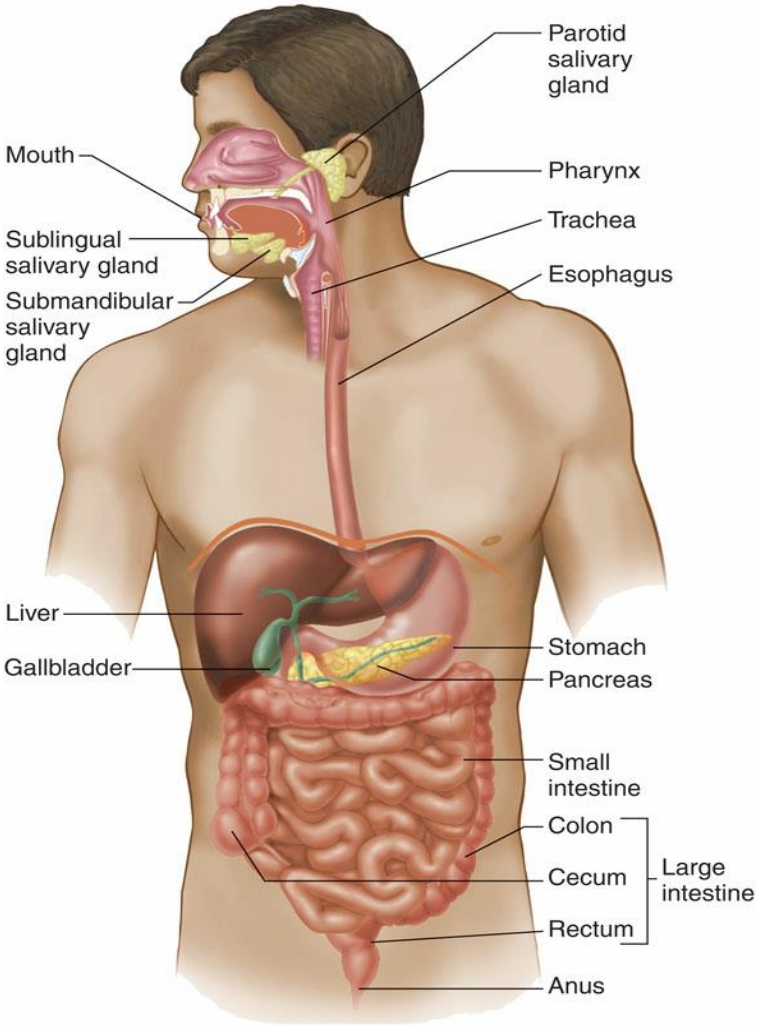
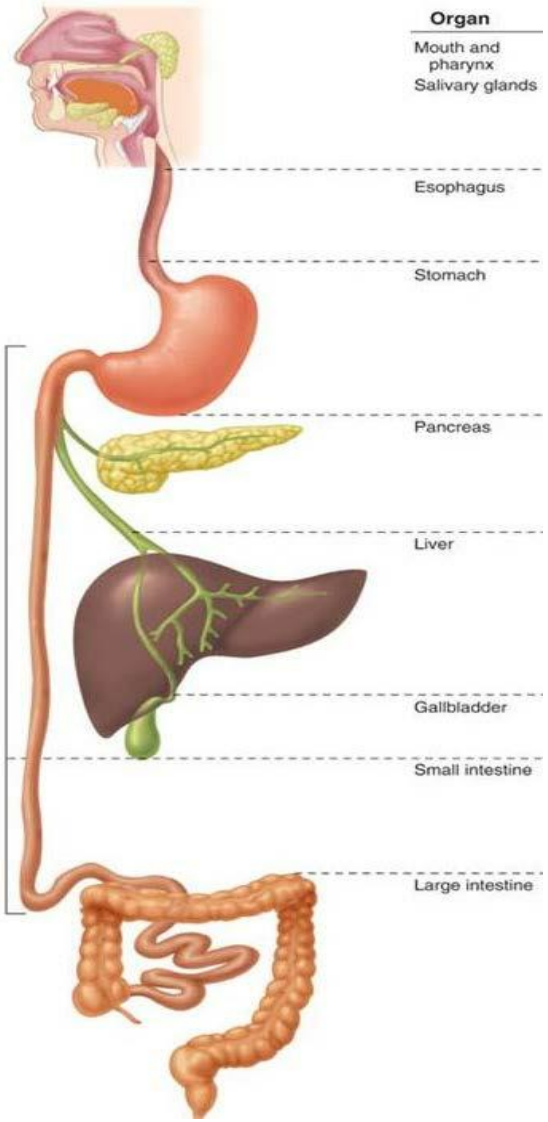
Gastrointestinal Tract





Organs of the Digestive system

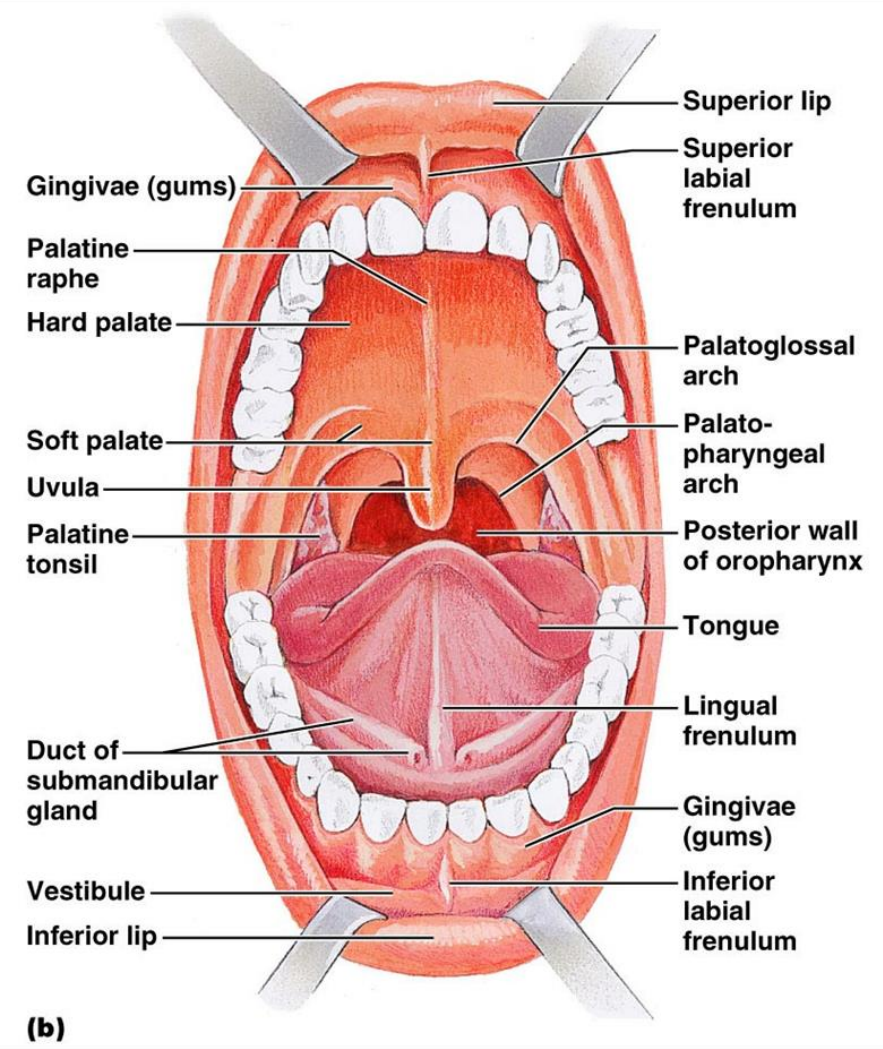
- **Alimentary canal**: performs the digestive functions (ingests, digests, absorbs, and defecates)
  -mouth, pharynx, esophagus, stomach, small intestine, And large intestine.

- **Accessory digestive organs**: assist the process of digestive breakdown in various ways
  -teeth, tongue, and several large digestive glands

Mouth

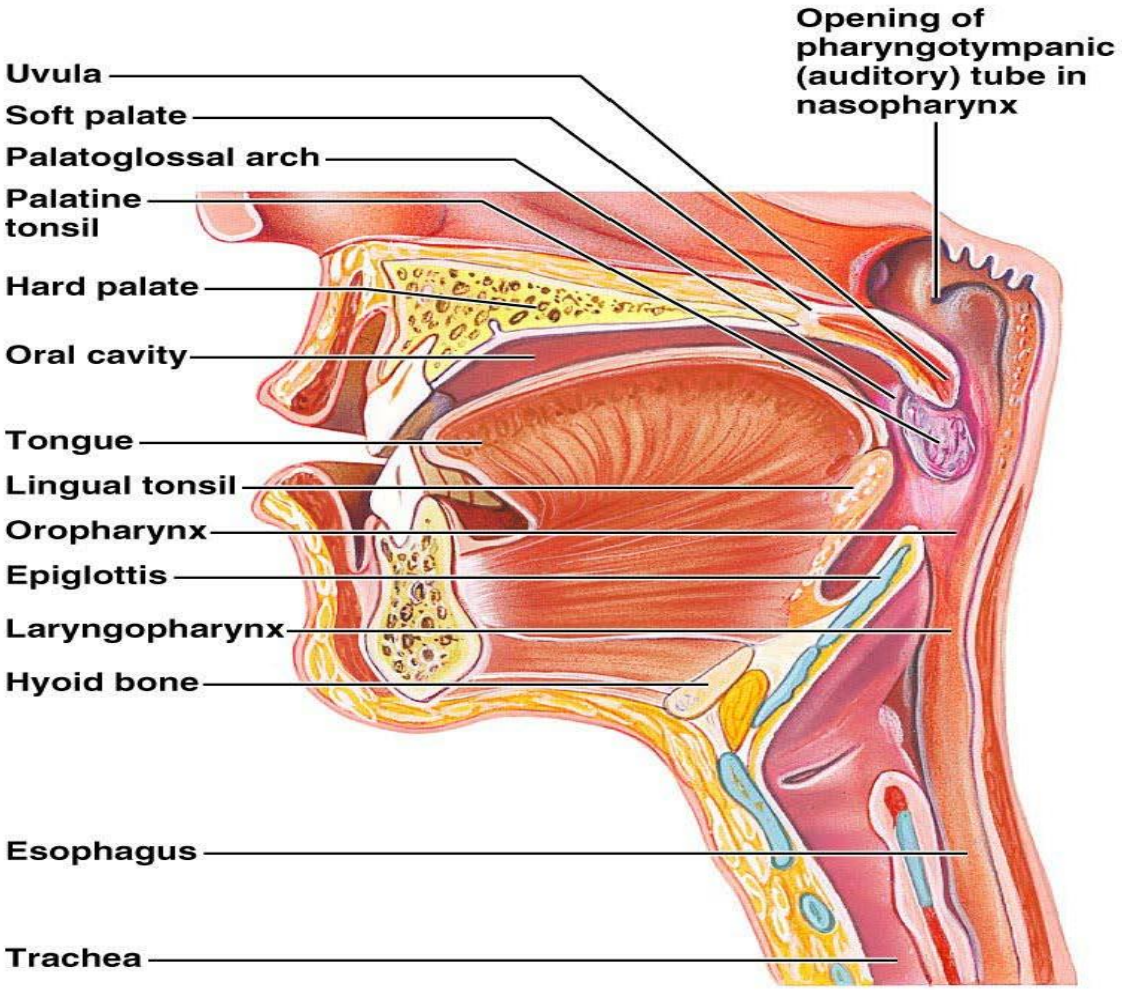
- **Oral or buccal cavity:**
  - Is bounded by lips, cheeks, palate, and tongue
    - Has the oral orifice as its anterior opening
    - Is continuous with the oropharynx posteriorly
- **To withstand abrasions:**
    - The mouth is lined with stratified squamous epithelium
    - The gums, hard palate, and dorsum of the tongue are slightly keratinized

Oral Cavity and Pharynx: Anterior View



Anatomy of the Oral Cavity:

Mouth



(a)

Tongue

- Intrinsic muscles change the shape of the tongue
- Extrinsic muscles alter the tongue's position
- Lingual frenulum secures the tongue to the floor of the mouth

Tongue

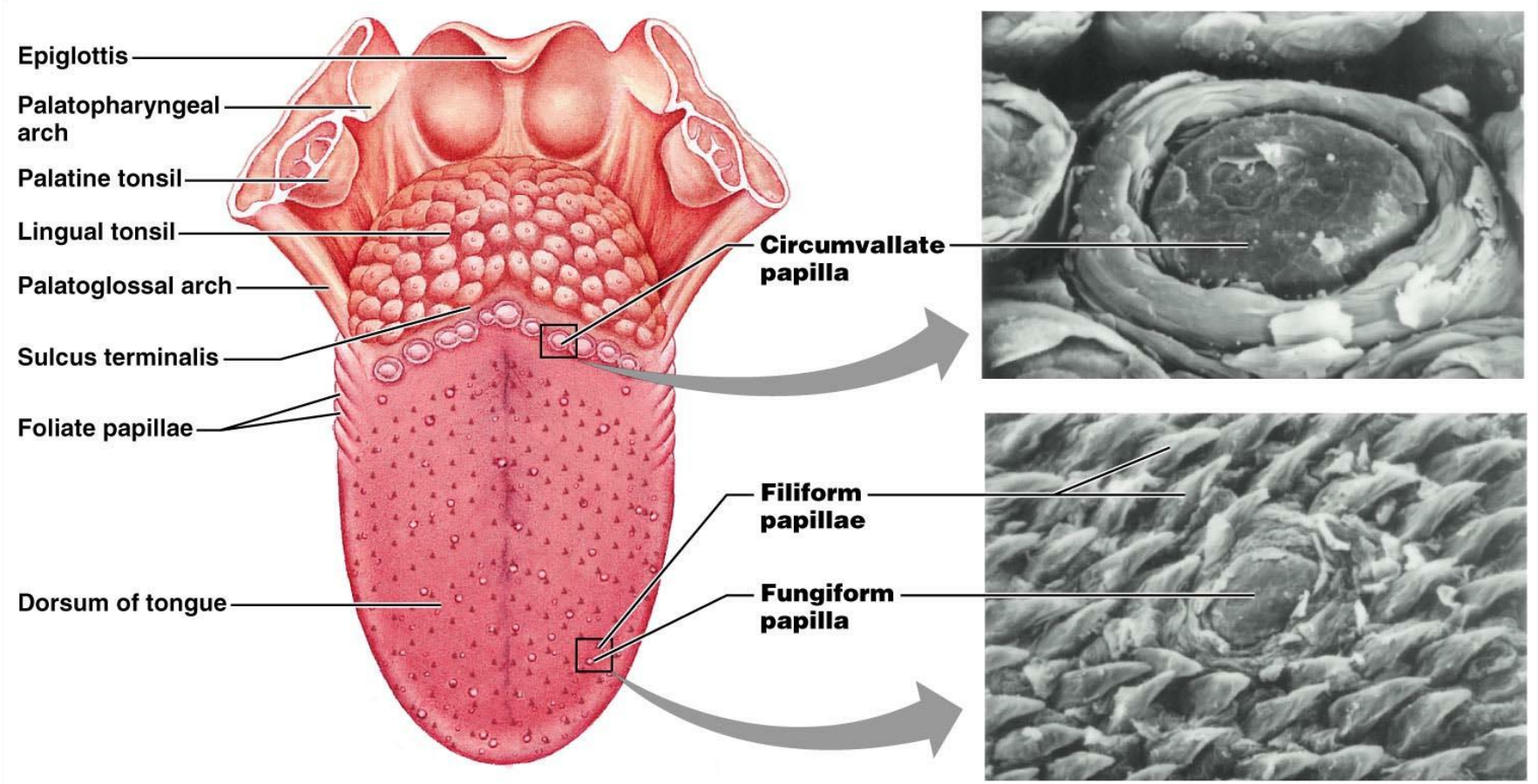


Figure 23.8

Salivary Glands

- Produce and secrete saliva that:
  - Cleanses the mouth
  - Moistens and dissolves food chemicals
  - Aids in bolus formation
  - Contains enzymes that break down starch
- Three pairs of extrinsic glands – parotid, submandibular, and sublingual

- Intrinsic salivary glands (buccal glands) – scattered throughout the oral mucosa

Salivary Glands

- **Parotid** – lies anterior to the ear between the masseter muscle and skin
- Parotid duct opens into the vestibule next to second upper molar
- **Submandibular** – lies along the medial aspect of the mandibular body

  Its ducts open at the base of the lingual frenulum
- **Sublingual** – lies anterior to the submandibular gland under the tongue

