Competency 5: The Digestive System

Upon successful completion of this course, the student will be able to understand the digestive system and its related functions by:

1. Naming and describing the major organs of digestion.
2. Explaining how food travels through the alimentary canal and discussing the mechanical and enzymatic activity occurring along the GI tract.
3. Listing and describing the factors that regulate food intake.

The Digestive System

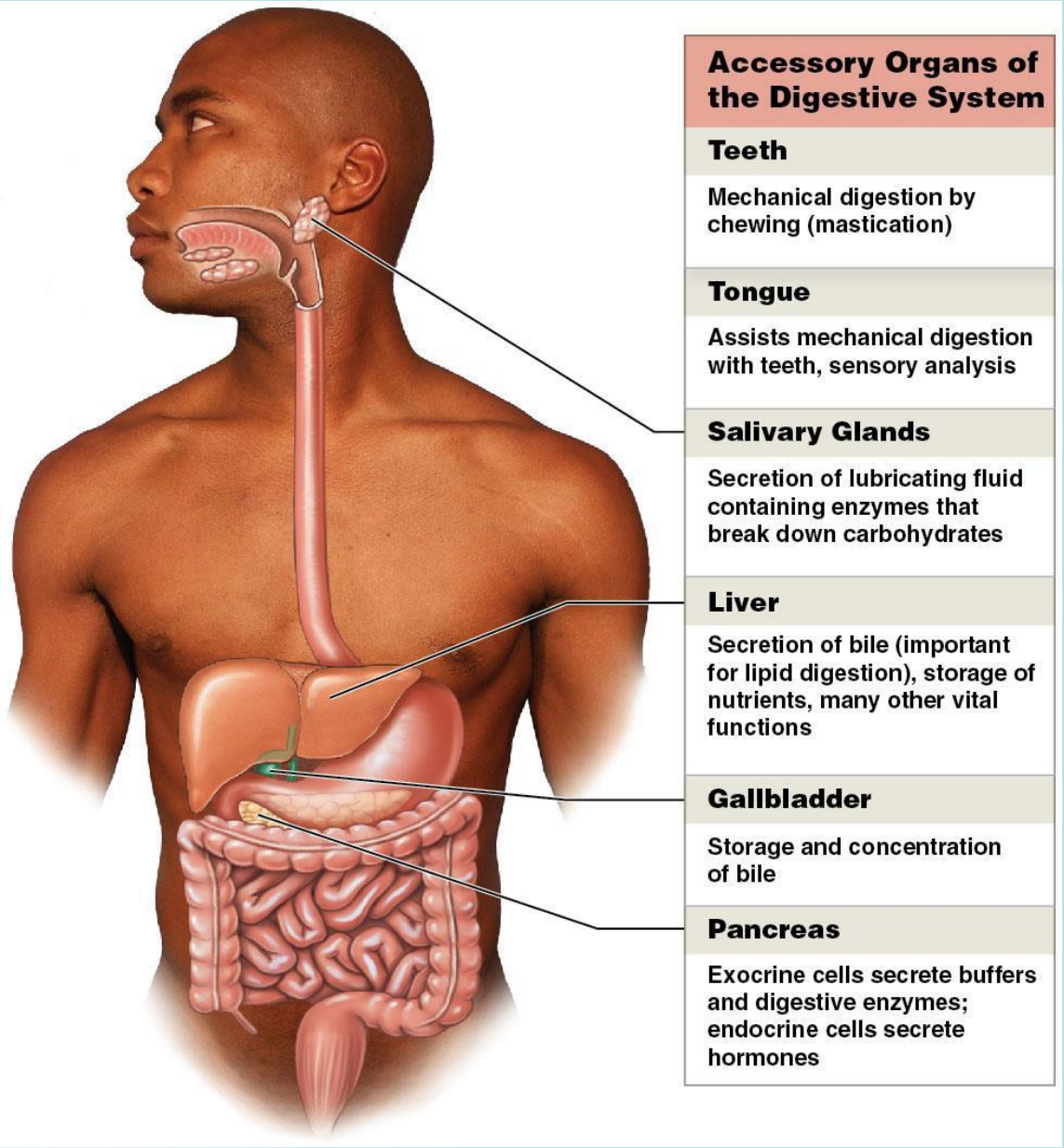
The function of the digestive system is to acquire nutrients from the solid and liquid foods we ingest and convert them by the processes of catabolism and anabolism, into molecules that can be used to grow, repair, and give energy to our body cells. The digestive system breaks down, absorbs, and dispose of waste molecules.

