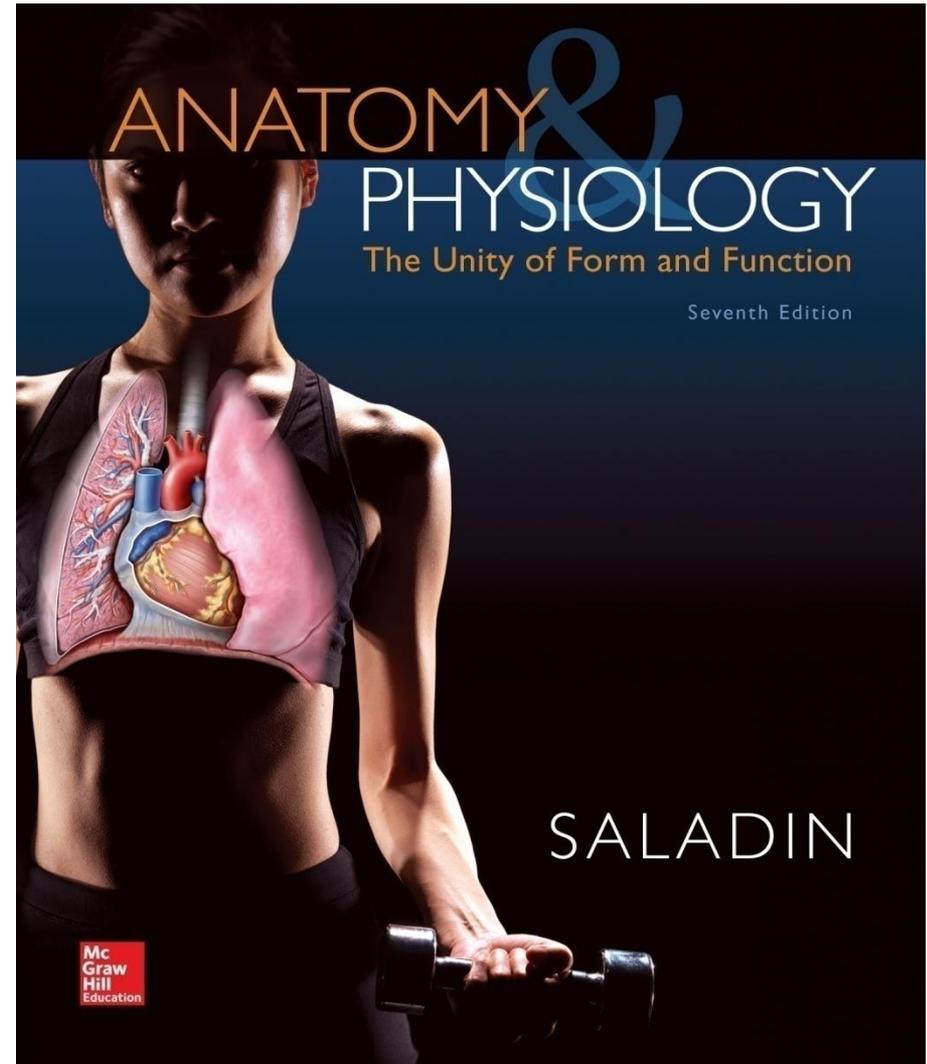


# Chapter 25

## Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.



# Introduction

- Most **nutrients** we eat cannot be used in existing form
  - Must be broken down into smaller components before body can make use of them
- Digestive system—acts as a **disassembly line**
  - To break down nutrients into forms 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

# General Anatomy and Digestive Processes

- **Expected Learning Outcomes**

- List the functions and major physiological processes of the digestive system.
- Distinguish between mechanical and chemical digestion.
- Describe the basic chemical process underlying all chemical digestion, and name the major substrates and products of this process.

# General Anatomy and Digestive Processes

## (Continued)

- List the regions of the digestive tract and the accessory organs of the digestive system.
- Identify the layers of the digestive tract and describe its relationship to the peritoneum.
- Describe the general neural and chemical controls over digestive function.

# Digestive Function

- **Digestive system**—organ system that processes food, extracts nutrients, and eliminates 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

# Digestive Function

- **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 digestive enzymes

# Digestive Function

- **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 and can be directly absorbed**
  - Vitamins, amino acids, minerals, cholesterol, and water

# General Anatomy

- Digestive system has two **subdivisions**: digestive tract and accessory organs
- **Digestive tract (alimentary canal)**
  - 30 ft 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

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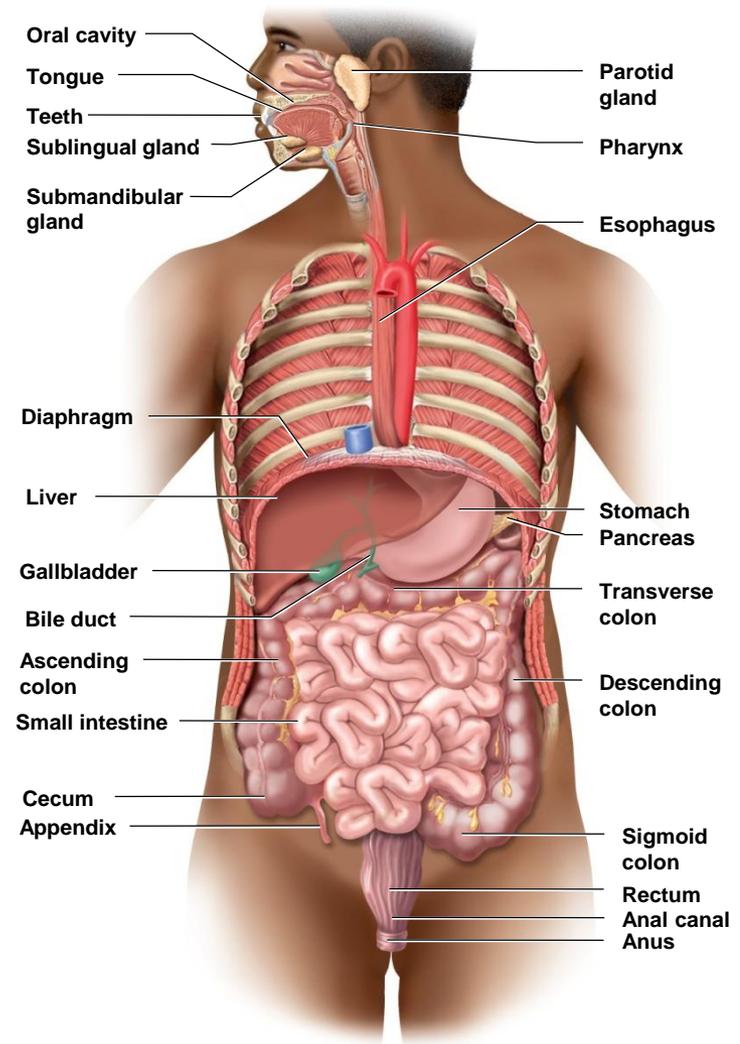


Figure 25.1

# General Anatomy

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**(Continued)**

- **Accessory organs**

- Teeth, tongue, salivary glands, liver, gallbladder, and pancreas

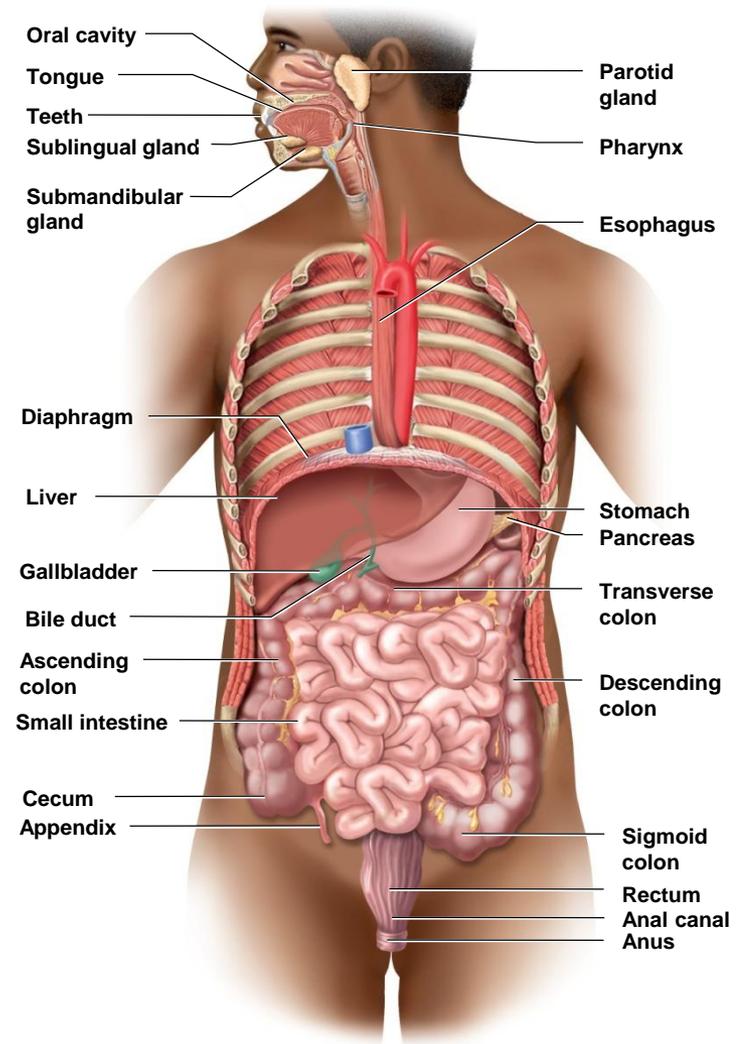


Figure 25.1

# General Anatomy

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

# General Anatomy

- Most of digestive tract follows a **basic structural plan** with the digestive tract wall consisting of layers:
  - **Mucosa**
    - Epithelium
    - Lamina propria
    - Muscularis mucosae
  - **Submucosa**
  - **Muscularis externa**
    - Inner circular layer
    - Outer longitudinal layer
  - **Serosa**
    - Areolar tissue
    - Mesothelium

# General Anatomy

- **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

# General Anatomy

- **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

# General Anatomy

- **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

# General Anatomy

- **Serosa**—composed of a thin layer of areolar tissue topped by simple squamous mesothelium
  - Begins in the lower 3 to 4 cm of the esophagus
  - Ends just before the rectum
  - **Adventitia**: fibrous connective tissue layer that binds and blends the pharynx, most of the esophagus, and the rectum into adjacent connective tissue of other organs

# Tissue Layers of the Digestive Tract

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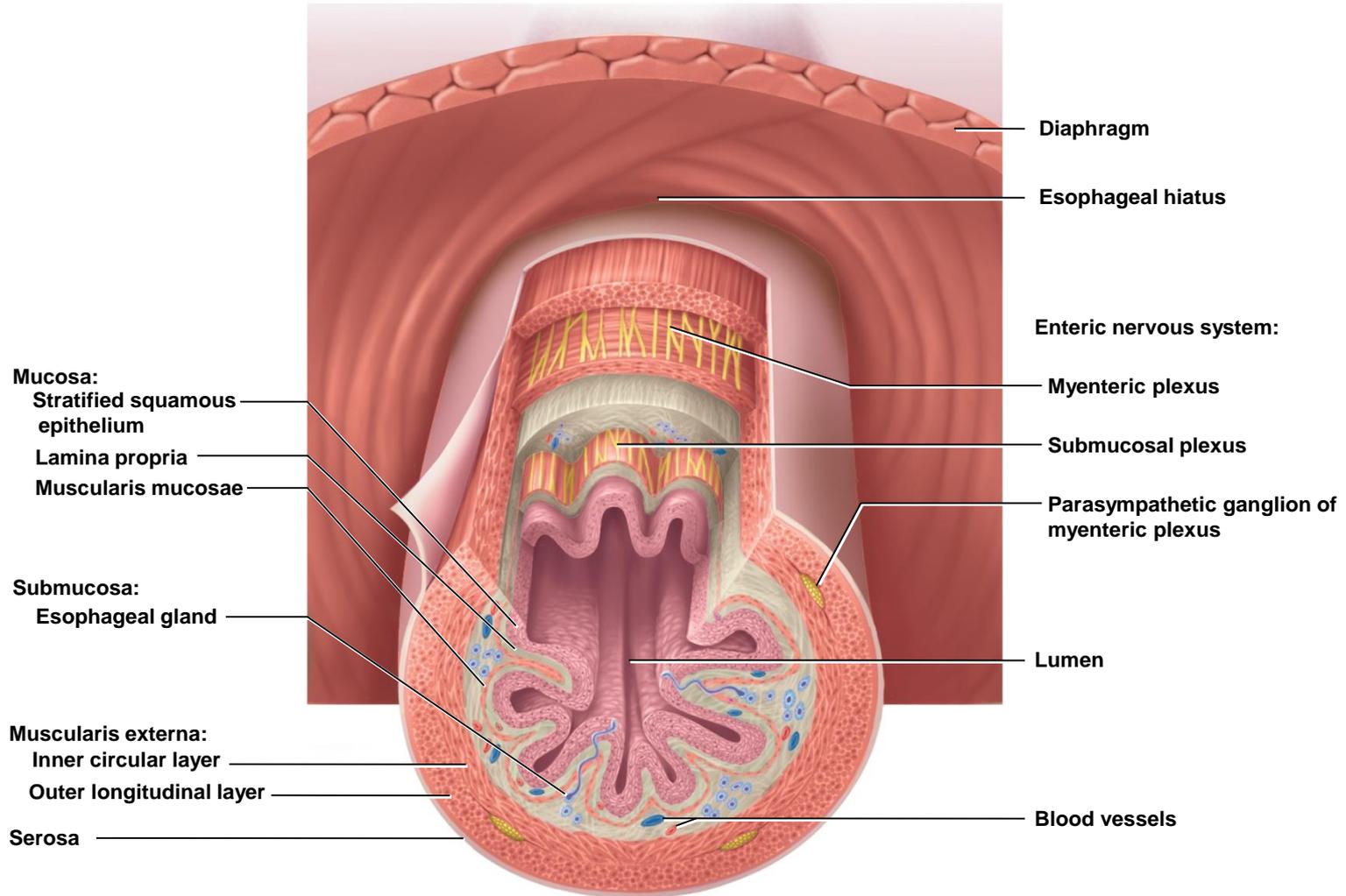


Figure 25.2

# General Anatomy

- **Enteric nervous system**—nervous network in esophagus, stomach, and intestines that regulates digestive tract motility, secretion, and blood flow
  - Thought to have over 100 million neurons
  - Can function independently of central nervous system
    - But CNS usually exerts influence on its action
  - Often considered part of autonomic nervous system

# General Anatomy

- Enteric nervous system is composed of **two networks of neurons**
  - **Submucosal (Meissner) plexus:** in submucosa
    - Controls glandular secretions of mucosa
    - Controls movements of muscularis mucosae
  - **Myenteric (Auerbach) plexus:** parasympathetic ganglia and nerve fibers between the two layers of the muscularis externa
    - Controls peristalsis and other contractions of muscularis externa

# Relationship to the Peritoneum

- **Mesenteries**—connective tissue sheets that suspend stomach and intestines from abdominal wall
  - Looseness allows stomach and intestines to undergo strenuous contractions with freedom of movement in the abdominal cavity
  - Hold abdominal viscera in proper relationship to each other
  - Prevent intestines from becoming twisted and tangled by changes in body position and by its own contractions
  - Provide passage of blood vessels and nerves that supply digestive tract
  - Contain many lymph nodes and lymphatic vessels

# Relationship to the Peritoneum

- **Parietal peritoneum**—a serous membrane that lines the wall of the abdominal cavity
  - Turns inward along posterior midline
  - 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, called the **anterior (ventral) mesentery**
    - May hang freely in the abdominal cavity
    - May attach to the anterior abdominal wall or other organs

# Relationship to the Peritoneum

- **Lesser omentum**—a ventral mesentery that extends from the **lesser curvature of the stomach** to the **liver**
- **Greater omentum**—hangs from the **greater curvature of the stomach** (its left inferior margin)
  - Covers small intestine 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

# Relationship to the Peritoneum

- **Mesocolon**—extension of the mesentery that anchors the colon to the abdominal wall
- **Intraperitoneal**—when an organ is enclosed by mesentery on both sides
  - Considered within the peritoneal cavity
  - Stomach, liver, and parts of small and large intestine
- **Retroperitoneal**—when an organ lies against the posterior body wall and is covered by peritoneum on its anterior side only
  - Considered to be outside the peritoneal cavity
  - Duodenum, pancreas, and parts of the large intestine

# Serous Membranes

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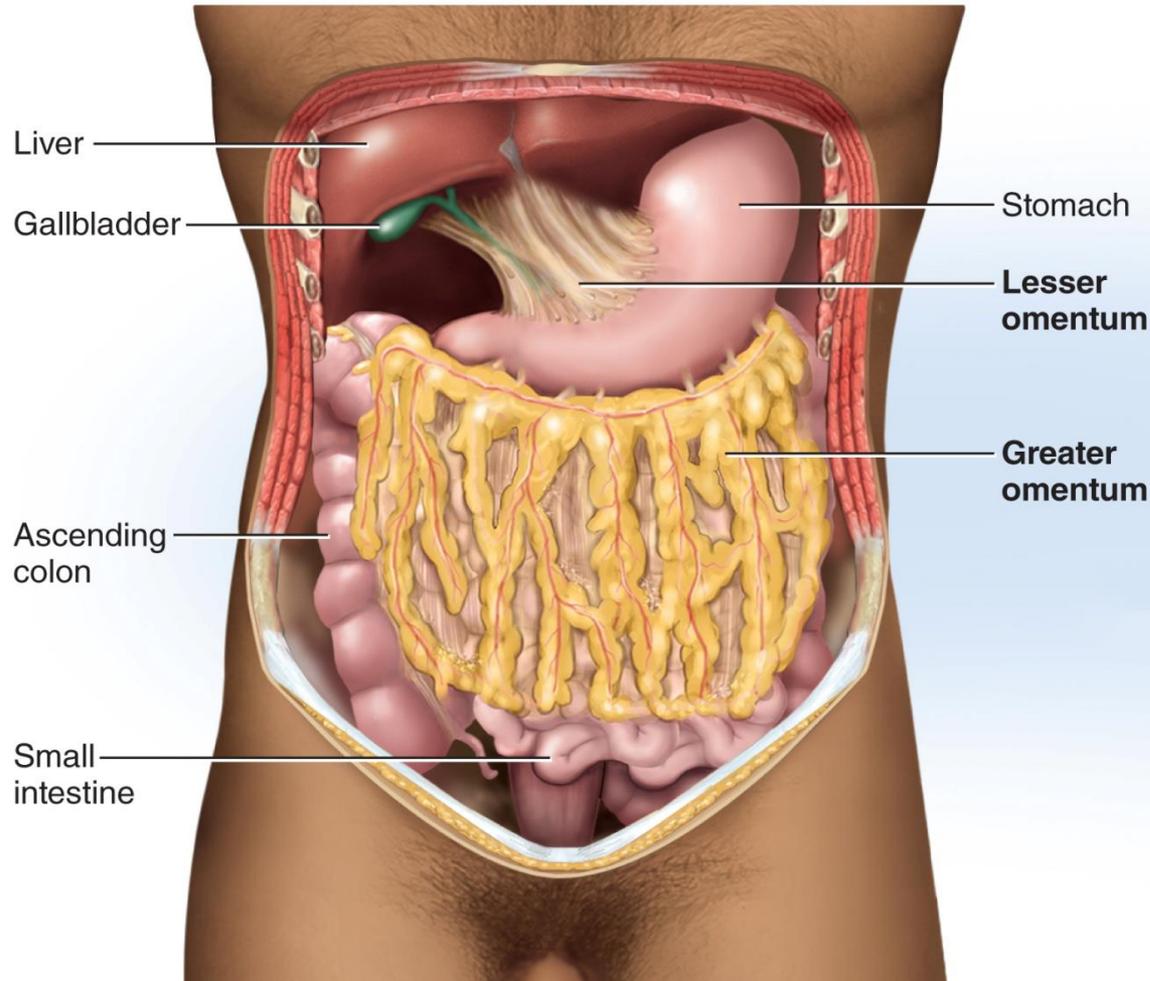


Figure 25.3a

(a)

- **Lesser omentum**—attaches stomach to liver
- **Greater omentum**—covers small intestines like an apron

# Serous Membranes

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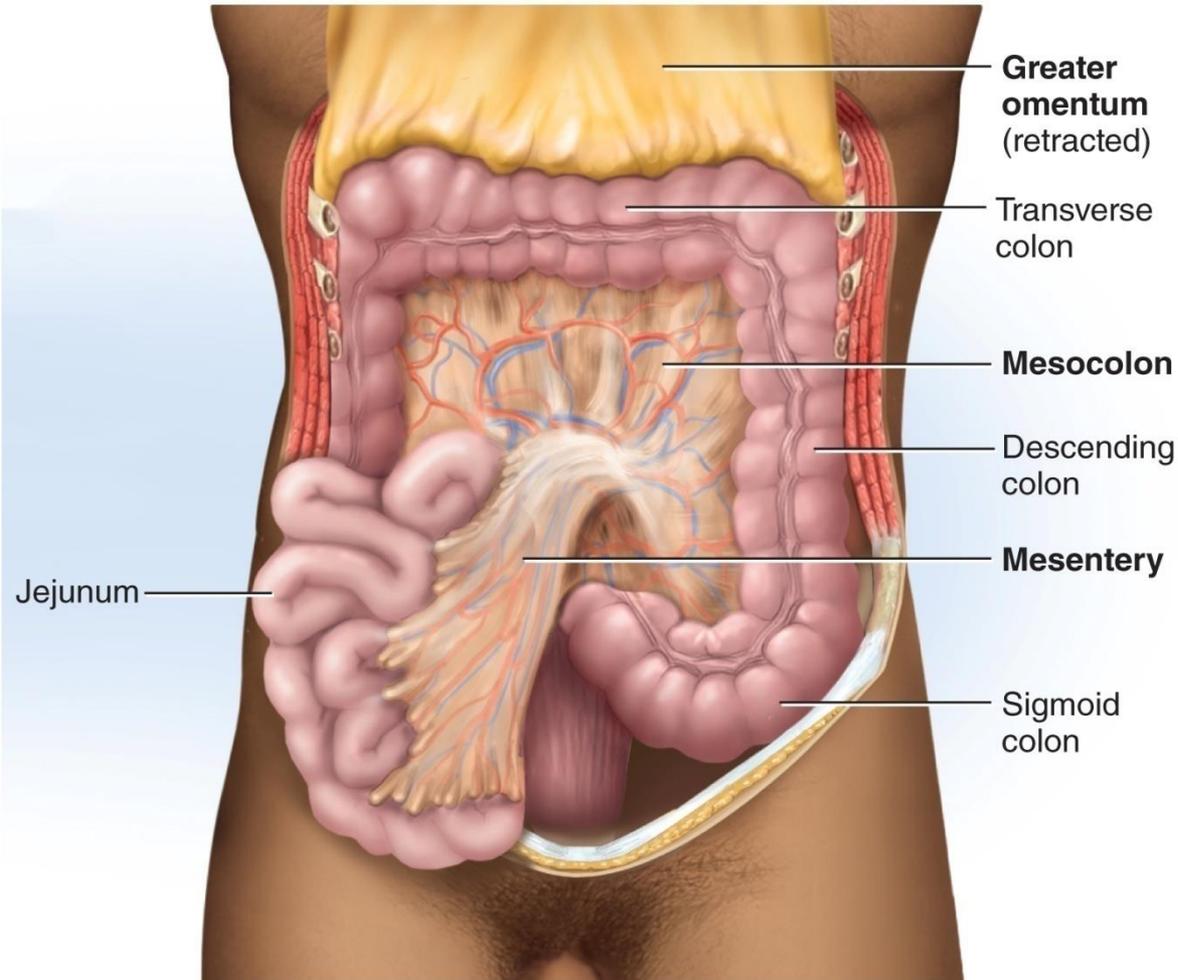


Figure 25.3b

(b)

- **Mesentery of small intestines holds many blood vessels**
- **Mesocolon anchors colon to body wall**

# Regulation of the 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 peristaltic contractions of **swallowing**
  - **Long (vagovagal) reflexes:** parasympathetic stimulation of digestive **motility** and **secretion**

# Regulation of the Digestive Tract

- **Hormones**

- Chemical messengers secreted into bloodstream that stimulate distant parts of the digestive tract
- Gastrin and secretin

- **Paracrine secretions**

- Chemical messengers that diffuse through the tissue fluids to stimulate nearby target cells

# The Mouth Through Esophagus

- **Expected Learning Outcomes**
  - Describe the gross anatomy of the digestive tract from the mouth through the esophagus.
  - Describe the composition and functions of saliva.
  - Describe the neural control of salivation and swallowing.