  It opens via 10-12 ducts into the floor of the mouth

Salivary Glands

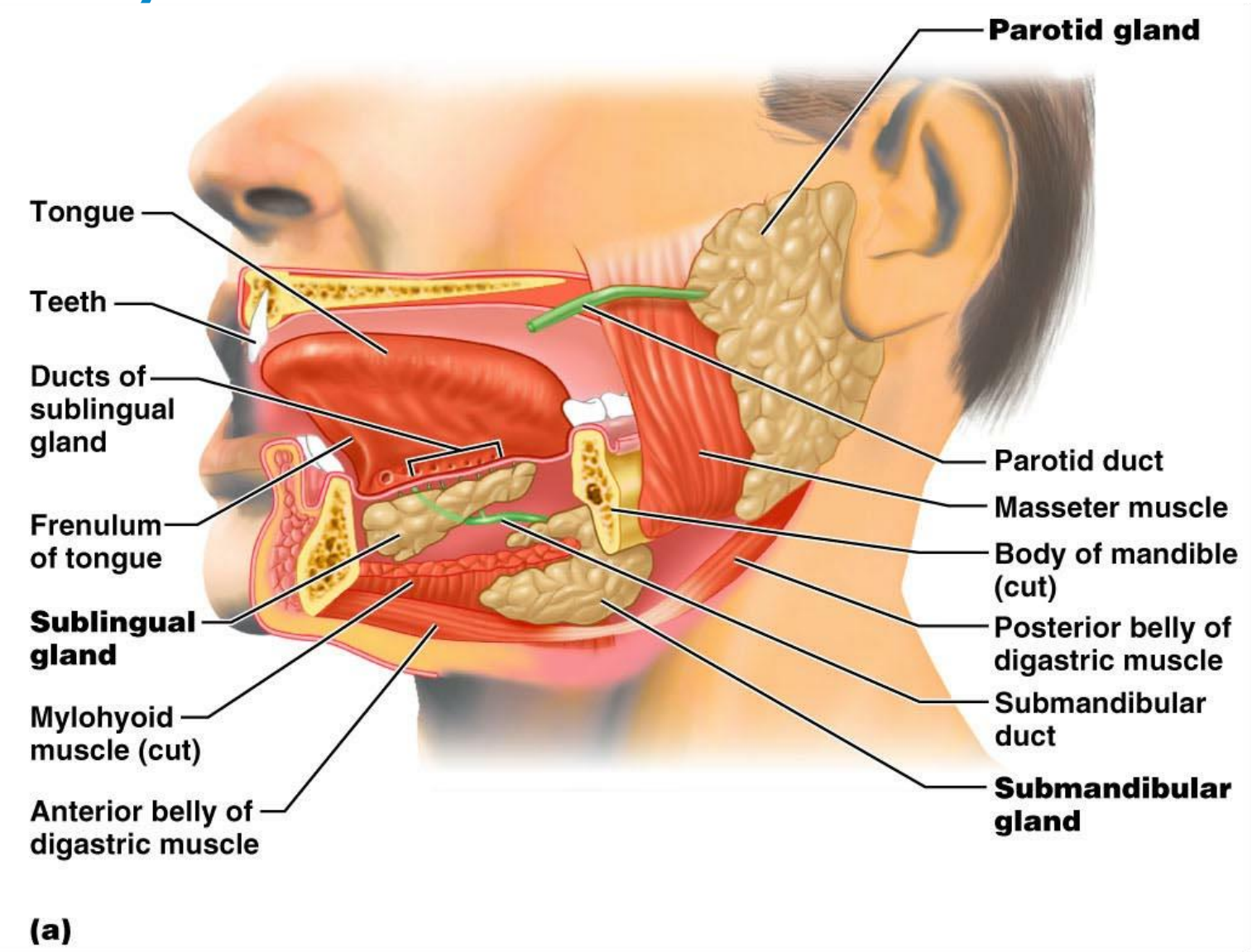


Figure 23.9a

Control of Salivation

- Intrinsic glands keep the mouth moist
- Extrinsic salivary glands secrete serous, enzyme rich saliva in response to:

  -Ingested food which stimulates chemoreceptors and pressoreceptors
  -The thought of food

- Strong sympathetic stimulation inhibits salivation and results in dry mouth

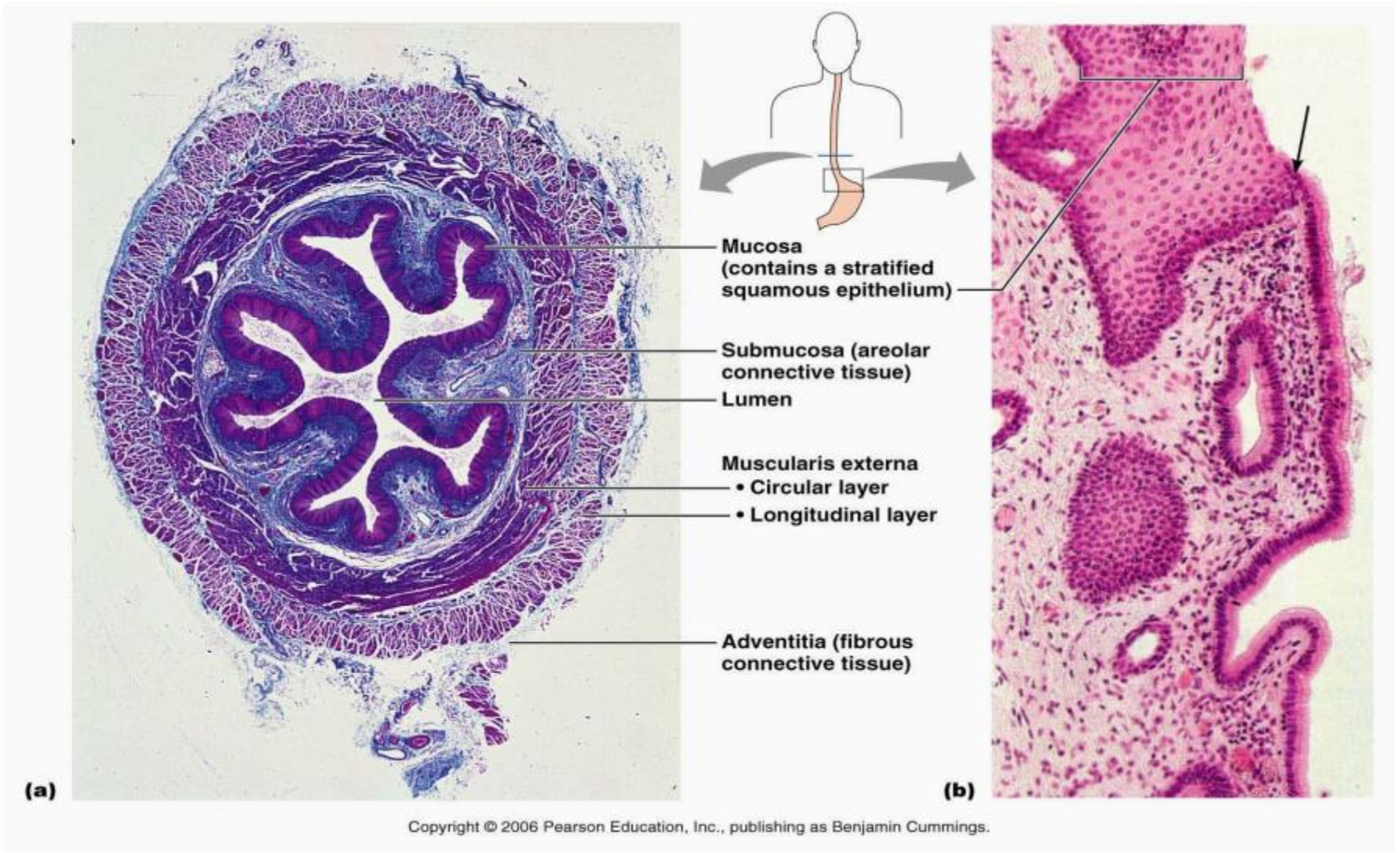
Pharynx

- From the mouth, the oro- and laryngopharynx allow passage of:
  - Food and fluids to the esophagus
  - Air to the trachea
- Lined with stratified squamous epithelium and mucus glands
- Has two skeletal muscle layers
  - Inner longitudinal
  - Outer pharyngeal constrictors

Esophagus

- Muscular tube going from the laryngopharynx to the stomach
- Travels through the mediastinum and pierces the diaphragm
- Joins the stomach at the cardiac orifice

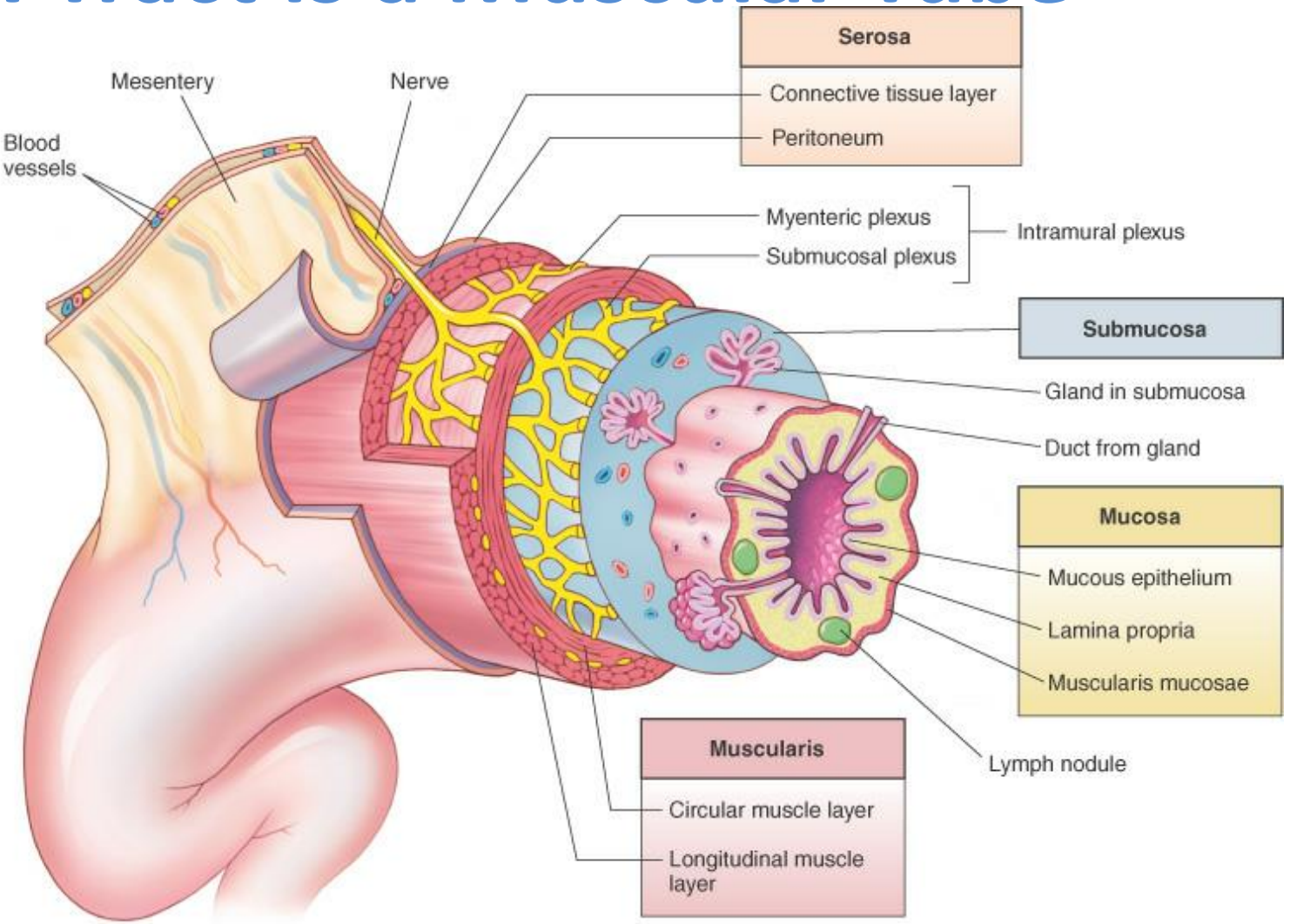
Esophagus



Esophageal Characteristics

- Esophageal mucosa – nonkeratinized stratified squamous epithelium
- The empty esophagus is folded longitudinally and flattens when food is present
- Glands secrete mucus as a bolus moves through the esophagus
- Muscularis changes from skeletal (superiorly) to smooth muscle (inferiorly)

GI Tract is a Muscular Tube



Mucosa

- Moist epithelial layer that lines the lumen of the
- alimentary canal

- Three major functions:
- Secretion of mucus
- Absorption of end products of digestion
- Protection against infectious disease
- Consists of three layers: a lining epithelium, lamina propria, and muscularis mucosae

Mucosa: Epithelial Lining

- Simple columnar epithelium and mucus-secreting
- goblet cells
- Mucus secretions:

  -Protect digestive organs from digesting themselves

  - Ease food along the tract
- Stomach and small intestine mucosa contain:
  - Enzyme-secreting cells
  - Hormone-secreting cells (making them endocrine and digestive organs)

Mucosa: Lamina Propria and Muscularis Mucosae

- **Lamina Propria**
  - Loose areolar and reticular connective tissue
  - Nourishes the epithelium and absorbs nutrients
  - Contains lymph nodes (part of MALT, mucosa associated lymphatic tissue) important in defense against bacteria
- **Muscularis mucosae** – smooth muscle cells that produce local movements of mucosa

Mucosa: Other Sublayers

- **Submucosa** – dense connective tissue containing elastic fibers, blood and lymphatic vessels, lymph nodes, and nerves
- **Muscularis externa** – responsible for segmentation and peristalsis
- **Serosa** – the protective visceral peritoneum
  - Replaced by the fibrous adventitia in the esophagus
  - Retroperitoneal organs have both an adventitia and serosa

Enteric Nervous System

- Composed of two major intrinsic nerve plexuses:
  - Submucosal nerve plexus – regulates glands and smooth muscle in the mucosa
  - Myenteric nerve plexus – Major nerve supply that controls GI tract mobility
- Segmentation and peristalsis are largely automatic involving local reflex arcs
- Linked to the CNS via long autonomic reflex arc

Digestive Processes in the Mouth

- Food is ingested
- Mechanical digestion begins (chewing)
- Propulsion is initiated by swallowing
- Salivary amylase begins chemical breakdown of starch
- The pharynx and esophagus serve as conduits to pass food from the mouth to the stomach

Deglutition (Swallowing)

- Coordinated activity of the tongue, soft palate, pharynx, esophagus, and 22 separate muscle groups
- Buccal phase – bolus is forced into the oropharynx

Deglutition (Swallowing)

Pharyngeal-esophageal phase – controlled by the medulla and lower pons

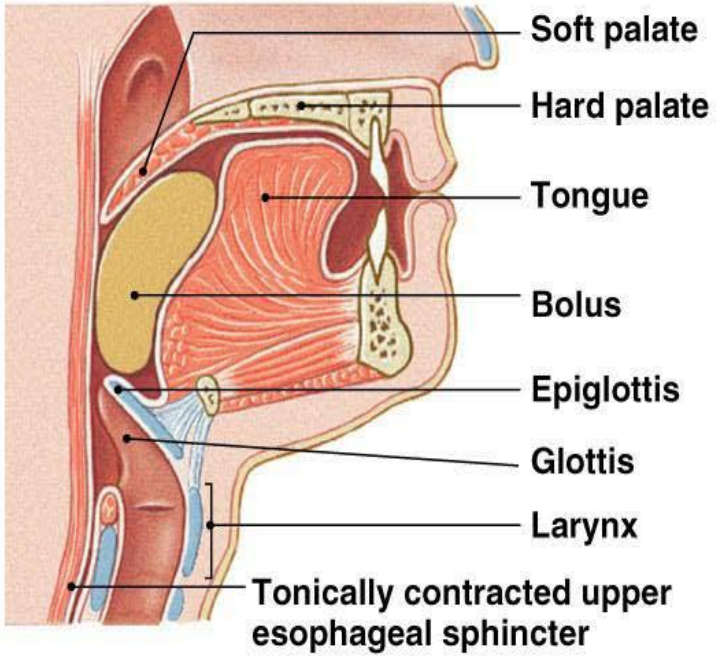
- All routes except into the digestive tract are sealed off

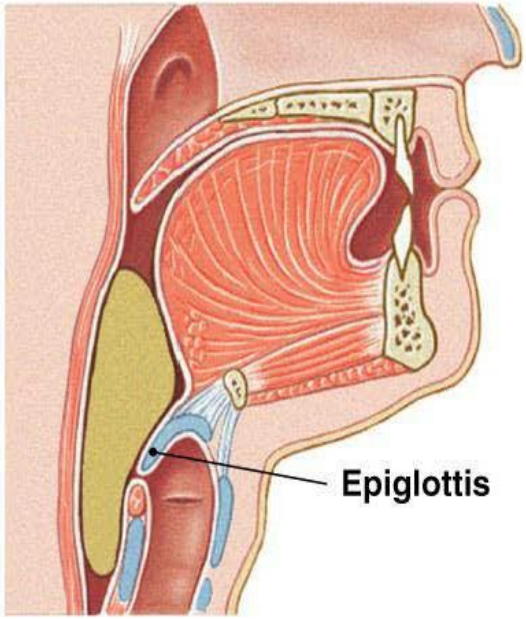
- Peristalsis moves food through the pharynx to the esophagus

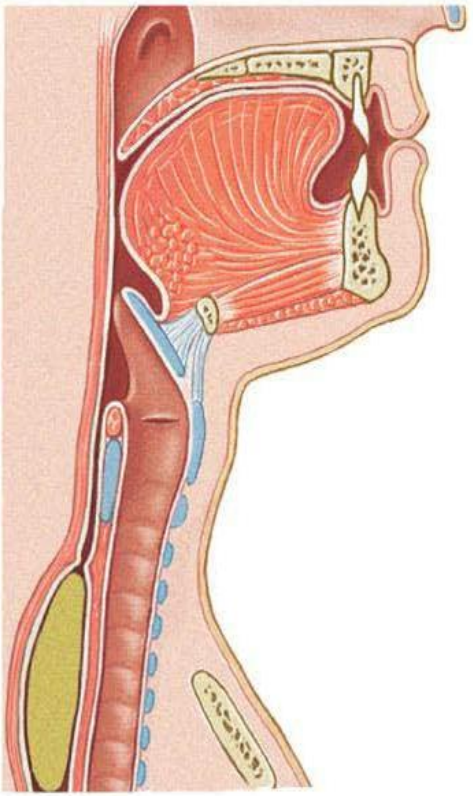
1 Tongue pushes bolus against soft palate and back of mouth, triggering swallowing reflex.