Digestive Organs

The Digestive Tract or Gastrointestinal tract: It is a continuous muscular tube that extends form mouth to anus. it digest and absorbs foods. It includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine or colon.

Accessory Digestive Organs: They help directly or indirectly in mechanical and chemical breakdown of food. They include the teeth, tongue, salivary glands, gallbladder, liver, and pancreas.

Figure 24-1
Organs of the Digestive System (Part 2 of 2).



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Major Organs of the Digestive Tract

Oral Cavity (Mouth)

Ingestion, mechanical digestion with accessory organs (teeth and tongue), moistening, mixing with salivary secretions

Pharynx

Muscular propulsion of materials into the esophagus

Esophagus

Transport of materials to the stomach

Stomach

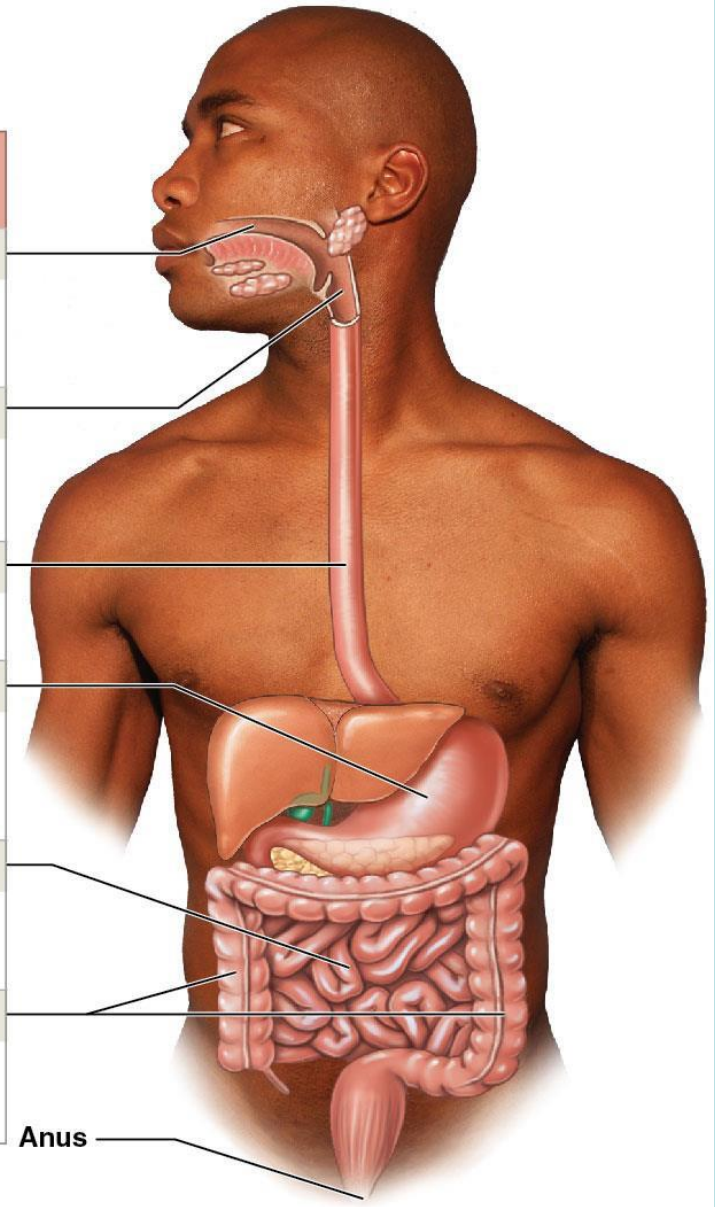
Chemical digestion of materials by acid and enzymes; mechanical digestion through muscular contractions

