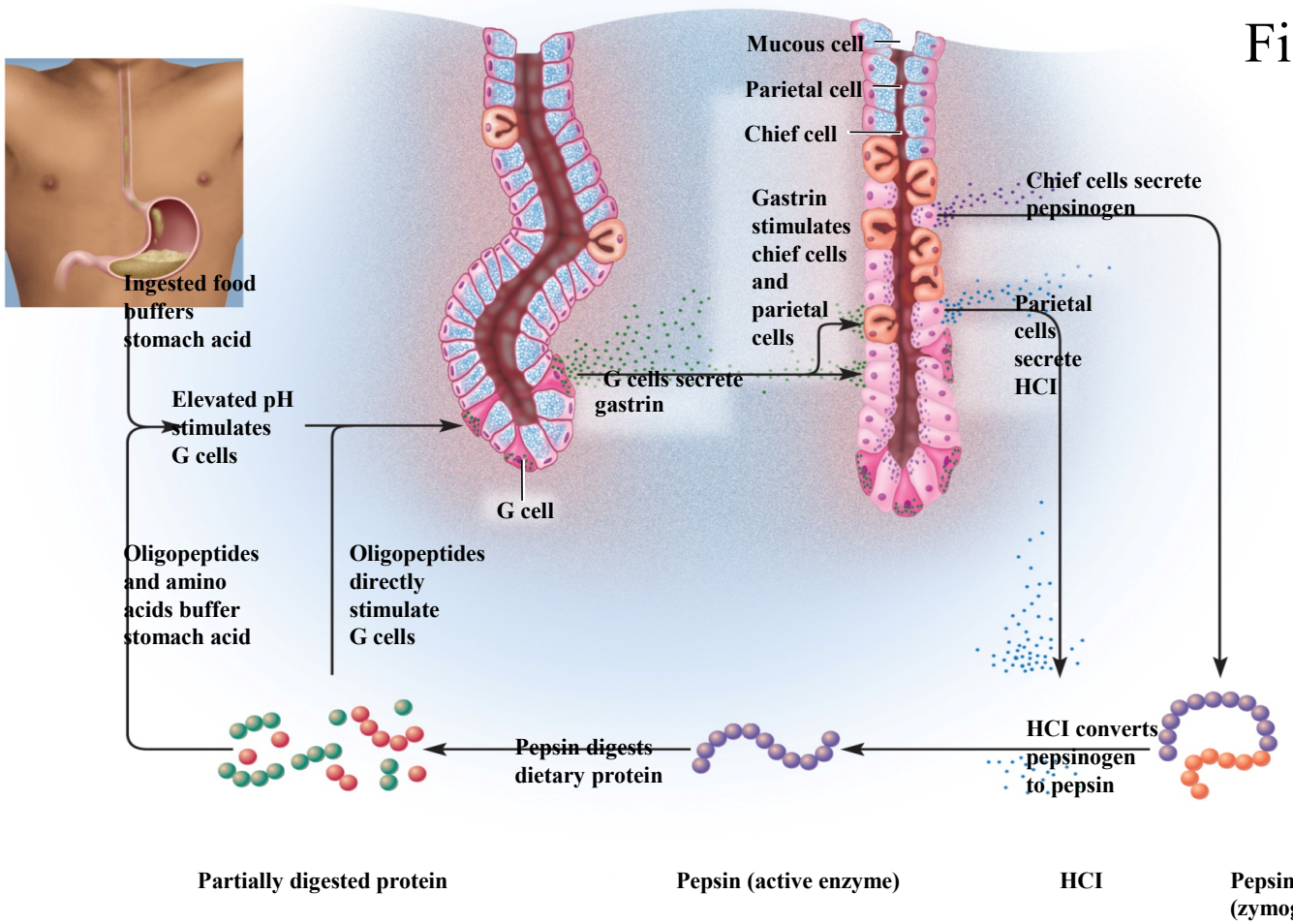


Figure 25.18

Liver, Gallbladder, and Pancreas

- **small intestine** receives **chyme** from stomach
- also **secretions from liver and pancreas**
  - enter digestive tract near the junction of stomach and small intestine

The Liver

- **liver** – reddish brown gland located immediately inferior to the diaphragm
- the **body's largest gland**
  - weighs about 1.4 kg
- variety of functions
  - **secretes bile** which contributes to digestion

Gross Anatomy of Liver

- four lobes - **right**, **left**, **quadrate**, and **caudate**

- **porta hepatis** – irregular opening between these lobes
  - point of **entry** for the **hepatic portal vein** and **proper hepatic artery**
  - point of **exit** for the **bile passages**
  - all travel in **lesser omentum**

- **gall bladder –** adheres to a depression on the inferior surface of the liver, between right and quadrate lobes