2 Upper esophageal sphincter relaxes while epiglottis closes to keep swallowed material out of the airways.

3 Food moves downward into the esophagus, propelled by peristaltic waves and aided by gravity.







Stomach

- Chemical breakdown of proteins begins and food is converted to chyme
- Cardiac region – surrounds the cardiac orifice
- Fundus – dome-shaped region beneath the diaphragm
- Body – midportion of the stomach
- Pyloric region – made up of the antrum and canal which terminates at the pylorus
- The pylorus is continuous with the duodenum through the pyloric sphincter

Stomach

- Greater curvature – entire extent of the convex lateral surface
- Lesser curvature – concave medial surface
- Lesser omentum – runs from the liver to the lesser curvature
- Greater omentum – drapes inferiorly from the greater curvature to the small intestine

Stomach

- Nerve supply – sympathetic and parasympathetic fibers of the autonomic nervous system
- Blood supply – celiac trunk, and corresponding veins (part of the hepatic portal system)

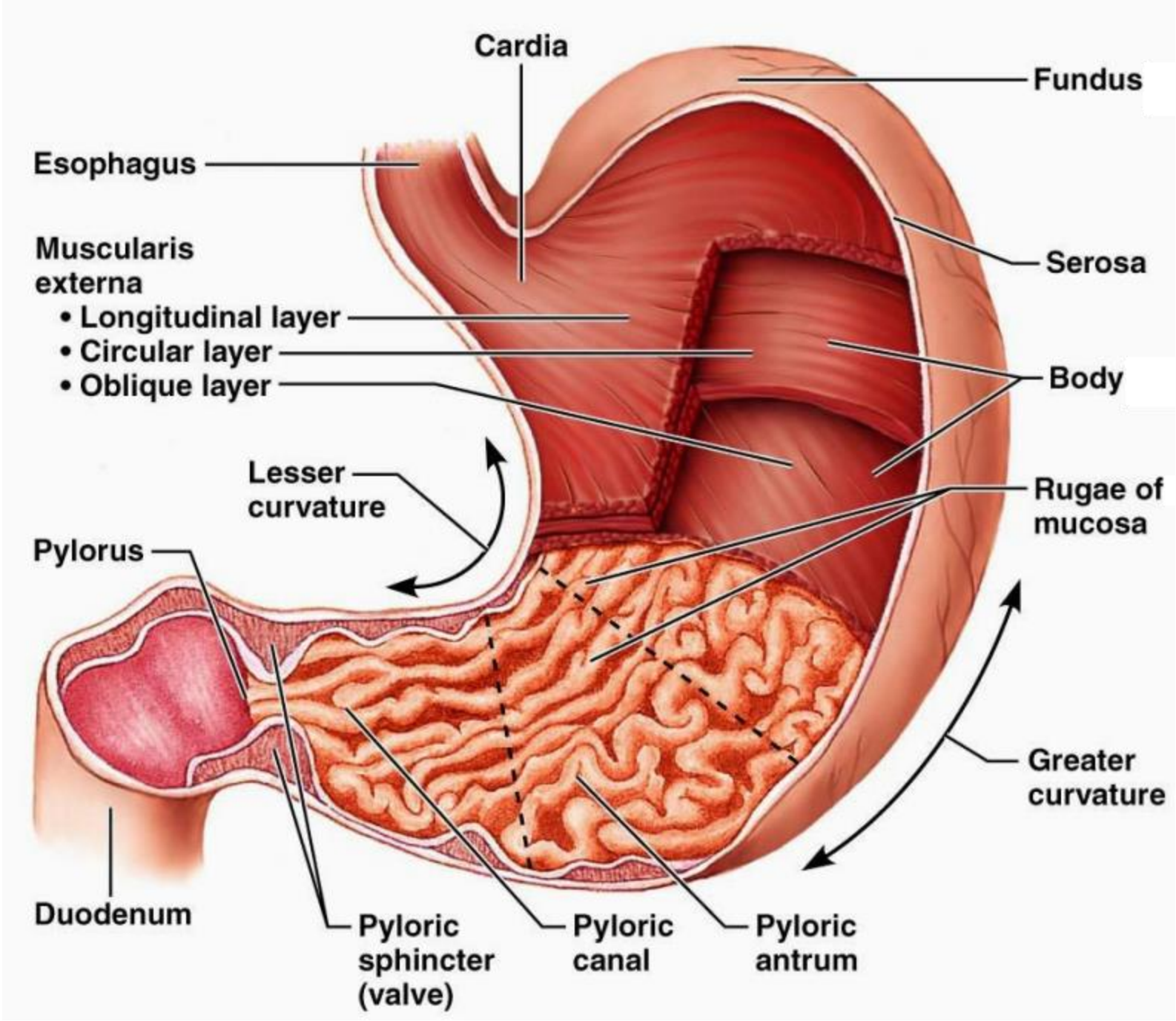


Figure 23.14a

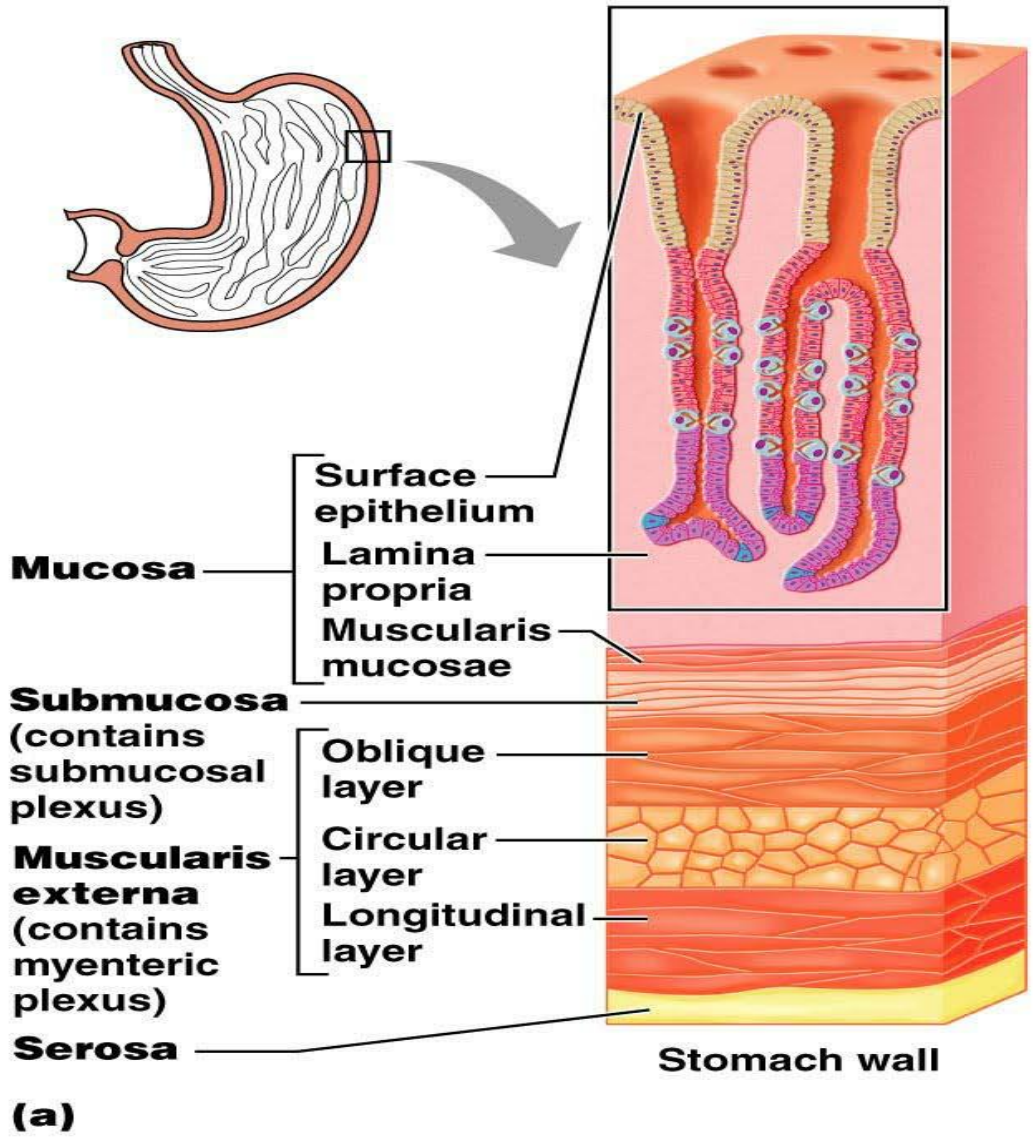
Microscopic Anatomy of the Stomach

- Muscularis – has an additional oblique layer that:
  - Allows the stomach to churn, mix, and pummel
  - food physically
- Breaks down food into smaller fragments

Microscopic Anatomy of the Stomach

- Epithelial lining is composed of:
  - Goblet cells that produce a coat of alkaline mucus
    - The mucous surface layer traps a bicarbonate-rich fluid beneath it
- Gastric pits contain gastric glands that secrete gastric juice, mucus, and gastrin