# The Mouth

- The **mouth** is known as the **oral**, or **buccal cavity**
- **Functions**
  - Ingestion (food intake)
  - Taste and other sensory responses to food
  - Chewing and chemical digestion
  - Swallowing, speech, and respiration
- **Mouth enclosed by cheeks, lips, palate, and tongue**

# The Mouth

- **Oral fissure**—anterior opening between lips
- **Fauces**—posterior opening to the throat
- **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 insides of cheeks and lips

# The Oral Cavity

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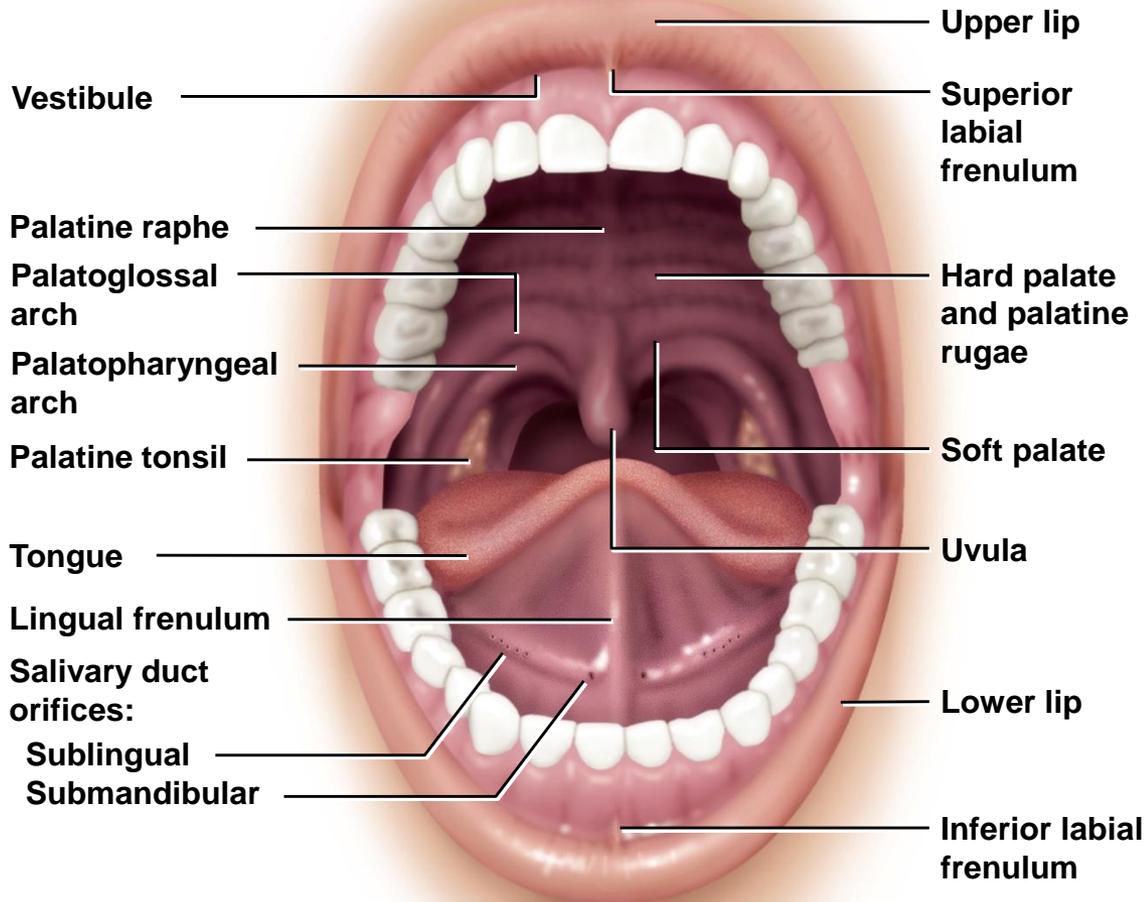


Figure 25.4

# The Cheeks and Lips

- **Cheeks and lips**

- Retain food and push it between the teeth
- Essential for speech
- Essential for sucking and blowing actions, including suckling by infants
- Fleshiness due to subcutaneous fat, buccinator muscle of the cheek, and orbicularis oris of the lips
- **Labial frenulum:** median fold that attaches each lip to the gum between the anterior incisors
- **Vestibule:** space between cheek or lips and the teeth

# The Cheeks and Lips

- **Lips divided into three areas**
  - **Cutaneous area:** colored like the rest of the face
    - Has hair follicles and sebaceous glands
  - **Red (vermillion) area:** hairless region where lips meet
    - Tall **dermal papilla** that allows blood vessels and nerves to come closer to epidermal surface
    - Redder and more sensitive than cutaneous area
  - **Labial mucosa:** the inner surface of the lips facing the gums and teeth

# The Tongue

- **Tongue**—muscular, bulky, but remarkably agile and sensitive organ
  - Manipulates food between teeth
  - Senses taste and texture of food
  - Can extract food particles from the teeth after a meal
  - **Nonkeratinized stratified squamous epithelium** covers its surface
  - **Lingual papillae**: bumps and projections that are the sites of most taste buds
  - **Body**: anterior two-thirds of tongue; it occupies oral cavity
  - **Root**: posterior one-third of the tongue; it occupies the oropharynx

# The Tongue

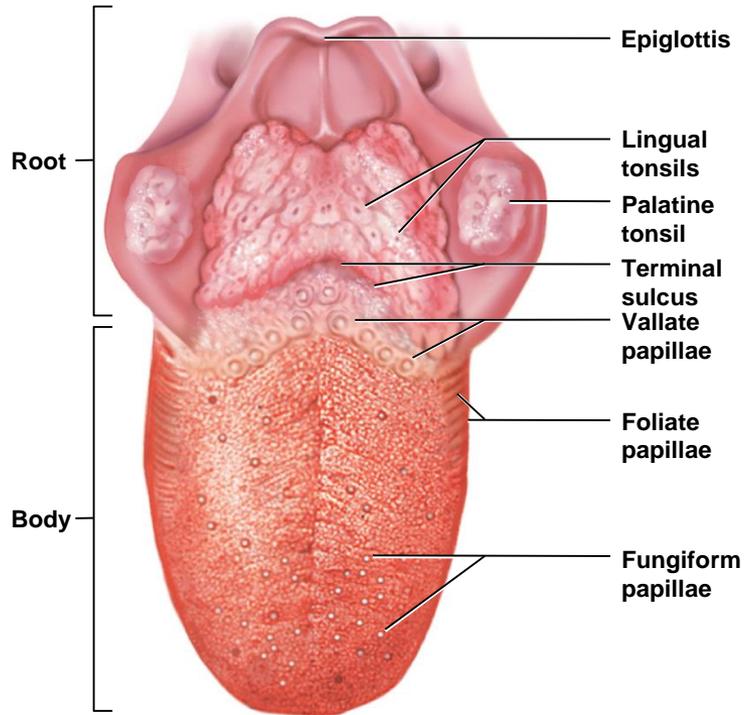
- **Vallate papillae:** a V-shaped row of papillae that mark the boundary between the body and root of the tongue
- **Terminal sulcus:** groove behind the vallate papillae
- **Lingual frenulum:** median fold that attaches the body of the tongue to the floor of the mouth
- **Intrinsic muscles**—contained entirely within the tongue
  - Produce 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

# The Tongue

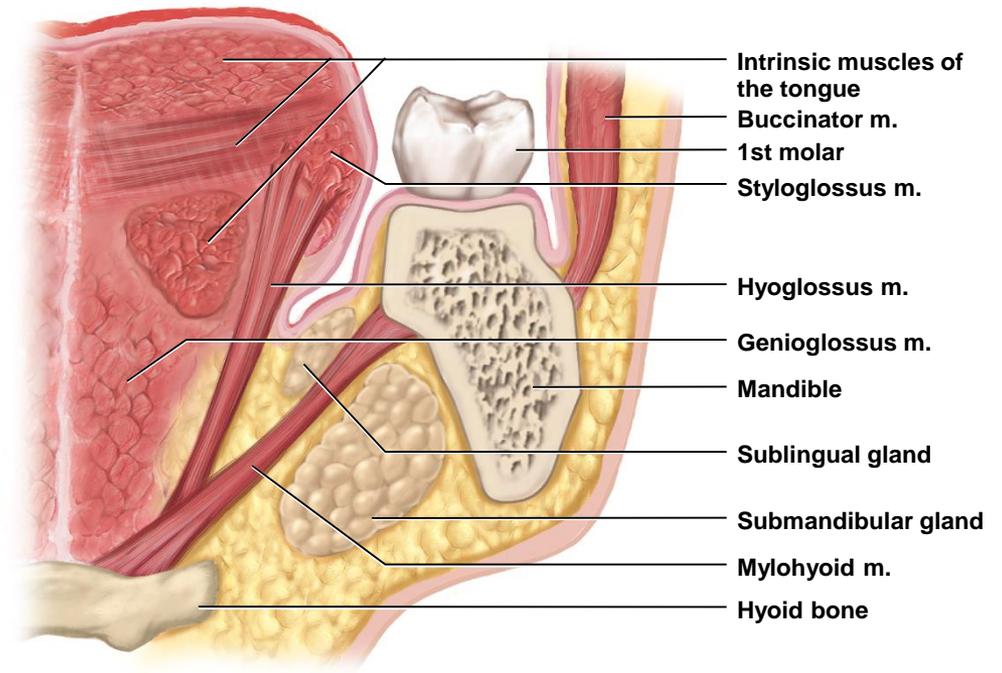
- **Lingual glands:** serous and mucous glands amid the extrinsic muscles
  - Secrete a portion of the saliva
- **Lingual tonsils:** contained in the root

# The Tongue

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(a) Superior view



(b) Frontal section, anterior view

Figure 25.5a,b

# The Palate

- **Palate**—separates oral cavity from nasal cavity
  - Makes it possible to breathe while chewing food
- **Hard (bony) palate**—anterior portion that is supported by the palatine processes of the **maxillae** and the **palatine** bones
  - **Palatine rugae**: transverse ridges that help the tongue hold and manipulate food

# The Palate

- **Soft palate**—posterior with a more spongy texture
  - Composed of skeletal muscle and glandular tissue
  - No bone
  - **Uvula:** conical medial projection visible at the rear of the mouth
    - Helps retain food in the mouth until one is ready to swallow
- **Pair of muscular arches** on each side of the oral cavity
  - **Palatoglossal arch:** anterior arch
  - **Palatopharyngeal arch:** posterior arch
  - **Palatine tonsils** are located on the wall between the arches

# The Teeth

- **Dentition**—the teeth
- **Masticate** (chew) food into smaller pieces
  - Makes food easier to swallow
  - Exposes more surface area for action of digestive enzymes, speeding chemical digestion

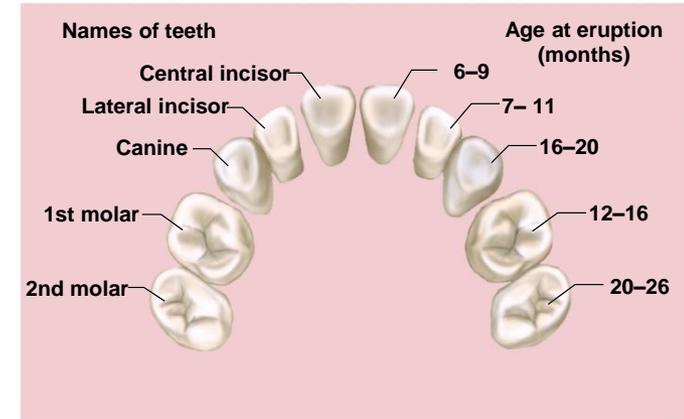
# The Teeth

- **32 adult 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, shredding, and grinding
    - **3 molars**—even broader surface for crushing, shredding, and grinding

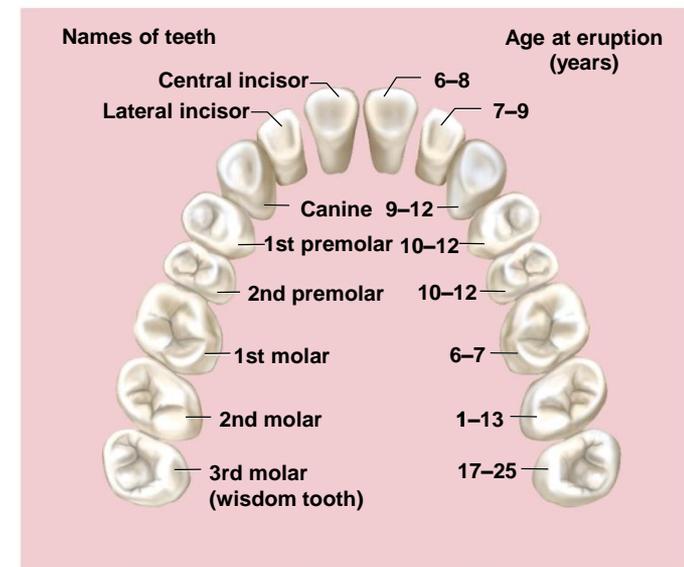
# The Teeth

- **Alveolus**—tooth socket in bone
  - **Gomphosis joint** formed between tooth and bone
- **Periodontal ligament**—modified periosteum whose collagen fibers penetrate into the bone on one side and into the tooth on the other
  - Anchors tooth firmly in alveolus
  - Allows slight movement under pressure of chewing
- **Gingiva (gum)**—covers the alveolar bone

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(a) Deciduous (baby) teeth



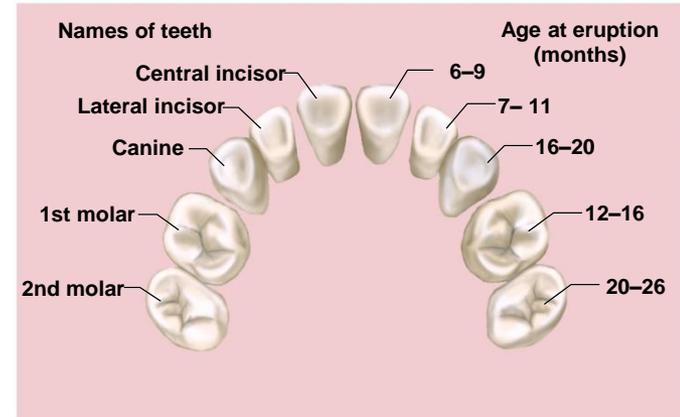
(b) Permanent teeth

# The Teeth

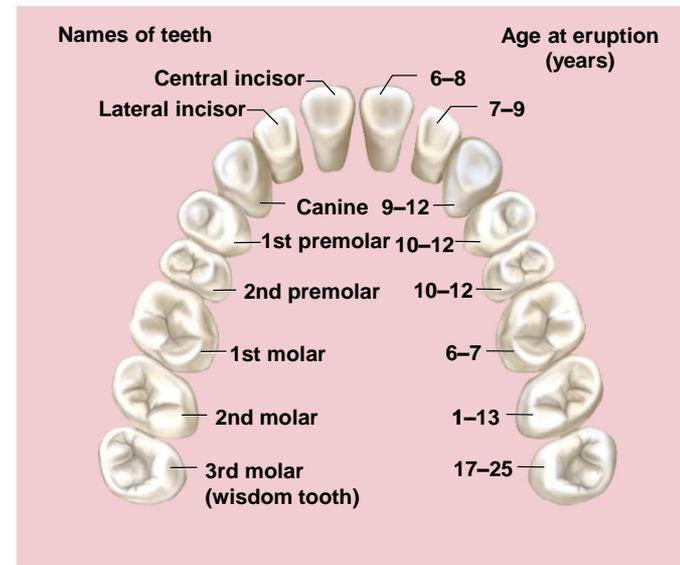
- **Regions of a tooth**

- **Crown:** portion above the gum
- **Root:** the portion below the gum, embedded in alveolar bone
- **Neck:** the point where crown, root, and gum meet
- **Gingival sulcus:** space between the tooth and the gum
  - Hygiene in the sulcus is important to dental health

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(a) Deciduous (baby) teeth



(b) Permanent teeth

# The Teeth

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- **Dentin**—hard yellowish tissue that makes up most of the tooth
- **Enamel**—covers crown and neck
  - A noncellular secretion that cannot regenerate
- **Cementum**—covers root
- **Cementum and dentin** are living tissue and can regenerate

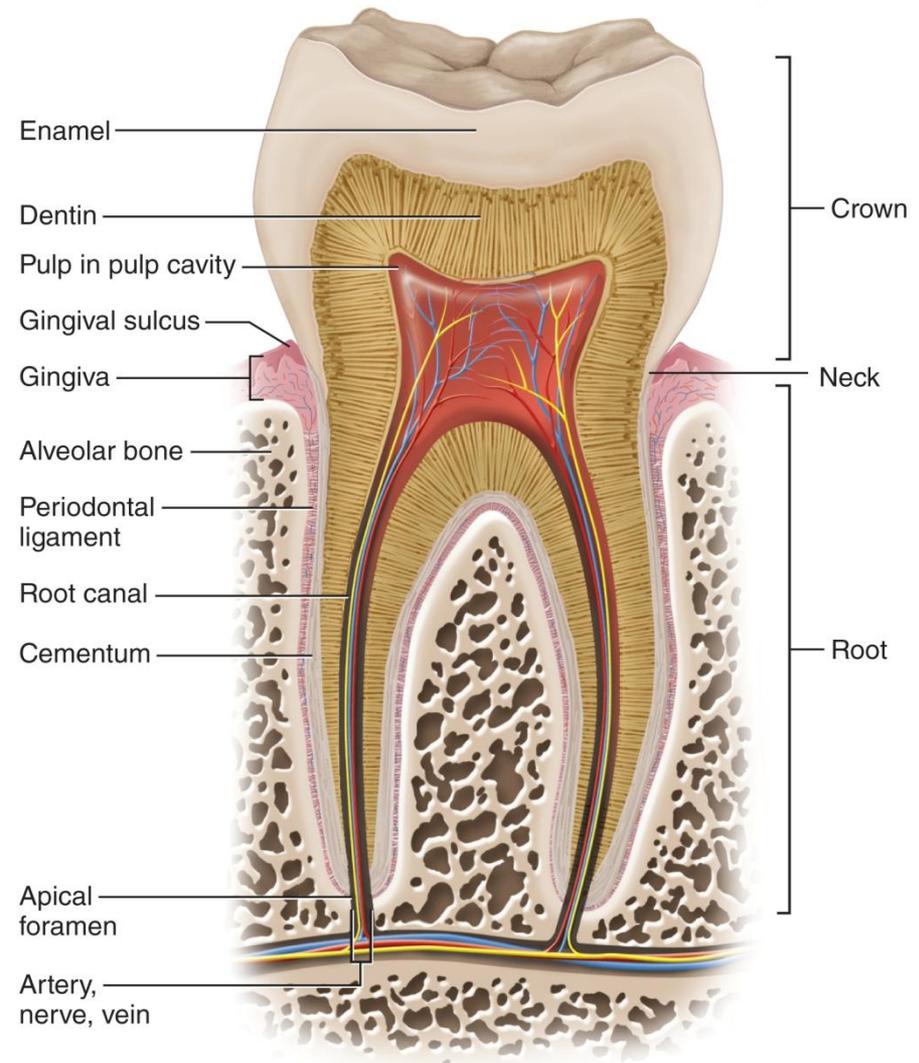


Figure 25.7

# The Teeth

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- **Root canal**—space in a root leading to **pulp cavity** in the crown
  - Nerves and blood vessels
  - **Apical foramen**: pore at the basal end of each root canal
- **Occlusion**—meeting of the teeth with the mouth closed

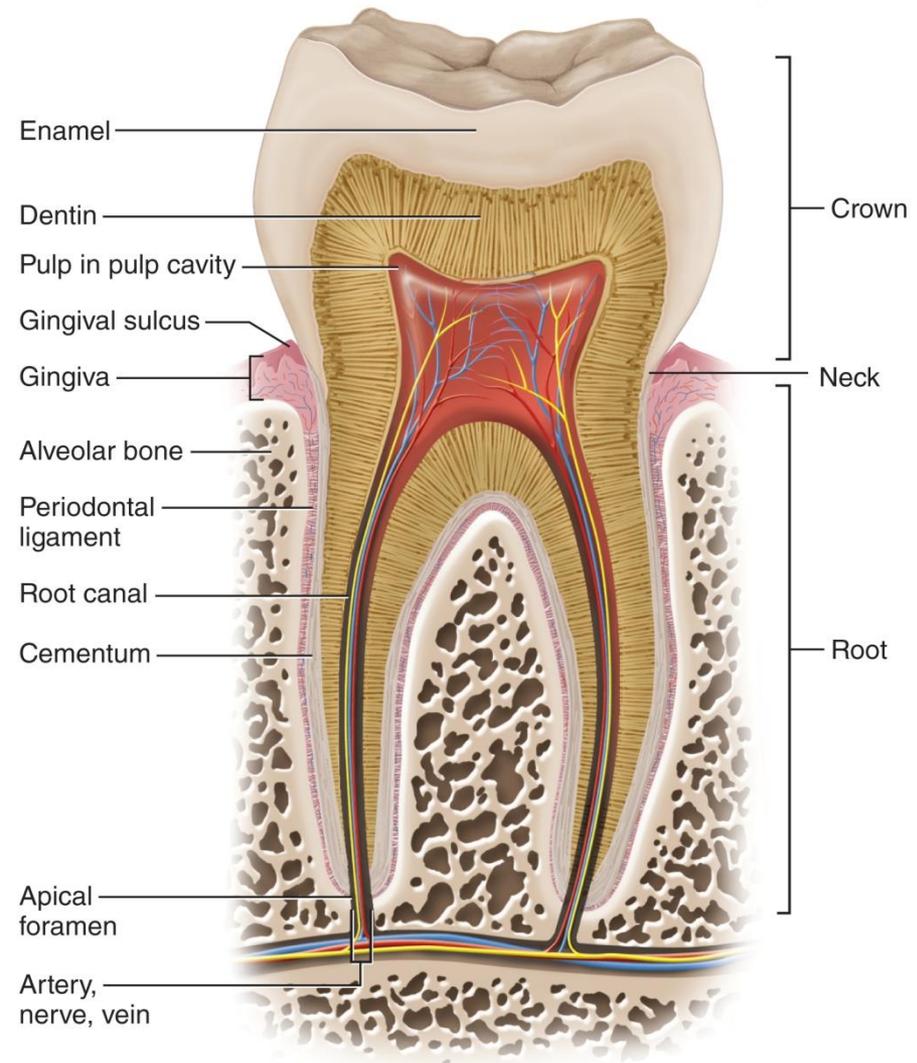
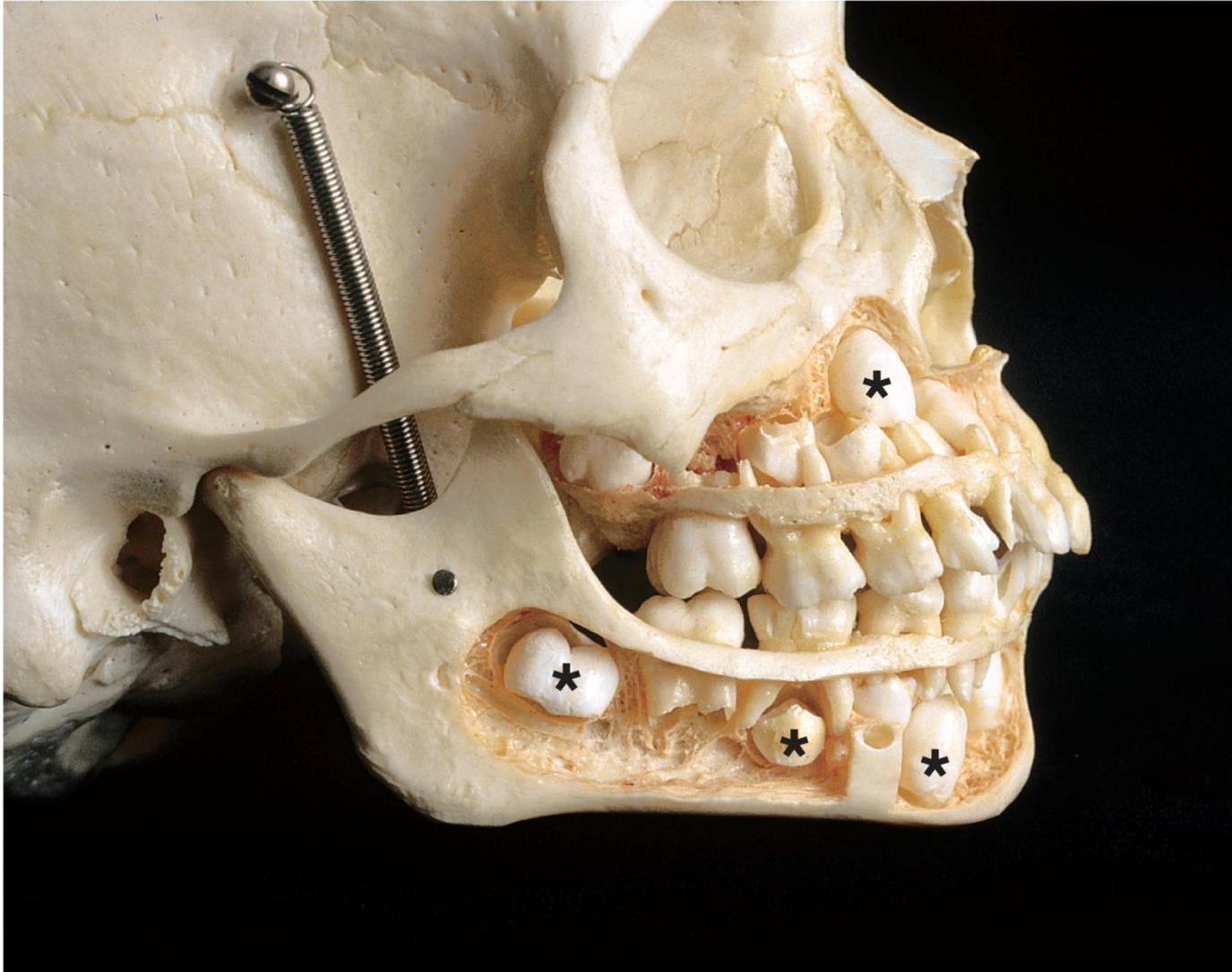