- **bare area** on superior surface where it is attach to diaphragm

Gross Anatomy of Liver

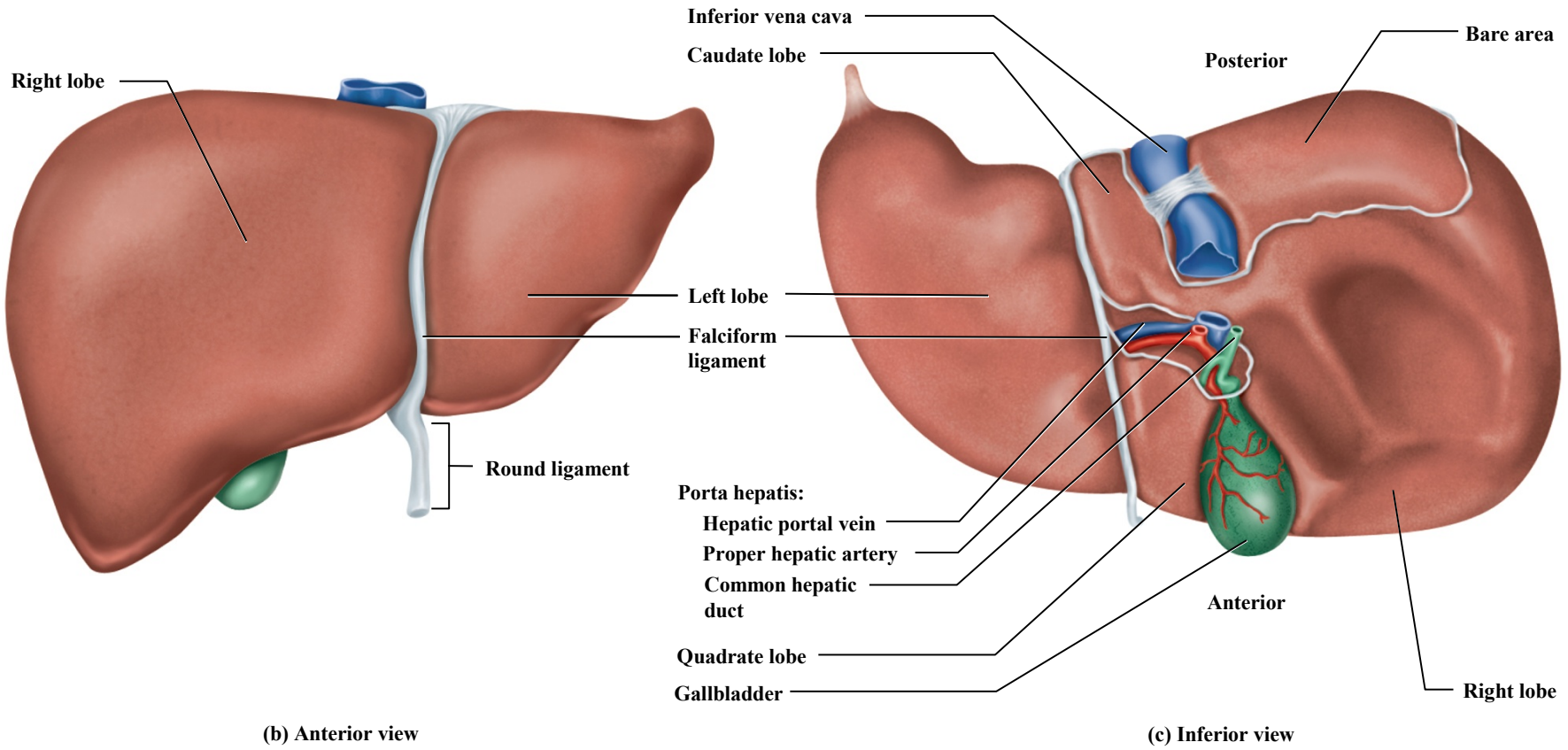


Figure 25.19 b-c

Microscopic Anatomy of Liver

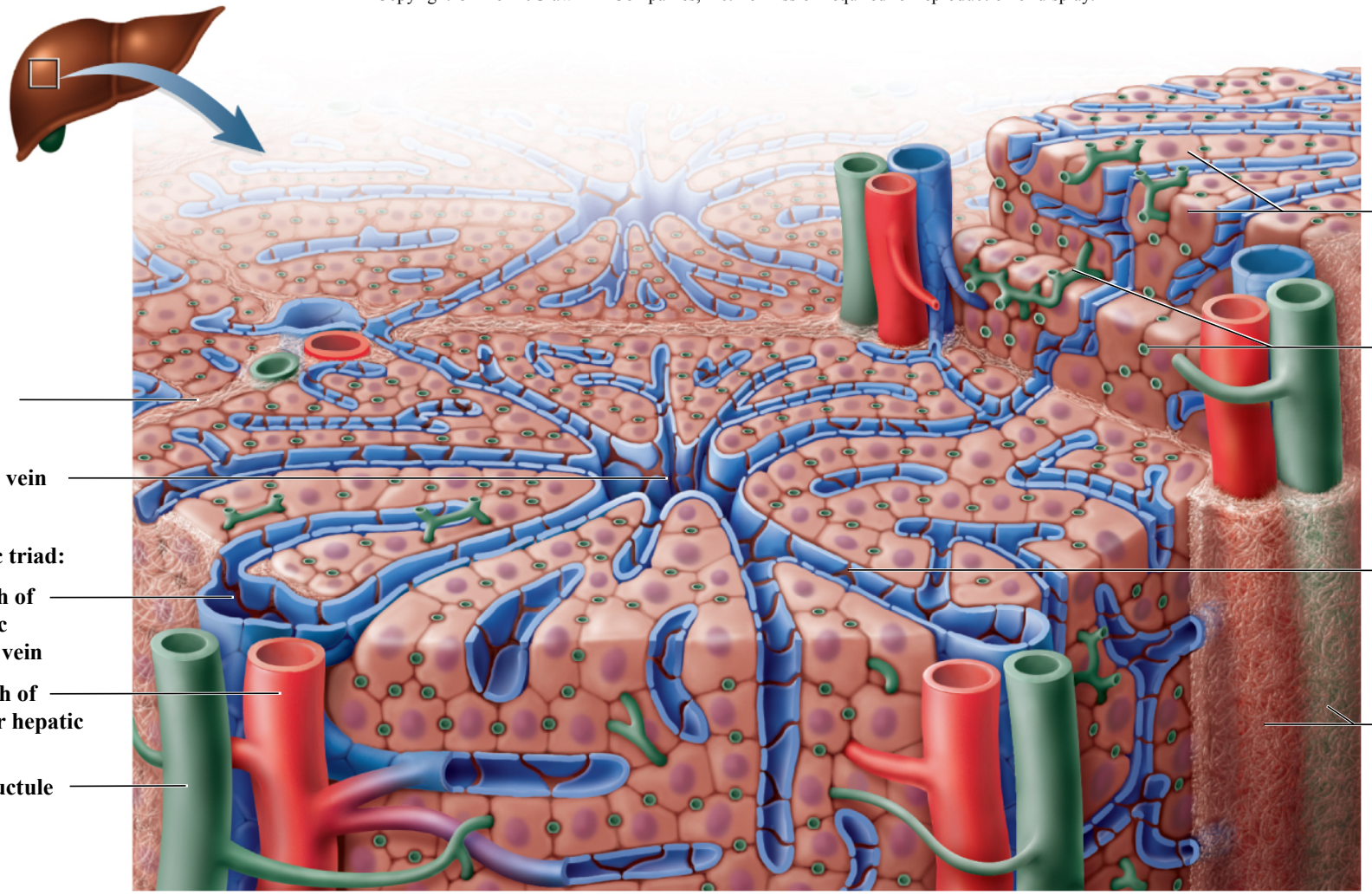


Figure 25.20a

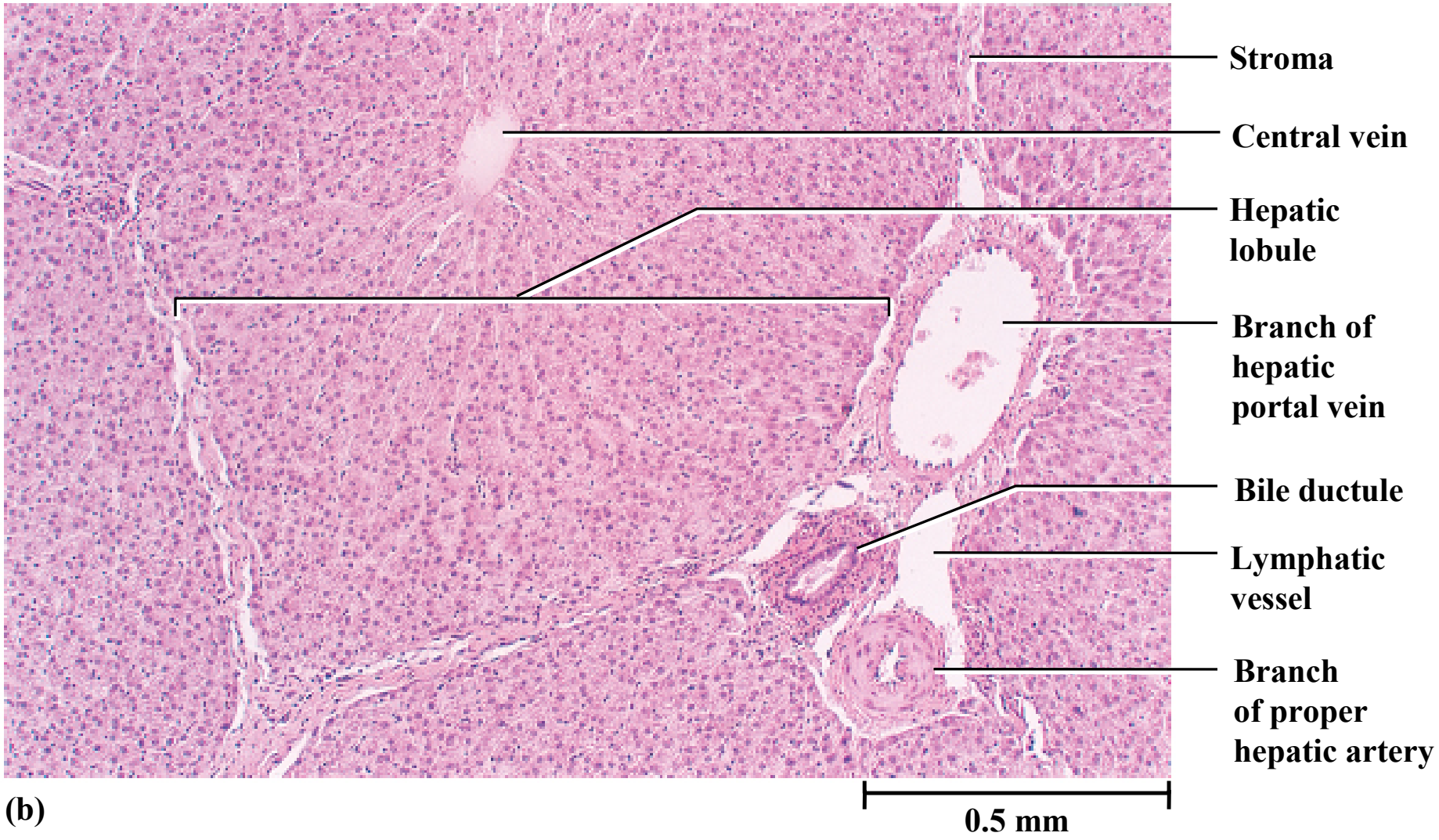
Microscopic Anatomy of Liver

- **hepatic lobules** – tiny innumerable cylinders that fill the interior of the liver
  - about 2 mm long and 1 mm in diameter
  - consists of:
    - **central vein** – passing down the core
    - **hepatocytes** – cuboidal cells surrounding central vein in radiating sheets or plates
      - each plate of hepatocytes is an epithelium one or two cells thick
    - **hepatic sinusoids** – blood-filled channels that fill spaces between the plates
      - lined by a **fenestrated endothelium** that separates hepatocytes from blood cells
      - allows plasma into the space between the hepatocytes and endothelium
      - hepatocytes have **brush border of microvilli** that project into this space
      - blood filtered through the sinusoids comes directly from the stomach and intestines
    - **hepatic macrophages (Kupffer cells)** – phagocytic cells in the sinusoids that remove bacteria and debris from the blood

Functions of Hepatocytes

- **absorb from the blood**
  - glucose, amino acids, iron, vitamins, and other nutrients for metabolism or storage
- **removes and degrades**
  - hormones, toxins, bile pigments, and drugs
- **secretes into the blood**:
  - albumin, lipoproteins, clotting factors, angiotensinogen, and other products
- **break down stored glycogen and releases glucose** into the blood

Histology of Liver - Hepatic Triad



(b)

Figure 25.20b

Gross Anatomy of the Gallbladder, Pancreas, and Bile Passages

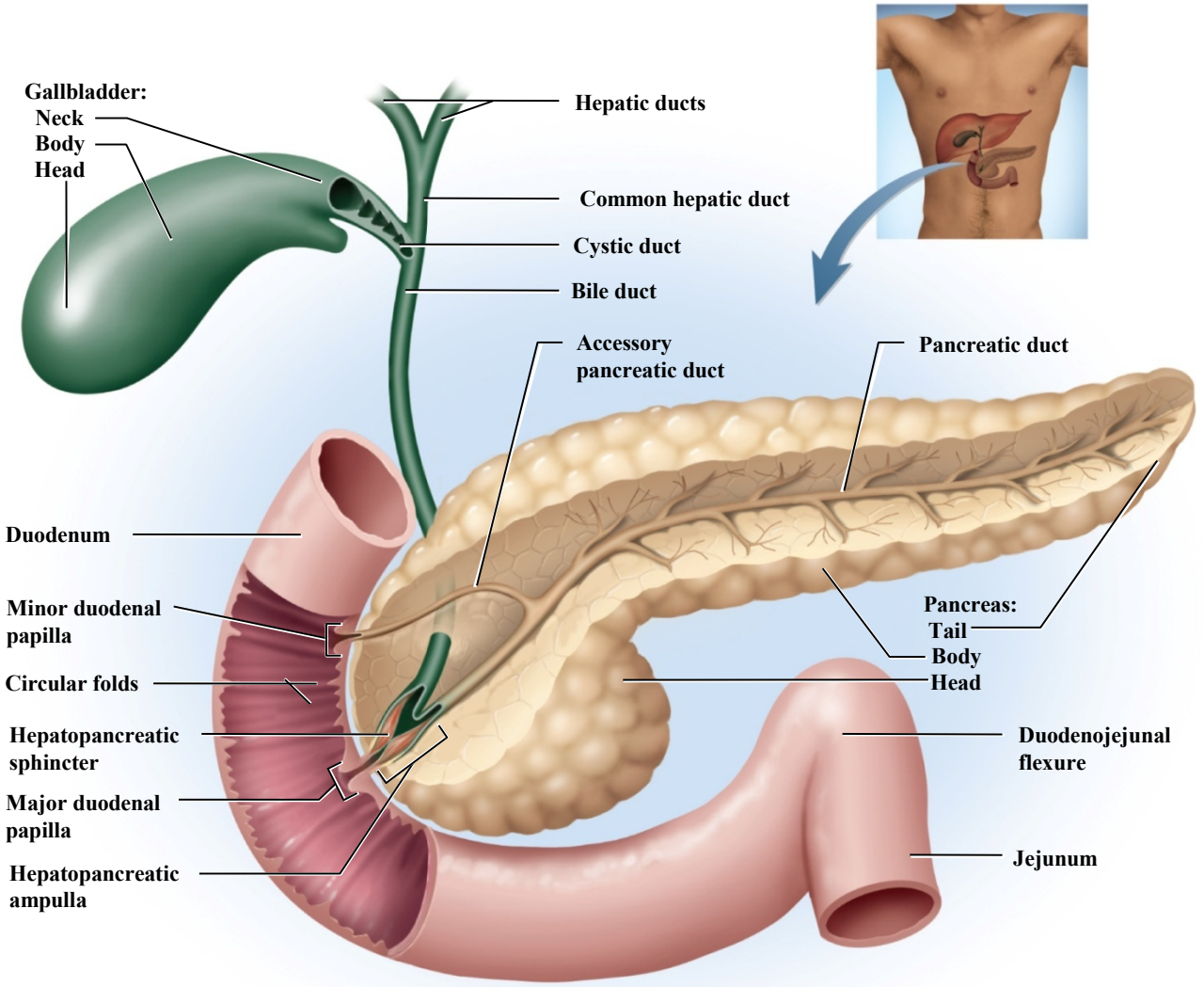


Figure 25.21

Gallbladder

- serves to **store and concentrate bile** by a factor of 20 by absorbing water and electrolytes
  - internally lined by highly folded mucosa with **simple columnar epithelium**
  - leads into the **cystic duct**