Small Intestine

Enzymatic digestion and absorption of water, organic substrates, vitamins, and ions

Large Intestine

Dehydration and compaction of indigestible materials in preparation for elimination



Digestive Tract Functions

1. **Ingestion:** it is the voluntary process of taking in food through the mouth or entering the oral cavity.
2. **Mechanical Processing:** includes all the movements of the food we ingest through the GI tract. The tearing and crushing by the teeth; the squashing and compacting by the tongue; the swallowing by the pharynx; and the peristalsis or involuntary process of waves of alternating contractions and relaxations that squeezes, swirls, churns, mixes and ultimately propels the food along the GI tract.
3. **Chemical Digestion:** it is the chemical break down of large un-absorbable molecules into small absorbable molecules. This process is carried out by hydrolytic enzymes that break large molecules such as the polysaccharides in starch into simple molecules such as the monosaccharide glucose.

These smaller molecules can then be absorbed by the digestive epithelium.

4. **Secretion:** it is the production and release of enzymes, hormones, water, acids, buffers, and salts carried out by the digestive epithelium and accessory organs of the GI tract.
5. **Absorption:** it is the passage of water, electrolytes, and the digested food products such as vitamins, glucose, amino acids, and others, across the digestive epithelium and into the GI tract interstitial fluid. These substances eventually move into the blood or lymph. Absorption occurs primarily at the small intestine.
6. **Excretion or Defecation:** it is the elimination of waste products (feces) out of the body in the process called defecation.

Feces are compacted, dehydrates wastes formed from undigested foods.

Lining of the Digestive Tract

It protects the surrounds tissues from: a- the corrosive effects of digestive acids and enzymes.; b- mechanical stressed like abrasion; c- bacteria that come in the food ingested or that reside in the digestive tract.

Relationships of Digestive Organs and Peritoneum

The peritoneal cavity of the abdominopelvic cavity is a slit like cavity lined by a serous membrane. It is the most extensive of the serous membranes. The serous membrane consists of a superficial mesothelium over a layer of areolar tissue.

The peritoneum is divided into the visceral peritoneum or serosa, which covers the organs inside; and the parietal peritoneum that lines the inner surfaces of the body walls. They secrete serous fluid to lubricate and reduce friction between the peritoneal surfaces. It separates the parietal and visceral surfaces.

Conditions such as liver and kidney disease, or heart failure can produce the accumulation of serous fluid, which cause abdominal swelling or inflammation called Ascites.