Microscopic Anatomy of the Stomach



Microscopic Anatomy of the Stomach

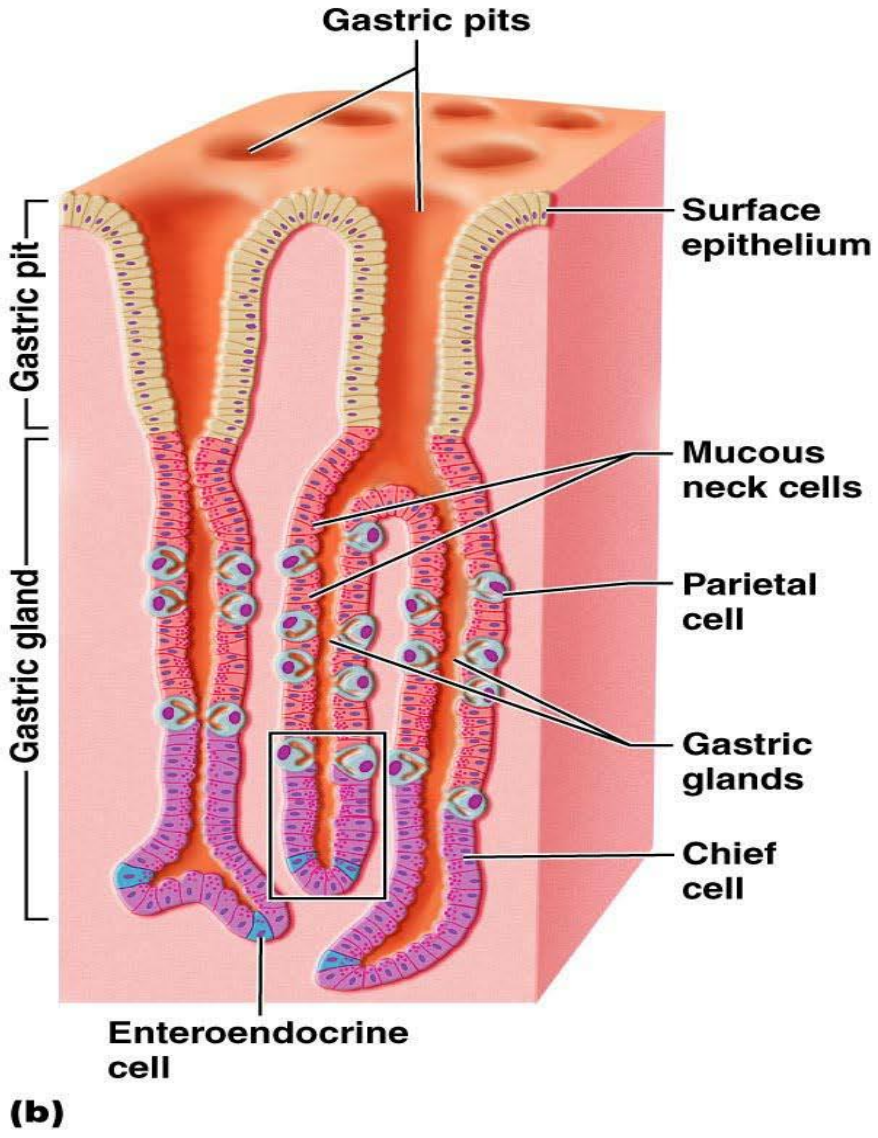


Figure 23.15b

Microscopic Anatomy of the Stomach

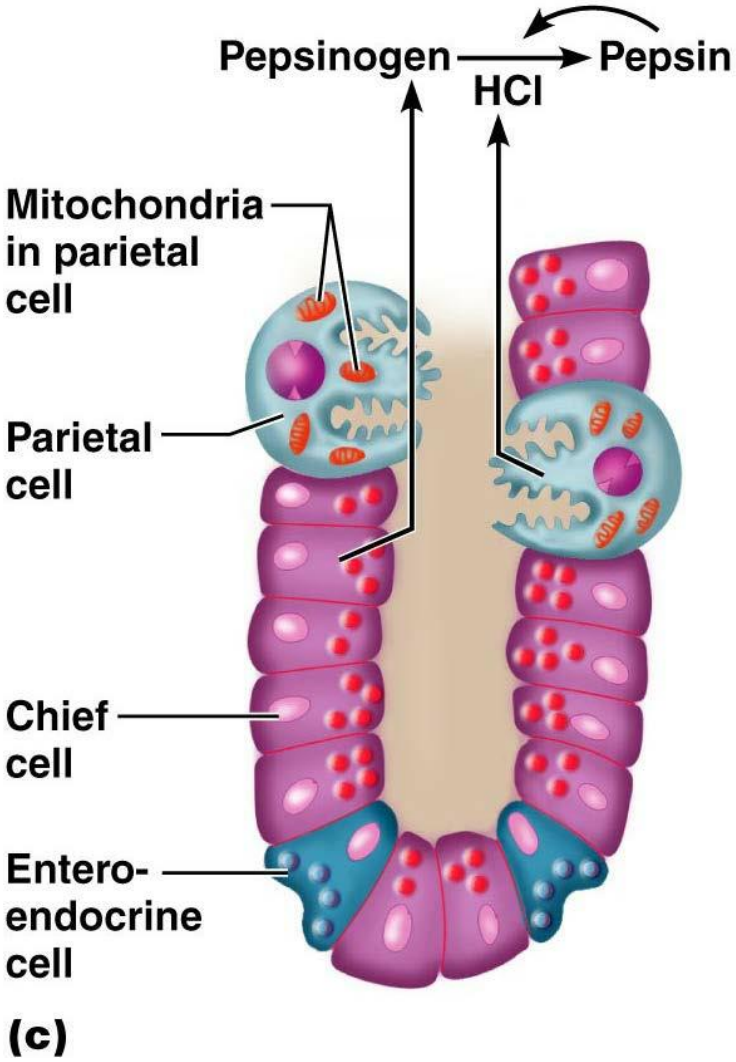


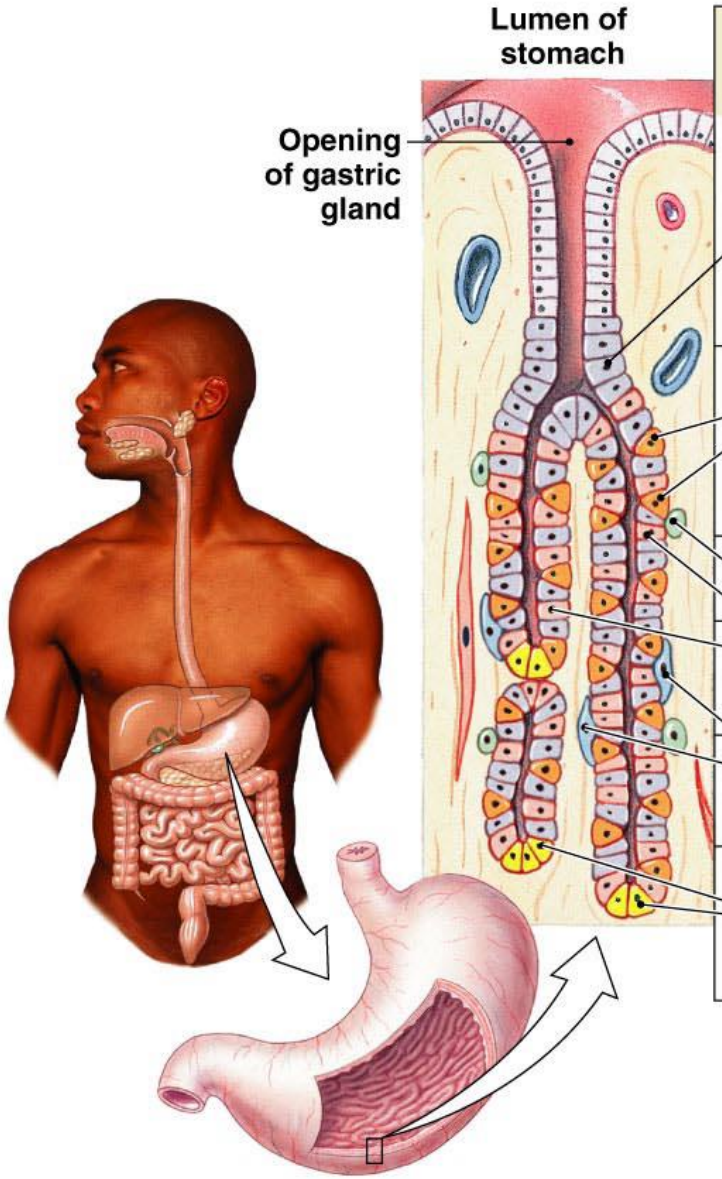
Figure 23.15c

Glands of the Stomach Fundus and Body

- Gastric glands of the fundus and body have a variety of secretory cells
  - – Mucous neck cells – secrete acid mucus
- Parietal cells – secrete HCl and intrinsic factor
- Chief cells – produce pepsinogen

-Pepsinogen is activated to pepsin by:

  - – HCl in the stomach
  - – Pepsin itself via a positive feedback mechanism
- Enteroendocrine cells – secrete gastrin, histamine,endorphins, serotonin, cholecystokinin (CCK), and somatostatin into the lamina prop



Cell Types	Substance Secreted	Stimulus for Release	Function of Secretion
Mucous neck cell	Mucus	Tonic secretion; with irritation of mucosa	Physical barrier between lumen and epithelium
	Bicarbonate	Secreted with mucus	Buffers gastric acid to prevent damage to epithelium
Parietal cells	Gastric acid (HCl)	Acetylcholine, gastrin, histamine	Activates pepsin; kills bacteria
	Intrinsic factor		Complexes with vitamin B_{12} to permit absorption
Enterochromaffin-like cell	Histamine	Acetylcholine, gastrin	Stimulates gastric acid secretion
Chief cells	Pepsin(ogen)	Acetylcholine acid, secretin	Digests proteins
	Gastric lipase		Digests fats
D cells	Somatostatin	Acid in the stomach	Inhibits gastric acid secretion
G cells	Gastrin	Acetylcholine, peptides, and amino acids	Stimulates gastric acid secretion

Regulation and Mechanism of HCl Secretion

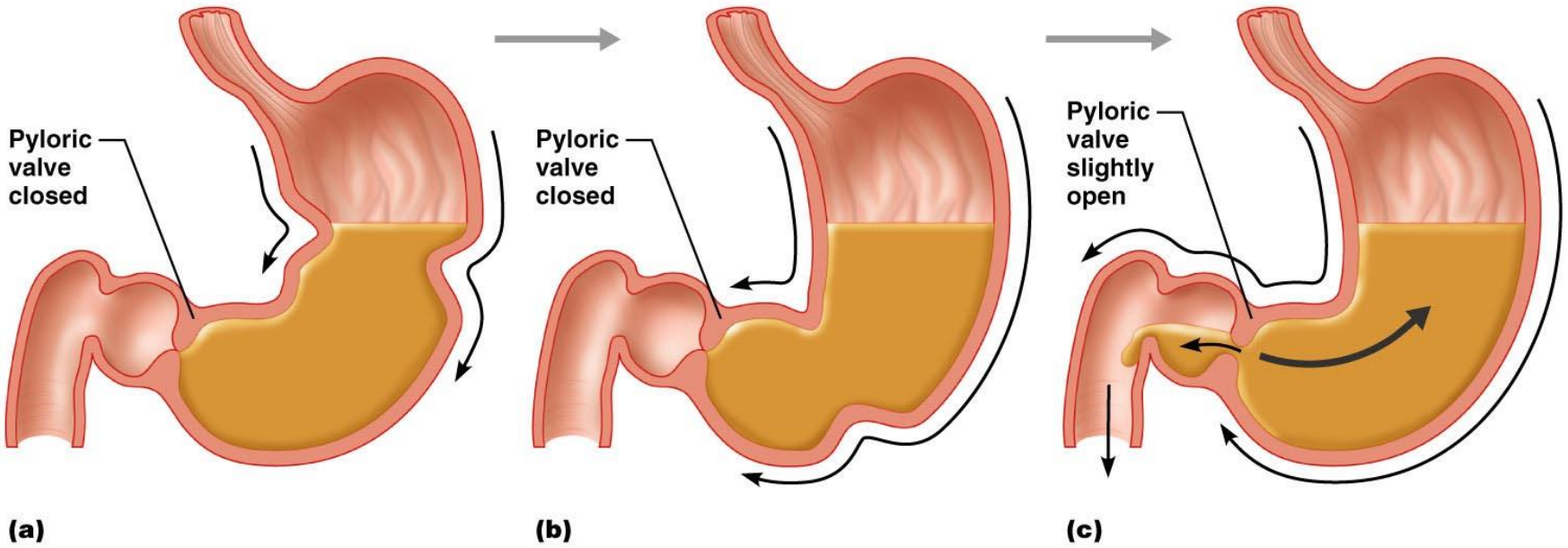
- HCl secretion is stimulated by ACh, histamine, and gastrin through second-messenger systems
- Release of hydrochloric acid:
  - Is low if only one ligand binds to parietal cells
  - Is high if all three ligands bind to parietal cells
- Antihistamines block H_2 receptors and decrease HCl release

Response of the Stomach to Filling

- Stomach pressure remains constant until about 1L of food is ingested
- Relative unchanging pressure results from reflex-mediated relaxation and plasticity
- Reflex-mediated events include:
  - Receptive relaxation – as food travels in the esophagus, stomach muscles relax
  - Adaptive relaxation – the stomach dilates in response to gastric filling
- Plasticity – intrinsic ability of smooth muscle to exhibit the stress-relaxation response

Gastric Contractile Activity

- Peristaltic waves move toward the pylorus at the rate of 3 per minute
- This basic electrical rhythm (BER) is initiated by pacemaker cells (cells of Cajal)
- Most vigorous peristalsis and mixing occurs near the pylorus
- Chyme is either:
  - delivered in small amounts to the duodenum or
  - Forced backward into the stomach for further mixing



Propulsion:
peristaltic wave moves from the fundus to the pylorus:
30 ml of chyme is held in the stomach each contraction of the stomach muscle squirts 3 ml of chyme.

Grinding: most vigorous peristalsis and mixing occur close to the pylorus, small amount of chyme is delivered in to the duodenum

Retropulsion: peristaltic wave closes the pyloric valve forcing most of the contents of the pylorus back in to the stomach

Figure 23.18

Regulation of Gastric secretion

- Neural and hormonal mechanisms regulate the release of gastric juice
- Stimulatory and inhibitory events occur in three phases:

	Excitatory	Inhibitory
Cephalic phase	Sight, taste, smell thinking about food	Loss of appetite or depression
Gastric phase	Release of gastrin to the blood, activation of stretch receptors, chemoreceptors by peptides, caffeine & rising PH	A PH lower than 2, emotional upset that override the Parasympathetic activation
Intestinal phase	Low PH, partially digested food enter the duodenum & encourages gastric gland activity	Distention of the duodenum, presence of fatty, acidic or hypertonic chyme

Regulation of Gastric Emptying

- Gastric emptying is regulated by:
  - The neural enterogastric reflex
  - Hormonal (enterogastrone) mechanisms
- These mechanisms inhibit gastric secretion and duodenal filling

Regulation of Gastric Emptying

- Carbohydrate-rich chyme quickly moves through the duodenum
- Fat-laden chyme is digested more slowly causing food to remain in the stomach longer

Small Intestine: Gross Anatomy

- Runs from pyloric sphincter to the ileocecal Valve, about 2 to 4 miters long
- Has three subdivisions: duodenum (10%), jejunum (40%), and ileum (55%)

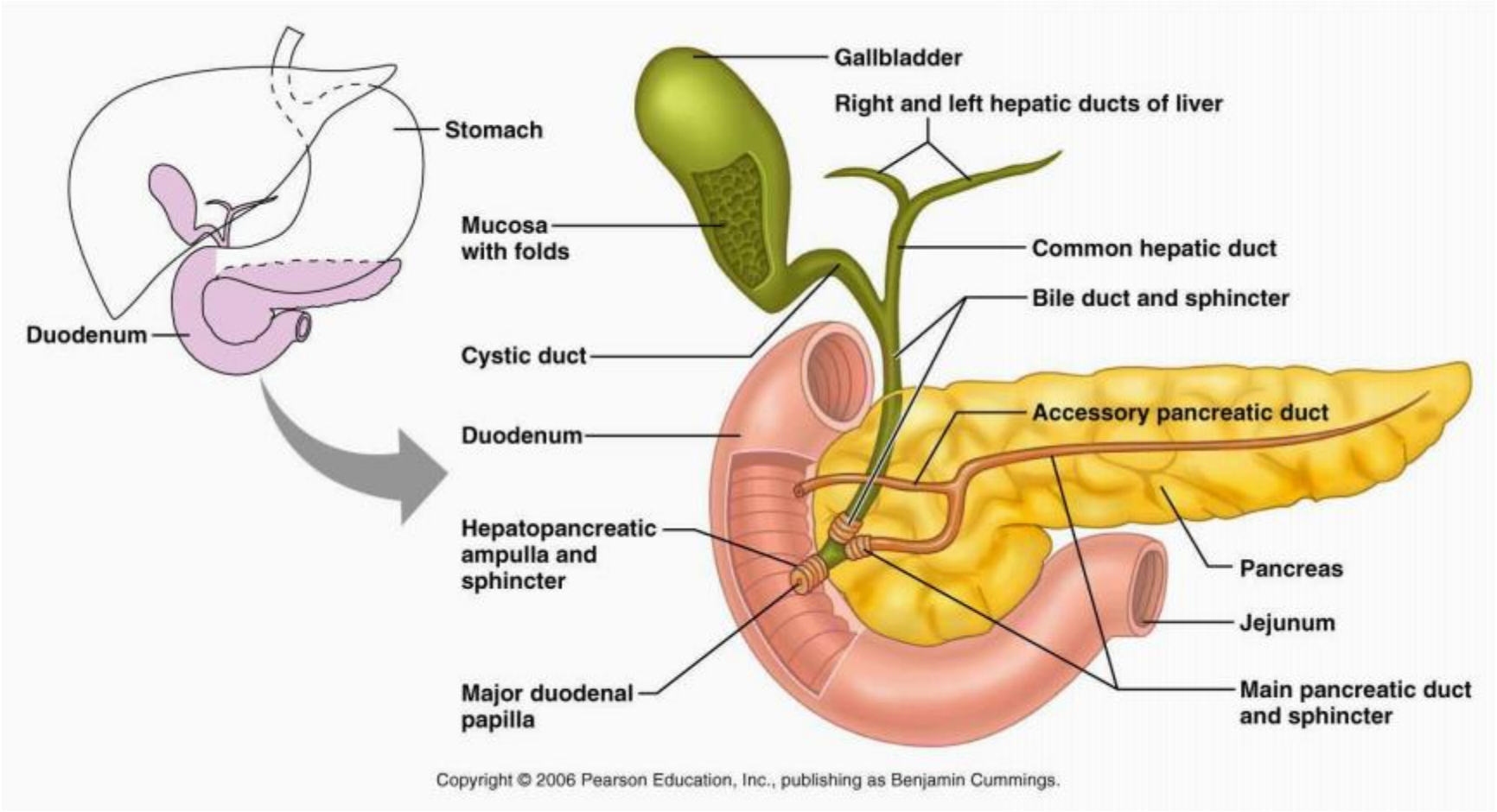
Small Intestine: Gross Anatomy

- The bile duct and main pancreatic duct:
  - Join the duodenum at the hepatopancreatic ampulla
  - Are controlled by the sphincter of Oddi
- The jejunum extends from the duodenum to the ileum
- The ileum joins the large intestine at the ileocecal valve

Small Intestine: Microscopic Anatomy

- Structural modifications of the small intestine wall increase surface area
  - Plicae circulares: deep circular folds of the mucosa and submucosa
  - Villi – fingerlike extensions of the mucosa
  - Microvilli – tiny projections of absorptive mucosal cells' plasma membranes