Figure 25.7

# Permanent and Deciduous Teeth

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Figure 25.8

# The Teeth

- **20 deciduous teeth (milk teeth or baby teeth)**
- **Teeth develop beneath gums and erupt in a predictable order**
  - Erupt from 6 to 30 months
  - Beginning with incisors
  - Between 6 and 25 years of age, are replaced by 32 permanent teeth
- **Third molars (wisdom teeth) erupt from age 17 to 25 years**
  - May be **impacted**: crowded against neighboring teeth and bone so they 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

# Tooth and Gum Disease

- **Calculus** in the gingival sulcus wedges the tooth and gum apart
  - Allows bacterial invasion of the sulcus
  - **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 digestive enzymes
  - First step in **mechanical digestion**
  - Food stimulates oral receptors that trigger an **involuntary chewing reflex**
  - **Tongue, buccinator, and orbicularis oris** manipulate food
  - **Masseter** and **temporalis** elevate the lower teeth to crush food
  - **Medial and lateral pterygoids, and masseters** swing teeth in side-to-side grinding action

# Saliva and the Salivary Glands

- **Saliva**

- Moistens mouth
- Begins starch and fat digestion
- Cleanses teeth
- Inhibits bacterial growth
- Dissolves molecules so they can stimulate the taste buds
- Moistens food and binds it together into bolus to aid in swallowing

# Saliva and the Salivary Glands

- **Saliva is a 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 food is swallowed
  - **Mucus:** binds and lubricates a mass of food and aids in swallowing
  - **Lysozyme:** enzyme that kills bacteria
  - **Immunoglobulin A (IgA):** an antibody that inhibits bacterial growth
  - **Electrolytes:** Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, phosphate, and bicarbonate
- **pH: 6.8 to 7.0**

# Saliva and the Salivary Glands

- **Intrinsic salivary glands**—small glands dispersed amid other oral tissues
  - **Lingual glands:** in the tongue; produce lingual lipase
  - **Labial glands:** inside of the lips
  - **Palatine glands:** roof of mouth
  - **Buccal glands:** inside of the cheek
  - All secrete saliva at a fairly constant rate

# Saliva and the Salivary Glands

- **Extrinsic salivary glands**—three pairs 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 gland:** located in the floor of the mouth
    - Has multiple ducts that empty posterior to the papilla of the submandibular duct

# The Extrinsic Salivary Glands

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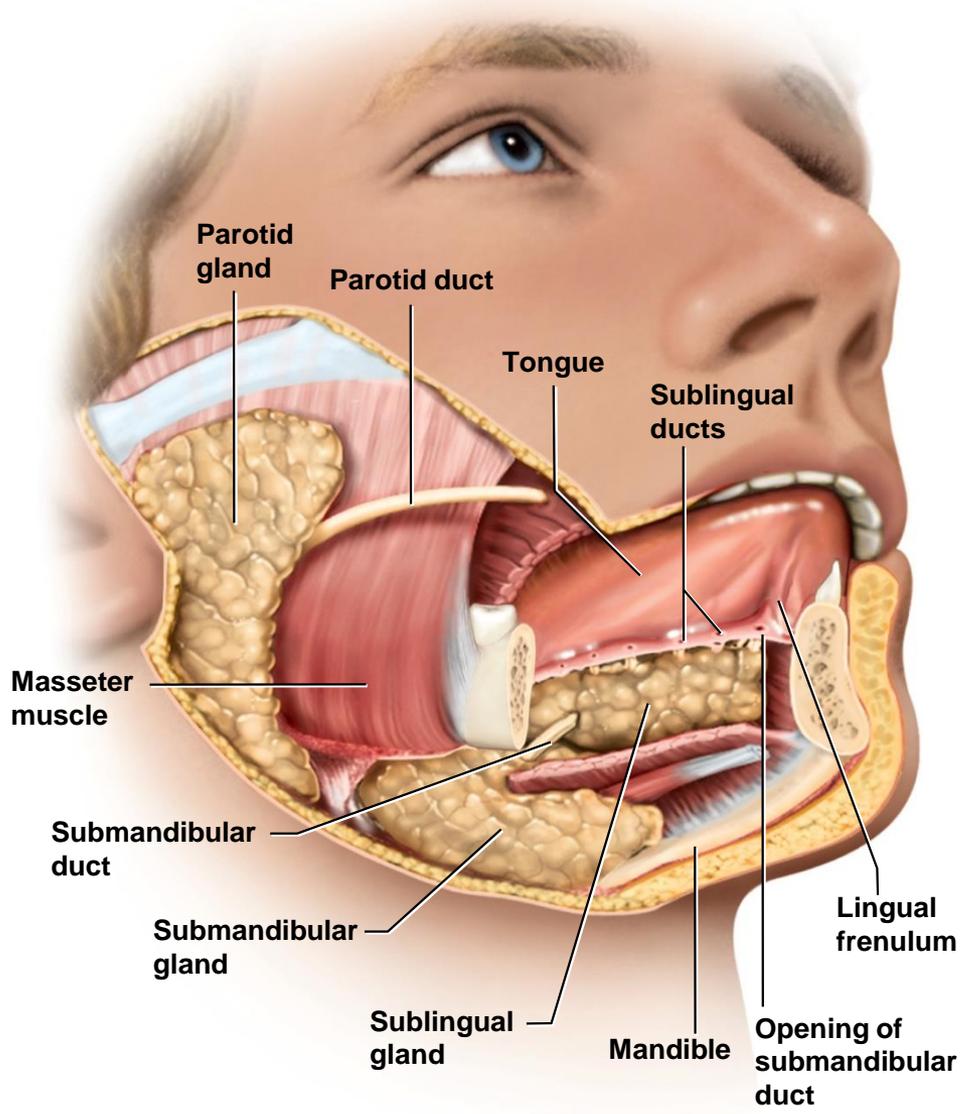
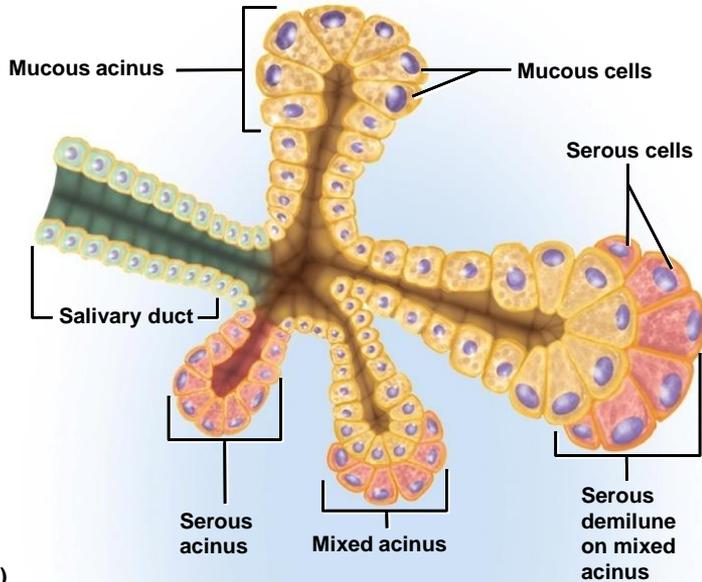


Figure 25.9

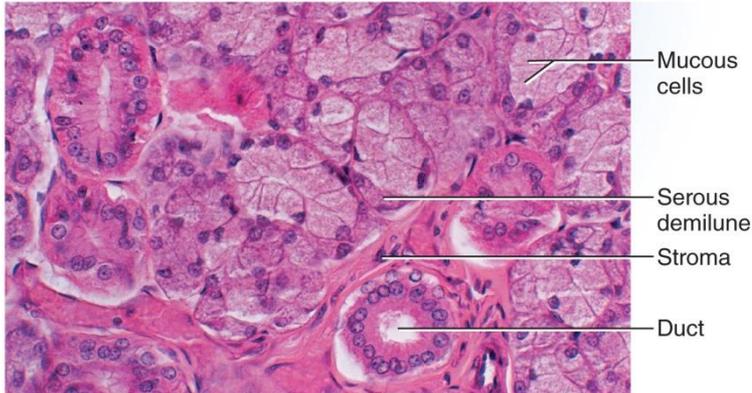
# Histology of Salivary Glands

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(a)

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(b)

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Figure 25.10a,b

- **Compound tubuloacinar glands**
  - Branched ducts ending in **acini**
- **Mucous cells** secrete mucus
- **Serous cells** secrete thin fluid rich in enzymes and electrolytes
- **Mixed acinus** has both mucous and serous cells

# Salivation

- **Extrinsic salivary glands secrete about 1 to 1.5 L of saliva per day**
- **Cells of acini** filter water and electrolytes from blood and add amylase, mucin, and lysozyme
- **Salivatory nuclei** in medulla oblongata and pons respond to signals generated by presence of food
  - Excited by tactile, pressure, and taste receptors
  - Salivatory nuclei receive input from **higher brain centers** as well
    - Odor, sight, thought of food stimulates salivation

# Salivation

## Salivatory nuclei (Continued)

- Send signals by way of autonomic fibers in the facial and glossopharyngeal nerves to the glands
  - **Parasympathetic** fibers stimulate the glands to produce an abundance of thin, enzyme-rich saliva
  - **Sympathetic** activity stimulates the glands to produce less, and thicker, saliva with more mucus
- **Bolus**—mass swallowed as a result of saliva binding food particles into a soft, slippery, easily swallowed mass

# The Pharynx

- **Pharynx**—muscular funnel connecting oral cavity to esophagus and nasal cavity to larynx
  - Digestive and respiratory tracts intersect
  - Has deep layer of longitudinal skeletal muscle
  - Has superficial layer of circular skeletal muscles that form **pharyngeal constrictors** (superior, middle, and inferior) that force food downward during swallowing
    - When not swallowing, the **inferior constrictor (upper esophageal shincter)** remains contracted to exclude air from the esophagus
    - Disappears at the time of death when the muscles relax, so it is a **physiological sphincter**, not an anatomical structure

# The Esophagus

- **Esophagus**—straight muscular tube 25 - 30 cm long
  - Begins at level between C6 and the cricoid cartilage
  - Extends from **pharynx** to **cardiac orifice** of stomach passing through **esophageal hiatus** in diaphragm
  - **Lower esophageal sphincter**: food pauses here because of constriction
    - Prevents stomach contents from regurgitating into the esophagus
    - Protects esophageal mucosa from erosive stomach acid
    - **Heartburn**—burning sensation produced by acid reflux into the esophagus

# The Esophagus

## (Continued)

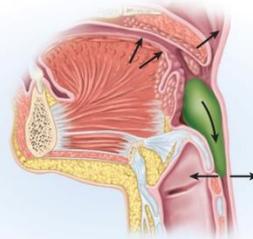
- **Nonkeratinized stratified squamous epithelium**
- **Esophageal glands** in submucosa secrete mucus
- Deeply folded into longitudinal ridges when empty
- Skeletal muscle in upper one-third, mix of muscle types in middle one-third, and only smooth muscle in bottom one-third
- Meets stomach at level of T7
- Covered with **adventitia**

# Swallowing

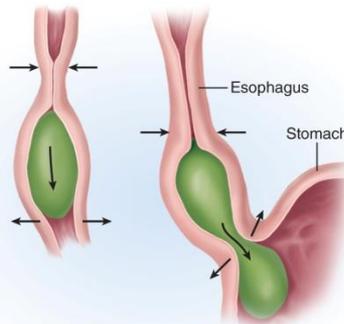
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1 **Oral phase.** The tongue forms a food bolus and pushes it into the laryngopharynx.



2 **Pharyngeal phase.** The palate, tongue, vocal cords, and epiglottis block the oral and nasal cavities and airway while pharyngeal constrictors push the bolus into the esophagus.



3 **Esophageal phase.** Peristalsis drives the bolus downward, and relaxation of the lower esophageal sphincter admits it into the stomach.

Figure 25.11

# Swallowing

- **Swallowing (deglutition)**—a complex action involving over 22 muscles in the mouth, pharynx, and esophagus
  - **Swallowing center:** pair of nuclei in medulla oblongata that coordinates swallowing
    - Communicates with muscles of the pharynx and esophagus by way of trigeminal, facial, glossopharyngeal, and hypoglossal nerves

# Swallowing

- **Swallowing occurs in three phases:** oral, pharyngeal, and esophageal
  - **Oral phase:** under voluntary control
    - Tongue collects food, presses it against palate forming bolus, and pushes it posteriorly
    - Food accumulates in oropharynx in front of epiglottis
    - Epiglottis tips posteriorly and food bolus slides around it and into laryngopharynx

# Swallowing

## (Continued)

- **Pharyngeal phase:** involuntary
  - Prevents food and drink from reentering mouth or entering the nasal cavity
  - Breathing is suspended
  - Infrahyoid muscles pull larynx up to meet epiglottis and cover laryngeal opening
  - Vocal cords adduct to close airway
  - Upper esophagus widens
  - Food bolus is driven downward by constriction of the upper, then middle, and finally the lower pharyngeal constrictors

# Swallowing

## (Continued)

- **Esophageal phase—peristalsis:** involuntary wave of muscular contraction that pushes the bolus ahead of it
  - When standing or sitting upright, food and liquid drops through esophagus by **gravity** faster than peristalsis can keep up with it
  - Peristalsis ensures you can swallow regardless of body position
  - Liquid reaches the stomach in 1 to 2 seconds; food bolus in 4 to 8 seconds
  - When it reaches lower end of the esophagus, the lower esophageal sphincter relaxes to let food pass into the stomach

# The Stomach

- **Expected Learning Outcomes**

- Describe the gross and microscopic anatomy of the stomach.
- State the function of each type of epithelial cell in the gastric mucosa.
- Identify the secretions of the stomach and state their functions.
- Explain how the stomach produces hydrochloric acid and pepsin.
- Describe the contractile responses of the stomach to food.
- Describe the three phases of gastric function and how gastric activity is activated and inhibited.

# The Stomach

- **Stomach**—a muscular sac in upper left abdominal cavity immediately inferior to the diaphragm
  - Primarily functions as a **food storage organ**
    - Internal volume of about **50 mL when empty**
    - **1.0 to 1.5 L after a typical meal**
    - Up to **4 L when extremely full** – can extend nearly as far as the pelvis

# The Stomach

- **Mechanically breaks up food, liquefies it, 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

- **Stomach—J-shaped**
  - Relatively vertical in tall people, horizontal in short people
  - **Divided into four regions**
    - **Cardiac region (cardia)**—small area within about 3 cm of the cardiac orifice
    - **Fundic region (fundus)**—dome-shaped portion superior to esophageal attachment
    - **Body (corpus)**—makes up the greatest part of stomach
    - **Pyloric region**—narrower pouch at the inferior end
      - Subdivided into the funnel-like **antrum**
      - Narrower **pyloric canal** that terminates at pylorus
      - **Pylorus**: narrow passage to duodenum
      - **Pyloric (gastroduodenal) sphincter**—regulates the passage of chyme into the duodenum

# Gross Anatomy

- Stomach has **greater** and **lesser curvatures**
  - Curvatures are the margins of the stomach
  - Greater curvature is about 40 cm long, on inferolateral surface
    - Greater omentum hangs from greater curvature
  - Lesser curvature is about 10 cm long, on superomedial margin
    - Lesser omentum connects lesser curvature of stomach to liver

# Gross Anatomy

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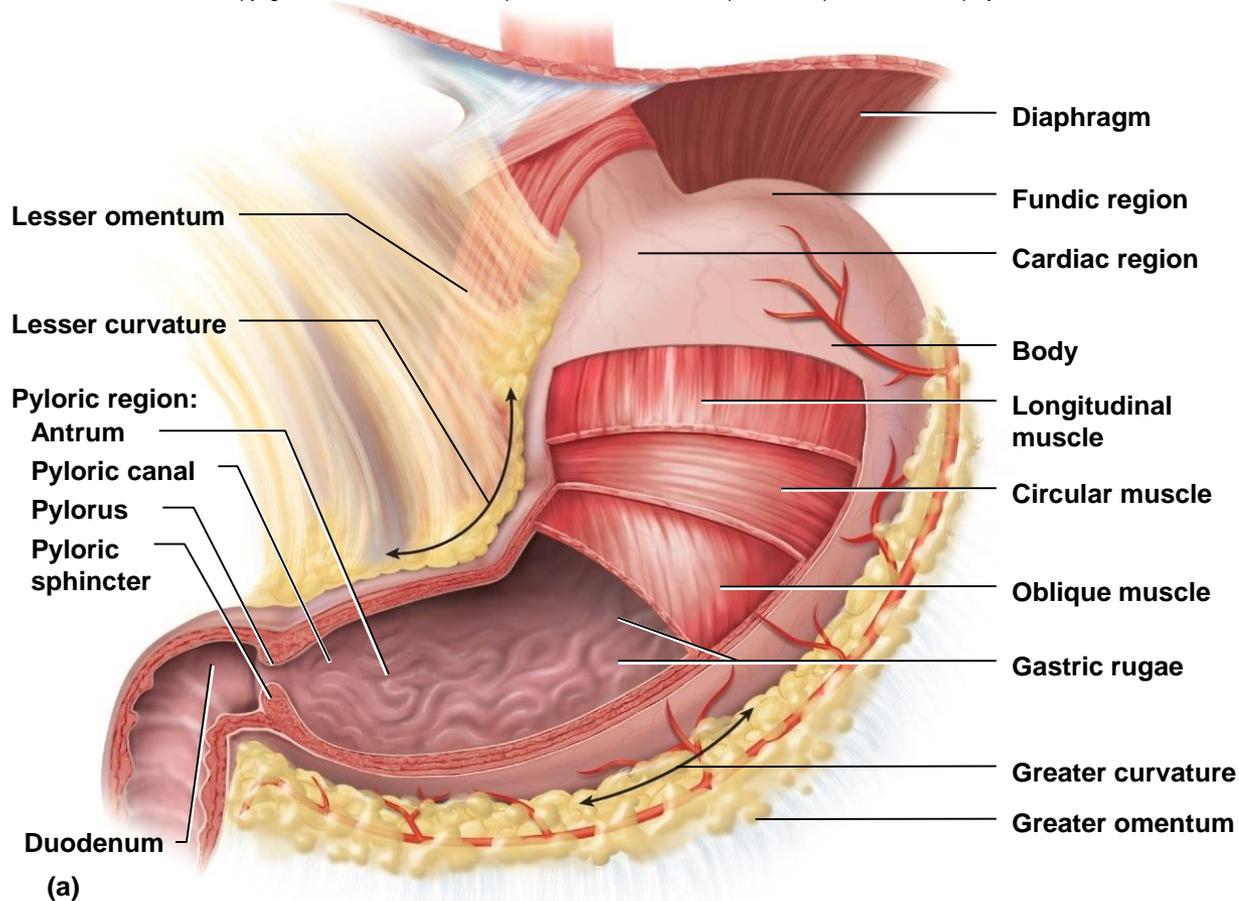
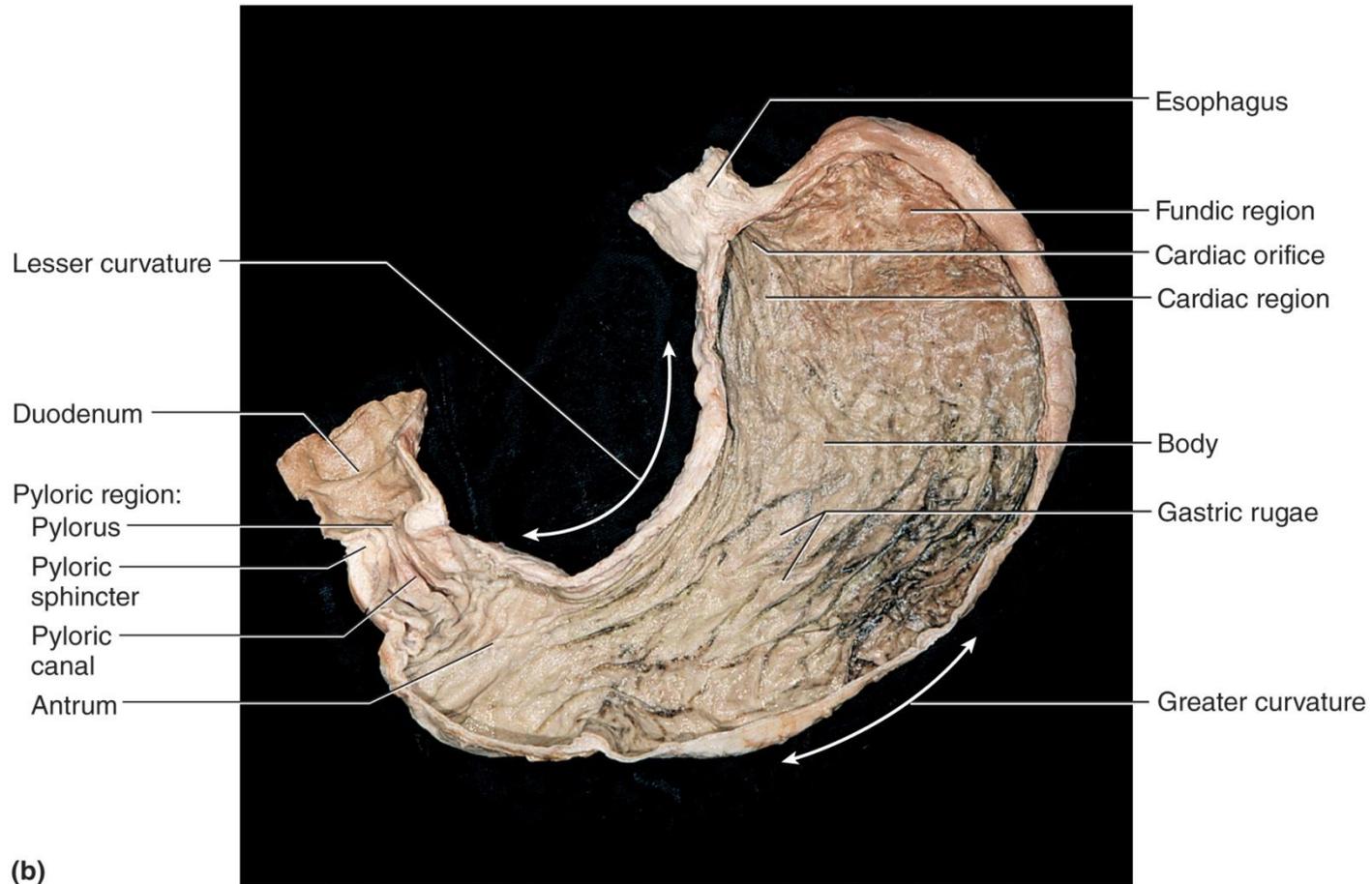


Figure 25.12a

- **Note the bulge of fundus, narrowing of pyloric region, thickness of pyloric sphincter, and greater and lesser curvatures**

# Gross Anatomy

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b: ©McGraw-Hill Education/Rebecca Gray/Don Kincaid, dissections

Figure 25.12b

- Longitudinal wrinkles called **rugae** can be seen in empty stomach wall

# Innervation and Circulation

- **Stomach receives:**
  - **Parasympathetic fibers** from vagus
  - **Sympathetic fibers** from celiac ganglia
- Supplied with blood by branches of the **celiac trunk**
- Blood drained from stomach and intestines enters **hepatic portal circulation** and is filtered through liver before returning to heart

# Microscopic Anatomy

- Stomach has a **simple columnar epithelium** covers mucosa
  - Apical regions of its surface cells are filled with **mucin**
  - Mucin swells with water and becomes **mucus** after it is secreted
- Mucosa and submucosa are flat when stomach is full, but form longitudinal wrinkles called **gastric rugae** when empty
- **Muscularis externa** has three layers (instead of the two seen elsewhere)
  - Outer longitudinal, middle circular, and inner oblique layers

# Microscopic Anatomy

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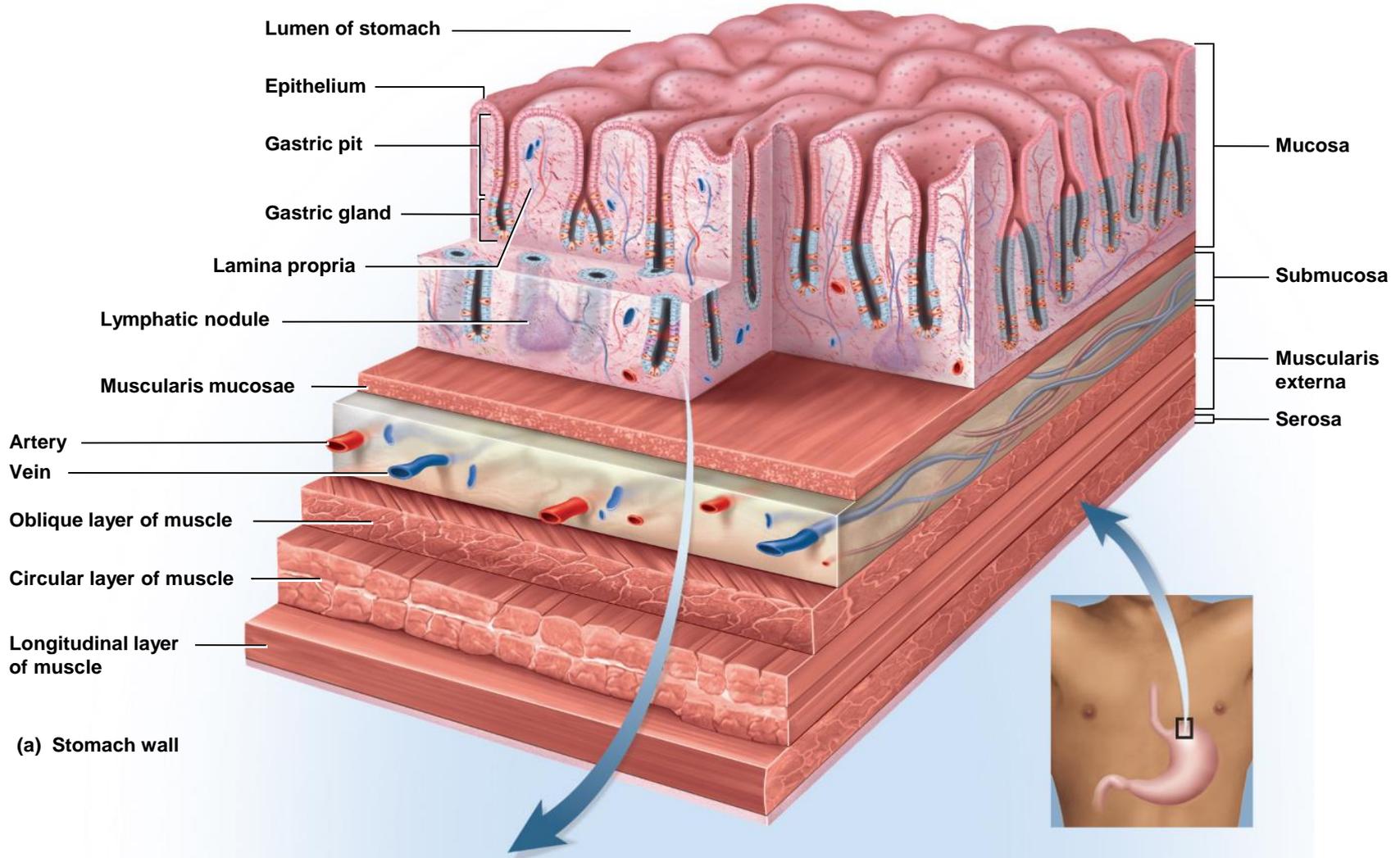