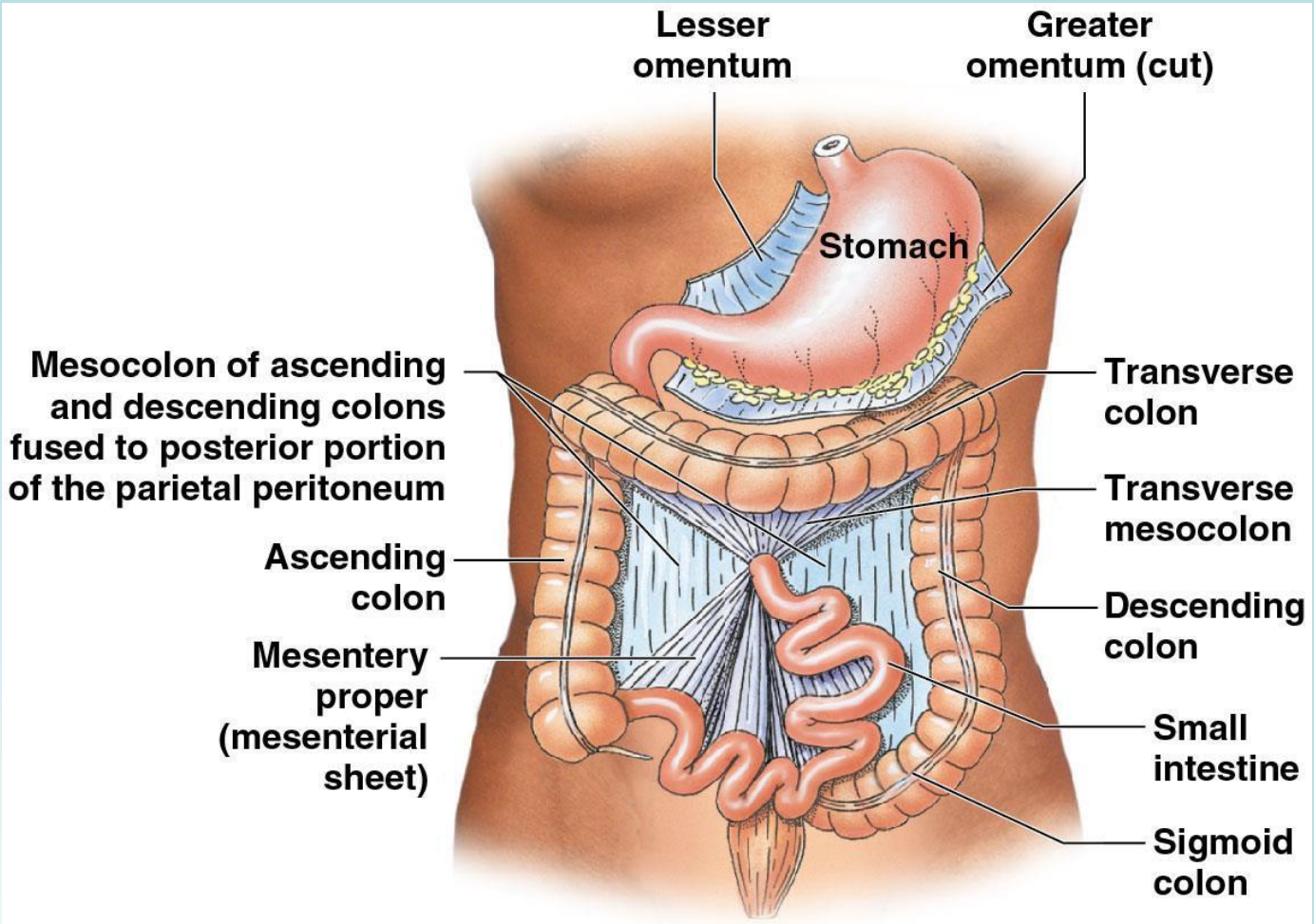
Mesenteries: They are sheets of serous membranes formed by the fused double layer of parietal peritoneum connecting both the visceral and the parietal membranes. They allow the passage of blood and lymphatic vessels, and nerves.

They hold the abdominopelvic organs in place, stabilizing their positions, so that they do not entangle when the body or digestive organs move.

The most important mesenteries include: **the lesser omentum** between the stomach and liver which stabilizes the stomach; the falciform ligament between the liver and anterior abdominal wall which stabilizes the liver;