Duodenum and Related Organs



Small Intestine: Microscopic Anatomy

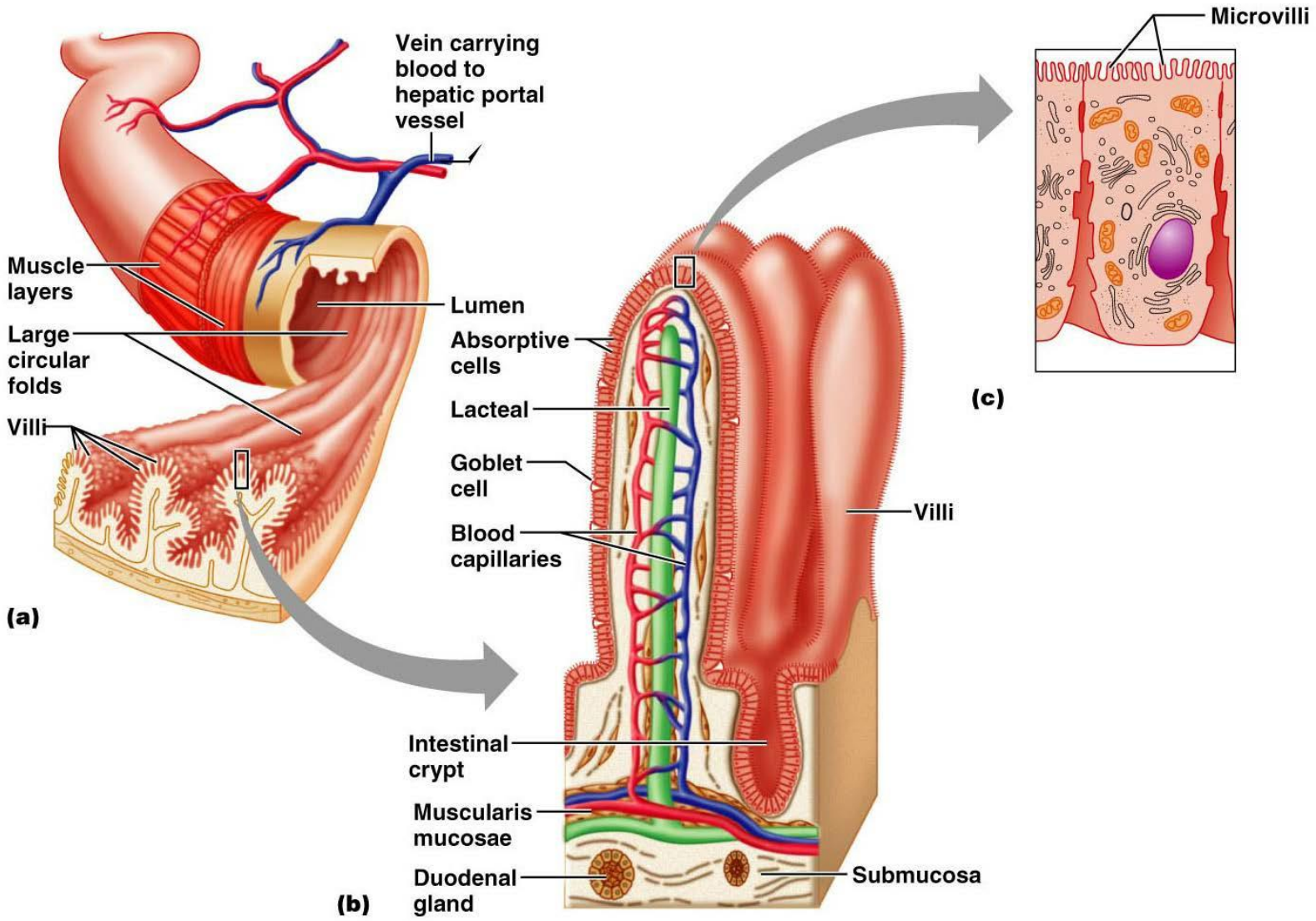
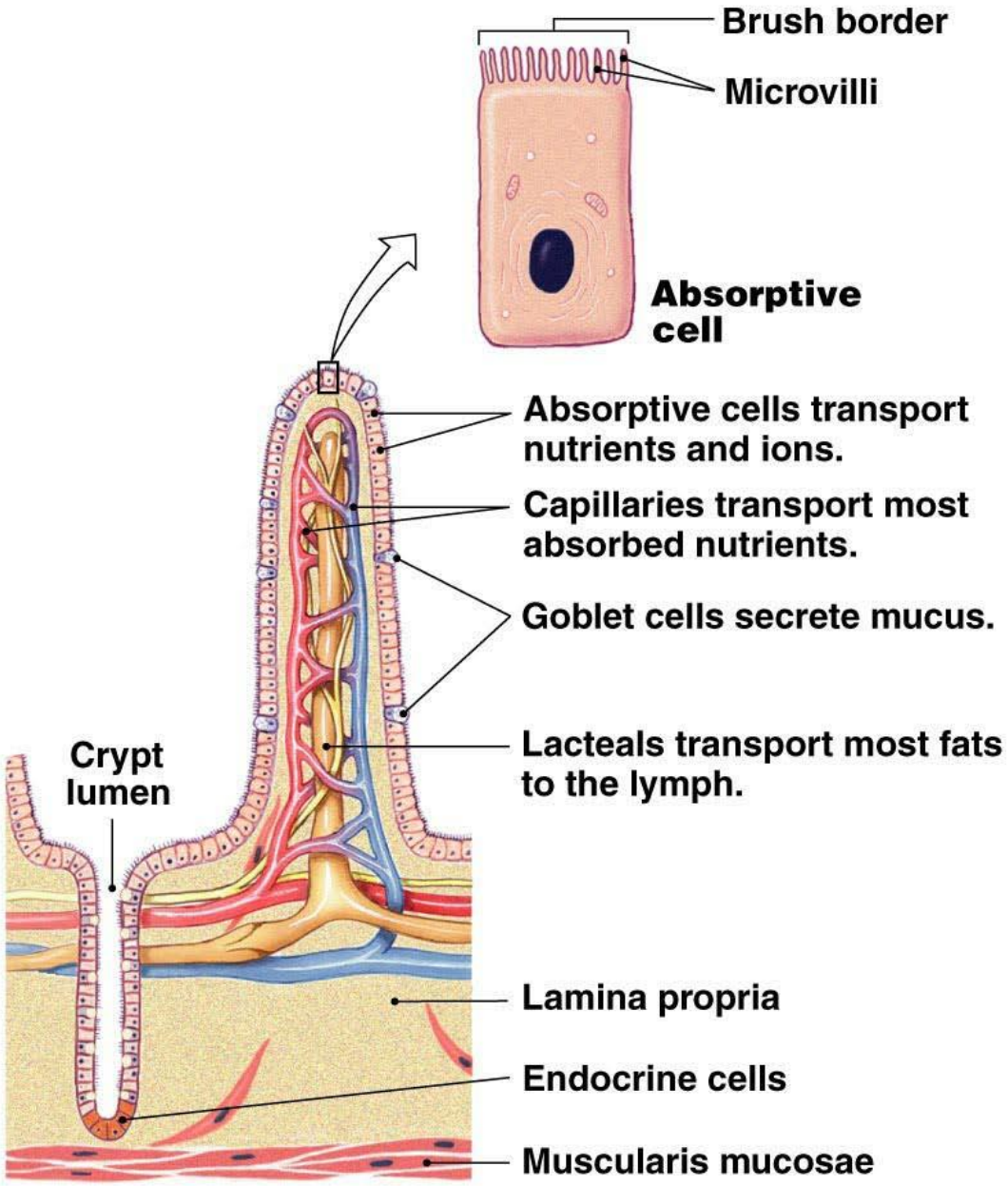


Figure 23.21



Small Intestine: Histology of the Wall

- The epithelium of the mucosa is made up of:
  - Absorptive cells and goblet cells
  - Enteroendocrine cells
  - Interspersed T cells called intraepithelial lymphocytes (IELs)

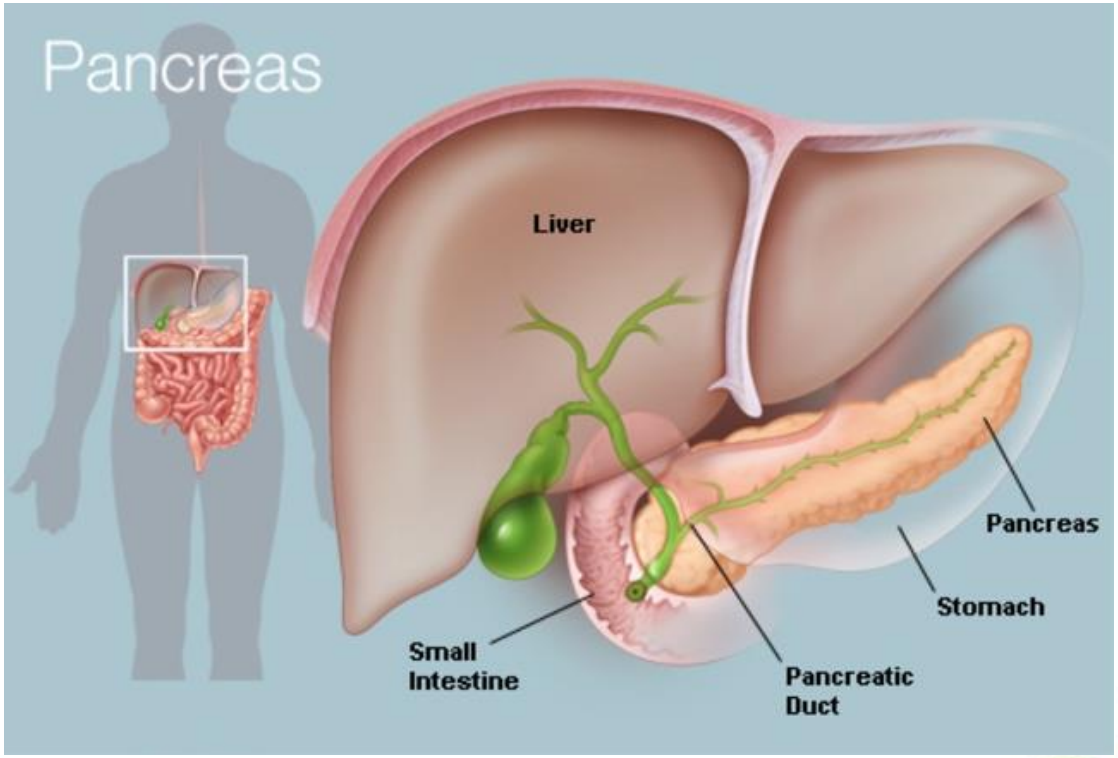
-Cells of intestinal crypts secrete intestinal juice

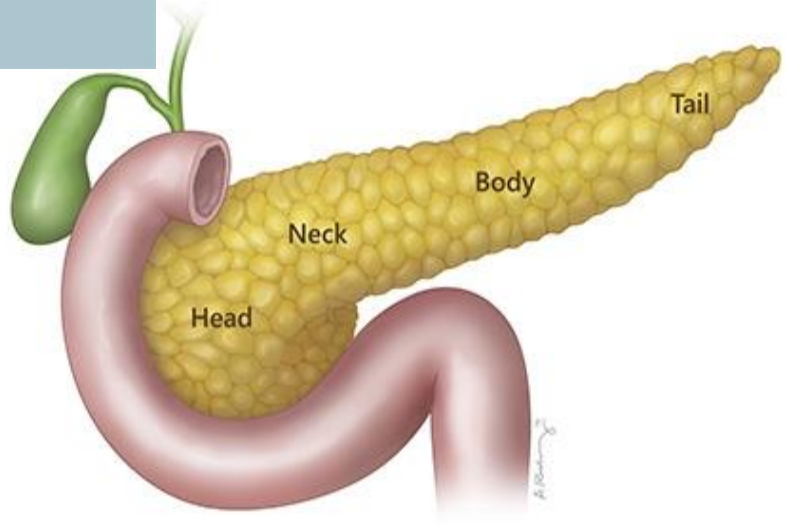
-Peyer ’s patches are lymphatic tissues found in the submucosa, increase in numbers toward the end of the small intestine

-Brunner’s glands in the duodenum secrete alkaline mucus

Intestinal Juice

- Secreted by intestinal glands in response to distension or irritation of the mucosa
- Slightly alkaline and isotonic with blood plasma
- Largely water, enzyme-poor, but contains mucus





Liver

- The largest gland in the body
- Superficially has four lobes – right, left, caudate, and quadrate
- The falciform ligament:
  - Separates the right and left lobes anteriorly
  - Suspends the liver from the diaphragm and anterior abdominal wall

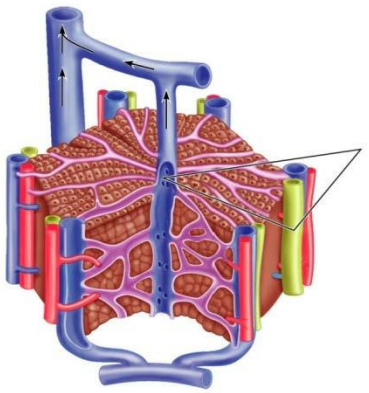
Liver: Associated Structures

- Bile leaves the liver via:
- right and left hepatic ducts, which fuse into the common hepatic duct

- The common hepatic duct fuses with the cystic duct to form the common Bile duct

Liver: Microscopic Anatomy

- Hexagonal-shaped liver lobules are the structural and functional units of the liver
- Composed of hepatocyte (liver cell) plates radiating outward from a central vein
- Portal triads are found at each of the six corners of each liver lobule



(c)

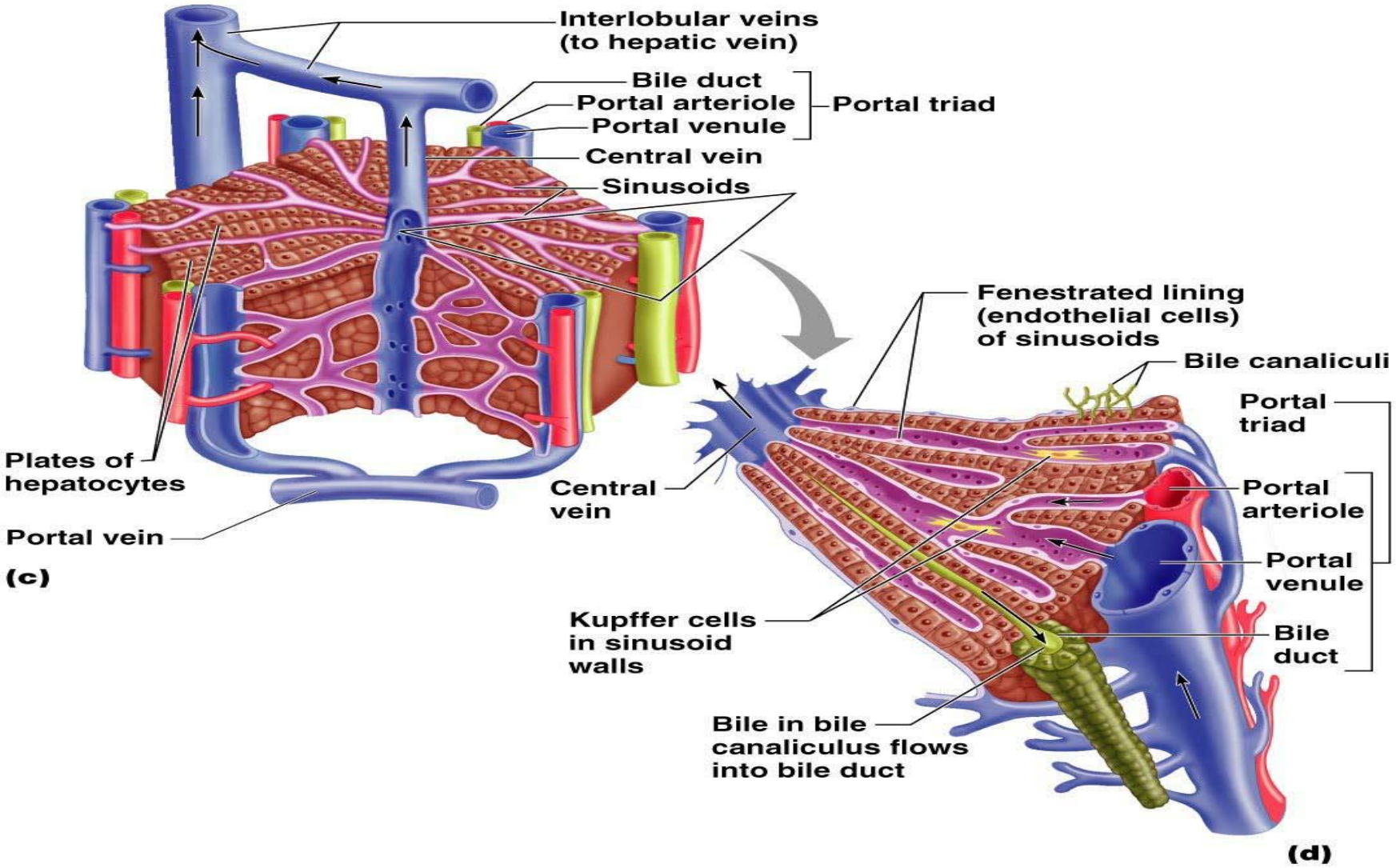
Liver: Microscopic Anatomy

- Portal triads consist of a bile duct and
  - Hepatic artery – supplies oxygen-rich blood to the liver
  - Hepatic portal vein – carries venous blood with nutrients from digestive viscera
- Liver sinusoids – enlarged, leaky capillaries located between hepatic plates
- Kupffer cells – hepatic macrophages found in liver sinusoids

Liver: Microscopic Anatomy

- Hepatocytes' functions include:
  - Production of bile
  - Processing bloodborne nutrients
  - Storage of fat-soluble vitamins
  - Detoxification
- Secreted bile flows between hepatocytes toward the bile ducts in the portal triads

Microscopic Anatomy of the Liver



Composition of Bile

- A yellow-green, alkaline solution containing bile salts, bile pigments, cholesterol, neutral fats, phospholipids, and electrolytes
  - Bile salts are cholesterol derivatives that:
  - Emulsify fat
  - Facilitate fat and cholesterol absorption
  - Help solubilize cholesterol
- Enterohepatic circulation recycles bile salts
- The chief bile pigment is bilirubin, a waste product of heme

The Gallbladder

- Thin-walled, green muscular sac on the ventral surface of the liver
- Stores and concentrates bile by absorbing its water and ions
- Releases bile via the cystic duct, which flows into the bile duct