Bile

- **bile** – yellow-green fluid
  - **bilirubin** – principal pigment derived from the **decomposition of hemoglobin**
  - bacteria in large intestine metabolize **bilirubin to urobilinogen**
  - **bile acids (bile salts)** – steroids synthesized from cholesterol
    - **bile acids** aid in fat digestion and absorption
  - **80% of bile acids are reabsorbed** in the ileum and returned to the liver
  - **20% of the bile acids are excreted in the feces**
    - this is the body's only way of eliminating excess cholesterol
    - liver synthesizes new bile acids from cholesterol to replace those lost in feces

gallstones may form if bile becomes excessively concentrated

Gallstones

- **gallstones** - hard masses in either the gallbladder or bile ducts
  - composed of cholesterol, calcium carbonate, and bilirubin
  - obstruction of ducts
  - painful
  - cause jaundice - yellowing of skin due to bile pigment accumulation, poor fat digestion, and impaired absorption of fat-soluble vitamins
- **lithotripsy** - use of ultrasonic vibration to pulverize stones without surgery

The Pancreas

- **pancreas**
  - both an endocrine and exocrine gland
    - **endocrine portion** – pancreatic islets that secrete insulin and glucagon
    - **exocrine portion** – 99% of pancreas that secretes 1200 to 1500 mL of **pancreatic juice** per day
      - **secretory acini** release their secretion into small ducts that converge on the main **pancreatic duct**

The Pancreas

- **pancreatic duct** runs lengthwise through the middle of the gland
  - **hepatopancreatic sphincter** controls release of both bile and pancreatic juice into the duodenum
- **accessory pancreatic duct** – smaller duct that branches from the main pancreatic duct
  - **bypasses the sphincter** and allows pancreatic juice to be released into the duodenum even when bile is not
- **pancreatic juice** – alkaline mixture of water, enzymes, zymogens, sodium bicarbonate, and other electrolytes
  - acini secrete the enzymes and zymogens
  - **ducts** secrete bicarbonate
    - bicarbonate **buffers HCl** arriving from the stomach

Pancreatic Acinar Cells

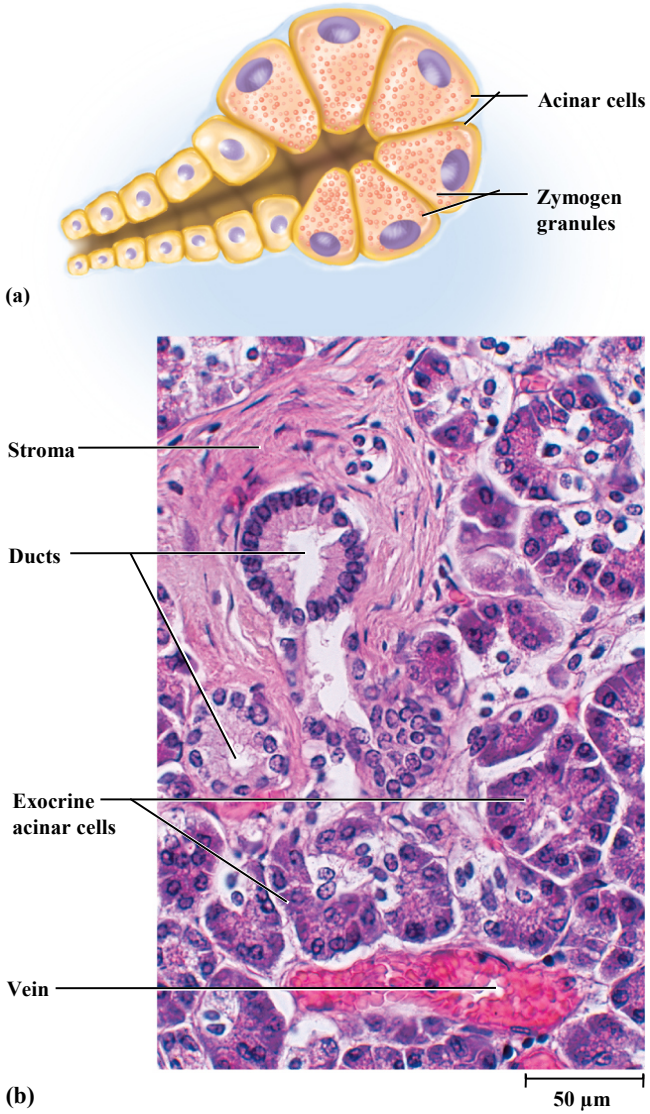


Figure 25.22 a-b

Pancreatic Zymogens

- **pancreatic zymogens** are:
  - **Trypsinogen**
  - secreted into intestinal lumen
  - converted to trypsin by enterokinase, and enzyme secreted by mucosa of small intestine
  - **trypsin** is autocatalytic – converts trypsinogen into still more trypsin
  - **chymotrypsinogen** – converted to trypsinogen by trypsin
  - **procarboxypeptidase** – converted to **carboxypeptidase** by trypsin

- other **pancreatic enzymes**
  - **pancreatic amylase** – digests starch
  - **pancreatic lipase** – digests fat
  - **ribonuclease** and **deoxyribonuclease** – digest RNA and DNA respectively

Activation of Pancreatic Enzymes in the Small Intestine

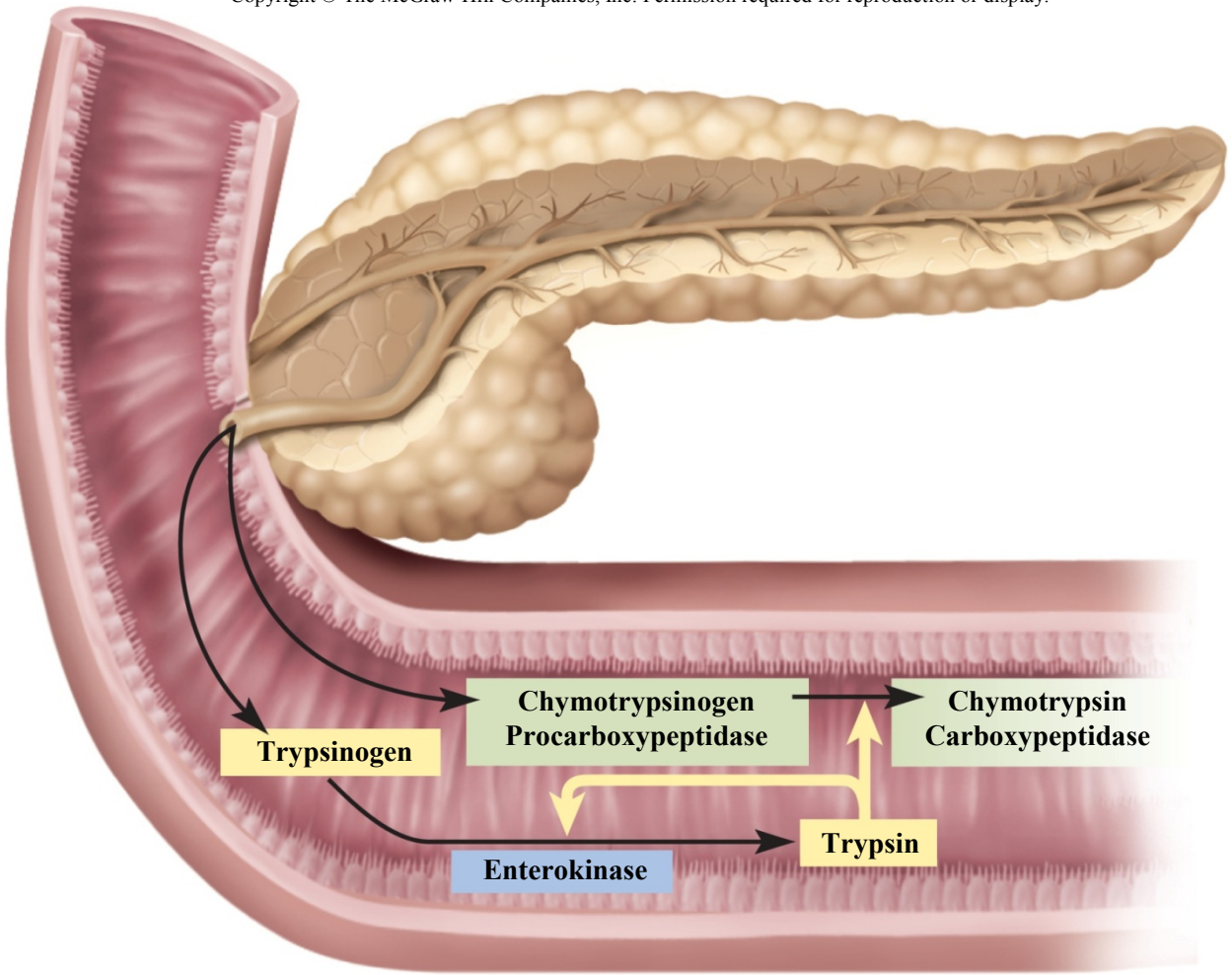


Figure 25.23

Regulation of Secretion

- **three stimuli** are chiefly responsible for the release of **pancreatic juice and bile**
  - **acetylcholine (ACh) -** from vagus and enteric nerves
    - External stimuli (ie smell, taste, watching food network ...)
  - **cholecystokinin (CCK) -** secreted by mucosa of duodenum in response to arrival of fats in small intestine
  - **secretin -** released from duodenum in response to acidic chyme arriving from the stomach
    - stimulates ducts of both liver and pancreas **to secrete more sodium bicarbonate**
    - raising pH to level pancreatic and intestinal digestive enzymes require