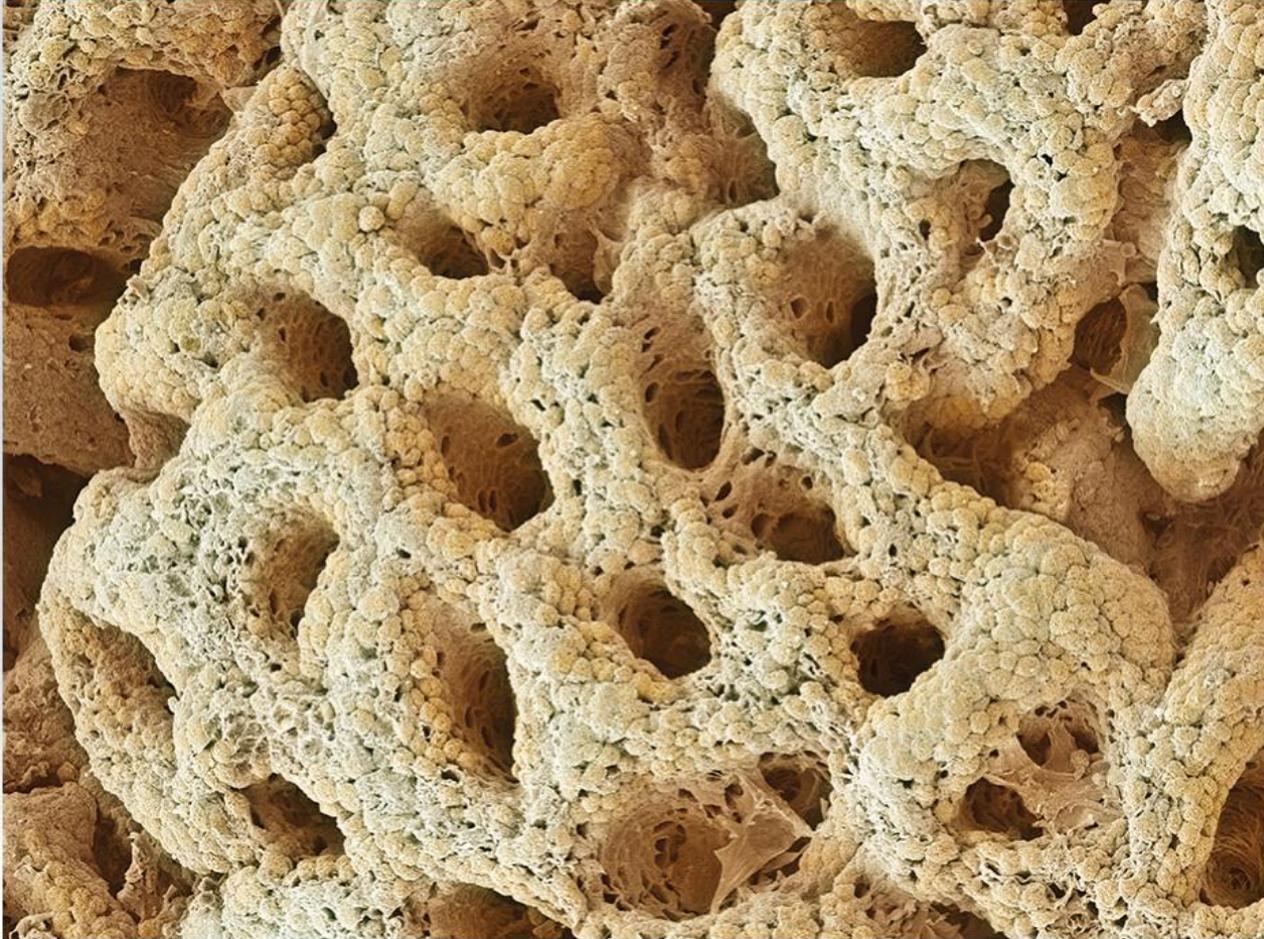
Figure 25.13a

# Microscopic Anatomy

- **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

# Gastric Pits

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**(d) Gastric pit**

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Figure 25.13d

# Microscopic Anatomy

- **Mucous cells**—secrete mucus
  - Predominate in cardiac and pyloric glands
  - In gastric glands, called **mucous neck cells** since they are concentrated at the neck of the gland
- **Regenerative (stem) cells**—found in base of pit and in neck of gland
  - Divide rapidly and produce continual supply of new cells to replace cells that die
- **Parietal cells**—found mostly in the upper half of the gland
  - Secrete **hydrochloric acid (HCl)**, **intrinsic factor**, and a hunger hormone called **ghrelin**

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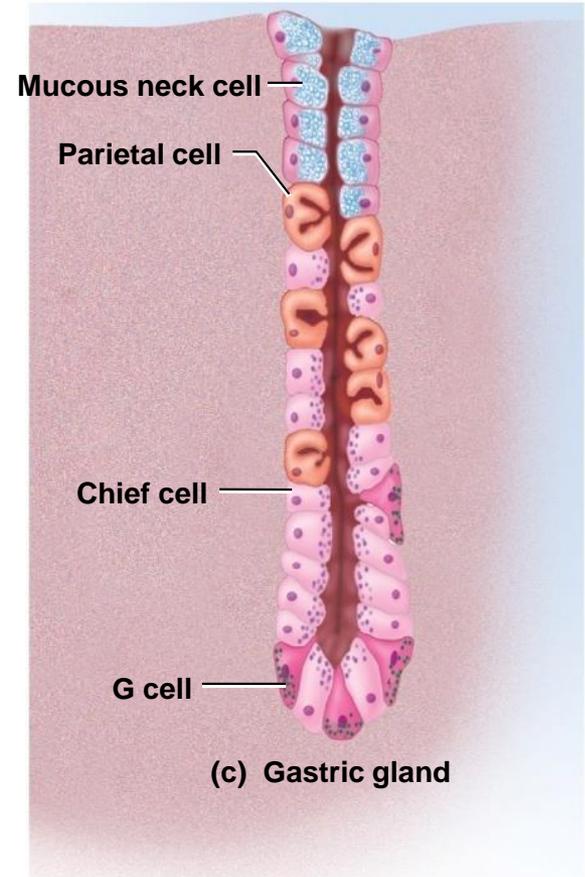


Figure 25.13c

# Microscopic Anatomy

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- **Chief cells**—most numerous
  - Secrete **gastric lipase** and **pepsinogen**
  - Dominate lower half of gastric glands
  - Absent from pyloric and cardiac glands
- **Enteroendocrine cells**—concentrated in lower end of gland
  - Secrete **hormones** and **paracrine messengers** that regulate digestion

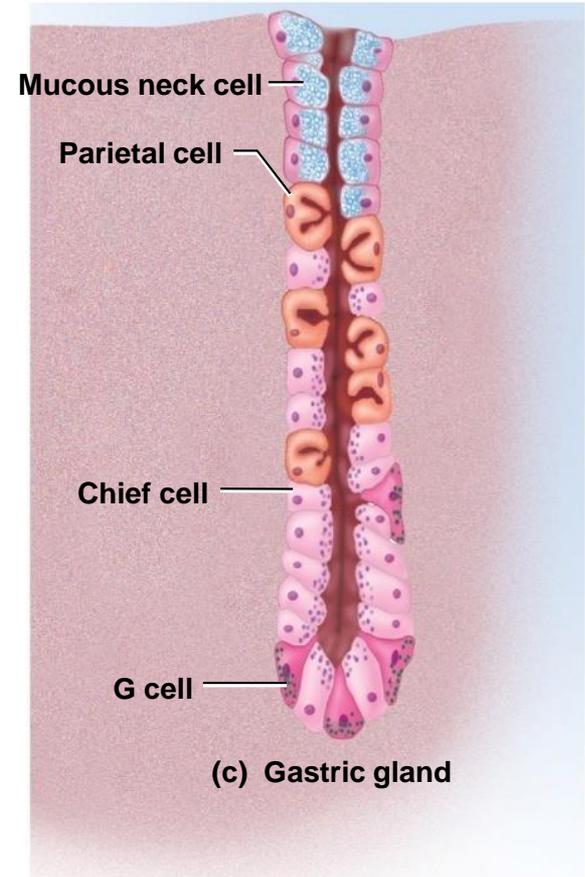


Figure 25.13c

# Pyloric and Gastric Glands

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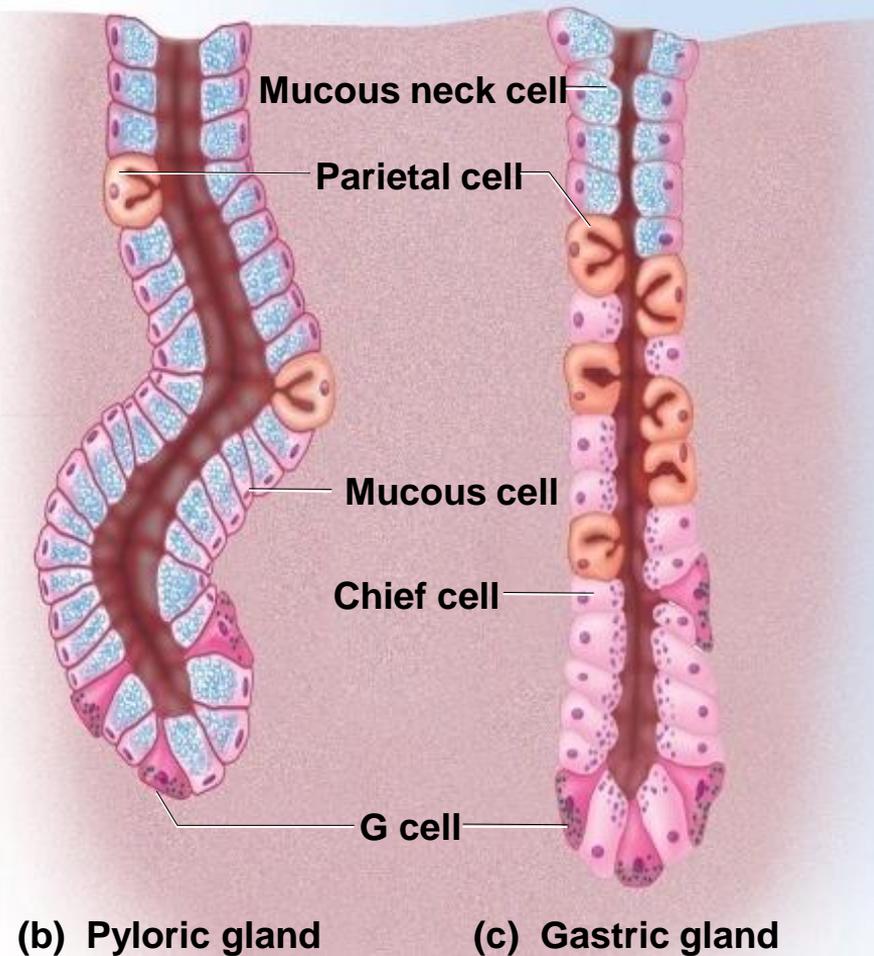


Figure 25.13b,c

# Gastric Secretions

- **Gastric juice**—2 to 3 L per day produced by the gastric glands
- **Mainly a mixture of water, hydrochloric acid, and pepsin**

# Hydrochloric Acid

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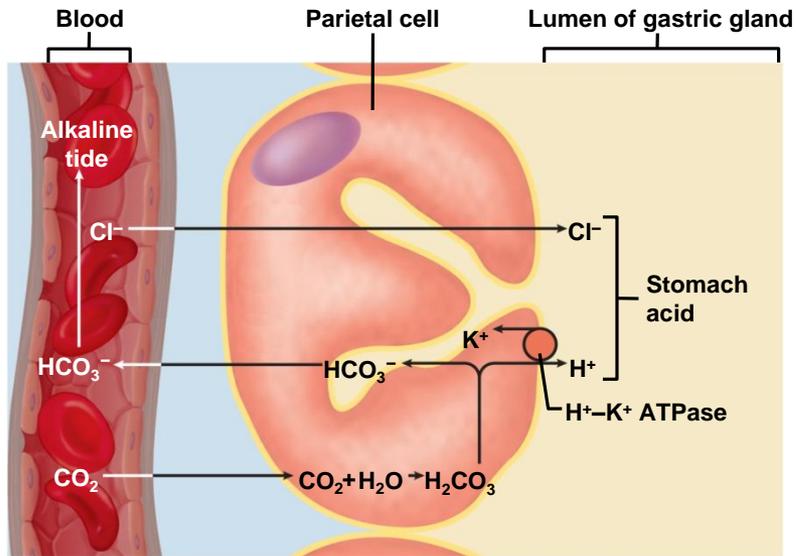


Figure 25.14

- **Gastric juice** has a high concentration of **hydrochloric acid (HCl)**
  - pH as low as 0.8

# Hydrochloric Acid

- **Parietal cells produce HCl and contain carbonic anhydrase (CAH)**



- **H<sup>+</sup>** is pumped into gastric gland lumen by **H<sup>+</sup>–K<sup>+</sup> ATPase** pump
  - Antiporter uses ATP to pump H<sup>+</sup> out and K<sup>+</sup> in
- **HCO<sub>3</sub><sup>-</sup>** exchanged for **Cl<sup>-</sup> (chloride shift)** from blood plasma
  - **Cl<sup>-</sup> (chloride ion)** pumped into the lumen of gastric gland to join H<sup>+</sup> forming **HCl**
  - Elevated HCO<sub>3</sub><sup>-</sup> (bicarbonate ion) in blood causes **alkaline tide** (high pH of blood leaving stomach) when digestion is occurring

# Hydrochloric Acid

- **HCl** activates **pepsin** and **lingual lipase**
- Breaks up connective tissues and plant cell walls
  - Helps liquefy food to form **chyme**
- Converts ingested **ferric ions ( $\text{Fe}^{3+}$ )** to **ferrous ions ( $\text{Fe}^{2+}$ )**
  - $\text{Fe}^{2+}$  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 **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 peptides
  - Protein digestion is completed in the small intestine

# The Production and Action of Pepsin

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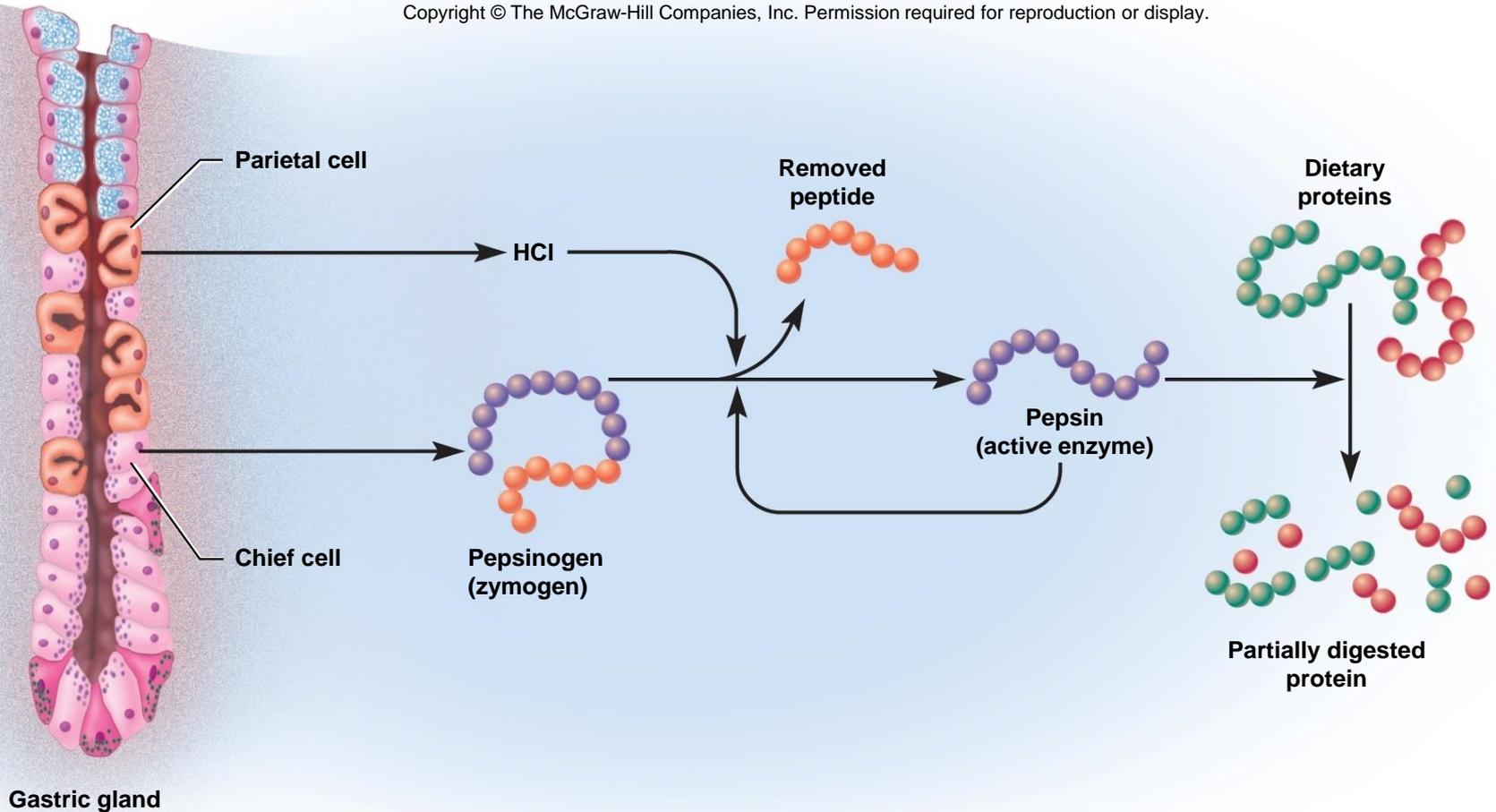


Figure 25.15

# Gastric Lipase

- **Gastric lipase**—produced by **chief cells**
- **Gastric lipase** and **lingual lipase** play a minor role in digesting dietary fats
  - Digests 10% to 15% of dietary fats in the stomach
  - Rest digested in the small intestine

# Intrinsic Factor

- **Intrinsic factor**—a glycoprotein secreted by **parietal cells**
- Essential to absorption of **vitamin B<sub>12</sub>** by the small intestine
  - Binds vitamin B<sub>12</sub> and then intestinal cells absorb this complex by **receptor-mediated endocytosis**

# Intrinsic Factor

- **Vitamin B<sub>12</sub> is needed to synthesize hemoglobin**
  - Deficiency causes **anemia**
- **Secretion of intrinsic factor is the only indispensable function of the stomach**
  - Digestion can continue if stomach is removed (gastrectomy), but B<sub>12</sub> supplements will be needed

# Chemical Messengers

- **Gastric and pyloric glands have a variety of cells that produce a variety of chemical messengers**
  - Most are **hormones** that enter blood and stimulate distant cells
  - Some are **paracrine** secretions that stimulate neighboring cells
  - Several are **peptides** produced in both the digestive tract and the central nervous system: **gut–brain peptides**
    - Substance P, vasoactive intestinal peptide (VIP), secretin, gastric inhibitory peptide (GIP), cholecystokinin, and neuropeptide Y (NPY)

# Gastric Motility

- **Swallowing center of medulla oblongata signals stomach to relax**
- Vagus nerve relays message from medulla and activates a **receptive-relaxation response** in stomach
  - Resists stretching briefly, but relaxes to hold more food

# Gastric Motility

- Soon stomach shows a **rhythm of peristaltic contractions** controlled by **pacemaker cells** in longitudinal layer of muscularis externa
  - A ring of constriction every 20 seconds
  - Becomes stronger contraction at pyloric region
  - After 30 minutes or so these contractions become quite strong
    - They churn the food, mix it with gastric juice, and promote its physical breakup and chemical digestion

# Gastric Motility

## (Continued)

- Thick muscularis of **antrum** acts as a strong pump that breaks up semidigested food and prepares it for intestine
- Antral contractions come in waves that churn and break up the chyme into small particles
- Only about 3 mL of chyme is squirted into the duodenum at a time; this small amount allows duodenum to:
  - Neutralize the stomach acid
  - Digest nutrients little by little
- If duodenum is overfilled it inhibits gastric motility
- Typical meal emptied from stomach in **4 hours**
  - Less time if the meal is more liquid
  - As long as 6 hours for a high-fat meal

# Vomiting

- **Vomiting**—forceful ejection of stomach and intestinal contents (chyme) from the mouth
- **Emetic center** in the medulla oblongata integrates multiple muscle actions
- **Vomiting induced by:**
  - Overstretching of the stomach or duodenum
  - Chemical irritants such as alcohol and bacterial toxins
  - Visceral trauma
  - Intense pain or psychological and sensory stimuli

# Vomiting

- Vomiting is usually preceded by **nausea** and **retching**
- **Retching**—thoracic expansion and abdominal contraction creates a pressure difference that dilates the esophagus
  - Lower esophageal sphincter relaxes while the stomach and duodenum contract spasmodically
  - Chyme enters esophagus but then drops back to the stomach as the stomach relaxes
  - Does not get past the upper esophageal sphincter
  - Usually accompanied by tachycardia, profuse salivation, and sweating

# Vomiting

- **Vomiting**—occurs when abdominal contractions and rising thoracic pressure force the upper esophageal sphincter to open
  - Esophagus and body of the stomach relax
  - Chyme is driven out of the stomach and mouth by **strong abdominal contractions** combined with **reverse peristalsis** of gastric antrum and duodenum
- **Projectile vomiting**—sudden vomiting with no prior nausea or retching
  - Common in infants after feeding

# Vomiting

- **Chronic vomiting**

- Results in dangerous fluid, electrolyte, and acid–base imbalances
- **Bulimia**: eating disorder; hydrochloric acid in vomit causes tooth enamel to erode
- **Aspiration (inhalation)** of acid is very destructive to the respiratory tract
- Surgical anesthesia may induce nausea and must be preceded by **fasting** until the stomach and small intestine are empty

# Digestion and Absorption

- **Salivary and gastric enzymes partially digest protein and lesser amounts of starch and fat in the stomach**
- **Most digestion and nearly all absorption occur after the chyme has passed into the small intestine**

# Digestion and Absorption

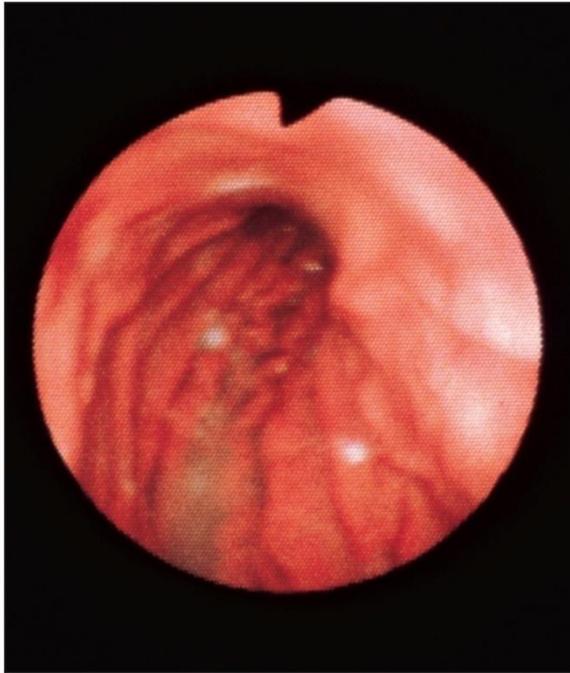
- **Stomach does not absorb any significant amount of nutrients**
  - But does absorb aspirin and some lipid-soluble drugs
- **Alcohol** is absorbed mainly by small intestine
  - Intoxicating effects depend partly on how rapidly the stomach is emptied