Regulation of Bile Release

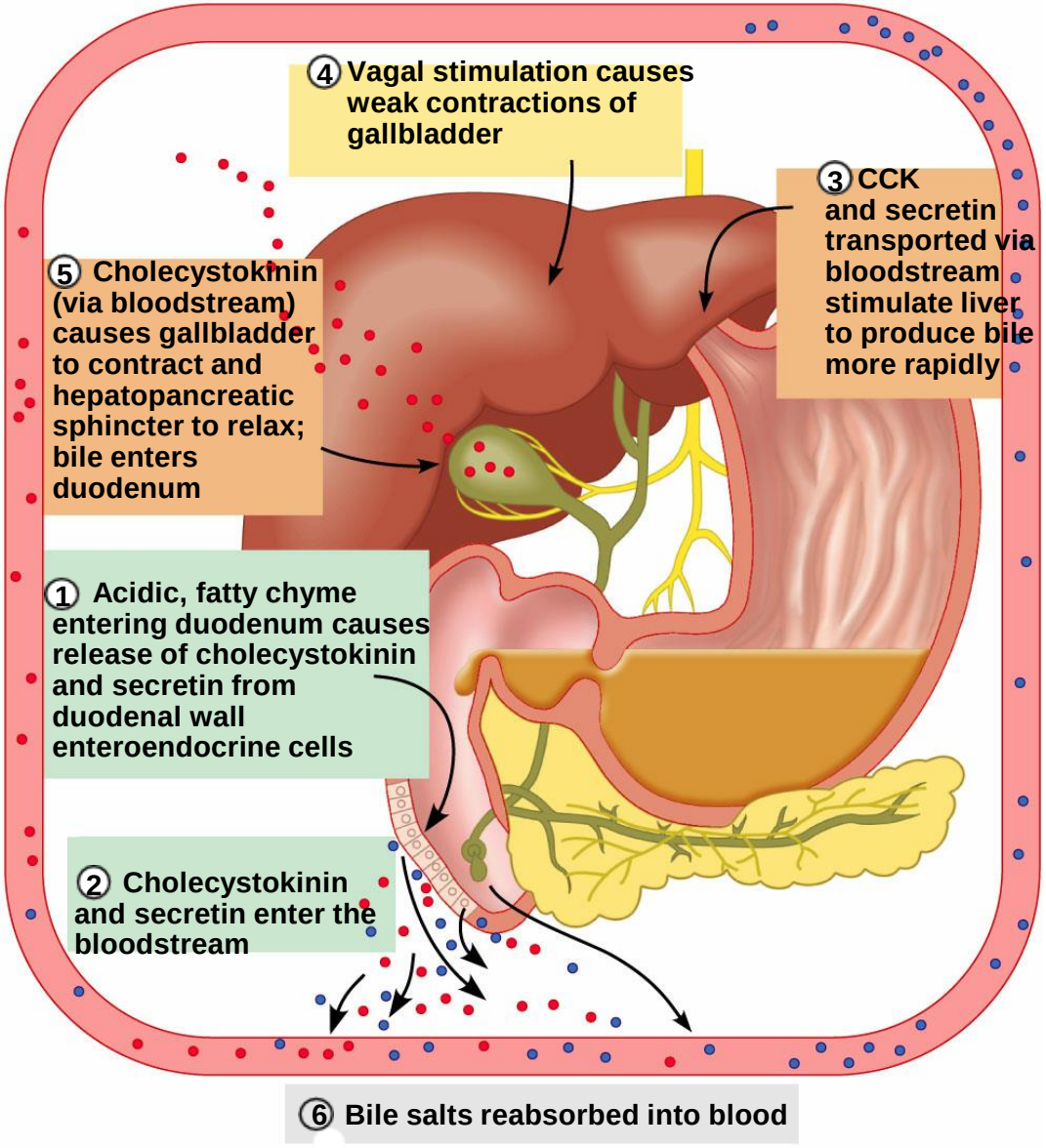


Figure 23.25

Pancreas

- Location
  - Lies deep to the greater curvature of the stomach
  - The head is encircled by the duodenum and the tail abuts the spleen

Pancreas

- Exocrine function
  - Secretes pancreatic juice which breaks down all categories of foodstuff
  - Acini (clusters of secretory cells) contain zymogen granules with digestive enzymes
- The pancreas also has an endocrine function – release of insulin and glucagon

Acinus of the Pancreas

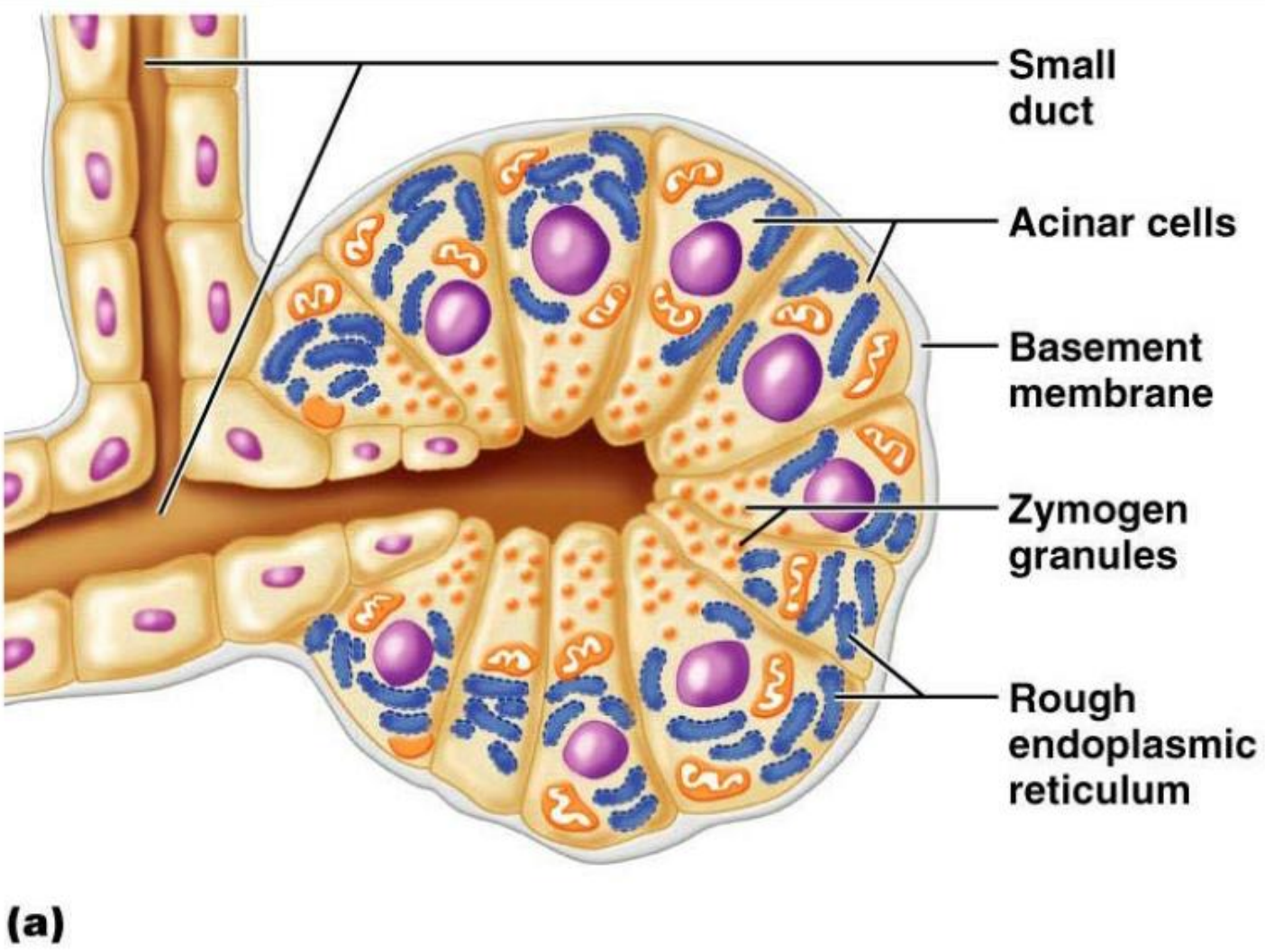


Figure 23.26a

Pancreatic Activation

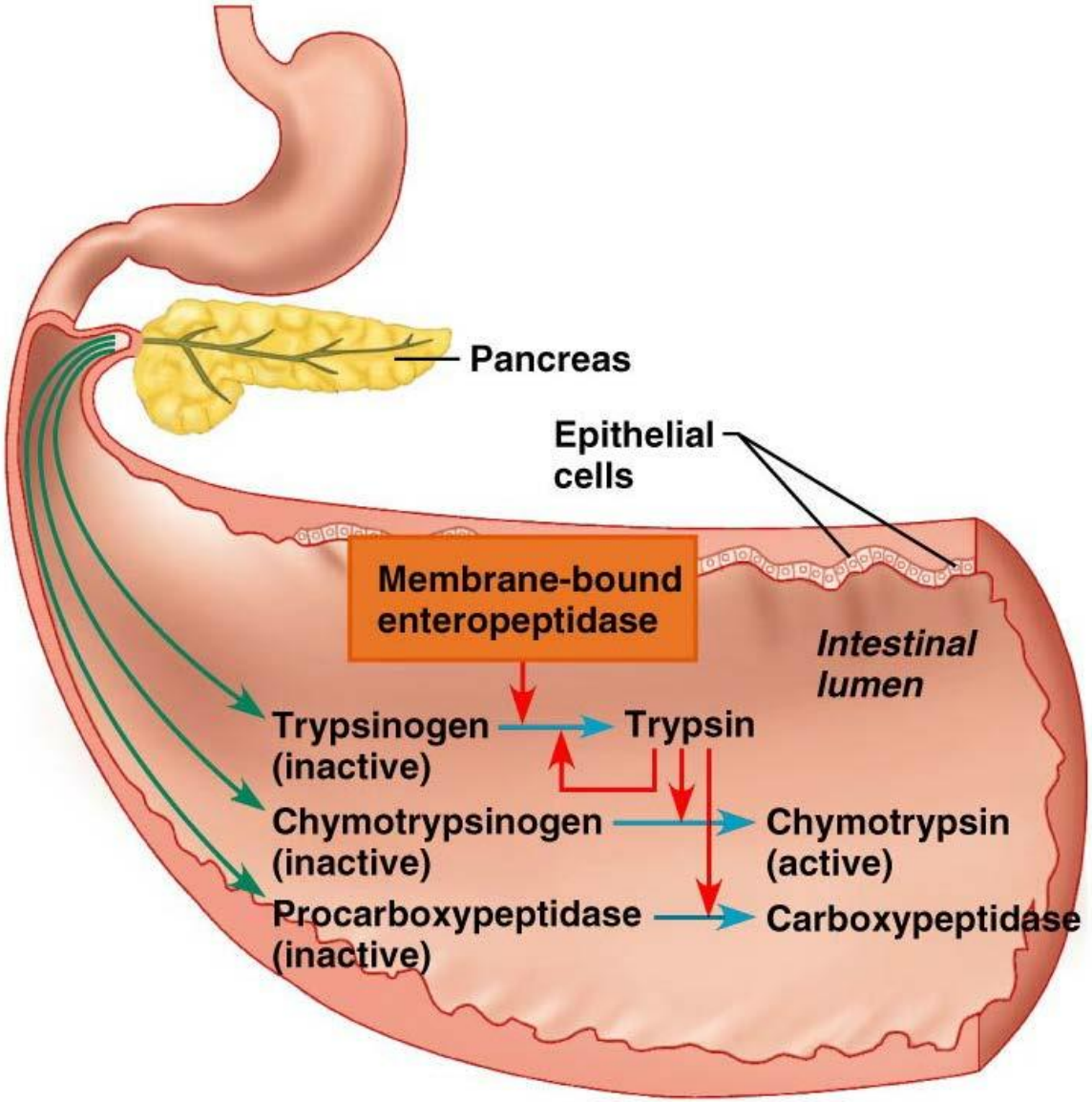


Figure 23.27

Composition and Function of Pancreatic Juice

- Water solution of enzymes and electrolytes (primarily HCO_3^-)
  - Neutralizes acid chyme
  - Provides optimal environment for pancreatic enzymes
- Enzymes are released in inactive form and activated in the duodenum

Composition and Function of Pancreatic Juice

- Examples include
  - Trypsinogen is activated to trypsin
  - Procarboxypeptidase is activated to carboxypeptidase
- Active enzymes secreted
  - Amylase, lipases, and nucleases
  - These enzymes require ions or bile for optimal activity

Regulation of Pancreatic Secretion

- Secretin and CCK are released when fatty or acidic chyme enters the duodenum
- CCK and secretin enter the bloodstream
- Upon reaching the pancreas:
  - CCK induces the secretion of enzyme-rich pancreatic juice
  - Secretin causes secretion of bicarbonate-rich pancreatic juice
- Vagal stimulation also causes release of pancreatic juice

Regulation of Pancreatic Secretion

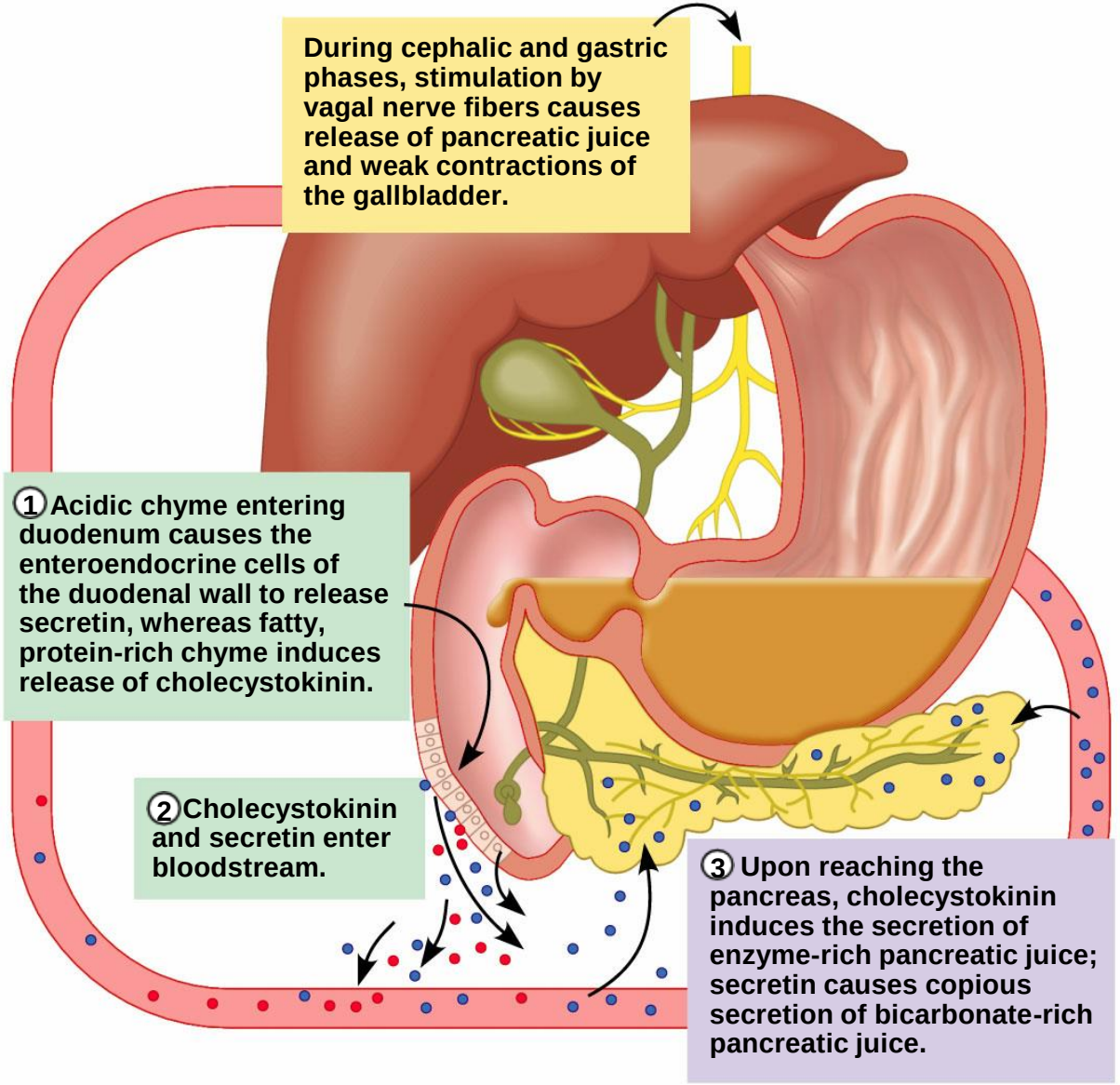


Figure 23.28

Large Intestine

- Has three unique features:
  - Teniae coli – three bands of longitudinal smooth muscle in its muscularis
  - Haustra – pocketlike sacs caused by the tone of the teniae coli
  - Epiploic appendages – fat-filled pouches of visceral peritoneum

Large Intestine

- Is subdivided into the cecum, appendix, colon, rectum, and anal canal
- The saclike cecum:
  - Lies below the ileocecal valve in the right iliac fossa
  - Contains a wormlike vermiform appendix