Small Intestine

- **small intestine**
  - nearly all chemical digestion and nutrient absorption occurs in small intestine
  - the longest part of the digestive tract
    - 2.7 to 4.5 m long in a living person
    - “small” intestine refers to the diameter not length
    - 2.5 cm (1 inch)

Small Intestine

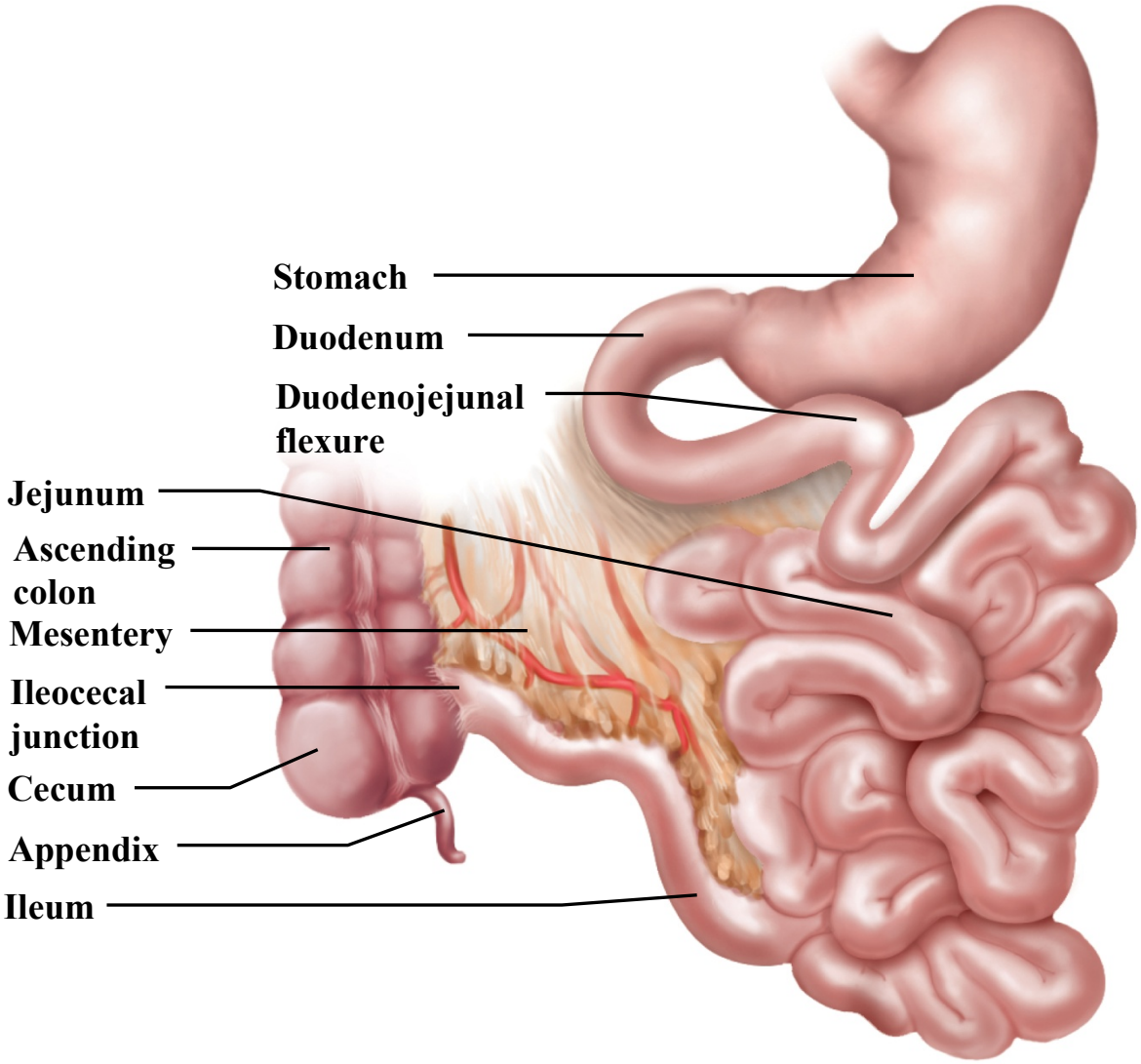


Figure 25.24

Gross Anatomy

- **small intestine** – coiled mass filling most of the abdominal cavity inferior to the stomach and the liver
- **small intestine divided into three regions**:
  - **duodenum** – the first 25 cm (10 inches)
    - begins at the **pyloric valve**
      - receives **major and minor pancreatic ducts** respectively
    - receives stomach contents, pancreatic juice, and bile
    - stomach acid is neutralized here
    - fats are **physically broken up (emulsified)** by the bile acids
    - **pepsin** is inactivated by increased pH
    - **pancreatic enzymes** take over the job of chemical digestion

Gross Anatomy

- **jejunum** – first 40% of small intestine beyond duodenum
  - **most digestion and nutrient absorption occurs here**
- **ileum** – forms the last 60% of the postduodenal small intestine
  - **Peyer patches** – prominent **lymphatic nodules** in clusters on the side opposite the mesenteric attachment

Gross Anatomy

- **ileocecal junction** – the end of the small intestine
  - where the **ileum** joins the **cecum** of the large intestine
- **ileocecal valve** – a sphincter formed by the thickened muscularis of the ileum
  - protrudes into the cecum
  - regulates passage of food residue into the large intestine

Microscopic Anatomy

- tissue layers have **modifications for nutrient digestion and absorption**
  - **large internal surface area** for effective digestion and absorption
    - great length and **three types of internal folds** or projections
      - **circular folds** - increase surface area by a factor of 2 to 3
      - **villi** – increase surface area by a factor of 10
      - **microvilli** – increase the surface area by a factor of 20

Microscopic Anatomy

- blood capillaries of villus absorb most of the nutrients
- lacteal absorbs most lipids

- **microvilli** – fuzzy border of microvilli on apical surface of each absorptive cell
  - **brush border**
  - **brush border enzymes** – contained in the plasma membrane of microvilli
    - **carry out some of the final stages of enzymatic digestion**
    - not released into the lumen
    - **contact digestion** – the chyme must contact the brush border for digestion to occur

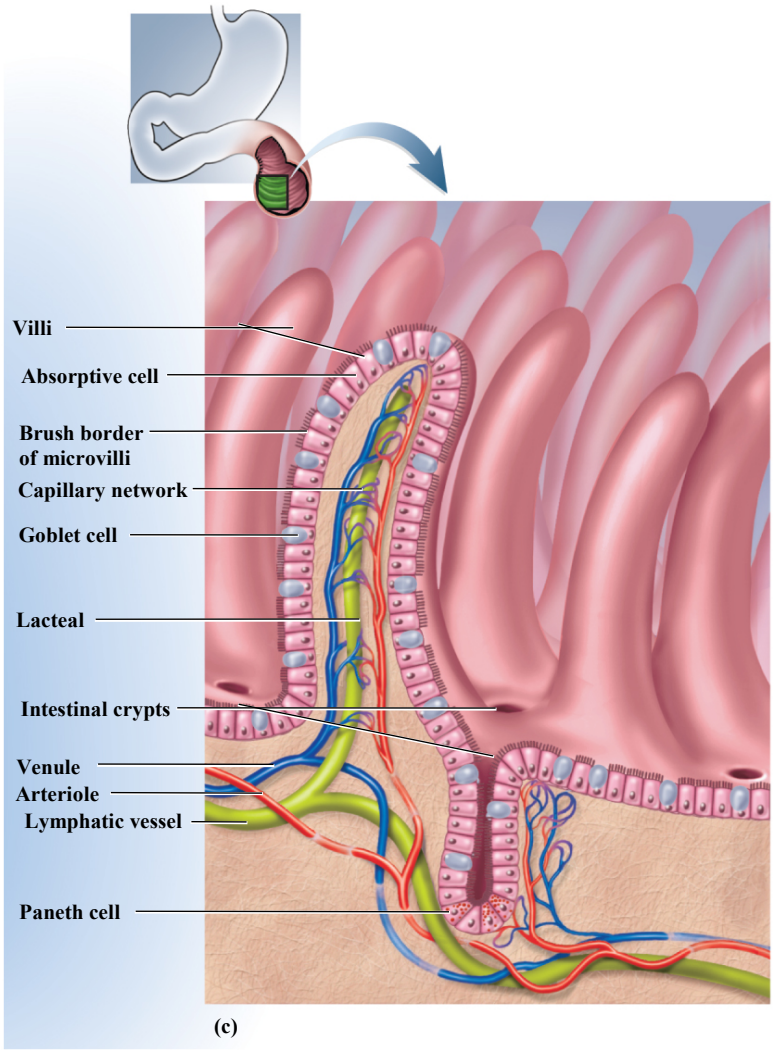
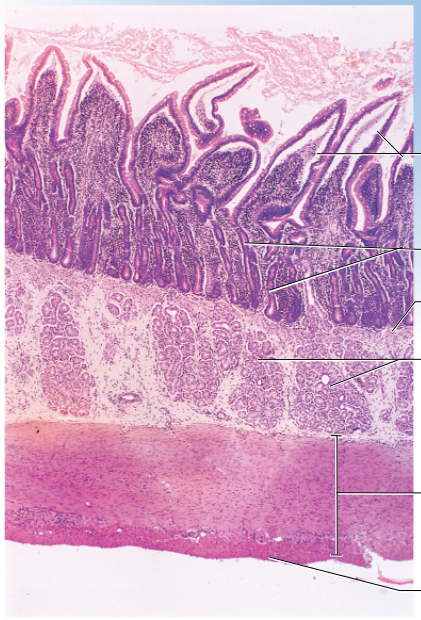


Figure 25.25 c

Intestinal Villi

(a)