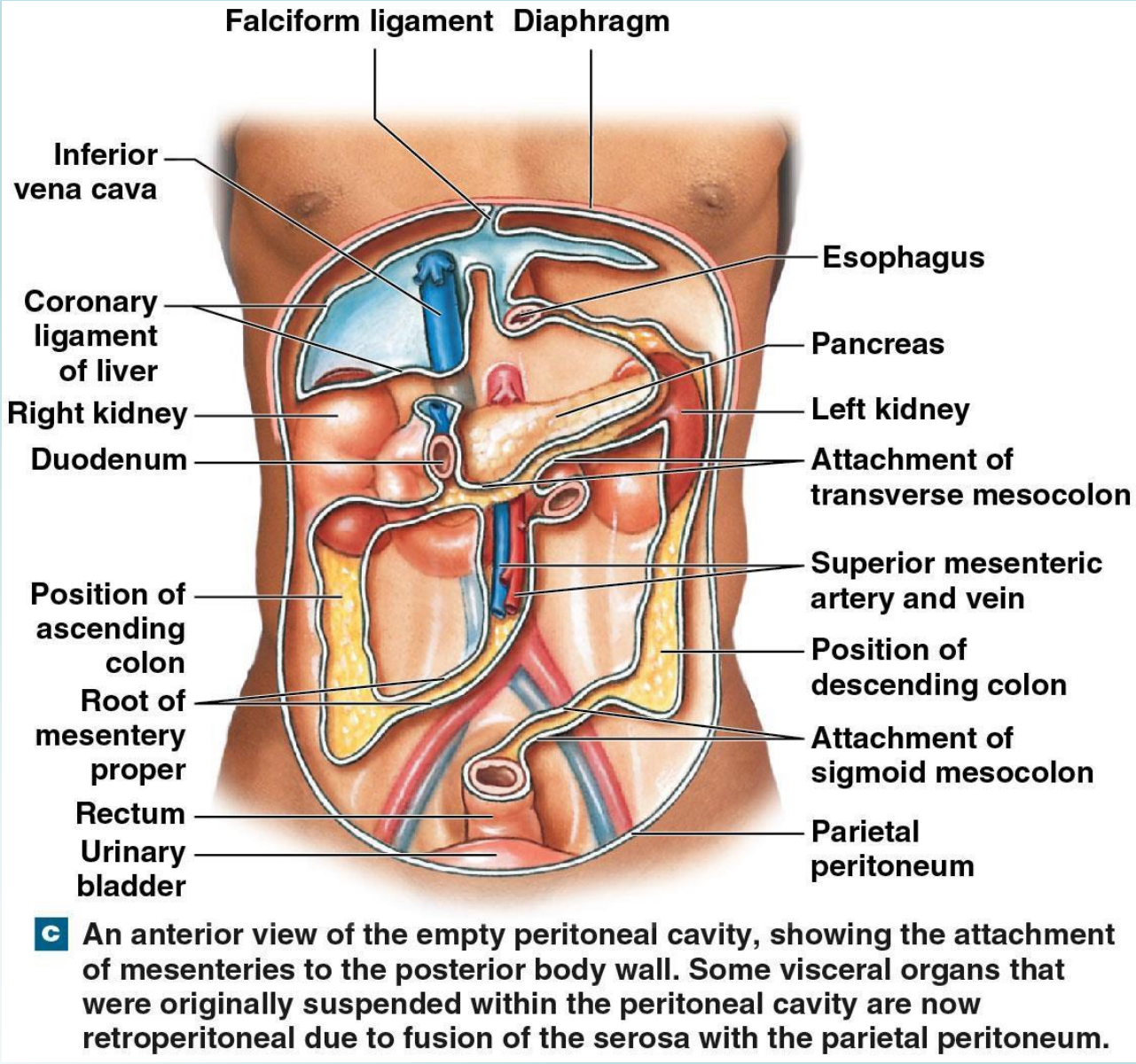
the **greater omentum** between the body wall and the anterior surface of the small intestine; the mesentery proper which holds most of the small intestine and covers the anterior surfaces of some of the retroperitoneal organs; and the mesocolons associated with the various parts of the large intestine. The adipose tissue in the greater omentum pads and protects the surfaces of the abdomen, provides insulation to reduce heat loss, stores lipid energy reserves, and contributes to the beer belly.

The retroperitoneal organs do not lie within the peritoneal cavity, but adhere to the dorsal abdominal wall. They include the esophagus, the duodenum, the ascending and descending colon, and most of the pancreas.



b A diagrammatic view of the organization of mesenteries in an adult. As the digestive tract enlarges, mesenteries associated with the proximal portion of the small intestine, the pancreas, and the ascending and descending portions of the colon fuse to the body wall.

A diagrammatic view of the organization of mesenteries in an adult. As the digestive tract enlarges, mesenteries associated with the proximal portion of the small intestine, the pancreas, and the ascending and descending portions of the colon fuse to the body wall.



C An anterior view of the empty peritoneal cavity, showing the attachment of mesenteries to the posterior body wall. Some visceral organs that were originally suspended within the peritoneal cavity are now retroperitoneal due to fusion of the serosa with the parietal peritoneum.