Large Intestine

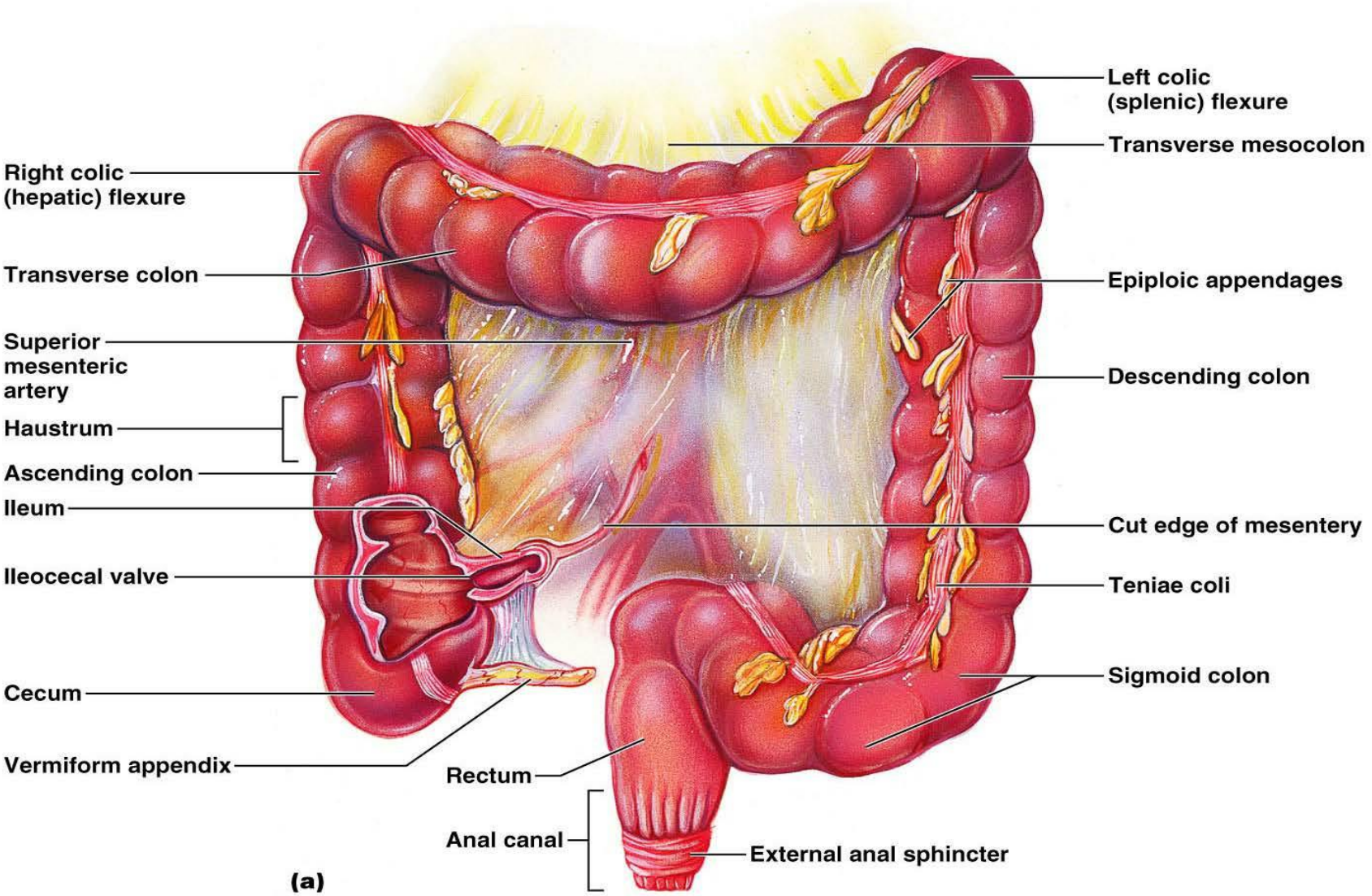


Figure 23.29a

Colon

- Has distinct regions: ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, and sigmoid colon
- The transverse and sigmoid portions are anchored via mesenteries called mesocolons
- The sigmoid colon joins the rectum

- The anal canal, the last segment of the large intestine, opens to the exterior at the anus

Bacterial Flora

- The bacterial flora of the large intestine consist of:
  - Bacteria surviving the small intestine that enter the cecum and
    - Those entering via the anus
- These bacteria:
  - Colonize the colon
  - Ferment indigestible carbohydrates
  - Release irritating acids and gases (flatus)
  - Synthesize B complex vitamins and vitamin K

Functions of the Large Intestine

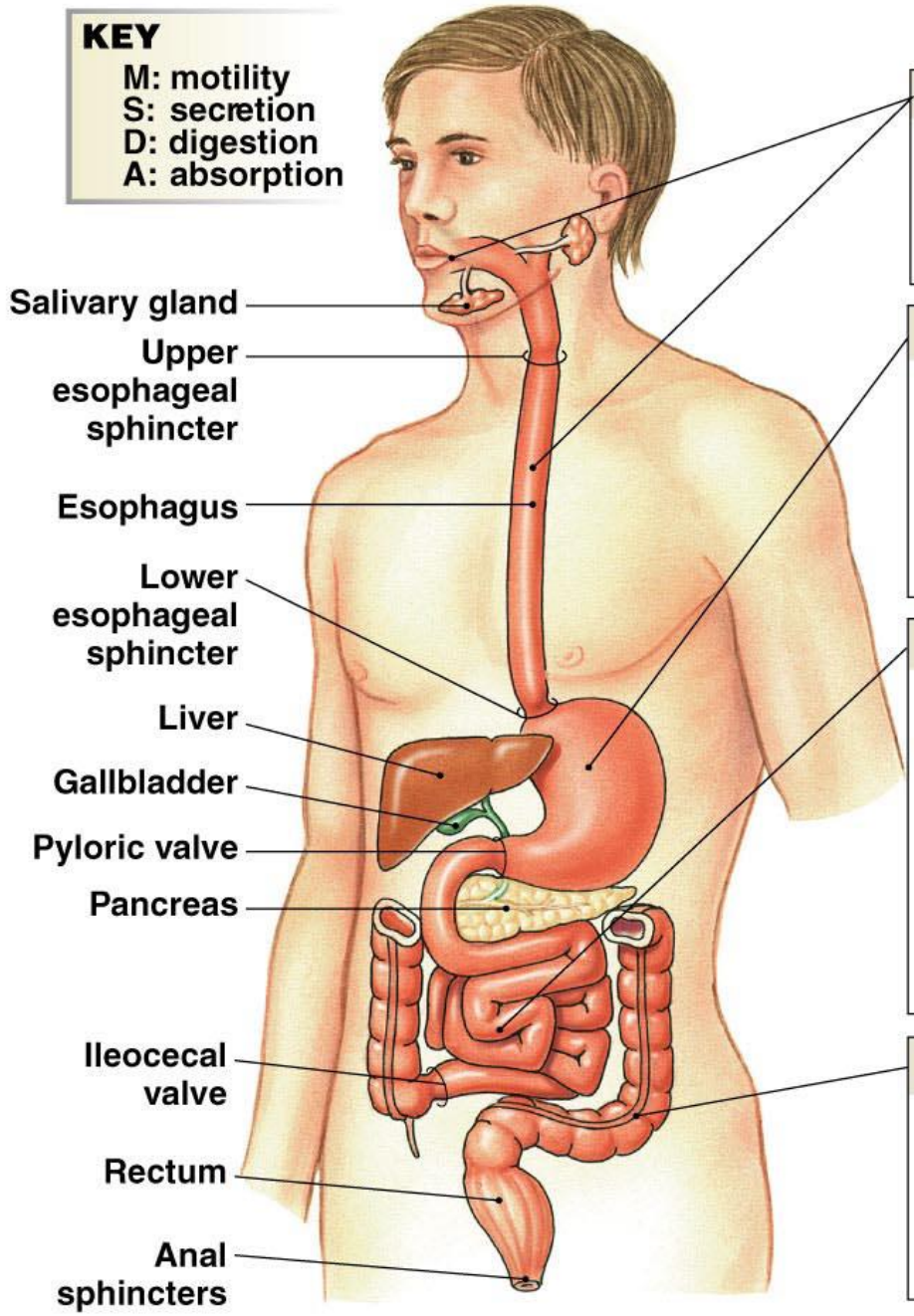
- Other than digestion of enteric bacteria, no further digestion takes place
- Vitamins, water, and electrolytes are reclaimed
- Its major function is propulsion of fecal material toward the anus

TABLE 21-1 The Digestive Hormones

	SECRETED BY	TARGET(S)	EFFECTS ON ENDOCRINE SECRETION	EFFECTS ON EXOCRINE SECRETION
Gastrin	G cells in stomach antrum	ECL cells; parietal cells	None	Stimulates gastric acid
Cholecystokinin (CCK)	Endocrine cells of small intestine; neurons of brain and gut	Gallbladder, pancreas, gastric smooth muscle	None	Stimulates pancreatic enzyme secretion; potentiates bicarbonate secretion; inhibits acid secretion
Secretin	Endocrine cells in small intestine	Pancreas, stomach	None	Stimulates bicarbonate secretion; inhibits gastric acid and gastrin
Gastric inhibitory peptide (GIP)	Endocrine cells in small intestine	Beta cells of endocrine pancreas	Stimulates insulin release (feedforward mechanism)	Inhibits acid secretion
Motilin	Endocrine cells in small intestine	Smooth muscle of antrum and duodenum	None	None
Glucagon-like peptide 1	Endocrine cells in small intestine	Endocrine pancreas	Stimulates insulin release; inhibits glucagon release	Possibly inhibits acid secretion

TABLE 21-1 The Digestive Hormones

	EFFECTS ON MOTILITY	OTHER EFFECTS	STIMULUS FOR RELEASE	RELEASE INHIBITED BY	OTHER INFORMATION
Gastrin	None	Enhanced mucosal cell growth	Peptides and amino acids in lumen; gastrin releasing peptide and ACh in nervous reflexes	pH < 1.5; somatostatin	—
Cholecystokinin (CCK)	Stimulates gallbladder contraction for bile release; inhibits gastric emptying; promotes intestinal motility	Stimulates satiety	Fatty acids and some amino acids	Somatostatin	Some effects may be due to CCK as a neuropeptide rather than as a hormone
Secretin	Inhibits gastric emptying	None	Acid in small intestine	Somatostatin	—
Gastric inhibitory peptide (GIP)	None	Satiety and lipid metabolism(?)	Glucose, fatty acids, and amino acids in small intestine	NA	Acid inhibition questionable at physiological concentrations
Motilin	Stimulates migrating motor complex	Action in brain(?)	Fasting: periodic release every 1.5–2 hours by neural stimulus	NA	Changes associated with both constipation and diarrhea, but relationship is unclear
Glucagon-like peptide 1	Slows gastric emptying	Satiety	Mixed meal that includes carbohydrates or fats in the lumen	NA	Related to but not identical to pancreatic glucagon; acts in concert with GIP



ORAL CAVITY AND ESOPHAGUS

M: swallowing, chewing
S: saliva (salivary glands), lipase
D: carbohydrates, fats (minimal)
A: none

STOMACH

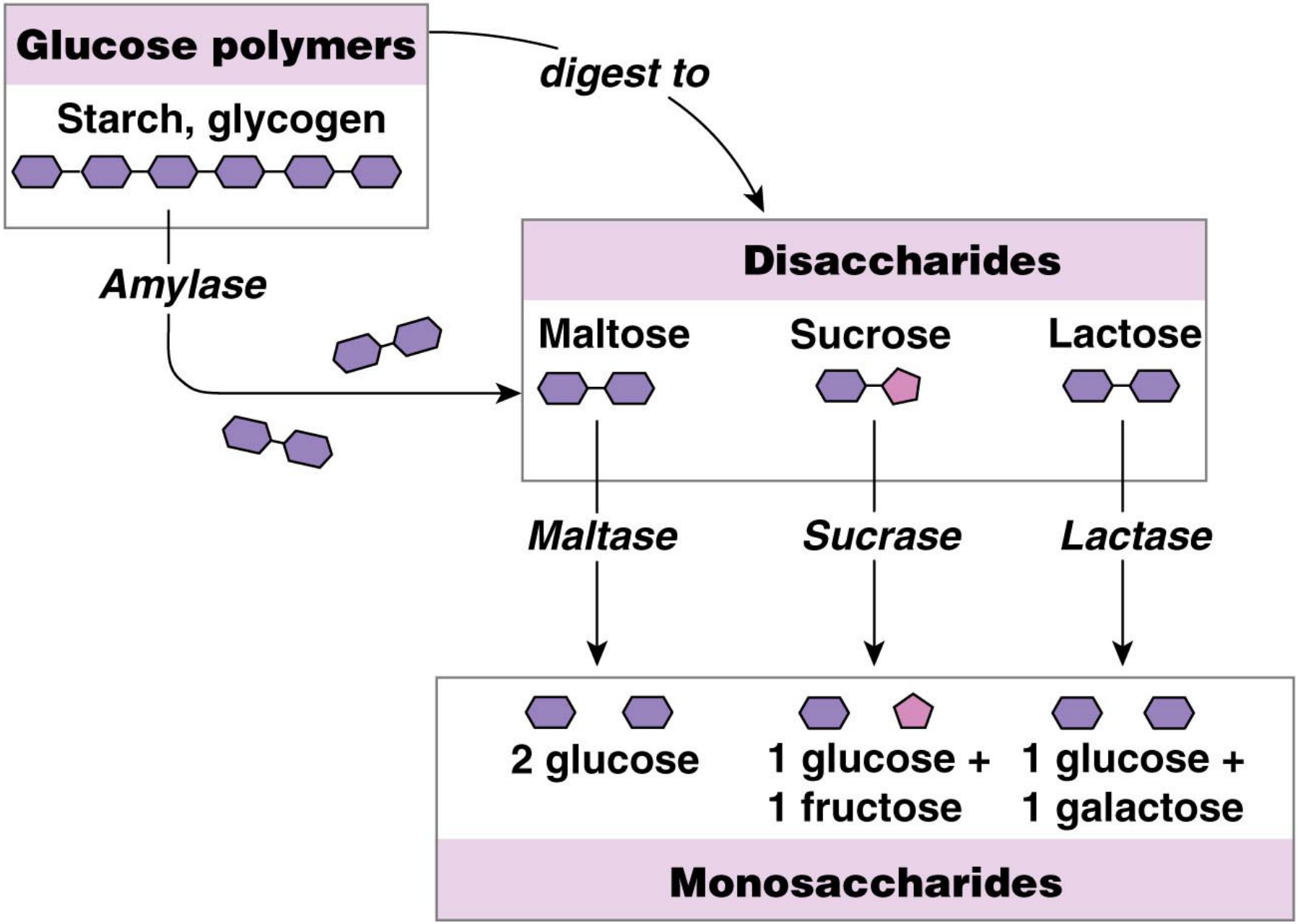
M: peristaltic mixing and propulsion
S: HCl (parietal cells); pepsinogen and gastric lipase (chief cells); mucus and HCO_3^- (surface mucous cells); gastrin (G cells); histamine (ECL cells)
D: proteins, fats
A: lipid-soluble substances such as alcohol and aspirin