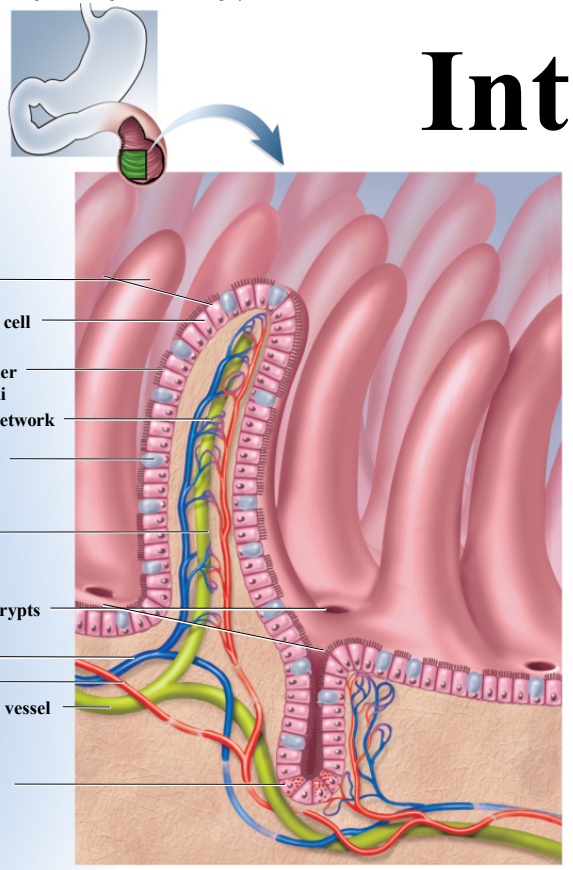
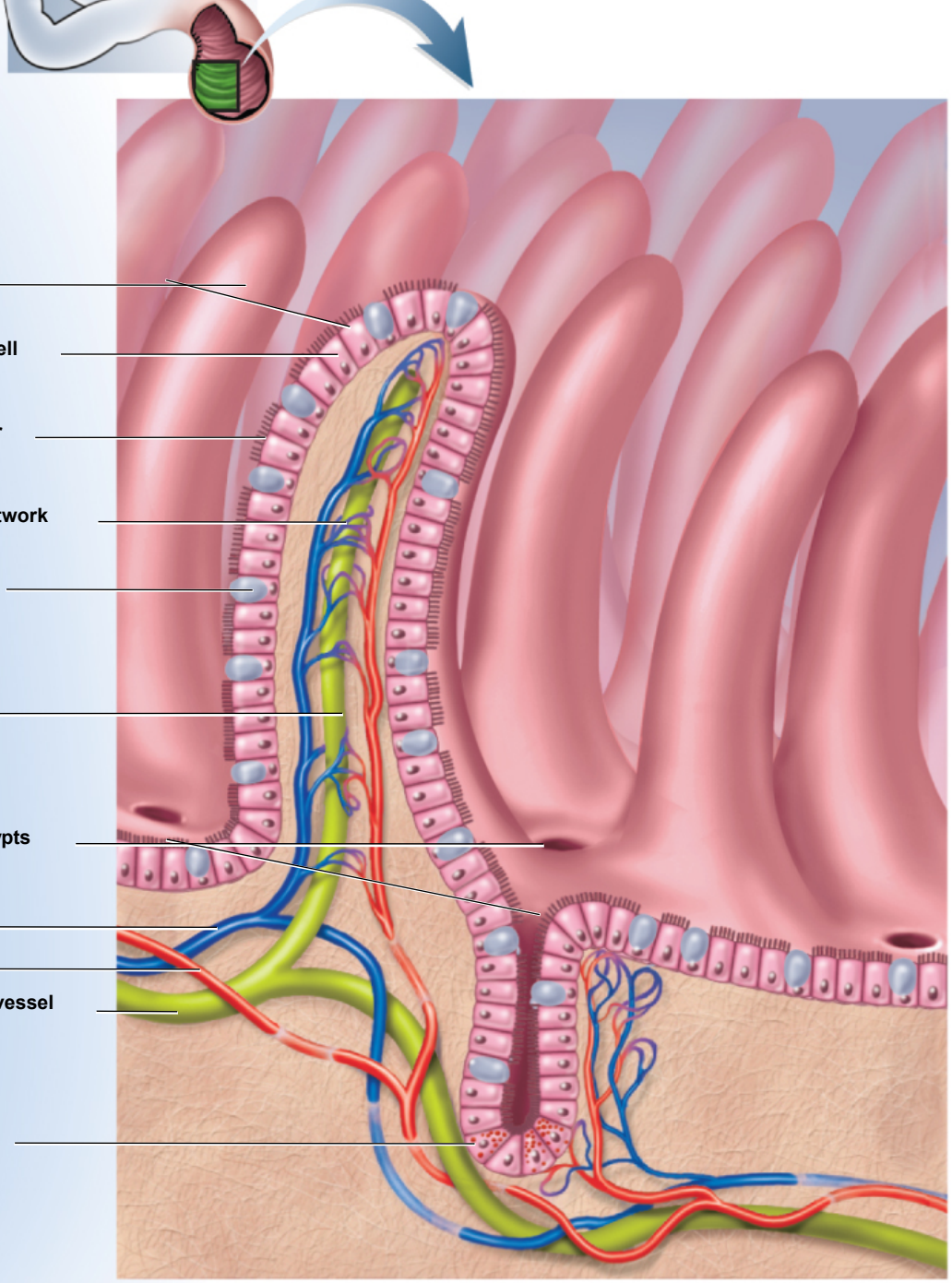


Figure 25.25 a–c


Villi
Absorptive cell
Brush border of microvilli
Capillary network
Goblet cell
Lacteal
Intestinal crypts
Venule
Arteriole
Lymphatic vessel
Paneth cell

(c)

Carbohydrate Digestion

- **starch** – the most digestible carbohydrate
  - cellulose is indigestible
  - starch is first digested to:
    - **oligosaccharides** up to eight glucose residues long
    - then into the **disaccharide maltose**
    - finally to **glucose** which is absorbed by the small intestine
- process **begins in the mouth**
  - **salivary amylase** hydrolyzes starch into oligosaccharides

Carbohydrate Digestion

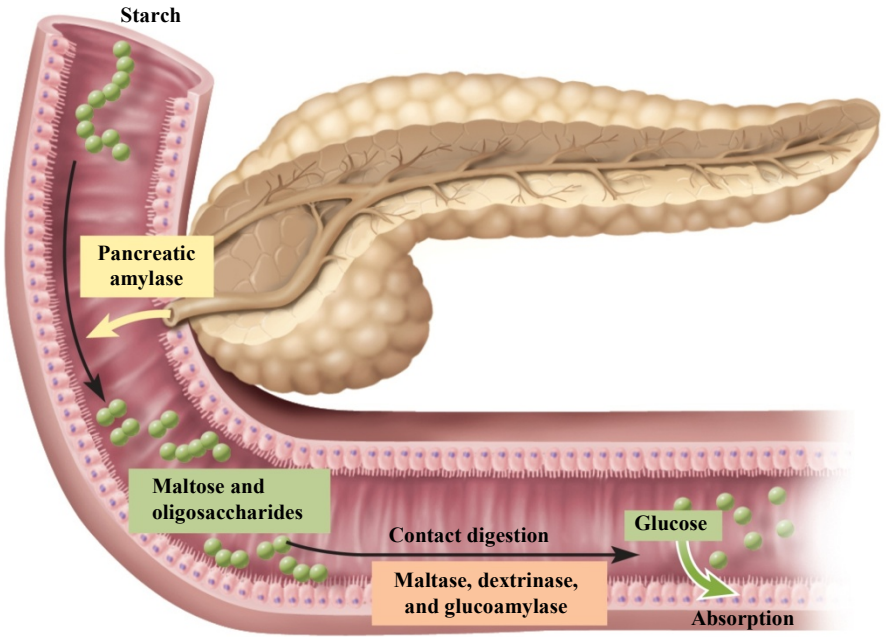


Figure 25.27

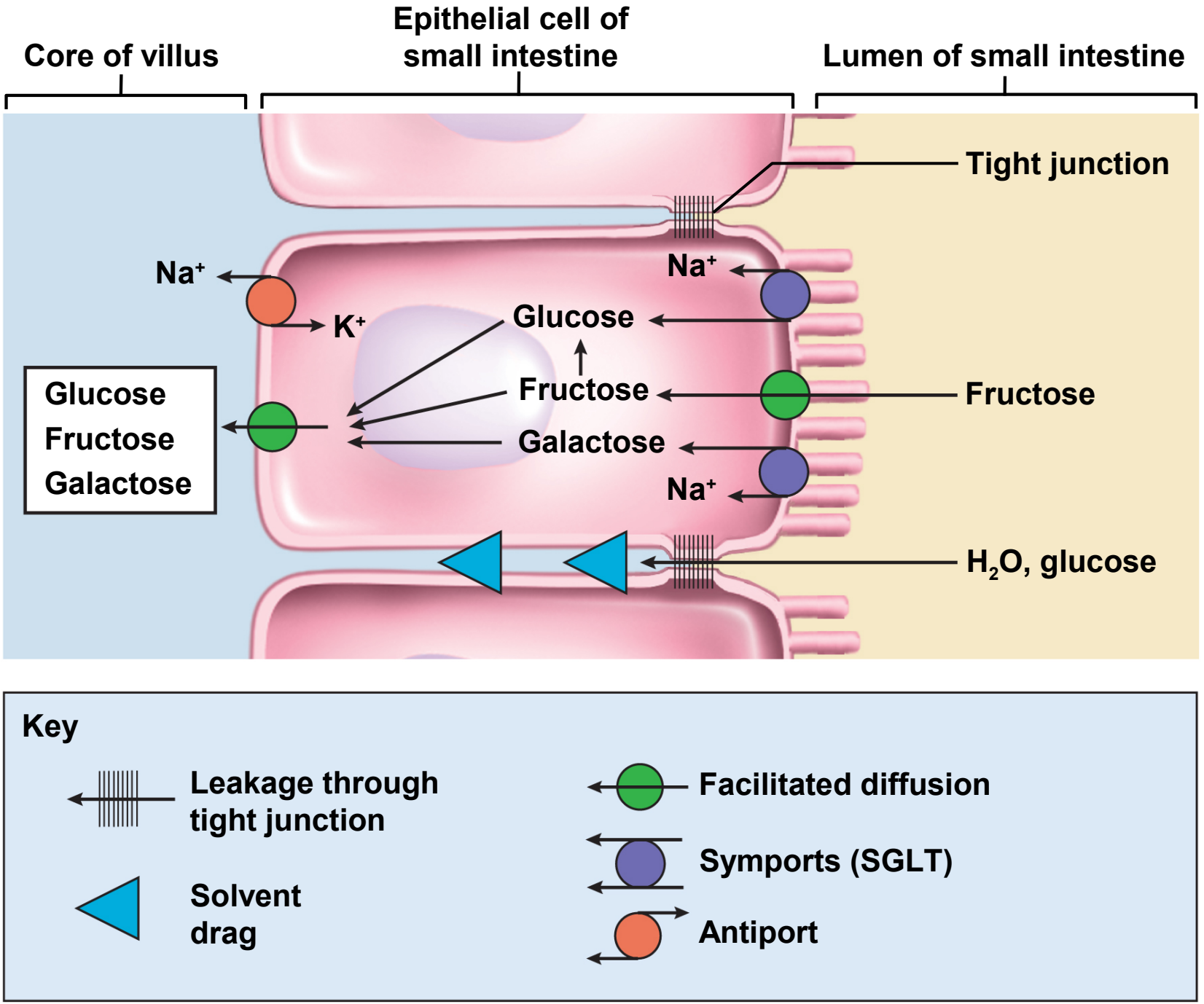
- **salivary amylase** stops working in stomach at pH less than 4.5