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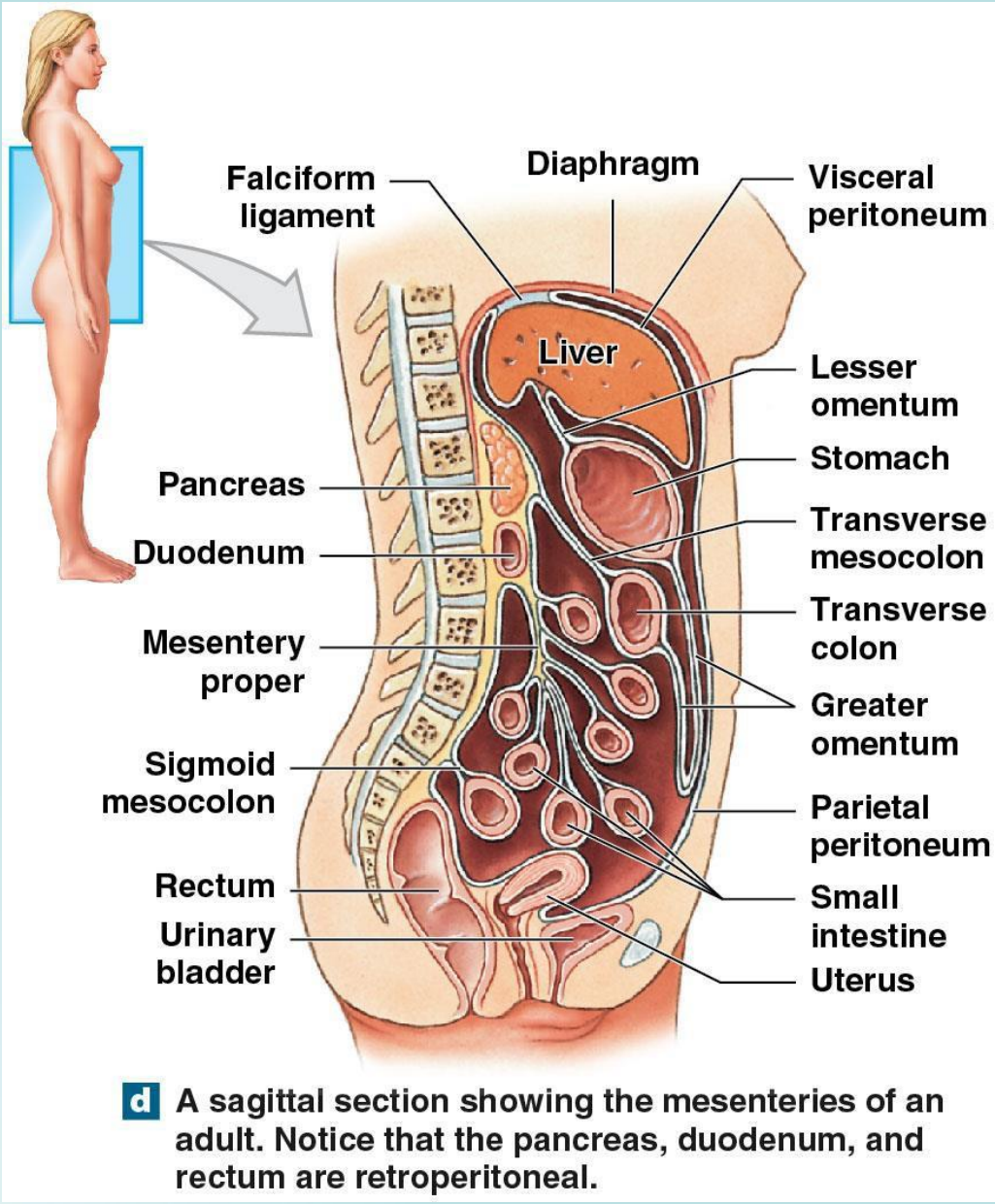


A sagittal section showing the mesenteries of an adult. Notice that the pancreas, duodenum, and rectum are retroperitoneal.