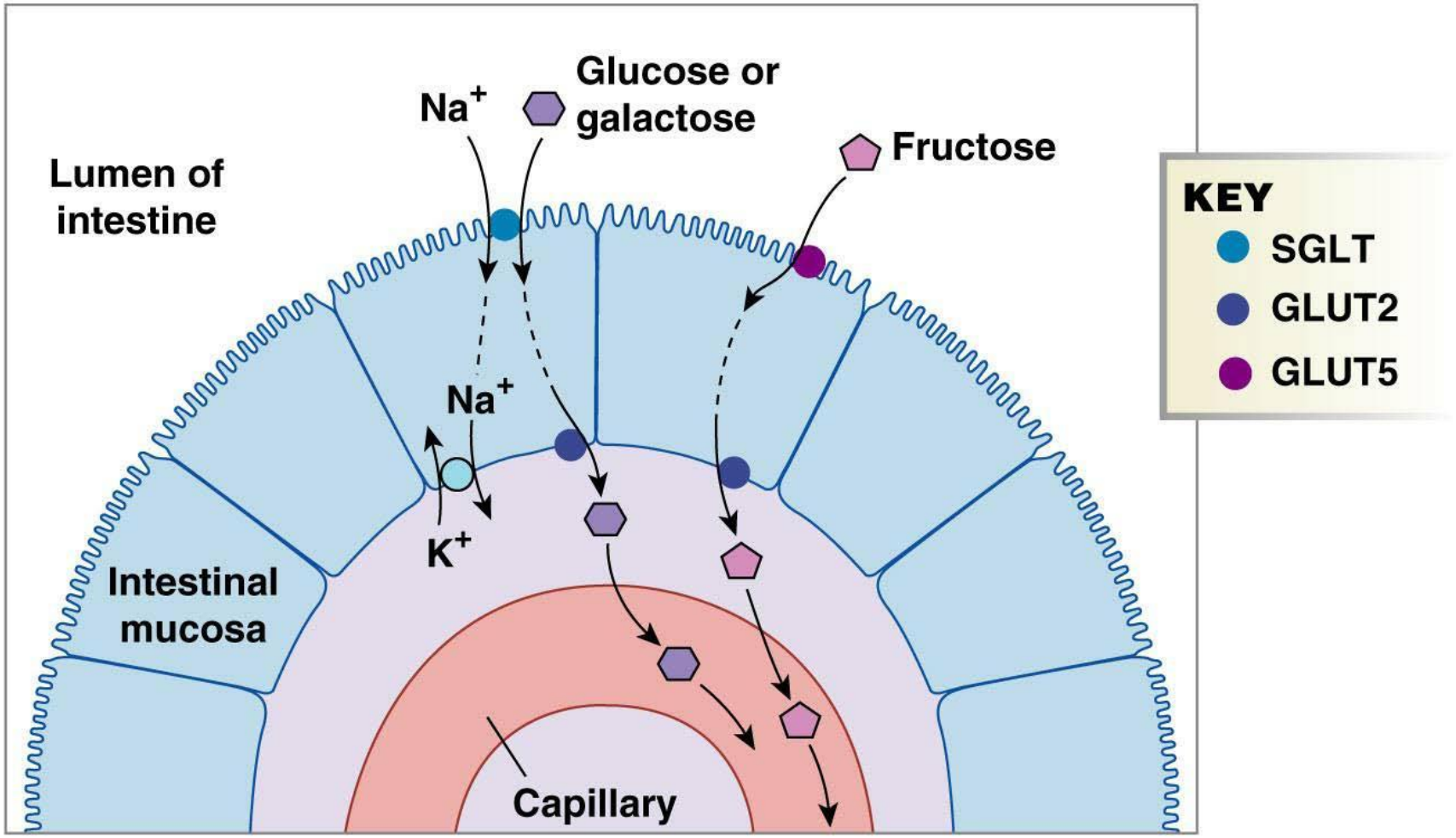
SMALL INTESTINE

M: mixing and propulsion primarily by segmentation;
S: enzymes; HCO_3^- and enzymes (pancreas); bile (liver); mucus (goblet cells); hormones: CCK, secretin, GIP, and other hormones
D: carbohydrates, fats, polypeptides, nucleic acids
A: peptides by active transport; amino acids, glucose, and fructose by secondary active transport; fats by simple diffusion; water by osmosis; ions minerals, and vitamins by active transport

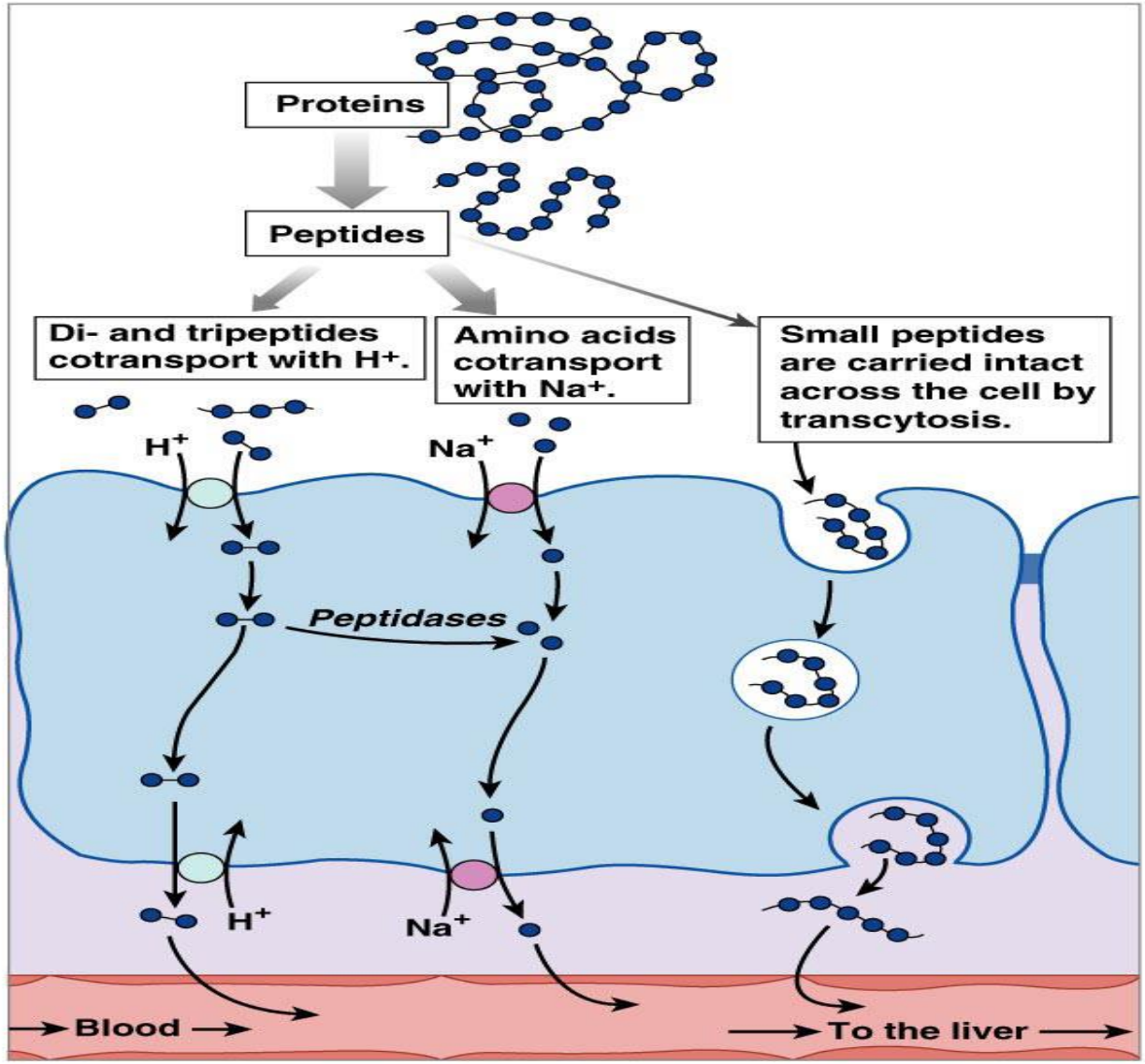
LARGE INTESTINE

M: segmental mixing; mass movement for propulsion
S: mucus (goblet cells)
D: none (except by bacteria)
A: ions, water, minerals, vitamins, and small organic molecles produced by bacteria

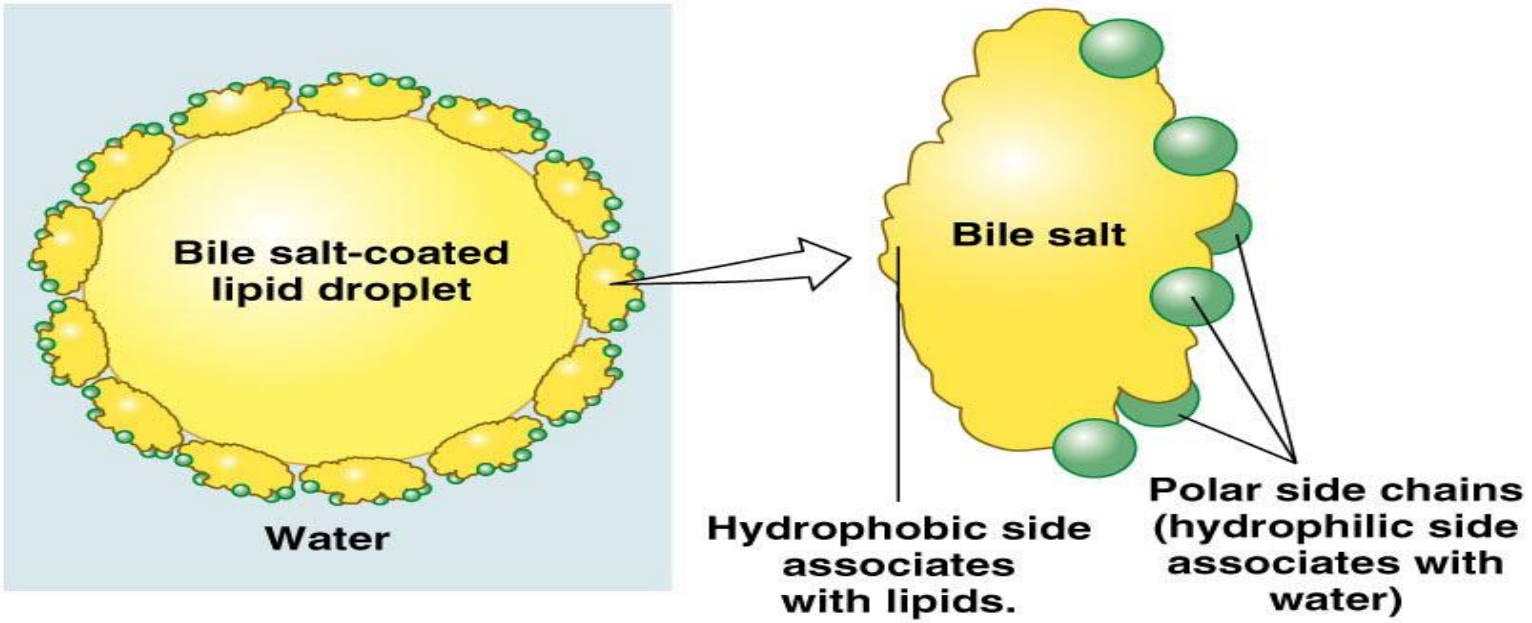




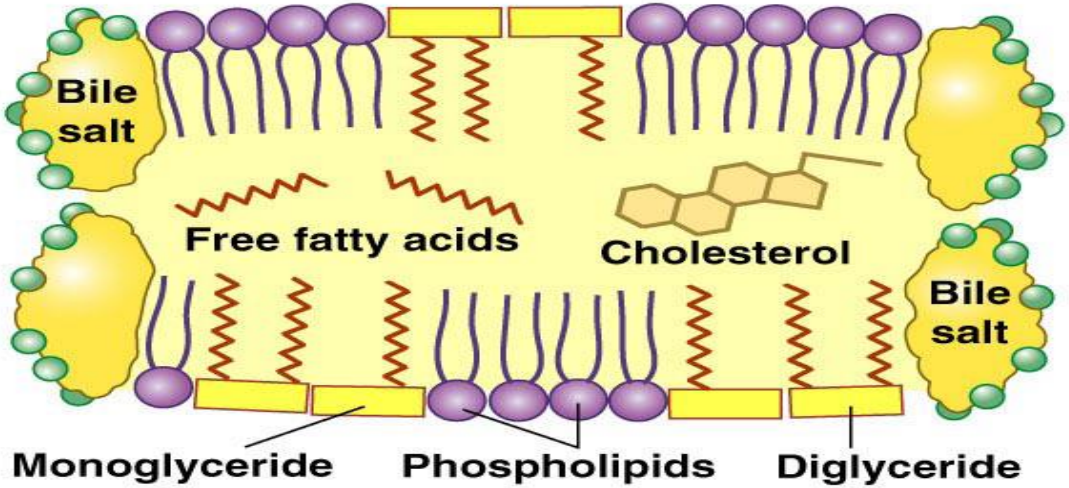
Glucose enters the cell with Na^+ on the SGLT symporter and exits on GLUT2. Fructose enters on GLUT5 and exits on GLUT 2.

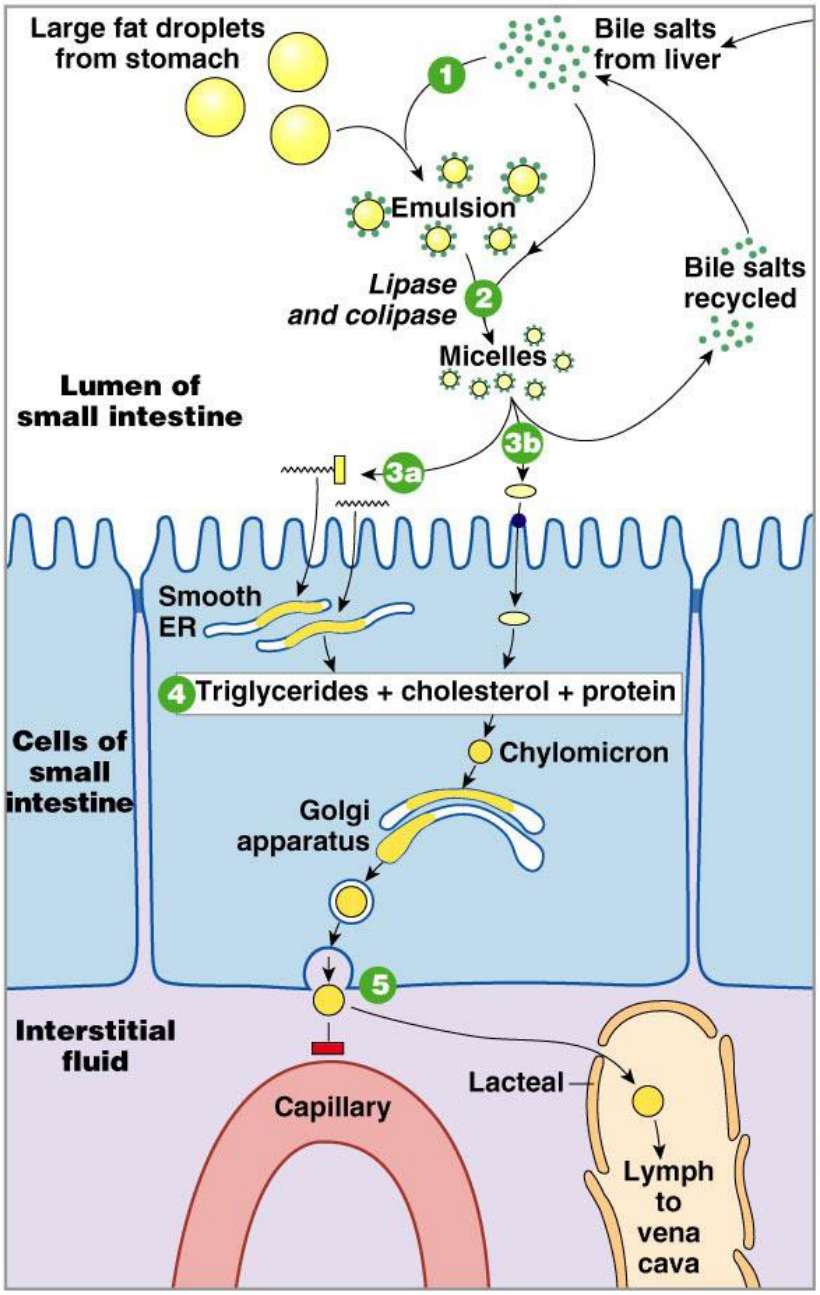


(a) Bile salts coat lipids to make emulsions.



(b) Micelles are small disks with bile salts, phospholipids, fatty acids, cholesterol, and mono- and diglycerides.





1. Bile salts from liver coat fat droplets.
2. Pancreatic lipase and colipase break down fats into monoglycerides and fatty acids stored in micelles.
3a. Monoglycerides and fatty acids move out of micelles and enter cells by diffusion.
3b. Cholesterol is transported into cells by a membrane transporter.
4. Absorbed fats combine with cholesterol and proteins in the intestinal cells to form chylomicrons.
5. Chylomicrons are released into the lymphatic system.

Chemical Digestion: Nucleic Acids

- Absorption: active transport via membrane carriers
- Absorbed in villi and transported to liver via hepatic portal vein
- Enzymes used: pancreatic ribonucleases and deoxyribonuclease in the small intestines

Electrolyte Absorption

- Most ions are actively absorbed along the length of small intestine
  - Na^+ is coupled with absorption of glucose and amino acids
  - Ionic iron is transported into mucosal cells where it binds to ferritin
- Anions passively follow the electrical potential established by Na^+

Electrolyte Absorption

- K^+ diffuses across the intestinal mucosa in response to osmotic gradients
- Ca^{2+} absorption:
  - Is related to blood levels of ionic calcium
  - Is regulated by vitamin D and parathyroid hormone (PTH)

Water Absorption

- 95% of water is absorbed in the small intestines by osmosis
- Water moves in both directions across intestinal mucosa
- Net osmosis occurs whenever a concentration gradient is established by active transport of solutes into the mucosal cells
- Water uptake is coupled with solute uptake, and as water moves into mucosal cells, substances follow along their concentration gradients

Malabsorption of Nutrients

- Results from anything that interferes with delivery of bile or pancreatic juice
- Factors that damage the intestinal mucosa (e.g., bacterial infection)
- Gluten enteropathy (adult celiac disease) – gluten damages the intestinal villi and reduces the length of microvilli
  - Treated by eliminating gluten from the diet (all grains but rice and corn)