- **pancreatic amylase** converts starch to oligosaccharides and maltose within 10 minutes
- oligosaccharides and maltose contacts **brush border enzymes** (dextrinase, glucoamylase, maltase, sucrase, and lactase) act upon oligosaccharides, maltose, sucrose, lactose, and fructose to glucose
  - **lactose** becomes indigestible after age 4 in most humans due to decline in lactase production – **lactose intolerance**

Carbohydrate Absorption

- plasma membrane of the **absorptive cells** has transport proteins that absorb monosaccharides as soon as the brush border enzymes release them
- 80% of absorbed sugar is glucose
  - taken up by **sodium-glucose transport proteins (SGLT)**
  - glucose is transported out the base of absorptive cell into ECF by **facilitated diffusion**
  - sugar entering ECF increases its osmolarity
  - draws water osmotically from the lumen of the intestine, through **now leaky tight junctions** between epithelial cells
  - water carries more glucose and other nutrients with it by **solvent drag**
- SGLT absorbs galactose, fructose is absorbed by facilitated diffusion
- glucose, galactose, and any remaining fructose are transported out of the base of the cell by **facilitated diffusion**
- absorbed by blood capillaries in the **villus**
- hepatic portal system delivers them to the **liver**

Fig. 25.28



Lactose Intolerance

- lactose passes undigested into large intestine
  - increases osmolarity of intestinal contents
  - causes water retention in the colon and diarrhea
  - gas production by bacterial fermentation of the lactose
- occurs in many parts of the population
  - 15% American whites, 90% of American blacks, 70% of Mediterranean's; and nearly all of Asian descent
- can consume yogurt and cheese since bacteria have broken down lactose

Proteins

- **amino acids** absorbed by the small intestine come from three sources:
  - **dietary proteins**
  - **digestive enzymes digested by each other**
  - **sloughed epithelial cells digested by enzymes**

- **proteases (peptidases)** - enzymes that digest proteins
  - begin their work in the stomach in optimum pH of 1.5 to 3.5
  - **pepsin** hydrolyzes any peptide bond between tyrosine and phenylalanine
    - **pepsin** digests 10-15% of dietary protein into shorter peptides and some free amino acids

Proteins

- **pepsin inactivated** when it passes into the duodenum and mixes with the alkaline pancreatic juice (pH 8)
  - pancreatic enzymes **trypsin** and **chymotrypsin** take over the process
  - hydrolyzing **polypeptides into** even shorter **oligopeptides**
  - oligopeptides taken apart one amino acid at a time by three more enzymes
    - **carboxypeptidase** – removes amino acids from –COOH end of the chain
    - **aminopeptidase** – removes them from the $–NH_2$ end
    - **dipeptidase** – split dipeptides in the middle and release two free amino acids
  - carboxypeptidase is a **pancreatic secretion**
  - aminopeptidase and dipeptidase are **brush border enzymes**