# Protection of the Stomach

- Stomach is **protected in three ways** from the harsh acidic and enzymatic environment it creates
  - **Mucous coat:** thick, highly alkaline mucus resists action of acid and enzymes
  - **Tight junctions** between epithelial cells prevent gastric juice from seeping between them and digesting deeper tissue
  - **Epithelial cell replacement:** cells live only 3 to 6 days
    - Sloughed off into the chyme and digested with food
    - Replaced rapidly by cell division in gastric pits
- Breakdown of these protective measures can result in **inflammation** and **peptic ulcer**

# Peptic Ulcer

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(a) Normal



(b) Peptic ulcer

a,b: ©CNR/SPL/Science Source

Figure 25.16a,b

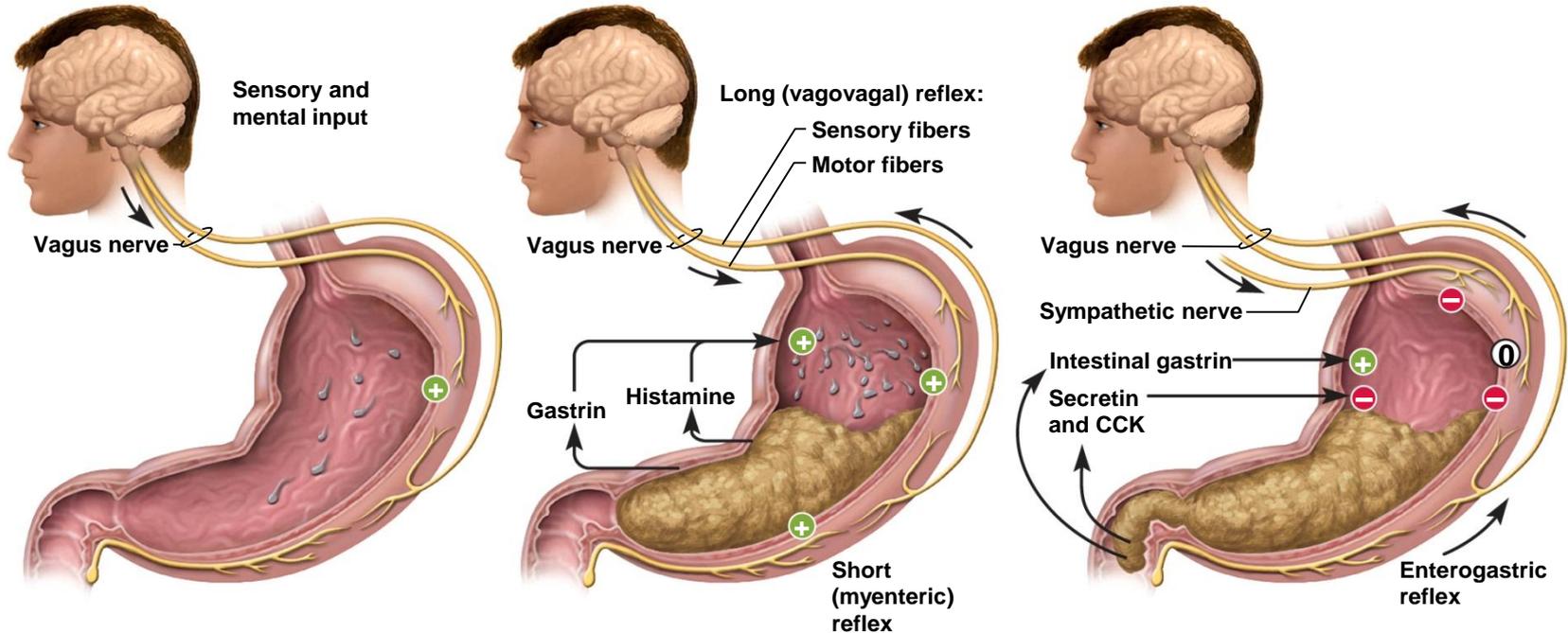
- **Gastritis, inflammation of the stomach, can lead to a peptic ulcer as pepsin and hydrochloric acid erode the stomach wall.**
- **Most ulcers are caused by acid-resistant bacteria *Helicobacter pylori*, that can be treated with antibiotics and Pepto-Bismol.**

# Regulation of Gastric Function

- **Nervous and endocrine systems** collaborate
  - Increase gastric secretion and motility when food is eaten; suppress 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 overlap and can occur simultaneously**

# Regulation of Gastric Function

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

Key	
+	Stimulation
-	Inhibition
0	Reduced or no effect

- 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 secretion.

- 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.

Figure 25.17

# Regulation of Gastric Function

- **Cephalic phase**

- **Stomach responds** to sight, smell, taste, or thought of food
- Sensory and mental inputs converge on **hypothalamus**
- Hypothalamus relays signals to **medulla oblongata**
- **Vagus nerve** fibers from medulla stimulate the **enteric nervous system** of stomach, stimulating gastric secretion
- 40% of stomach's acid secretion occurs in cephalic phase

# Regulation of Gastric Function

- **Gastric phase**

- Period in which swallowed food and semi-digested protein activate gastric activity
  - Two-thirds of gastric secretion and one-half of acid secretion occur in this phase
- **Ingested food stimulates gastric activity in two ways**
  - **By stretching the stomach**
    - Activates **short reflex** mediated through **myenteric plexus**
    - Activates **long reflex** mediated through the **vagus nerves and the brainstem**
  - **By increasing the pH** of its contents

# Regulation of Gastric Function

## (Continued)

- **Gastric secretion is stimulated by three chemicals**
  - **Acetylcholine (ACh)**—secreted by parasympathetic nerve fibers of both reflexes
  - **Histamine**—a paracrine secretion from enteroendocrine cells in the gastric glands
  - **Gastrin**—a hormone produced by the enteroendocrine **G cells** in pyloric glands

# Regulation of Gastric Function

- **Intestinal phase**

- 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 duodenum accentuates vagovagal reflex that stimulates stomach
  - Peptides and amino acids in chyme stimulate **G cells** of duodenum to secrete more **gastrin**, further stimulating stomach
  - Soon acids and fats trigger **enterogastric reflex**—duodenum sends **inhibitory signals** to stomach by way of enteric nervous system
  - Duodenum also signals medulla to: **inhibit vagal nuclei** (reducing vagal stimulation of stomach) and **stimulate sympathetic neurons** (sending inhibitory signals to the stomach)

# Regulation of Gastric Function

## Intestinal phase (Continued)

- Chyme also stimulates **duodenal enteroendocrine cells** to release **secretin** and **cholecystokinin**
  - They stimulate the pancreas and gallbladder
  - Also suppress gastric secretion
- Gastrin secretion declines and **pyloric sphincter** contracts tightly to limit chyme entering duodenum
  - Gives duodenum time to work on chyme
- Enteroendocrine cells also secrete **glucose-dependent insulinotropic peptide (GIP)** originally called gastrin-inhibiting peptide
  - Stimulates insulin secretion in preparation for processing nutrients about to be absorbed by small intestine

# Feedback Control of Gastric Secretion

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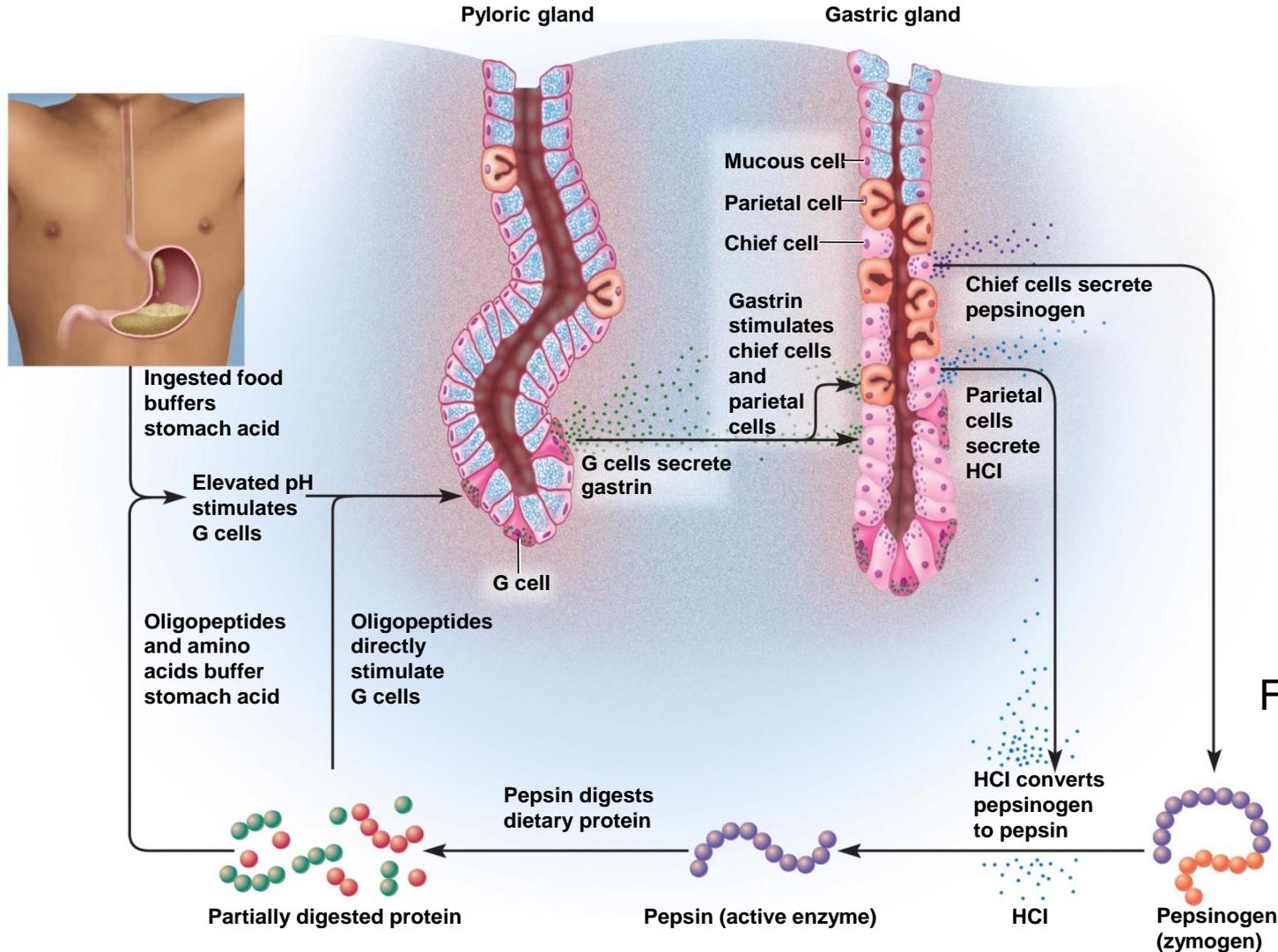


Figure 25.18

# The Liver, Gallbladder, and Pancreas

- **Expected Learning Outcomes**

- Describe the gross and microscopic anatomy of the liver, gallbladder, bile duct system, and pancreas.
- Describe the digestive secretions and functions of the liver, gallbladder, and pancreas.
- Explain how hormones regulate secretion by the liver and pancreas.

# The Liver, Gallbladder, and Pancreas

- **Small intestine** receives chyme from stomach and **secretions from liver and pancreas**
  - These secretions enter digestive tract near the junction of stomach and small intestine
  - These secretions are important to the digestive process of the small intestine

# The Liver

- **Liver**—reddish brown gland located immediately inferior to the diaphragm
- **The body's largest gland**
  - Weighs about 1.4 kg (3 lb)
- **Variety of functions**
  - **Secretes bile** which contributes to digestion

# Gross Anatomy of Liver

- Four lobes—**right, left, quadrate, and caudate**
  - **Falciform ligament** separates left and right lobes
    - Sheet of mesentery that suspends the liver from the diaphragm
  - **Round ligament (ligamentum teres)**—fibrous remnant of umbilical vein
    - Carries blood from umbilical cord to liver of the fetus
- From inferior view, squarish **quadrate lobe** next to the **gallbladder** and a tail-like **caudate lobe** posterior to that

# Gross Anatomy of Liver

- **Porta hepatis**—irregular opening between quadrate and caudate lobes
  - Point of **entry** for **hepatic portal vein** and **proper hepatic artery**
  - Point of **exit** for the **bile passages**
  - All travel in **lesser omentum**
- **Gallbladder**—adheres to a depression on the inferior surface of the liver, between right and quadrate lobes
- **Bare area** on superior surface where it attaches to diaphragm

# Gross Anatomy of the Liver

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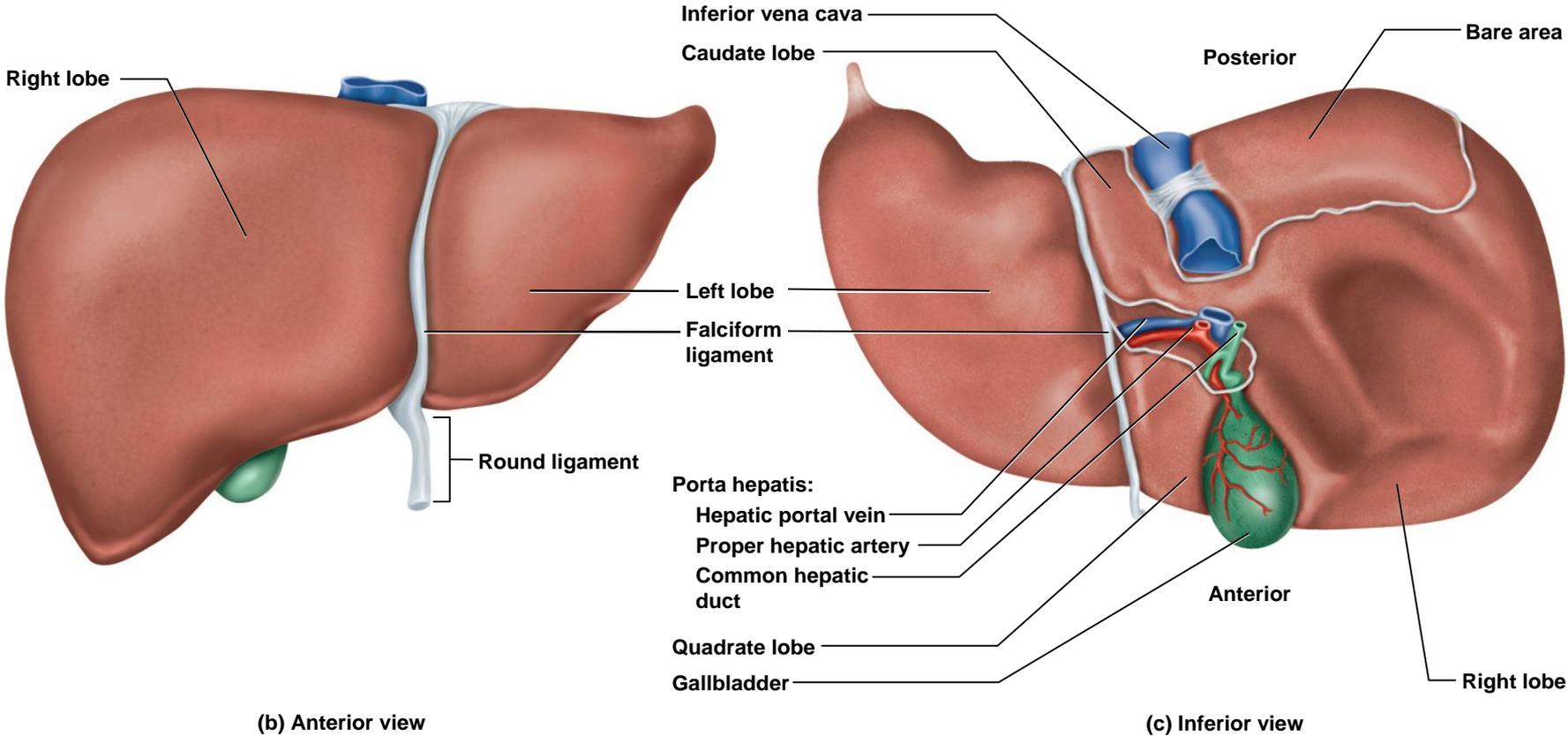


Figure 25.19b,c

# Microscopic Anatomy of the Liver

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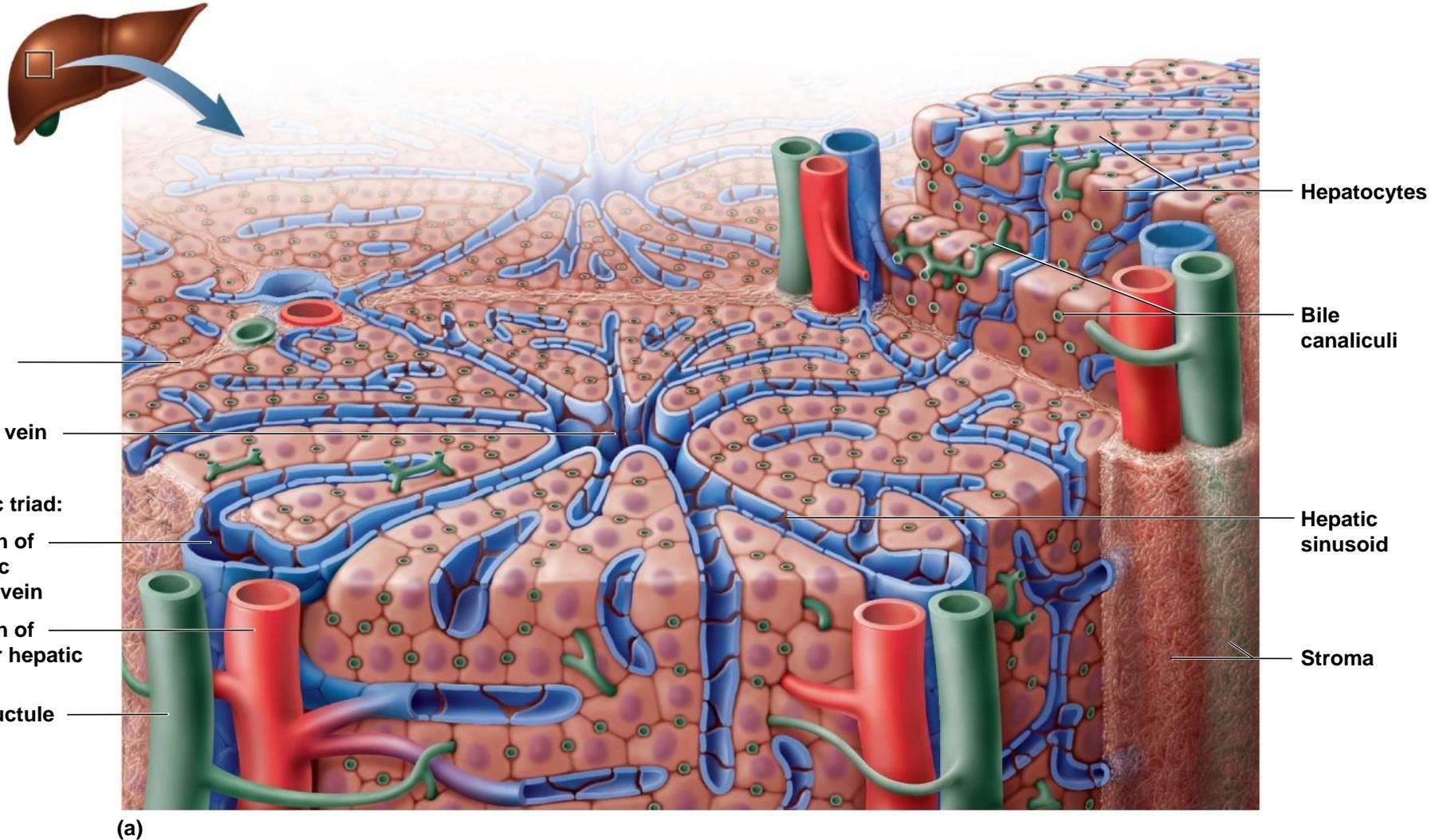


Figure 25.20a

# Microscopic Anatomy of the Liver

- **Hepatic lobules**—tiny cylinders that fill the interior of the liver
  - About 2 mm long and 1 mm in diameter
  - **Central vein:** passes 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

# Microscopic Anatomy of the Liver

## (Continued)

- 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

# Microscopic Anatomy of the Liver

- **Hepatocytes**

- After a meal, hepatocytes **absorb from the blood:** glucose, amino acids, iron, vitamins, and other nutrients for metabolism or storage
- Between meals, hepatocytes **break down stored glycogen and release glucose** into the blood
- **Remove and degrade:** hormones, toxins, bile pigments, and drugs
- **Secrete into the blood:** albumin, lipoproteins, clotting factors, angiotensinogen, and other products

# Microscopic Anatomy of the Liver

- **Hepatic lobules** are separated by a sparse connective tissue called stroma
- Between lobules is a **hepatic triad of two vessels and a bile ductule**
  - Other vessel: branch of hepatic portal vein
  - One vessel: branch of hepatic artery proper
  - Both vessels supply blood to sinusoids which receive a mixture of nutrient-laden venous blood from the intestines, and freshly oxygenated arterial blood from the celiac trunk

# Microscopic Anatomy of the Liver

- After filtering through the sinusoids, blood is collected in the **central vein**
- Ultimately flows into **the right and left hepatic veins**
- Blood leaves the liver at its superior surface and immediately drains into the **inferior vena cava**

# Microscopic Anatomy of the Liver

- **Bile canaliculi**—narrow channels into which the liver secretes bile
  - Bile passes into bile **ductules** of the triads
  - Ultimately into the **right and left hepatic ducts**
  - **Common hepatic duct:** formed from convergence of right and left hepatic ducts on inferior side of the liver
  - **Cystic duct** coming from gallbladder joins common hepatic duct
  - **Bile duct:** formed from union of cystic and common hepatic ducts
    - Descends through lesser omentum toward the duodenum

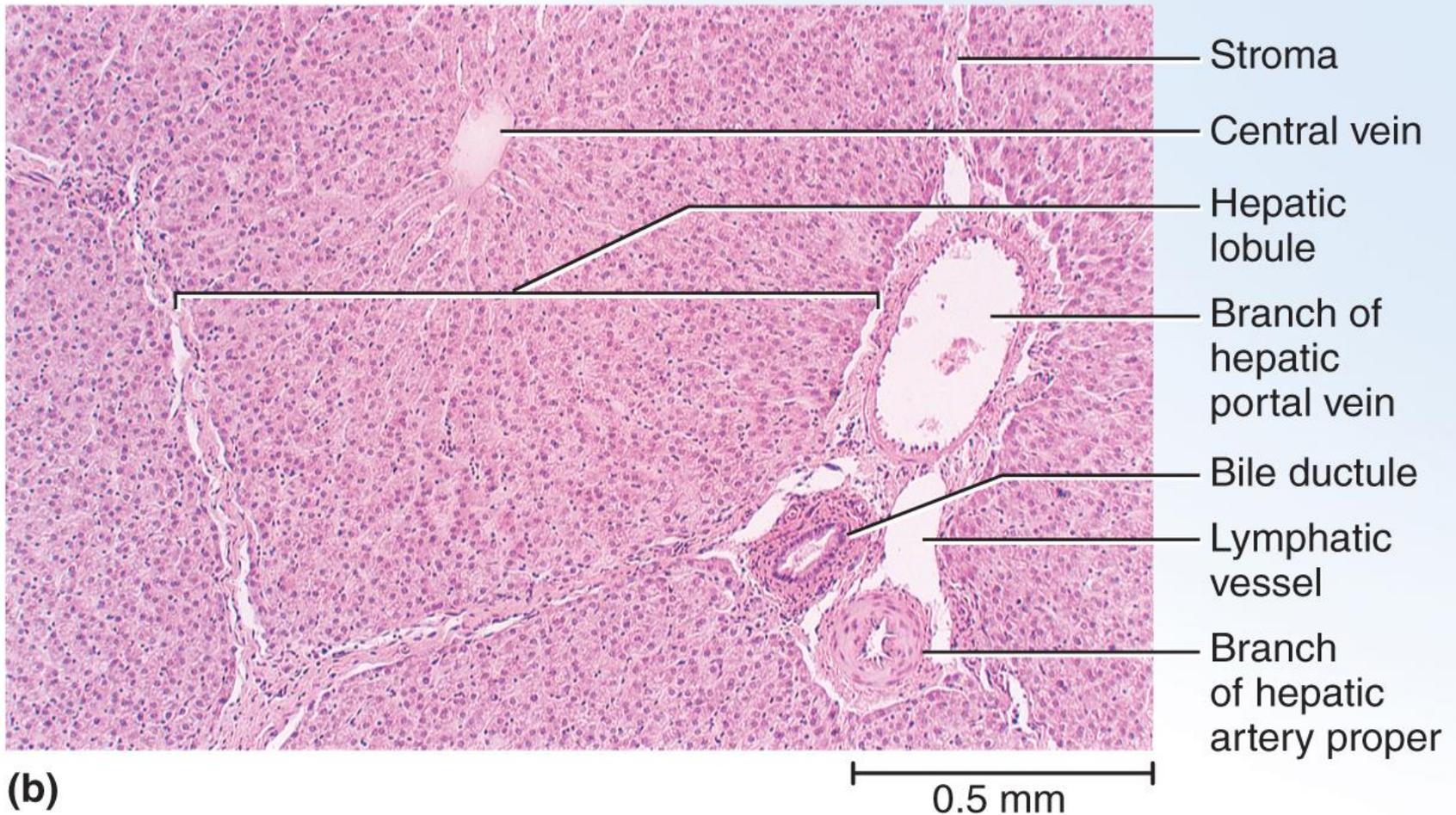
# Microscopic Anatomy of the Liver

## (Continued)

- Near duodenum, **bile duct joins duct of pancreas**
- Forms expanded chamber: **hepatopancreatic ampulla**
  - Terminates in a fold of tissue—**major duodenal papilla** on duodenal wall
- Major duodenal papilla contains muscular **hepatopancreatic sphincter (sphincter of Oddi)**
  - Regulates passage of bile and pancreatic juice into duodenum
  - Between meals, sphincter closes and prevents release of bile into the intestines