Protein Digestion and Absorption

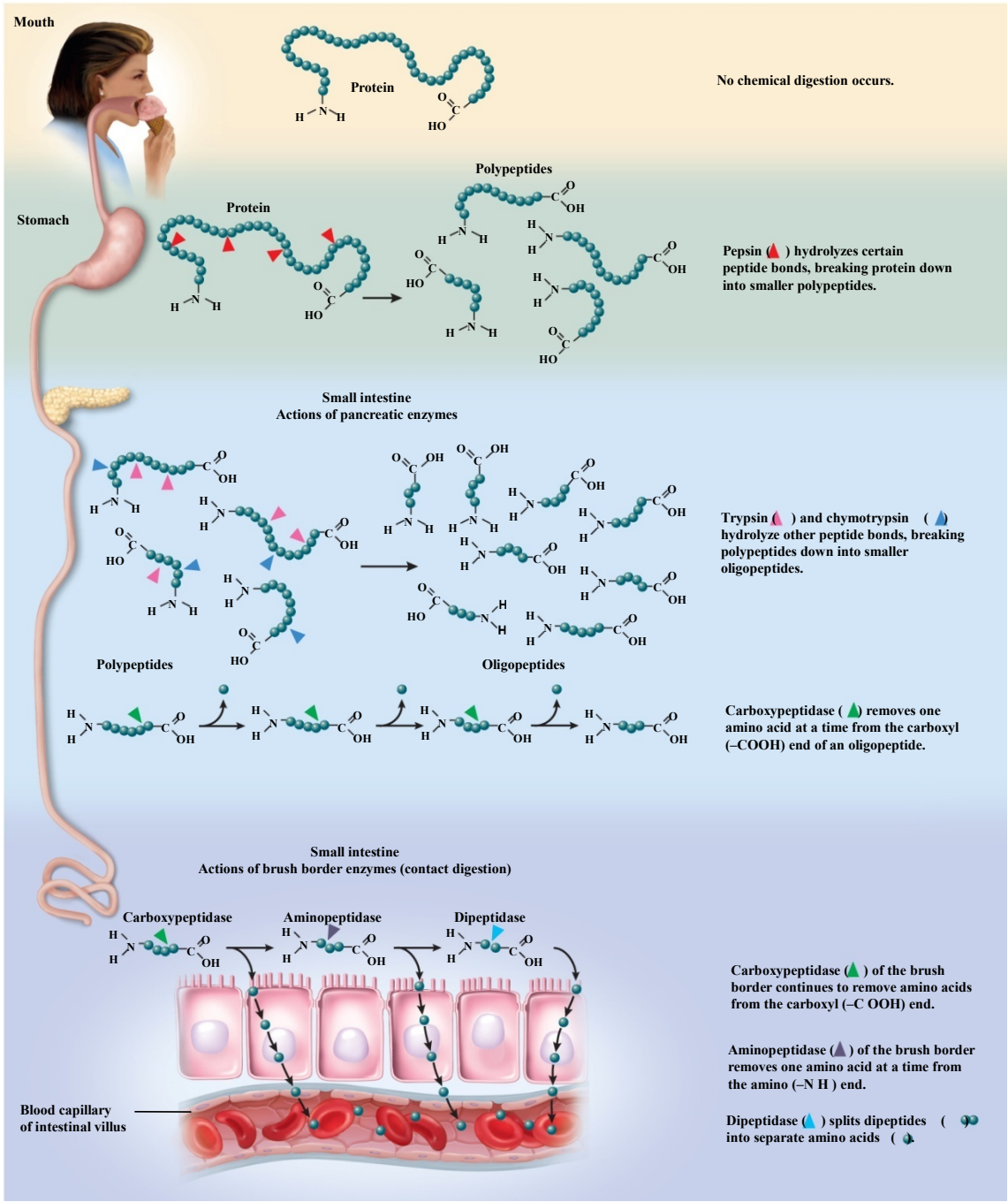


Figure 25.29

Protein Digestion and Absorption

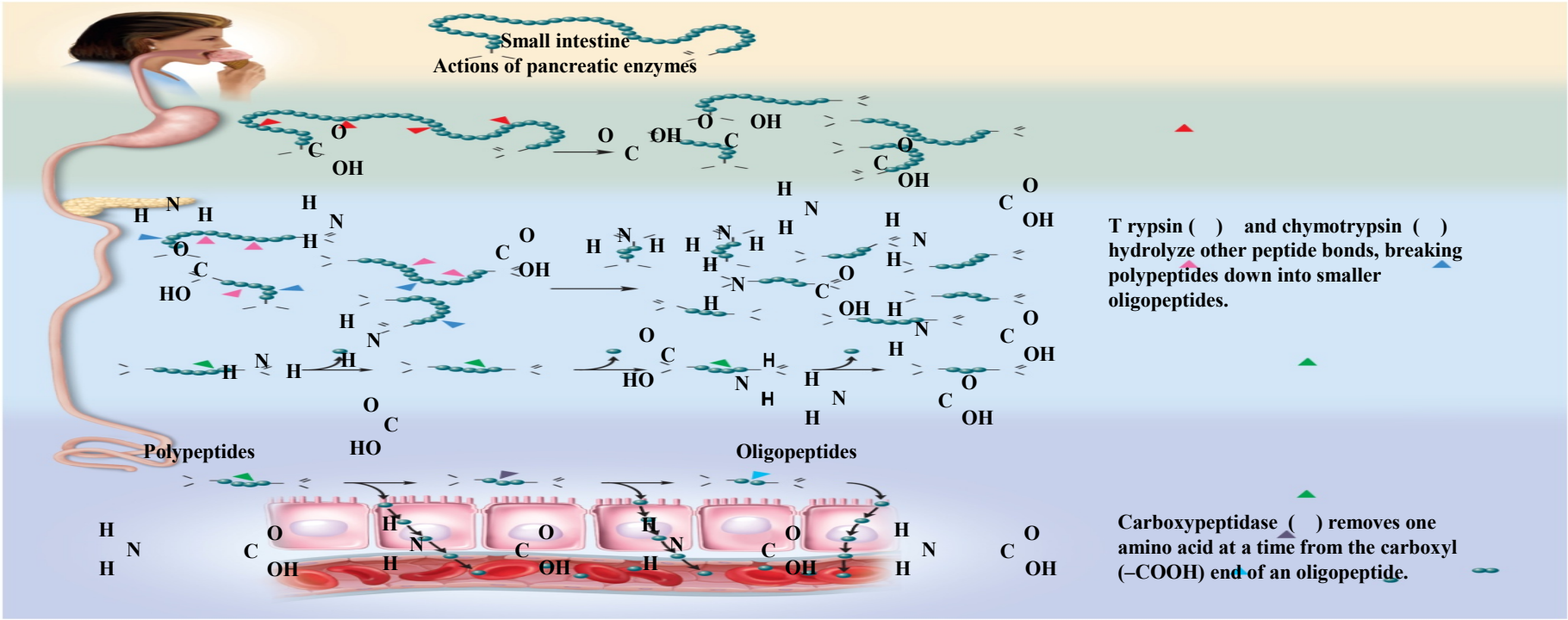


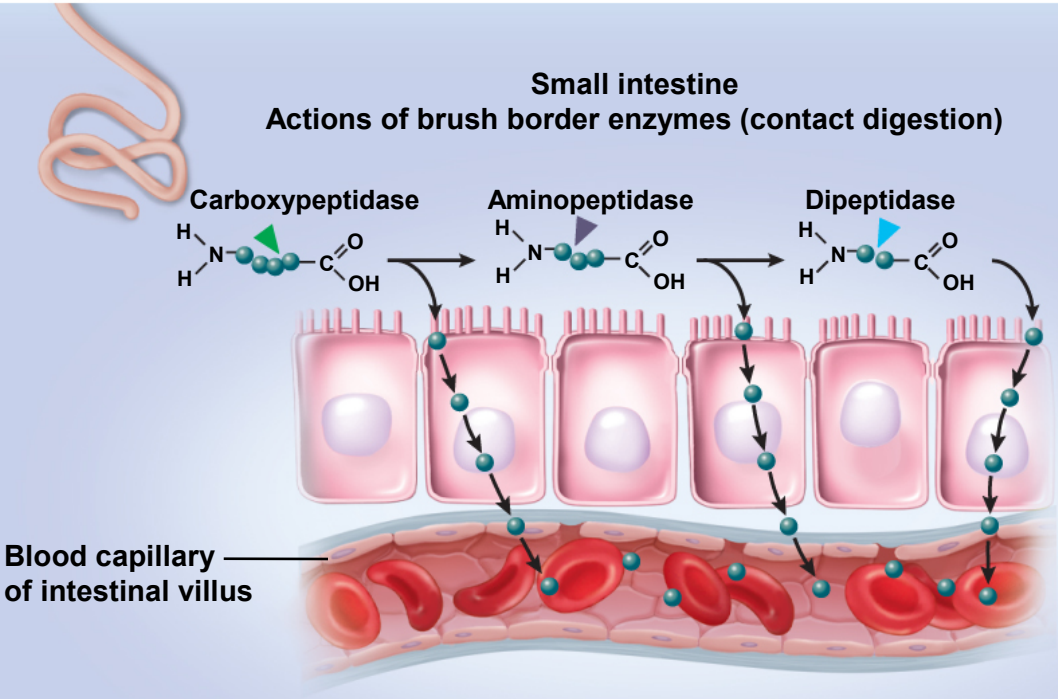
Figure 25.29

- pancreatic enzymes take over protein digestion in small intestine by hydrolyzing polypeptides into shorter oligopeptides

Protein Digestion and Absorption

- brush border enzymes finish task, producing free amino acids that are absorbed into intestinal epithelial cells
  - **sodium-dependent amino acid cotransporters** move amino acids into epithelial cells
  - **facilitated diffusion** moves amino acids out into blood stream
- infants absorb proteins by pinocytosis (maternal IgA) and release into the blood by exocytosis

Fig. 25.29d



Carboxypeptidase (▲) of the brush border continues to remove amino acids from the carboxyl (–COOH) end.

Aminopeptidase (▲) of the brush border removes one amino acid at a time from the amino ($–NH_2$) end.

Dipeptidase (▲) splits dipeptides (●●) into separate amino acids (●).

Lipids

- hydrophobic quality of lipids makes their digestion and absorption more complicated that carbohydrates and proteins

- **lipases** – fat digesting enzymes
  - **lingual lipase** secreted by the intrinsic salivary glands of the tongue
    - active in mouth, but more active in stomach along with **gastric lipase**
    - 10-15% of lipids digested before reaches duodenum
  - **pancreatic lipase** – in the small intestine digest most of the fats
  - fat enters duodenum as large globules exposed to lipase only at their surface
  - globules broken up into smaller **emulsification droplets** by certain components of **bile**
    - **lecithin** and **bile acids**

Lipids

- agitation by **segmentation breaks up the fats** into droplets as small as 1 μm in diameter
- the coating of lecithin and bile acids keep it broken up, exposing far more of its surface to enzymatic action
- there is enough pancreatic lipase in the small intestine after a meal to digest the average daily fat intake in as little as 1 to 2 minutes
- lipase acts on triglycerides
  - removes the first and third fatty acids from glycerol backbone
  - leaves the middle one
  - the product of lipase action are **two free fatty acids (FFAs)** and a **monoglyceride**

Emulsification

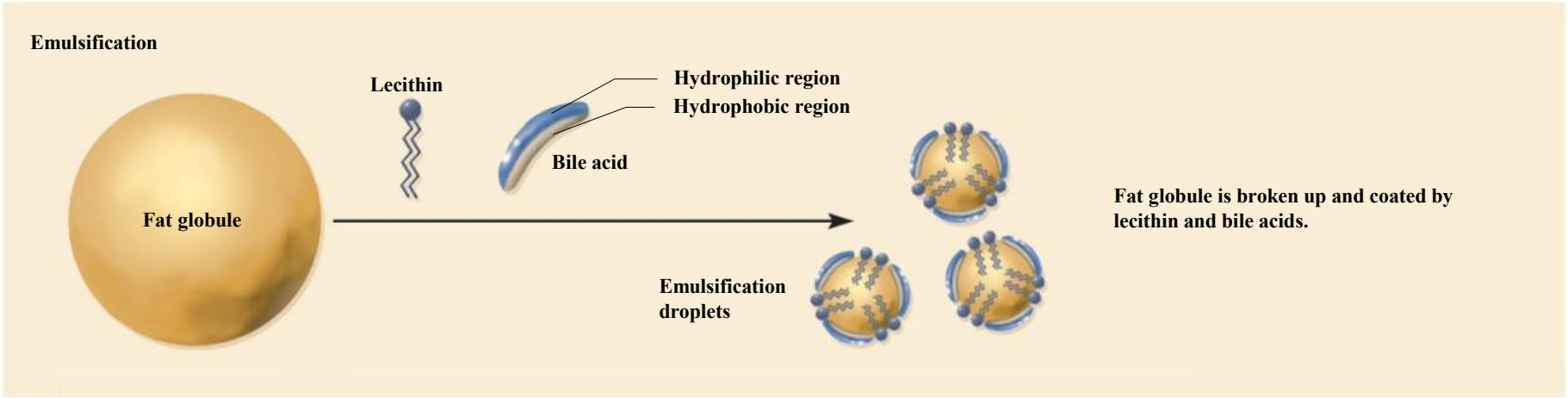


Figure 25.30

Lipid Absorption

- absorption of free fatty acids, monoglycerides, and other lipids depends on minute droplets in the bile called **micelles**
  - made in the liver
  - **bile phospholipids** and **cholesterol** diffuse into the center of the micelle to form its core
  - micelles pass down the **bile duct into the duodenum**
    - where they absorb fat soluble vitamins, more cholesterol, and the FFAs and monoglycerides produced by fat digestion
  - they transport lipids to the surface of the intestinal absorptive cells
  - lipids leave the micelles and diffuse through the plasma membrane into the cells
  - micelles are reused, picking up another cargo of lipid, transporting them to the absorptive cells

Fat Hydrolysis and Micelles

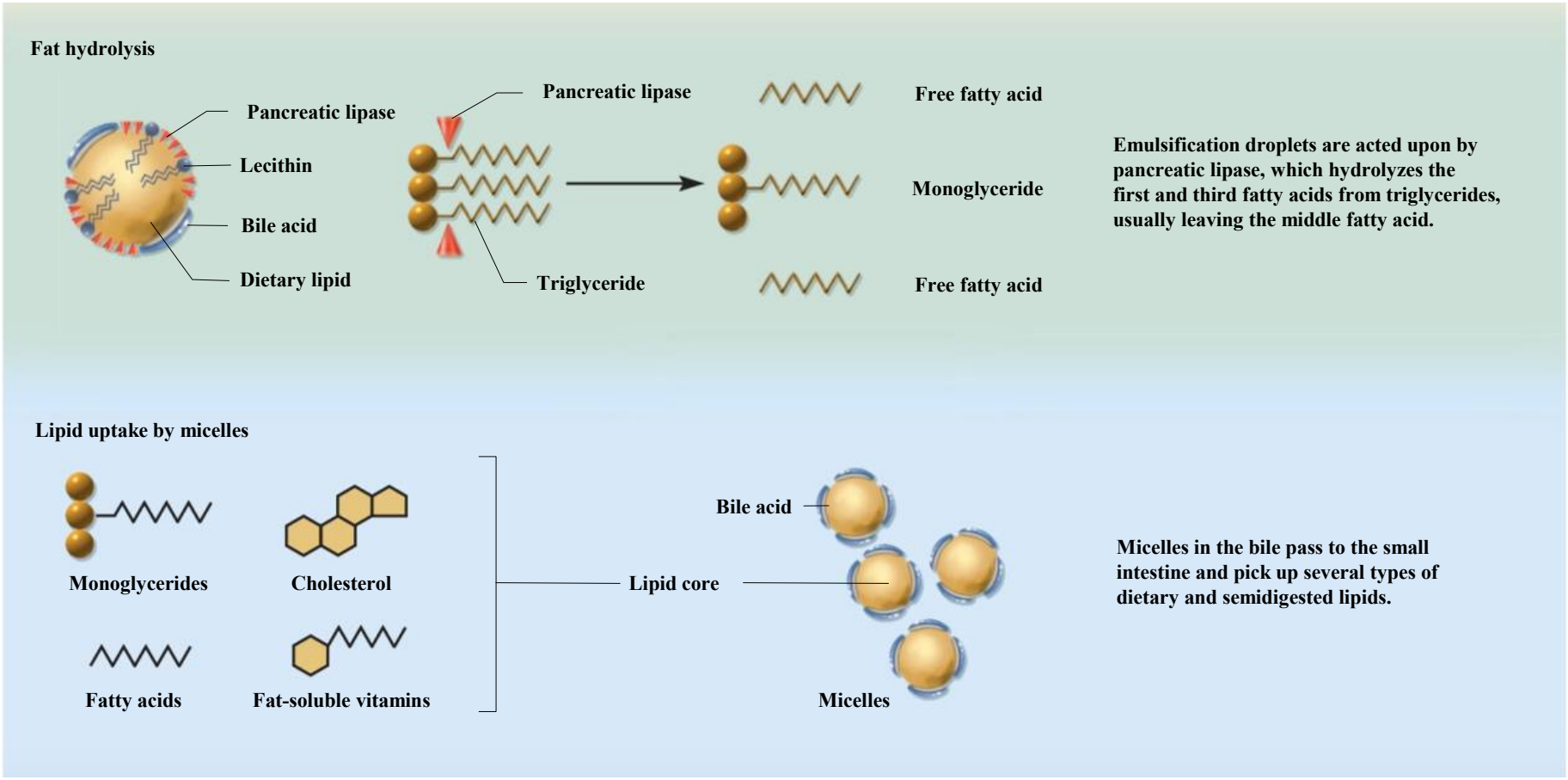


Figure 25.30

Lipid Absorption

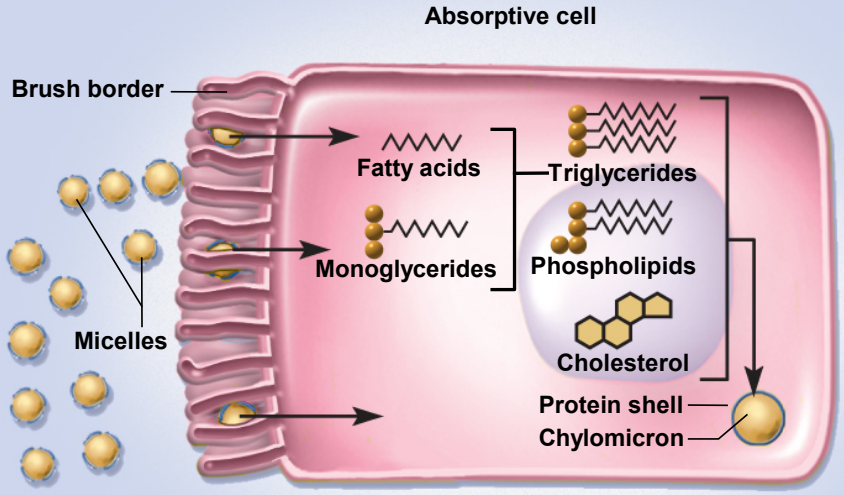
- within the intestinal cell, free fatty acids and monoglycerides are transported to **the smooth ER**
- **resynthesized into triglycerides**
- **golgi complex** coats these with **phospholipids and protein** to form **chylomicrons**
  - packaged into secretory vesicles that migrate to basal surface of cell
  - release their contents into the **core of the villus**
  - taken up by more **porous lacteal** into the lymph
  - **white, fatty intestinal lymph (chyle)** flows into larger and larger lymphatic vessels until they reenter the bloodstream

Chylomicrons and the Lymphatics

Chylomicrons are released into the lymphatic system in the lacteals of the villi. They enter the bloodstream when lymphatic fluid enters the subclavian vein via the thoracic duct.

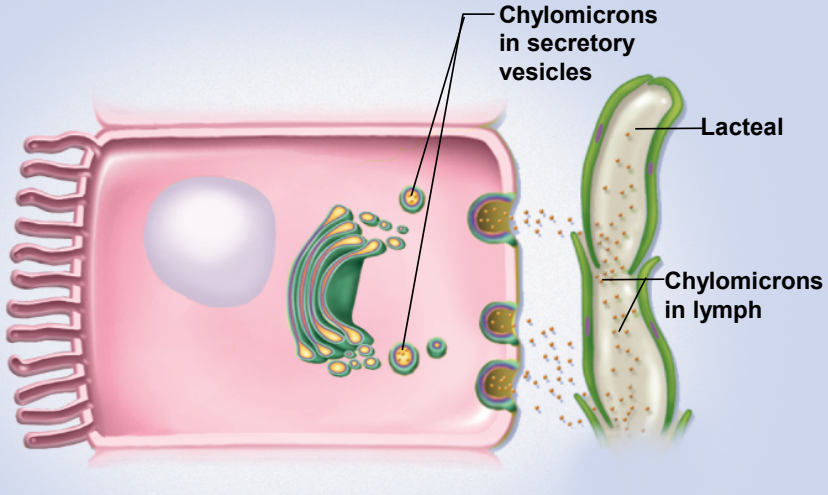
Fig. 25.30d

Chylomicron formation



Intestinal cells absorb lipids from micelles, resynthesize triglycerides, and package triglycerides, cholesterol, and phospholipids into protein-coated chylomicrons.

Chylomicron exocytosis and lymphatic uptake



Golgi complex packages chylomicrons into secretory vesicles; chylomicrons are released from basal cell membrane by exocytosis and enter the lacteal (lymphatic capillary) of the villus.

Nucleic Acids and Vitamins

- **nucleic acid**
  - **nucleases** (deoxyribonuclease and ribonuclease) hydrolyze DNA and RNA to nucleotides
  - **nucleosidases** and **phosphatases** of brush border split them into phosphate ions, ribose or deoxyribose sugar, and nitrogenous bases
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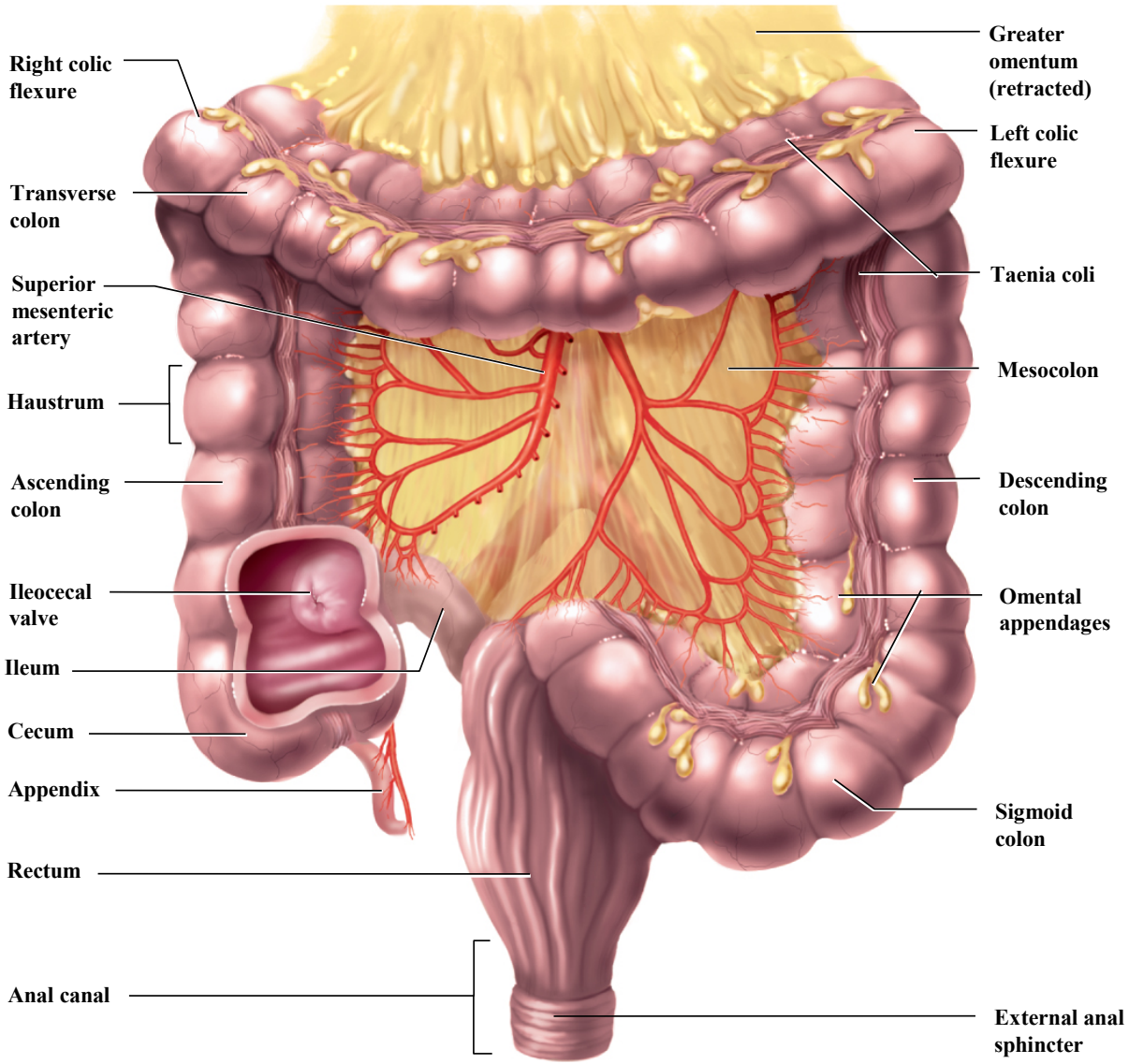
Anatomy of Large Intestine



(a) Gross anatomy

Figure 25.31a

Gross Anatomy of Large Intestine

- large intestine receives about 500 mL of indigestible residue per day
  - reduces it to about 150 mL of feces by absorbing water and salts
  - eliminates feces by **defecation**

- **large intestine**
  - measures 1.5 m (5 ft) long and 6.5 cm (2.5 in) in diameter in cadaver
  - begins as **cecum** inferior to ileocecal valve
  - **appendix** attached to the lower end of the cecum
    - densely populated with lymphocytes and is a significant source of immune cells
  - **ascending colon**, **transverse colon**, and **descending colon** frame the small intestine
  - **sigmoid colon** is S-shaped portion leading down into pelvis

Gross Anatomy of Large Intestine

- **rectum** - portion ending at anal canal
  - has 3 curves and 3 infoldings the transverse rectal folds (rectal valves)
- **anal canal** – final 3 cm of the large intestine
  - **large hemorrhoidal veins** for superficial plexus in anal columns and around orifice
  - **hemorrhoids** – permanently distended veins that protrude into the anal canal or form bulges external to the anus
- **muscularis externa** of colon is unusual