# Microscopic Anatomy of the Liver

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Figure 25.20b

# Gross Anatomy of the Gallbladder, Pancreas, and Bile Passages

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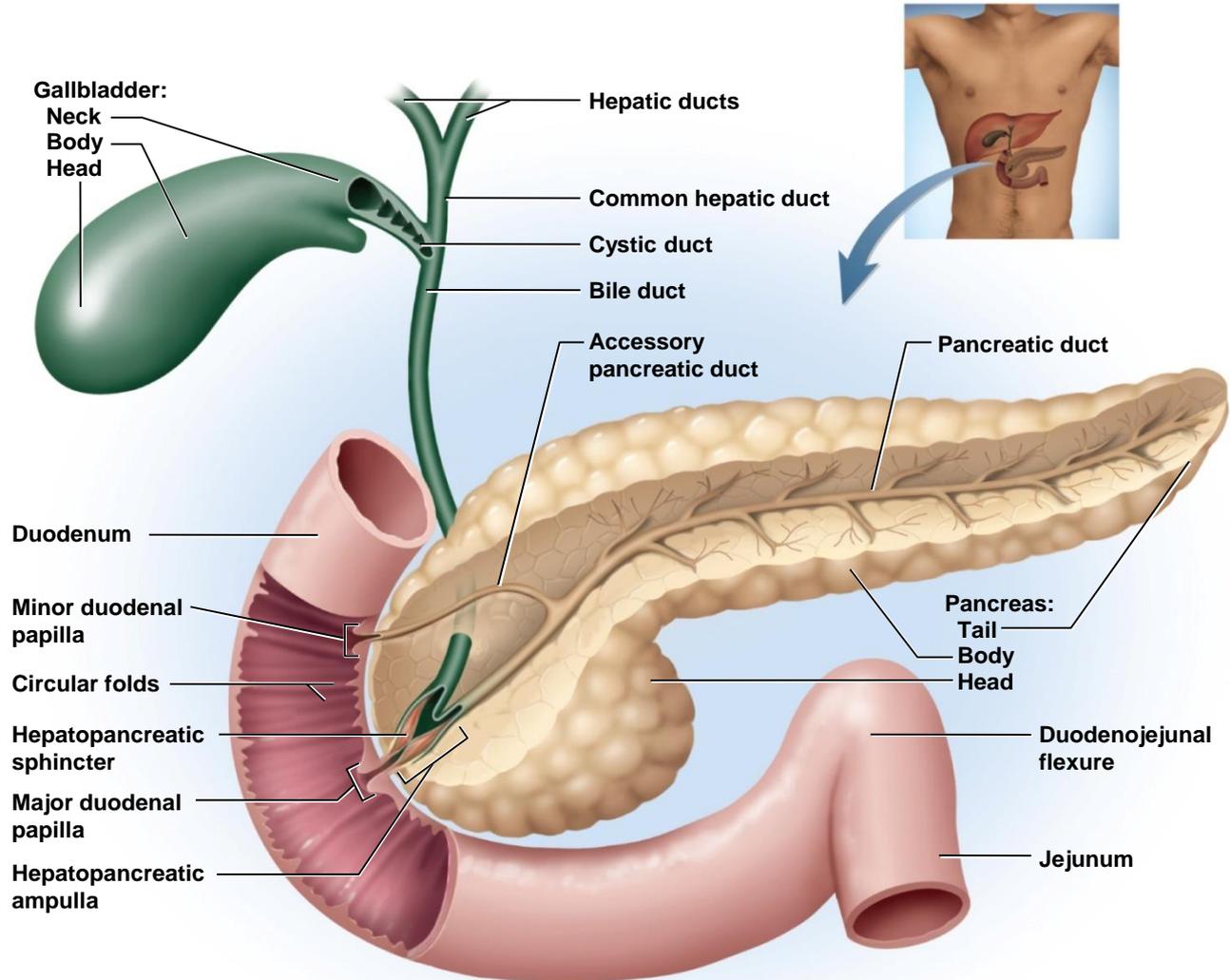


Figure 25.21

# The Gallbladder and Bile

- **Gallbladder**—a pear-shaped sac on underside of liver
  - Serves to **store and concentrate bile** by absorbing water and electrolytes
  - About 10 cm long
  - Internally lined by highly folded mucosa with **simple columnar epithelium**
  - **Head (fundus)** usually projects slightly beyond inferior margin of liver
  - **Neck (cervix)** leads into the **cystic duct**

# The Gallbladder and Bile

- **Bile**—yellow-green fluid containing minerals, cholesterol, neutral fats, phospholipids, bile pigments, and bile acids
  - **Bilirubin**: principal pigment derived from the **decomposition of hemoglobin**
  - Bacteria in large intestine metabolize **bilirubin to urobilinogen**
    - Responsible for the **brown color of feces**
  - **Bile acids (bile salts)**: steroids synthesized from cholesterol
    - **Bile acids** and **lecithin**, a phospholipid, aid in fat digestion and absorption
  - **Gallstones** may form if bile becomes excessively concentrated with wastes

# The Gallbladder and Bile

## (Continued)

- Bile gets to the gallbladder by first filling the bile duct then overflowing into the gallbladder
- Liver secretes about **500 to 1,000 mL of bile daily**
- **80% of bile acids are reabsorbed** in the ileum and returned to the liver
  - Hepatocytes absorb and resecrete them
  - **Enterohepatic circulation**—route of secretion, reabsorption, and resecretion of bile acids two or more times during digestion of an average meal
- **20% of the bile acids are excreted in the feces**
  - Body's only way of eliminating excess cholesterol
  - Liver synthesizes new bile acids from cholesterol to replace those lost in feces

# The Gallbladder and Bile

- **Gallstones (biliary calculi)**—hard masses in either the gallbladder or bile ducts
  - Composed of cholesterol, calcium carbonate, and bilirubin
- **Cholelithiasis**—formation of gallstones
  - Most common in obese women over 40 - excess cholesterol
- **Painful obstruction of ducts**
  - Result in jaundice (yellowing of skin), poor fat digestion, and impaired absorption of fat-soluble vitamins
- **Lithotripsy**—use of ultrasonic vibration to pulverize stones without surgery

# The Pancreas

- **Pancreas**—spongy retroperitoneal gland posterior to greater curvature of stomach
  - Measures 12 to 15 cm long, and 2.5 cm thick
  - Has a **head** encircled by duodenum, a **body** (midportion), and a **tail** on the left
  - Both an endocrine and exocrine gland
    - **Endocrine portion**—pancreatic islets that secrete insulin and glucagon
      - Concentrated in the tail of the gland
    - **Exocrine portion**—99% of pancreas that secretes 1,200 to 1,500 mL of **pancreatic juice** per day
      - **Secretory acini** release their secretion into small ducts that converge on the main **pancreatic duct**

# The Pancreas

## Pancreas (Continued)

- **Pancreatic duct** runs lengthwise through middle of the gland
  - Joins the bile duct at the **hepatopancreatic ampulla**
  - **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
  - Opens independently into the duodenum
  - **Bypasses the sphincter** and allows pancreatic juice to be released into duodenum even when bile is not

# The Pancreas

## (Continued)

- **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

# The Pancreas

- **Pancreatic zymogens are:**
  - **Trypsinogen**
    - Secreted into intestinal lumen
    - Converted to trypsin by enterokinase that is 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

# The Pancreas

- **Other pancreatic enzymes**
  - **Pancreatic amylase:** digests starch
  - **Pancreatic lipase:** digests fat
  - **Ribonuclease and deoxyribonuclease:** digest RNA and DNA respectively

# Microscopic Anatomy of the Pancreas

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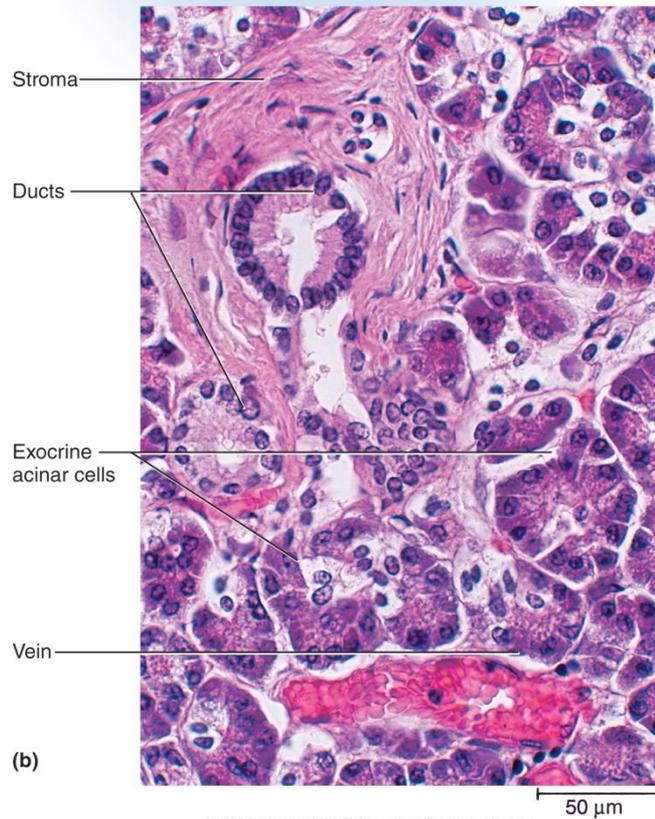
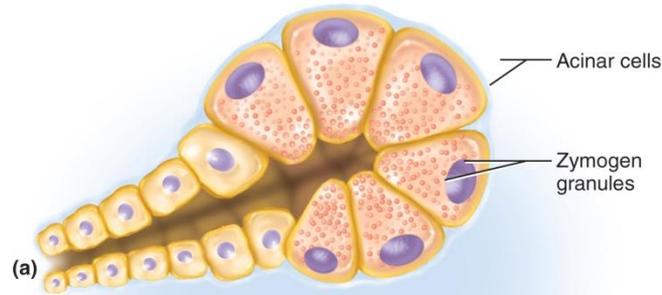


Figure 25.22a,b

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# The Activation of Pancreatic Enzymes in the Small Intestine

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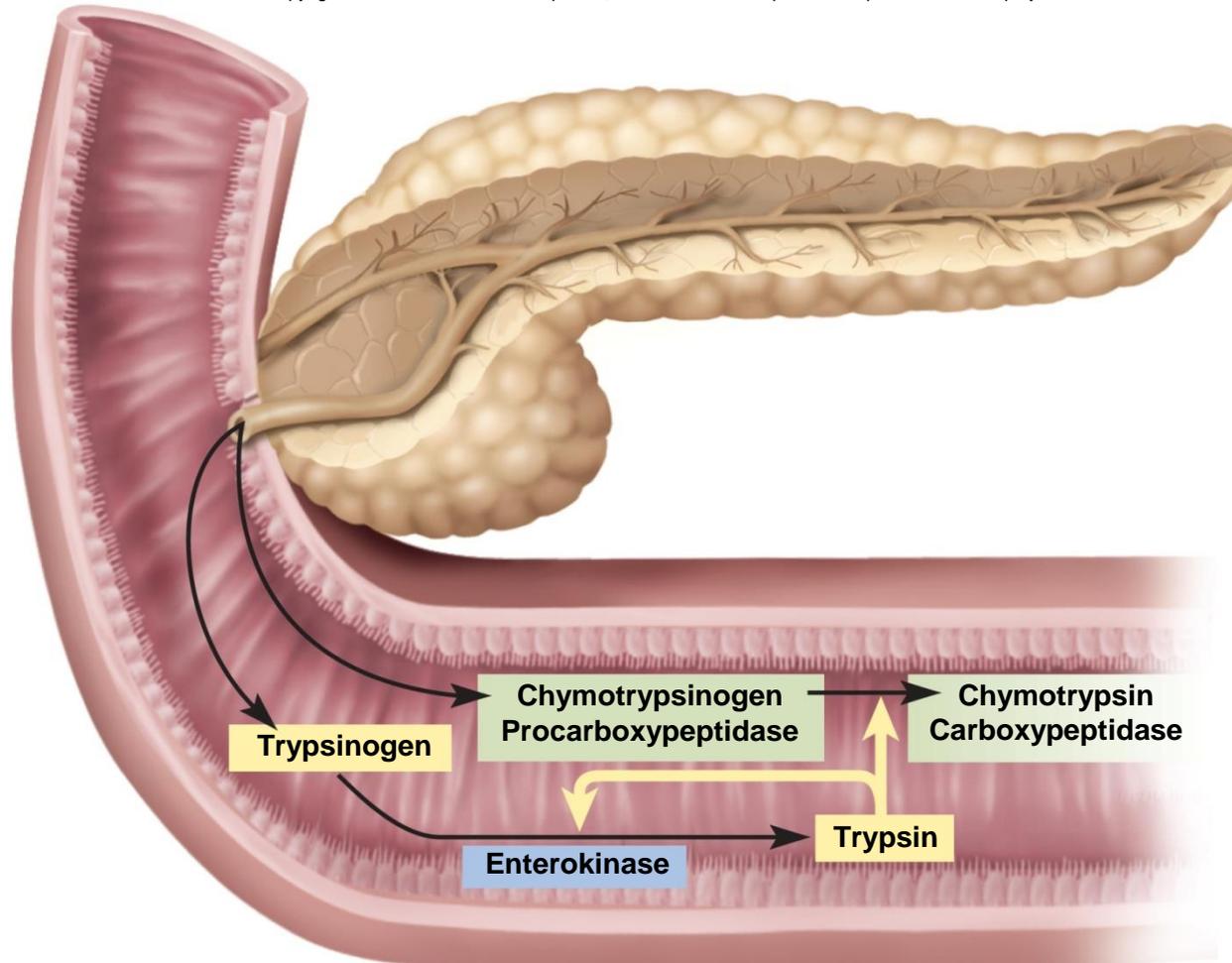


Figure 25.23

# Regulation of Secretion

- **Three stimuli** are chiefly responsible for the release of **pancreatic juice and bile:** acetylcholine, cholecystokinin, and secretin
  - **Acetylcholine (ACh):** from vagus and enteric nerves
    - Stimulates acini to secrete enzymes during cephalic phase of gastric control even before food is swallowed
      - Enzymes remain in acini and ducts until chyme enters the duodenum

# Regulation of Secretion

## (Continued)

- **Cholecystokinin (CCK):** secreted by mucosa of duodenum in response to arrival of fats in small intestine
  - Stimulates pancreatic acini to **secrete enzymes**
  - Strongly stimulates gallbladder
  - Induces contractions of gallbladder and relaxation of hepatopancreatic sphincter to discharge bile into duodenum
- **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**
  - Raises pH to the level required for activity of the pancreatic and intestinal digestive enzymes

# The Small Intestine

- **Expected Learning Outcomes**

- Describe the gross and microscopic anatomy of the small intestine.
- State how the mucosa of the small intestine differs from that of the stomach, and explain the functional significance of the differences.
- Define *contact digestion* and describe where it occurs.
- Describe the types of movement that occur in the small intestine.

# The Small Intestine

- **Nearly all chemical digestion and nutrient absorption occurs in the small intestine**
- **The longest part of the digestive tract**
  - About 5 m long in a living person
  - Up to 8 m long in a cadaver - no muscle tone
- **“Small” intestine refers to the diameter—not length**
  - Diameter is about 2.5 cm (1 in.)

# The Small Intestine

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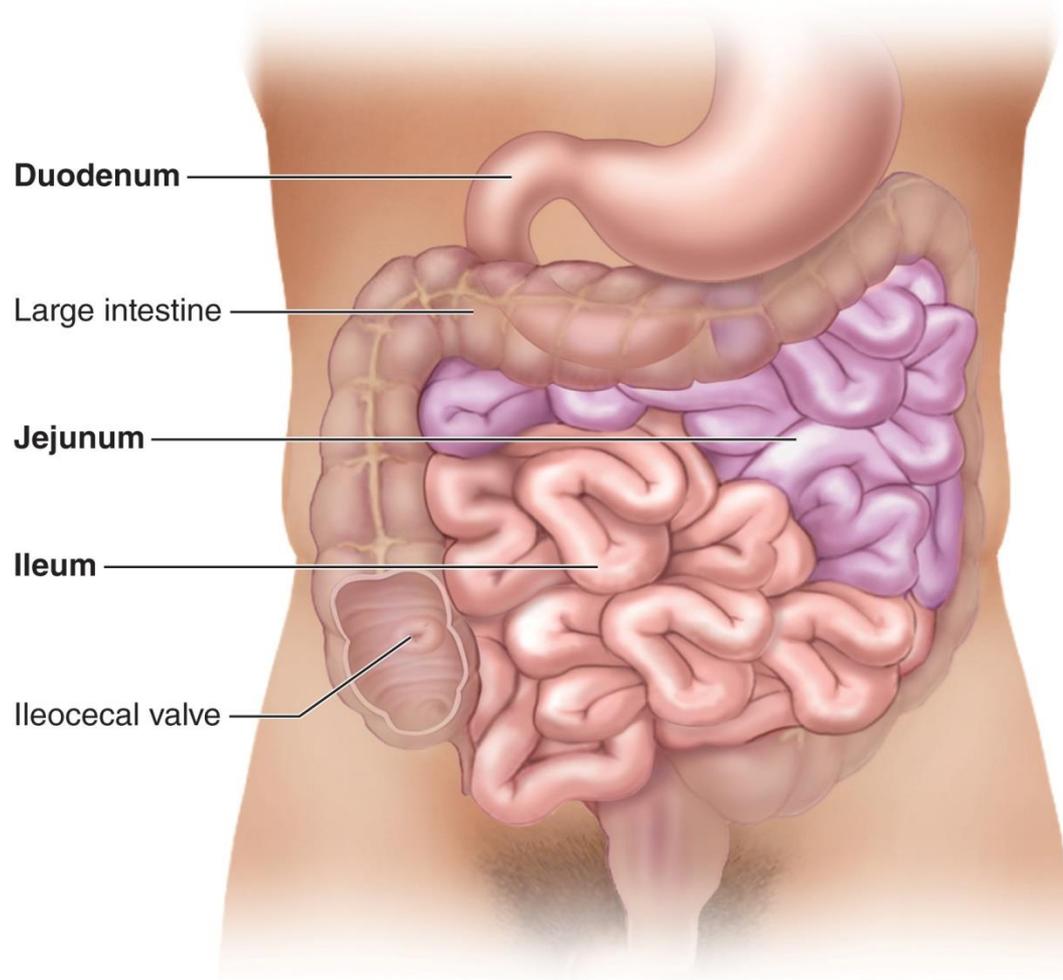


Figure 25.24

# Gross Anatomy

- **Small intestine**—coiled mass filling most of the abdominal cavity inferior to stomach and liver
- **Small intestine divided into three regions:** duodenum, jejunum, and ileum
  - **Duodenum:** first 25 cm (10 in.)
    - Begins at **pyloric valve**
      - **Major and minor duodenal papilla** distal to pyloric valve
      - Receives **major and minor pancreatic ducts** respectively
    - Arches around **head of the pancreas**
    - Ends at a sharp bend called the **duodenojejunal flexure**

# Gross Anatomy

## Small intestine regions

### Duodenum (Continued)

- Most is **retroperitoneal**
- Receives stomach contents, pancreatic juice, and bile
- Stomach acid is neutralized here
- Fats are **physically broken up (emulsified)** by bile acids
- **Pepsin** is inactivated by increased pH
- **Pancreatic enzymes** perform chemical digestion

# Gross Anatomy

- **Small intestine regions (Continued)**
  - **Jejunum:** first 40% of small intestine beyond duodenum
    - Roughly 1.0 to 1.7 m in a living person
    - Has large, tall, closely spaced circular folds
    - Its wall is relatively thick and muscular
    - Especially rich blood supply which gives it a red color
    - **Most digestion and nutrient absorption occurs here**

# Gross Anatomy

## Small intestine regions (Continued)

- **Ileum**: forms last 60% of the postduodenal small intestine
  - About 1.6 to 2.7 m
  - Thinner, less muscular, less vascular, and paler pink color
  - **Peyer patches**—prominent lymphatic nodules in clusters on the side opposite the mesenteric attachment
    - Visible to naked eye; become larger near large intestine
  - **Ileocecal junction**—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
- Both jejunum and ileum are **intraperitoneal** and covered with **serosa**

# Microscopic Anatomy

- Small intestine tissues designed for nutrient **digestion** and **absorption**
  - Lumen lined with **simple columnar epithelium**
  - **Muscularis externa** is noted for a thick inner circular layer and a thinner outer longitudinal layer
  - **Large internal surface area** - great length and **three types of internal folds** or projections
    - **Circular folds (plicae circulares)**—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

- **Circular folds (plicae circulares)**—largest folds of intestinal wall
  - Up to 10 mm high
  - Involve only mucosa and submucosa
  - Occur from duodenum to middle of ileum
    - Relatively small and sparse in ileum; not found in distal half, as most nutrient absorption is completed by this point
  - Cause chyme flow in spiral path causing more contact with mucosa
  - Promote more thorough mixing and nutrient absorption

# Microscopic Anatomy

- **Villi**—finger-like projections 0.5 to 1 mm tall
  - Make mucosa look fuzzy
  - Villus covered with two types of epithelial cells
    - **Absorptive cells (enterocytes)**
    - **Goblet cells**—secrete mucus
  - Epithelia joined by tight junctions that prevent digestive enzymes from seeping between them
  - Core of villus filled with areolar tissue of lamina propria
    - Contains arteriole, capillaries, venule, and lymphatic capillary called a **lacteal**

# Microscopic Anatomy

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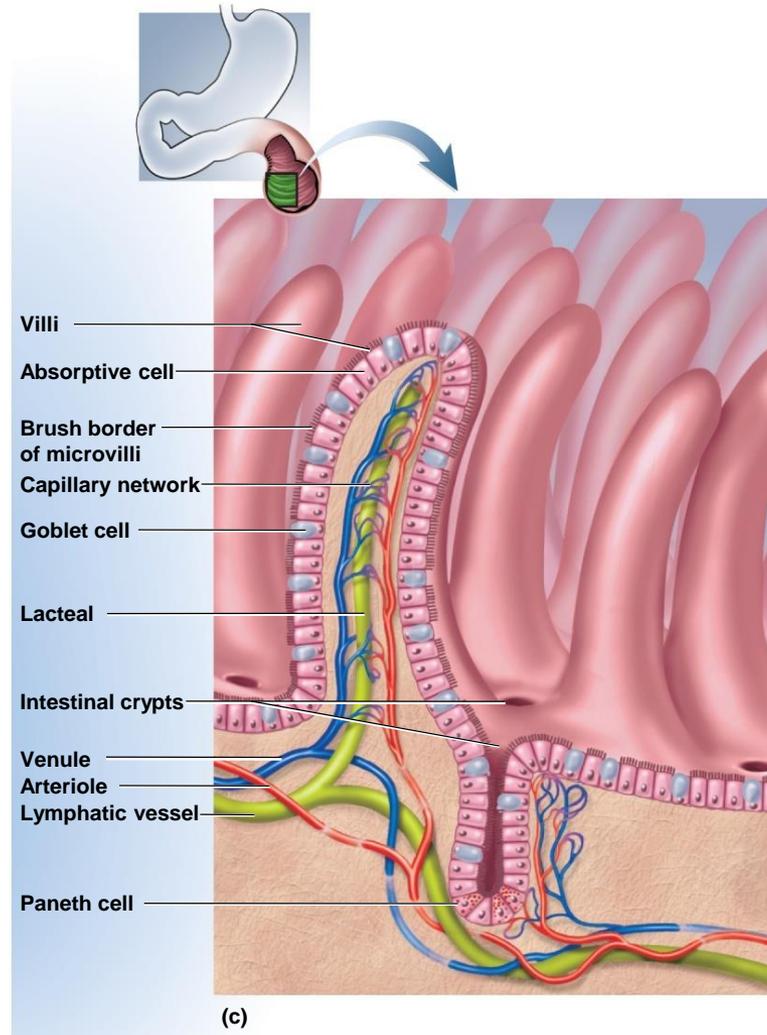


Figure 25.25c

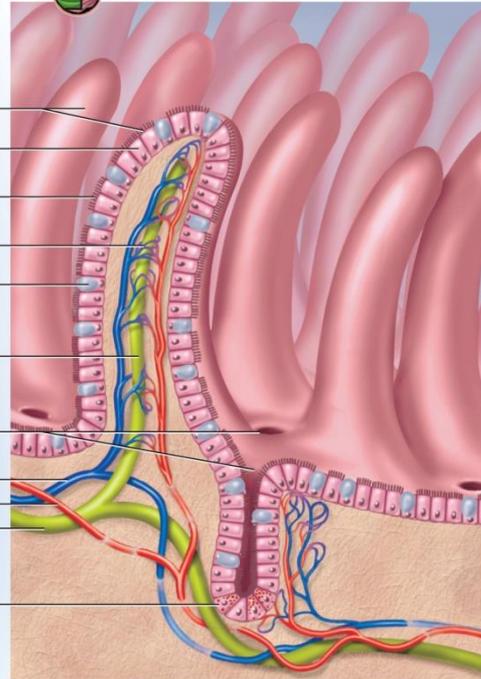
# Microscopic Anatomy

- **Microvilli**—form a fuzzy **brush border** on apical surface of each absorptive cell
  - About 1  $\mu\text{m}$  high
  - Increases absorptive surface area
- **Brush border enzymes**—contained in plasma membrane of microvilli
  - Carry out some of the final stages of enzymatic digestion
  - Not released into the lumen
  - **Contact digestion:** chyme must contact the brush border for digestion to occur
  - Intestinal churning of chyme ensures contact with the mucosa

# Microscopic Anatomy

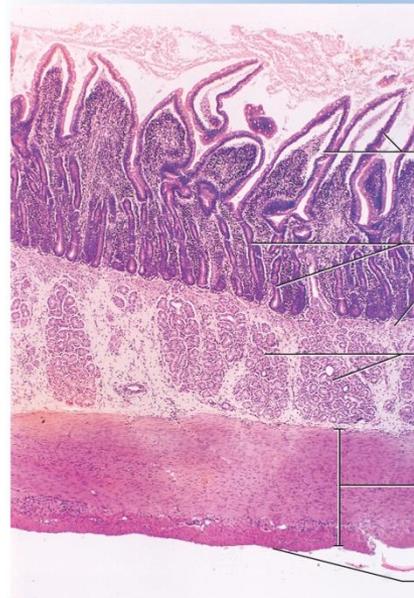
- **Intestinal crypts (crypts of Lieberkühn)**—numerous pores that open into tubular glands on the floor of the small intestine between bases of the villi
  - Similar to gastric glands
  - In upper half, have **enterocytes** and **goblet** cells like the villi
  - In lower half, dominated by dividing **stem cells**
    - Life span of 3 to 6 days
    - New epithelial cells migrate up the crypt to the tip of the villus where they are sloughed off and digested
  - A few **Paneth cells** are clustered at the base of each crypt
    - Secrete lysozyme, phospholipase, and **defensins**—defensive proteins that resist bacterial invasion of the mucosa

# Intestinal Villi



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

(a)



- Villi
- Intestinal crypts
- Muscularis mucosae
- Duodenal glands
- Muscularis externa
- Serosa

(c)

Figure 25.25a–c

(b)

0.5 mm

a: ©Meckes/Ottawa/Science Source; b: © McGraw-Hill Education/Dennis Stretz

# Microscopic Anatomy

- **Duodenal glands**—in submucosa of duodenum
  - Secrete an abundance of **bicarbonate-rich mucus**
  - Neutralize stomach acid and shield the mucosa from its erosive effects
- Large population of **lymphocytes** throughout lamina propria and submucosa of small intestine
  - Intercept pathogens before they can invade bloodstream
  - Aggregated into lymphatic nodules in ileum: **Peyer patches**

# Intestinal Secretion

- **Intestinal crypts** secrete 1 to 2 L of **intestinal juice** per day
  - In response to acid, hypertonic chyme, and distension of intestines
  - pH of 7.4 to 7.8
  - Contains water, mucus, and little enzyme
    - Most enzymes that function in small intestine are found in brush border and pancreatic juice

# Intestinal Motility

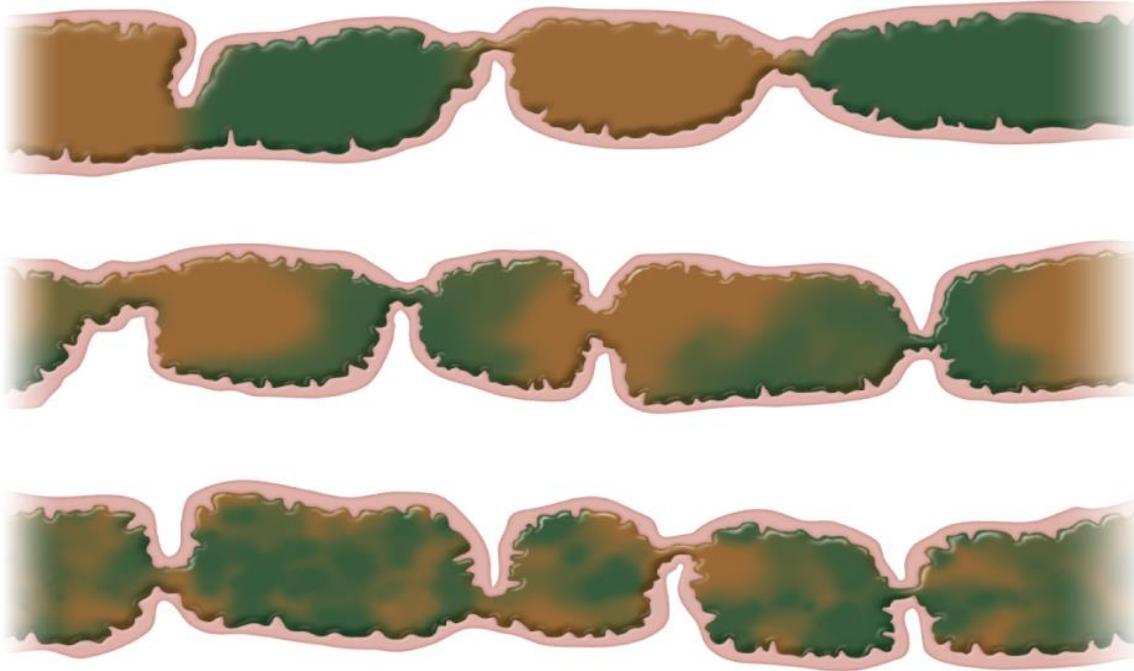
- **Contractions of small intestine serve three functions**
  - **To mix chyme with intestinal juice, bile, and pancreatic juice**
    - To neutralize acid
    - Digest nutrients more effectively
  - **To churn chyme and bring it in contact** with the mucosa for contact digestion and nutrient absorption
  - **To move residue toward large intestine**

# Intestinal Motility

- **Segmentation**—movement in which stationary ring-like constrictions appear in several places along the intestine
  - They relax and new constrictions form elsewhere
  - Most common kind of intestinal contraction
  - **Pacemaker cells** in muscularis externa set rhythm of segmentation
    - Contractions about 12 times per minute in the duodenum
    - 8 to 9 times per minute in the ileum
    - When most nutrients have been absorbed and little remains but undigested residue, **segmentation declines and peristalsis begins**

# Contractions of the Small Intestine

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(a) Segmentation

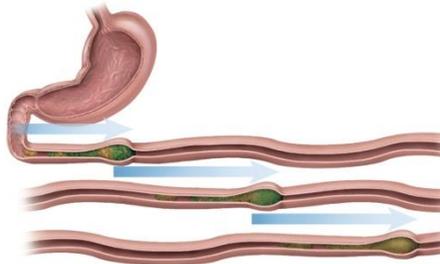
Figure 25.26a

- Purpose of segmentation is to mix and churn, not to move material along as in peristalsis

# Intestinal Motility

- **Peristalsis moves contents of small intestine toward colon**
- **Peristaltic wave** begins in duodenum, travels 10 to 70 cm and dies out
- **Followed by another wave starting further down the tract**
- **Migrating motor complex**—successive, overlapping waves of contraction
- **Milk chyme toward colon over a period of 2 hours**

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(b) Peristalsis

# Intestinal Motility

## (Continued)

- **Ileocecal valve** usually closed
  - Food in stomach triggers **gastroileal reflex** that enhances segmentation in the ileum and relaxes the valve
  - As **cecum** fills with residue, pressure pinches the valve shut
    - Prevents reflux of cecal contents into the ileum

# Chemical Digestion and Absorption

- **Expected Learning Outcomes**
  - Describe how each major class of nutrients is chemically digested, name the enzymes involved, and discuss the functional differences among these enzymes.
  - Describe how each type of nutrient is absorbed by the small intestine.

# Carbohydrates

- **Starch**—most digestible dietary carbohydrate
  - Cellulose is indigestible
  - Starch is first digested to **oligosaccharides** (up to eight glucose residues long)
  - Oligosaccharides then digested to the **disaccharide maltose**
  - Maltose finally digested to **glucose** which is absorbed by the small intestine

# Carbohydrates

- Process **begins in the mouth**
  - **Salivary amylase** hydrolyzes starch into oligosaccharides
  - Amylase works best at pH of 6.8 to 7.0 of oral cavity
  - Amylase quickly denatured on contact with stomach acid and digested by pepsin

# Carbohydrates

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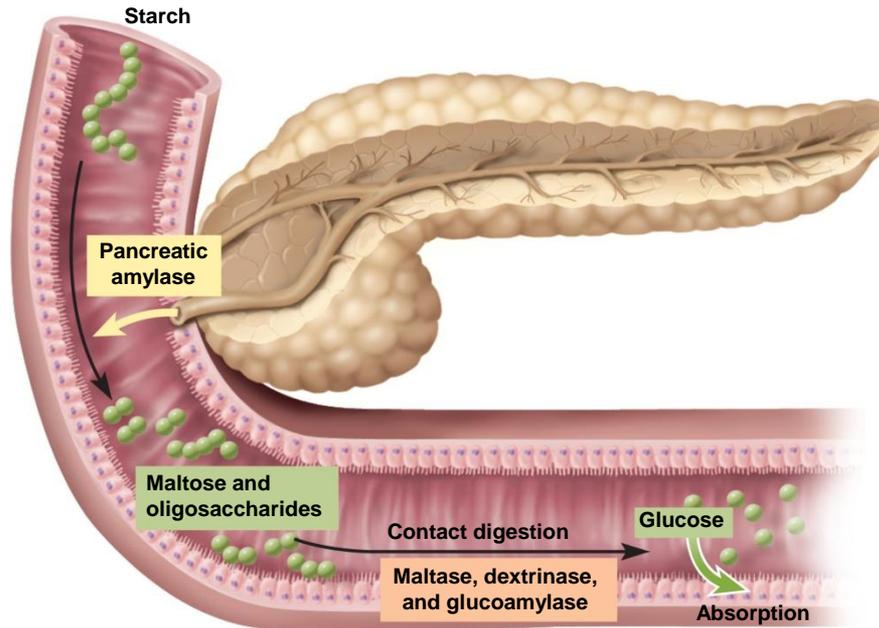


Figure 25.27

- About 50% of dietary starch is digested before it reaches small intestine
- Pancreatic amylase resumes starch digestion in intestine

# Carbohydrates

- When reaching small intestine, **pancreatic amylase** quickly converts starch to oligosaccharides and maltose
- Brush border enzymes continue carbohydrate digestion:
  - Dextrinase and glucoamylase hydrolyze oligosaccharides
  - Maltase hydrolyzes maltose (a disaccharide)
  - Sucrase and lactase hydrolyze the disaccharides sucrose and lactose
    - In most people, lactase production stops in childhood
  - Monosaccharides produced by disaccharide hydrolysis (such as glucose) are immediately absorbed

# Carbohydrates

- Plasma membrane of **absorptive cells** has transport proteins that absorb monosaccharides as soon as brush border enzymes release them
- **80% of absorbed sugar is glucose**
  - Taken up by **sodium–glucose transport (SGLT) proteins**
  - Glucose is transported out the base of absorptive cell into ECF by **facilitated diffusion**
  - Sugar entering ECF increases its osmolarity
  - Draws water osmotically from lumen of intestine, through leaky tight junctions between epithelial cells
  - Water carries more glucose and other nutrients with it by **solvent drag**

# Carbohydrates

- **SGLT also absorbs galactose**
- **Fructose is absorbed by facilitated diffusion (by a different carrier protein) and converted to glucose**
- **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**

# Lactose Intolerance

- **In people without lactase, 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 people**
  - 15% of American whites, 90% of American blacks, 70% of Mediterraneans; and nearly all of Asian descent
- **Can consume yogurt and cheese since bacteria have broken down the 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**
- **Endogenous amino acids** from last two sources total about 30 g/day
- **Exogenous amino acids** from our diet total about 44 to 60 g/day

# Proteins

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

# Proteins

- Protein digestion continues in **small intestine**
  - Pepsin inactivated when it passes into the duodenum and mixes with alkaline pancreatic juice (pH 8)
  - Pancreatic enzymes **trypsin** and **chymotrypsin** take over the process
  - Hydrolyze **polypeptides** into even shorter **oligopeptides**

# Proteins

## (Continued)

- Oligopeptides taken apart one amino acid at a time by three more enzymes
  - **Carboxypeptidase**—removes amino acids from – COOH end of the chain
    - Carboxypeptidase is a **pancreatic secretion**
  - **Amino peptidase**—removes amino acids from –NH<sub>2</sub> end
  - **Dipeptidase**—splits dipeptides in the middle and release two free amino acids
    - Amino peptidase and dipeptidase are **brush border enzymes**

# Protein Digestion and Absorption

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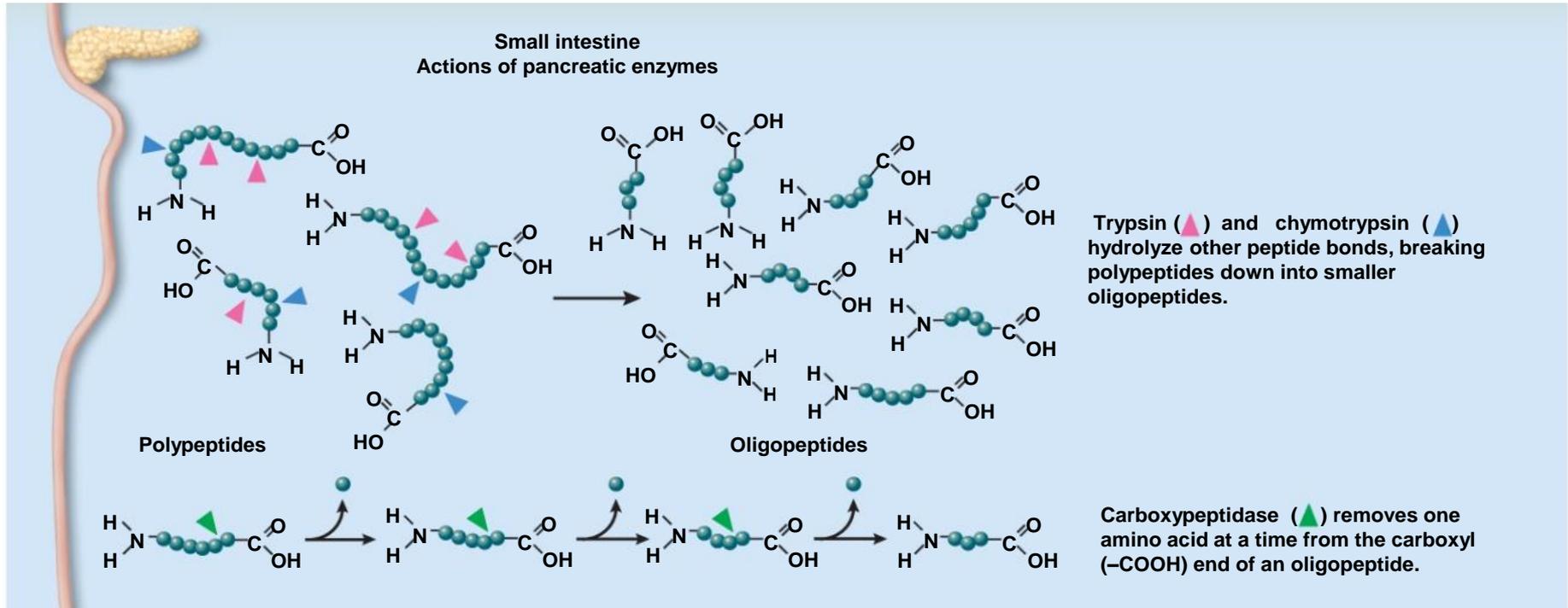


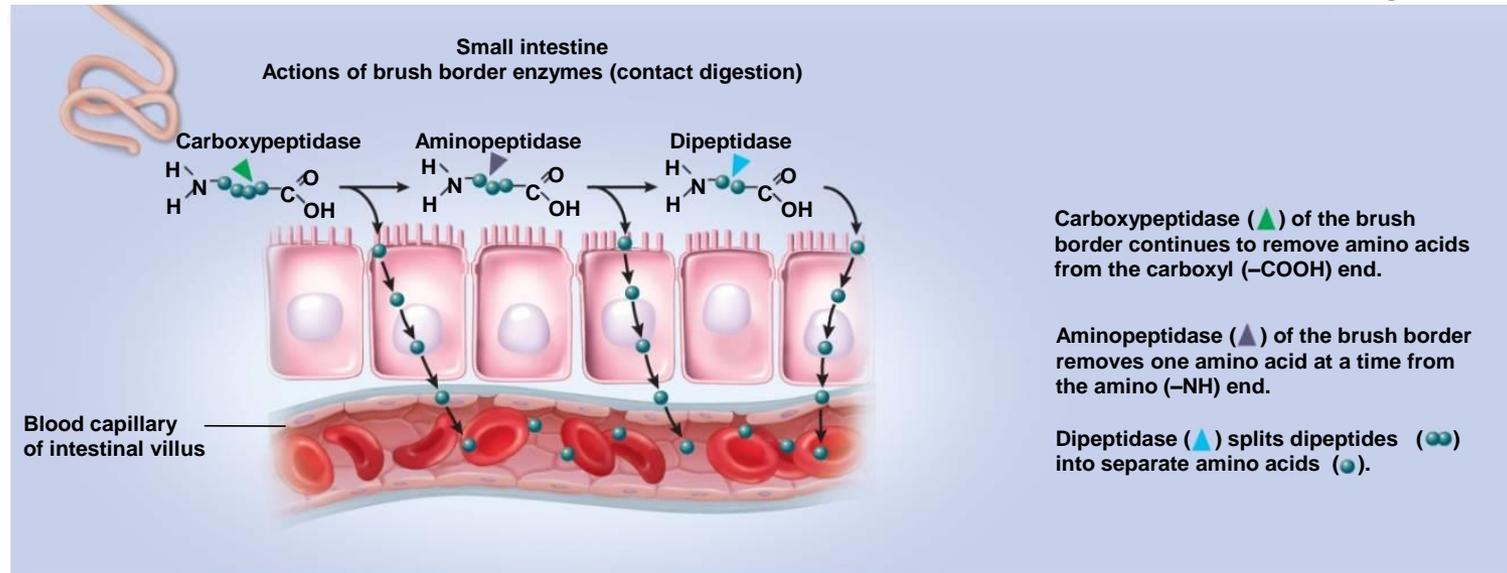
Figure 25.29

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

# Protein Digestion and Absorption

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Figure 25.29



- **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 bloodstream
- **Infants absorb proteins by pinocytosis (maternal IgA) and release them into the blood by exocytosis**

# Lipids

- **Hydrophobicity of lipids makes their digestion and absorption complicated**
- **Lipases**—fat-digesting enzymes
  - **Lingual lipase** secreted by intrinsic salivary glands of the tongue
    - Active in mouth, but more active in stomach along with **gastric lipase**
    - 10% to 15% of lipids digested before reaching duodenum
  - Before digestion in duodenum, vigorous pumping in stomach's antrum emulsifies the fat (breaks up globs)
    - Emulsification droplets are passed to small intestine

# Lipids

## (Continued)

- Emulsification droplets are broken down further by **bile**, **lecithin**, and **agitation** produced by intestinal segmentation
  - Exposes more fat 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 first and third fatty acids from glycerol backbone, but leaves the middle one
  - The product of lipase action are **two free fatty acids (FFAs)** and a **monoglyceride**

# Fat Digestion and Absorption

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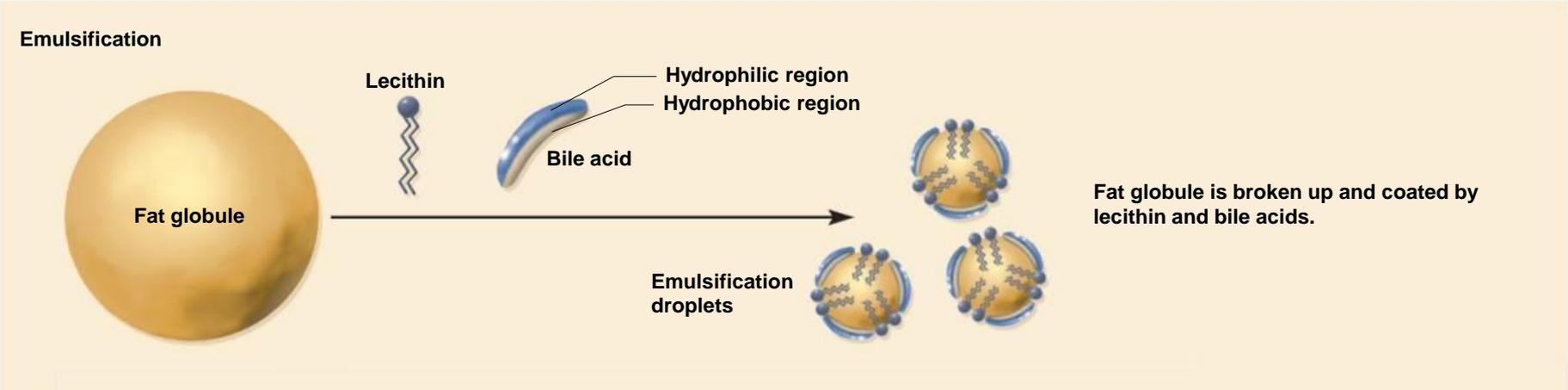


Figure 25.30

# Lipids

- Absorption of free fatty acids, monoglycerides, and other lipids depends on minute droplets in the bile called **micelles**
  - Made in the liver
  - Consist of **20 to 40 bile acid molecules** aggregated with their **hydrophilic side groups facing outward** and their **hydrophobic steroid rings facing inward**
  - **Bile phospholipids** and **cholesterol** diffuse into the center of the micelle to form its core

# Lipids

## (Continued)

- Micelles pass down the **bile duct into the duodenum**
  - There they absorb fat-soluble vitamins, 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 Digestion and Absorption

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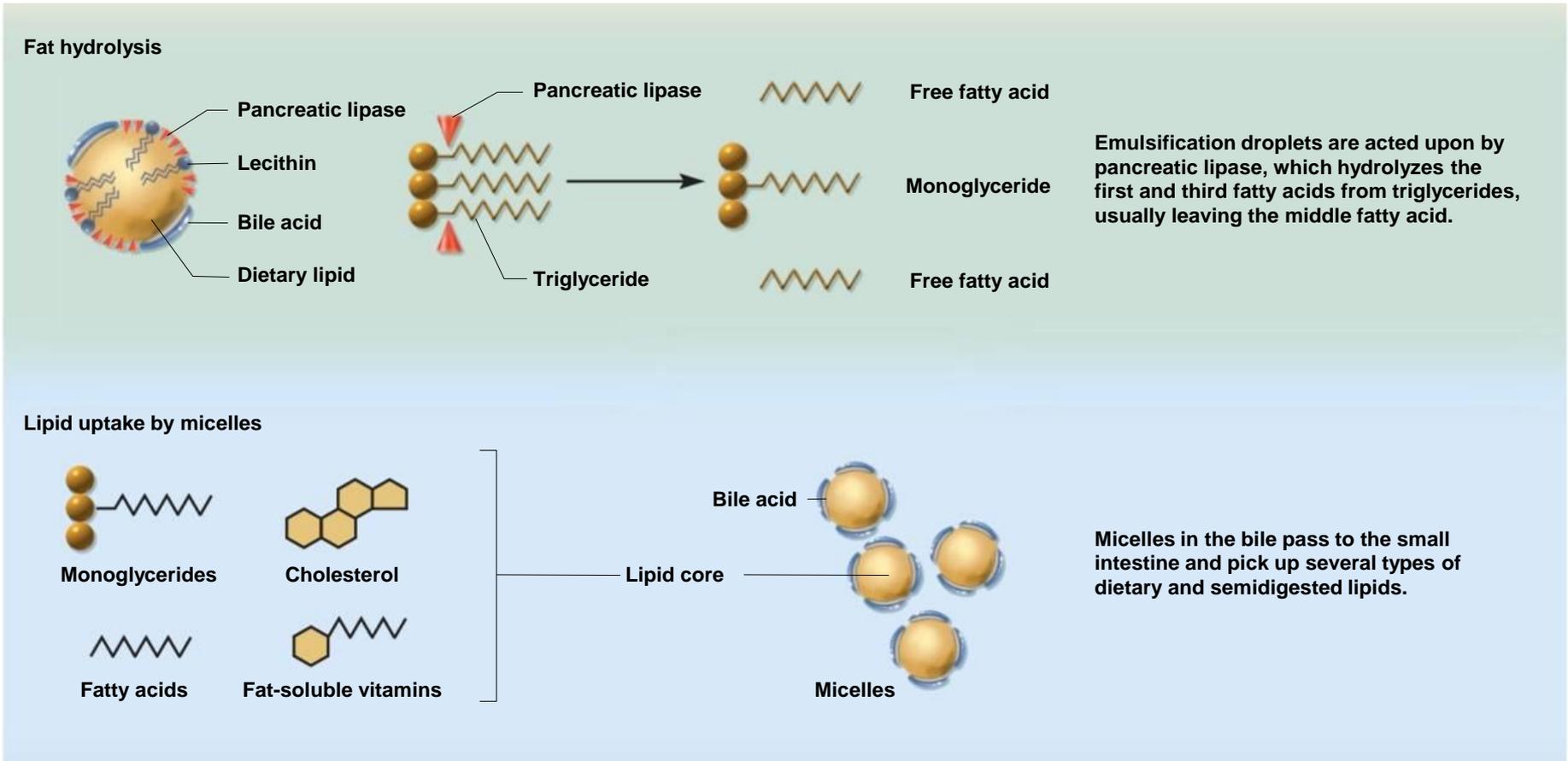


Figure 25.30

# Lipids

- 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 **core of villus**
  - Taken up by **lacteal** into lymph
  - **White, fatty intestinal lymph (chyle)** flows into larger and larger lymphatic vessels until it enters the bloodstream

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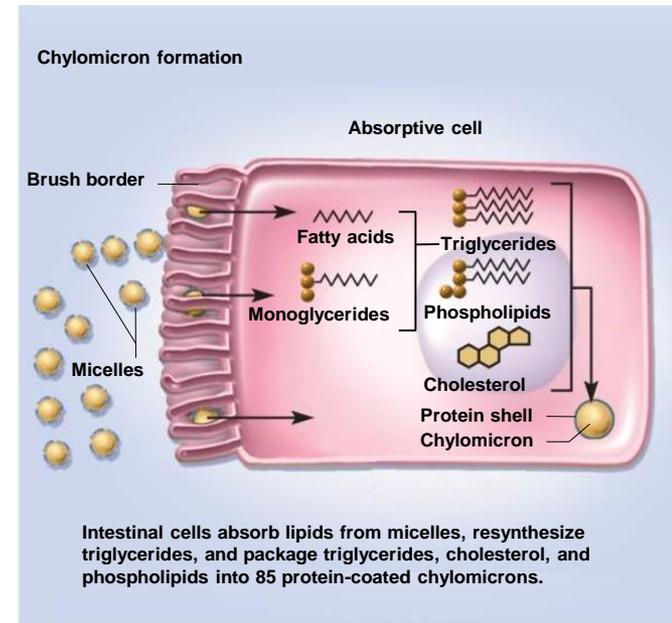


Figure 25.30

# Chylomicrons and the Lymphatics

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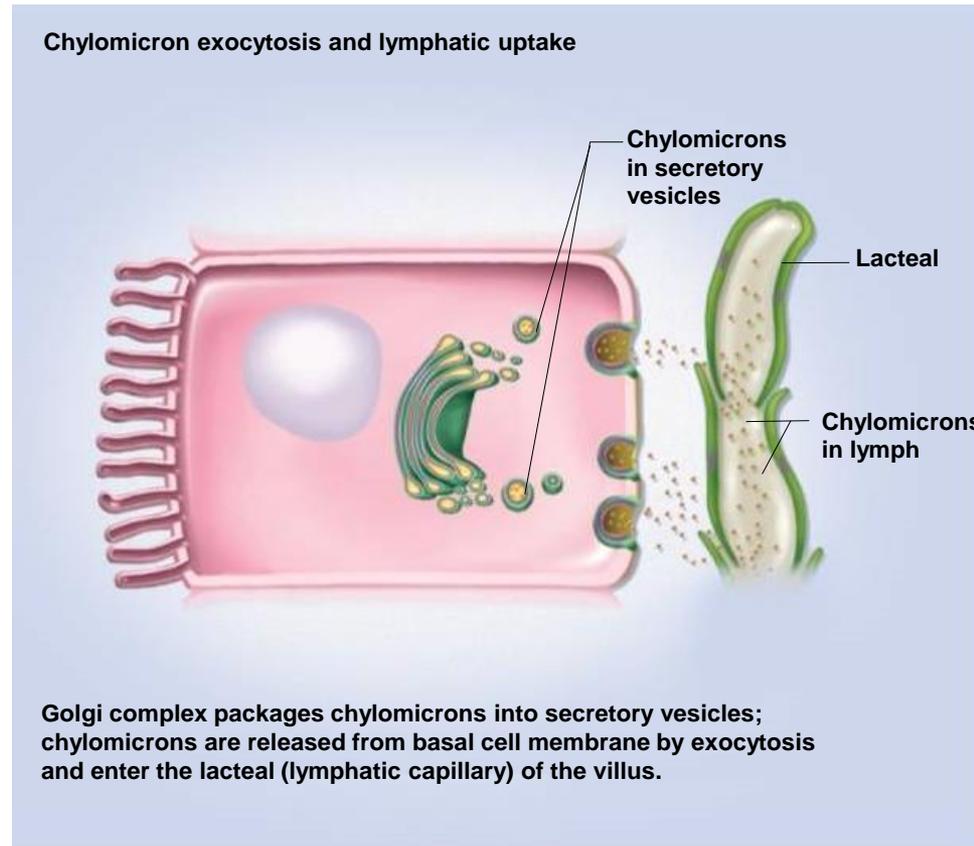


Figure 25.30

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.

# Summary of Nutrient Digestion

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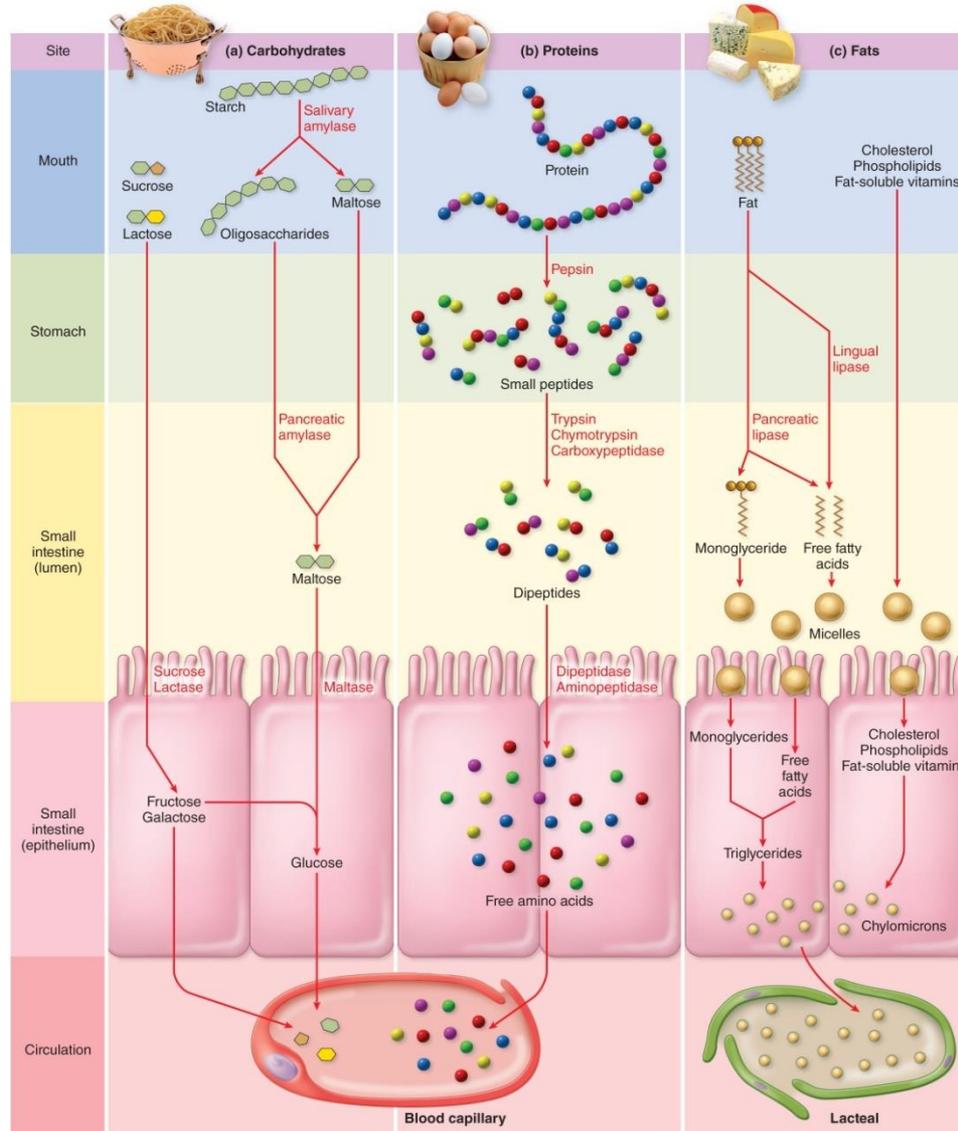


Figure 25.31

# Nucleic Acids

- **Nucleic acid**
  - **Nucleases** (deoxyribonuclease and ribonuclease) of pancreatic juice hydrolyze DNA and RNA to nucleotides
  - **Nucleosidases** and **phosphatases** of brush border split them into phosphate ions, ribose or deoxyribose sugar, and nitrogenous bases
  - Membrane carriers allow absorption

# Vitamins

- **Vitamins**

- Absorbed unchanged
- **Fat-soluble vitamins:** A, D, E, and K absorbed with other lipids
  - If ingested without fat-containing food, they are not absorbed at all, but are passed in the feces and wasted
- **Water-soluble vitamins,** B complex and C, absorbed by simple diffusion and B<sub>12</sub> if bound to intrinsic factor from the stomach

# Minerals

- **Minerals (electrolytes)**
  - Absorbed all along small intestine
  - **Na<sup>+</sup>** cotransported with sugars and amino acids
  - **Cl<sup>-</sup>** exchanged for bicarbonate reversing chloride–bicarbonate exchange that occurs in the stomach
  - **K<sup>+</sup>** absorbed by simple diffusion

# Minerals

## (Continued)

- **Iron** and **calcium** absorbed as needed
  - Iron absorption is stimulated by liver hormone **hepcidin**
  - Absorptive cells bind **ferrous ions ( $\text{Fe}^{2+}$ )** and internalize them by active transport
  - Unable to absorb ferric ions ( $\text{Fe}^{3+}$ ) but stomach acid reduces ferric ions to absorbable ferrous ions
  - **Transferrin (extracellular protein)** transports iron in blood to bone marrow, muscle, and liver

# Minerals

- **Calcium is absorbed throughout the intestine by different mechanisms**
  - **Transcellular** absorption in the **duodenum**
    - Enters through calcium **channels** in apical cell membrane
    - Binds to **calbindin** protein so concentration gradient will continue to favor calcium influx
    - Actively transported out of base of cell into bloodstream by **calcium–ATPase** and **Na<sup>+</sup>–Ca<sup>2+</sup> antiport**
  - Diffusion **between** epithelial cells in **jejunum** and **ileum**
  - Most absorbed calcium is from meat and dairy
    - Dietary fat retards calcium absorption

# Minerals

- **Parathyroid hormone**—secreted in response to a drop in blood calcium levels
  - Stimulates kidney to synthesize **vitamin D** from precursors made by epidermis and liver
  - Vitamin D affects absorptive cells of the duodenum in three ways
    - Increases number of calcium channels in apical membrane
    - Increases the amount of calbindin in cytoplasm
    - Increases the number of calcium–ATPase pumps at basal membrane
  - Parathyroid hormone increases the level of calcium in the blood

# Water

- **Digestive system is one of several systems involved in water balance**
- **Digestive tract receives about 9 L of water/day**
  - 0.7 L in food, 1.6 L in drink, 6.7 L in gastrointestinal secretions
  - 8 L is absorbed by small intestine and 0.8 L by large intestine
  - 0.2 L voided in daily fecal output

# Water

- **Water is absorbed by osmosis following the absorption of salts and organic nutrients**
- **Diarrhea**—occurs when large intestine absorbs too little water
  - Feces pass through too quickly if intestine is irritated
  - Feces contain high concentrations of a solute (such as lactose)
- **Constipation**—occurs when fecal movement is slow, too much water gets reabsorbed, and feces become hardened

# The Large Intestine

- **Expected Learning Outcomes**

- Describe the gross anatomy of the large intestine.
- Contrast the mucosa of the colon with that of the small intestine.
- State the physiological significance of intestinal bacteria.
- Discuss the types of contractions that occur in the colon.
- Explain the neurological control of defecation.

# Introduction to 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**

# Gross Anatomy

- **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 lower end of cecum
  - Densely populated with lymphocytes—a significant source of immune cells
- **Ascending colon, right colic (hepatic) flexure, transverse colon, left colic (splenic) flexure, and descending colon** frame the small intestine
- **Sigmoid colon** is S-shaped portion leading down into pelvic cavity

# Gross Anatomy

## (Continued)

- **Rectum:** portion ending at anal canal
  - Has three curves and three infoldings, called the transverse rectal folds (rectal valves)
- **Anal canal:** final 3 cm of the large intestine
  - Passes through **levator ani** muscle and pelvic floor, terminates at the anus
  - **Anal columns and sinuses**—exude mucus and lubricant into anal canal during defecation
  - Large **hemorrhoidal veins** for superficial plexus in anal columns and around orifice
  - **Hemorrhoids**—permanently distended veins that protrude into anal canal or bulge outside the anus

# Gross Anatomy

## (Continued)

- **Muscularis externa** of colon is unusual
  - **Taenia coli**—longitudinal fibers concentrated in three thickened, ribbon-like strips
  - **Haustra**—pouches in the colon caused by the muscle tone of the taeniae coli
  - **Internal anal sphincter**—smooth muscle of muscularis externa
  - **External anal sphincter**—skeletal muscle of pelvic diaphragm
- **Omental appendages**—club-like, fatty pouches of peritoneum adhering to the colon; unknown function

# Large Intestine Gross Anatomy

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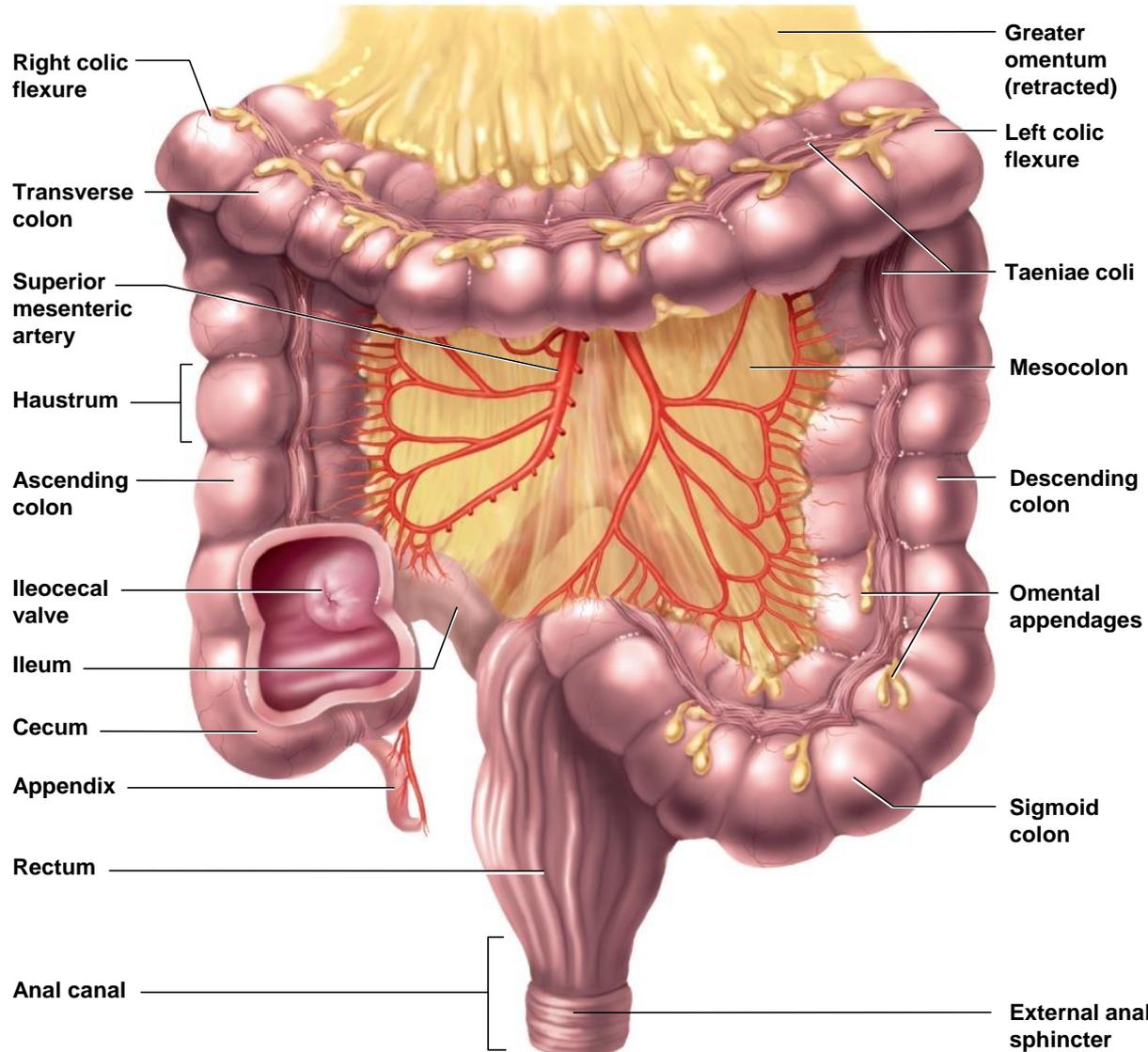


Figure 25.32a

(a) Gross anatomy

# The Large Intestine – Anal Canal

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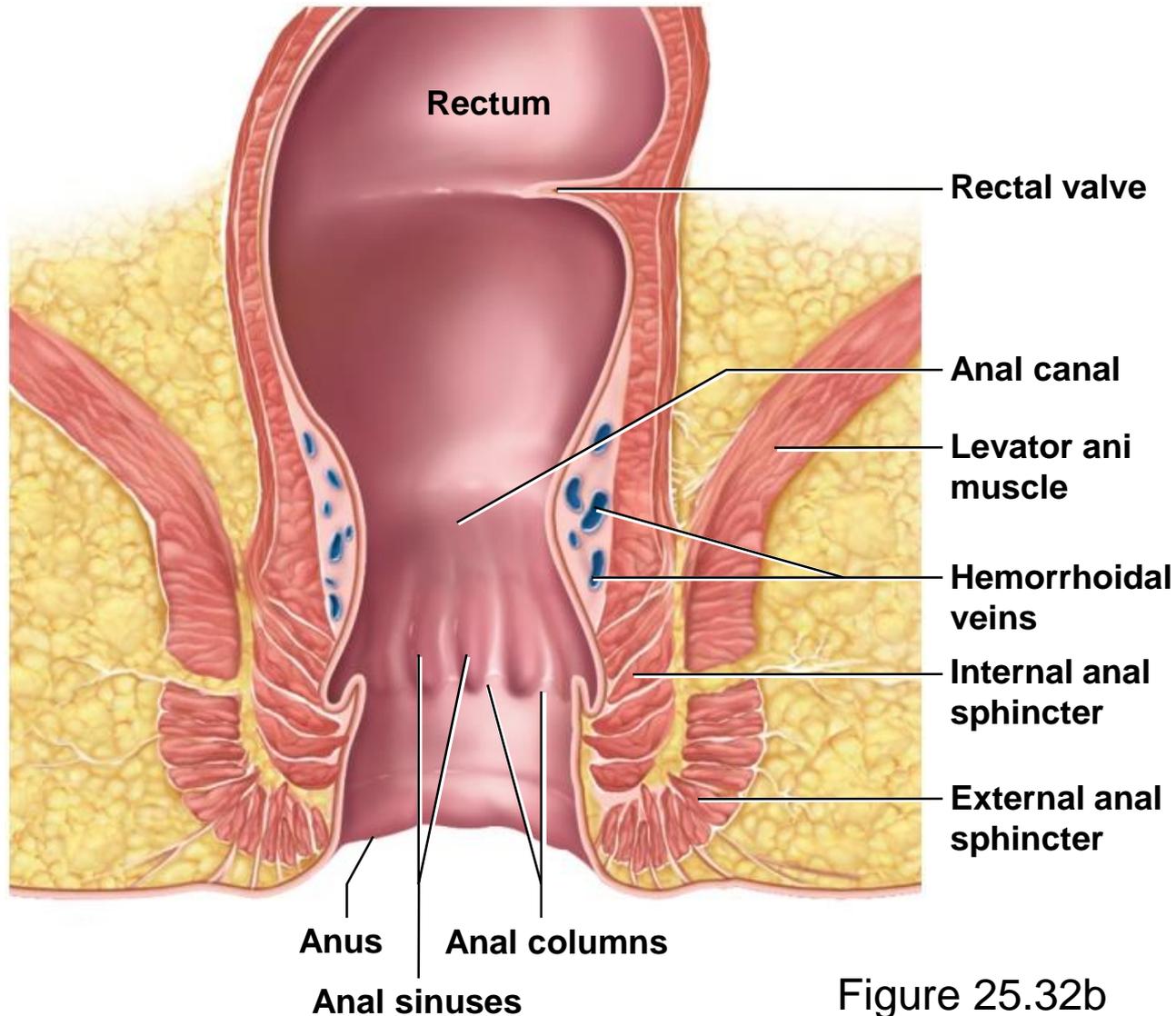


Figure 25.32b

(b) Anal canal

# Microscopic Anatomy

- **Mucosa**—simple columnar epithelium
  - **Anal canal** has nonkeratinized stratified squamous epithelium in its lower half for abrasion resistance
- **No circular folds or villi in large intestine**
- **Intestinal crypts**—glands sunken deep into lamina propria with a high density of **mucus-secreting goblet cells**
- **Lamina propria and submucosal have a lot of lymphatic tissue**
  - Provides protection from large population of bacteria in large intestine

# Intestinal Microbes and Gas

- **Gut microbiome**—about 800 species of bacteria that populate the large intestine
  - Bacteria digest cellulose, pectin, and other carbohydrates for which our cells lack enzymes
  - Help in synthesis of vitamins B and K
- **Flatus**—intestinal gas
  - Average person produces 500 mL of flatus per day
    - Most gas in large intestine is reabsorbed instead
  - Much of flatus is swallowed air, but bacteria add to it
  - **Hydrogen sulfide, indole, and skatole** produce odor
    - Hydrogen gas may explode during electrical cauterization used in surgery

# Absorption and Motility

- **Large intestine takes about 36 to 48 hours to reduce residue of a meal to feces**
  - Most time in transverse colon
  - Does not chemically change the residue
  - Reabsorbs water and electrolytes
- **Feces** consist of about 75% water and 25% solids
  - Solids: 30% bacteria, 30% undigested fiber, 10% to 20% fat, small amount of mucus, proteins, salts, digestive secretions, and sloughed epithelial cells

# Absorption and Motility

- **Haustral contractions** occur every 30 minutes
  - Distension of a haustrum stimulates it to contract
  - Churns and mixes residue promoting water and salt absorption
- **Mass** movements—stronger contractions that occur one to three times a day
  - Triggered by **gastrocolic** and **duodenocolic reflexes**
    - Filling of the stomach and duodenum stimulates motility of the colon
    - Move residue several centimeters

# Defecation

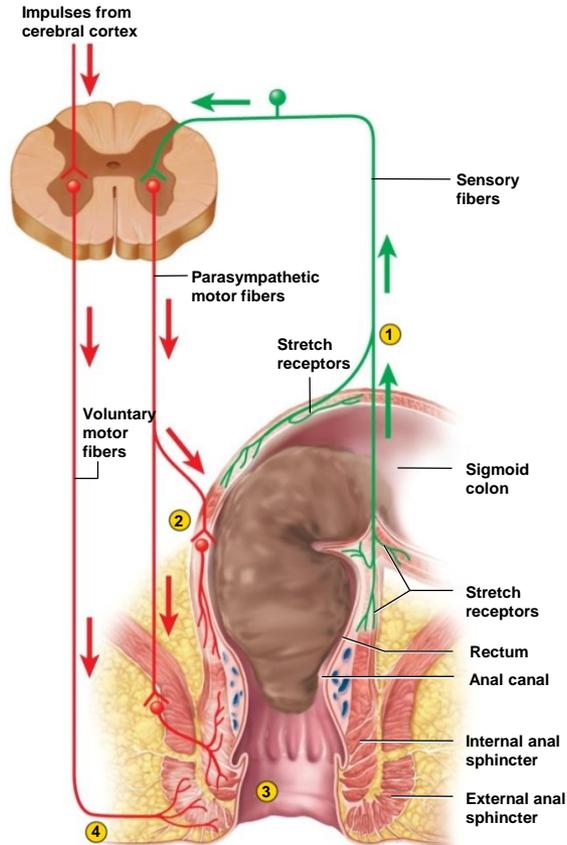
- **Stretching of rectum stimulates two defecation reflexes**
  - Accounts for urge to defecate often felt soon after a meal
  - **Intrinsic defecation reflex** works entirely within myenteric plexus to produce relatively weak response
    - Stretch signals travel through plexus to the muscularis, causing it to contract and the internal sphincter to relax
  - **Parasympathetic defecation reflex** involves spinal cord
    - Stretching of rectum sends sensory signals to spinal cord
    - Pelvic nerves return signals, intensifying peristalsis and relaxing the internal anal sphincter

# Defecation

- **Defecation occurs only if external anal sphincter and puborectalis muscles are voluntarily relaxed**
- **Abdominal contractions (Valsalva maneuver) increase abdominal pressure and compresses rectum**

# Neural Control of Defecation

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1. Filling of the rectum
2. Reflex contraction of rectum and relaxation of internal anal sphincter
3. Voluntary relaxation of external sphincter

- 1 Feces stretch the rectum and stimulate stretch receptors, which transmit signals to the spinal cord.
- 2 A spinal reflex stimulates contraction of the rectum.
- 3 The spinal reflex also relaxes the internal anal sphincter.
- 4 Impulses from the brain prevent untimely defecation by keeping the external anal sphincter contracted. Defecation occurs only if this sphincter also relaxes.

Figure 25.33

# The Man with a Hole in His Stomach

- **Canadian shot accidentally by shotgun in 1822**
  - A hole “large enough to receive forefinger” covered by a flap of tissue remained after wound healed
- **Physician William Beaumont experimented on him**
  - Removed samples and made observations
    - Proved digestion required HCl
  - Published book in 1833 that laid foundation for modern gastric physiology