Histological Organization of the Digestive Tract

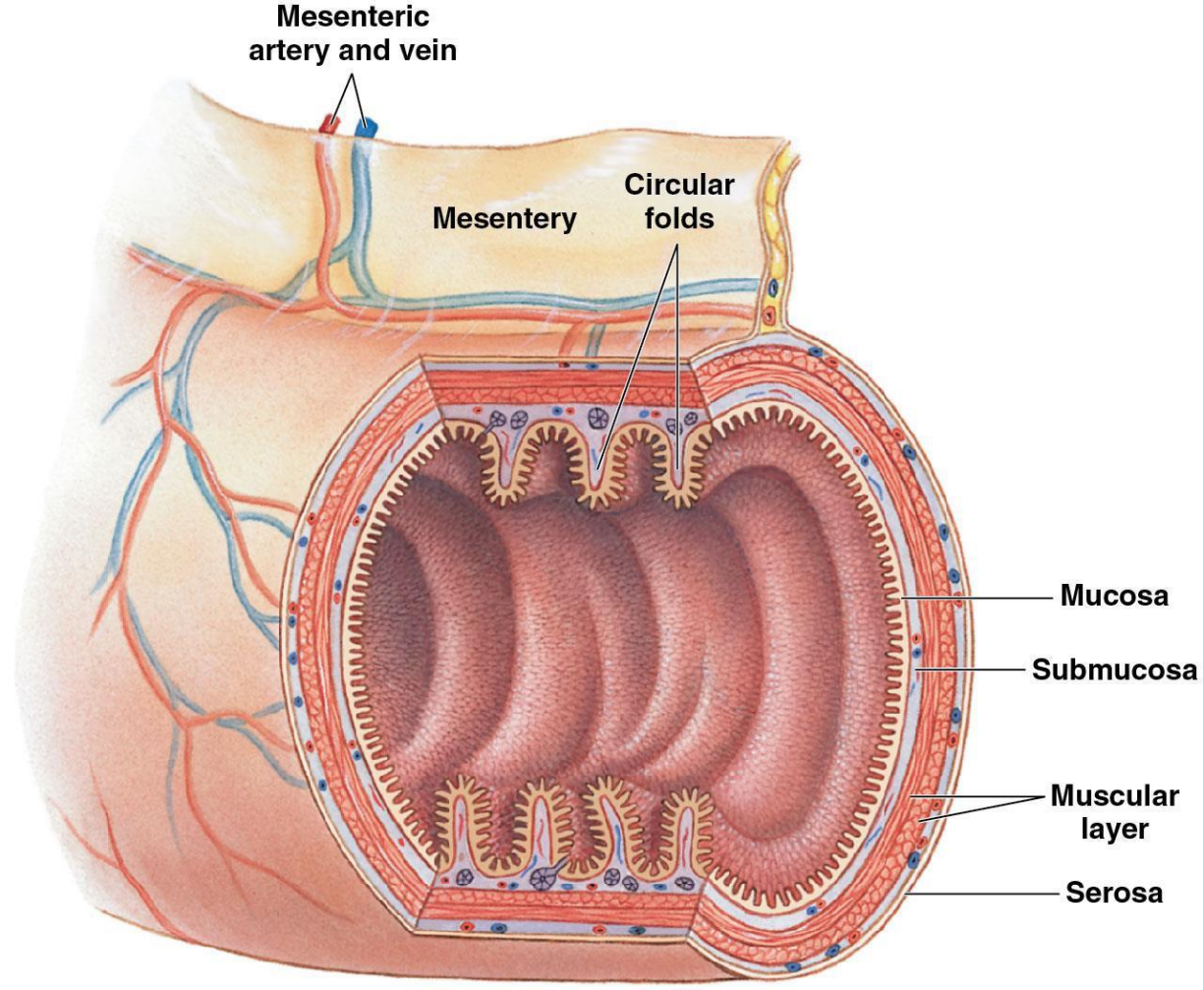
The different parts of the GI tract have specialized functions and some distinctive histological characteristic, but they share some histological and functional characteristics.

Histology of the GI tract

There are 4 layers with similar tissue composition, but some regional variations. They include the mucosa, submucosa, muscular layer, and serosa.

1. **The Mucosa:** It is the mucous membrane of the GI tract and its inner lining. It is composed of an epithelial layer that varies regionally, and a connective tissue layer or lamina propria. It functions to secrete protective mucous, digestive enzymes, and hormones, and to absorb digested substances. It is separated from the submucosa by a muscular muscularis mucosae.

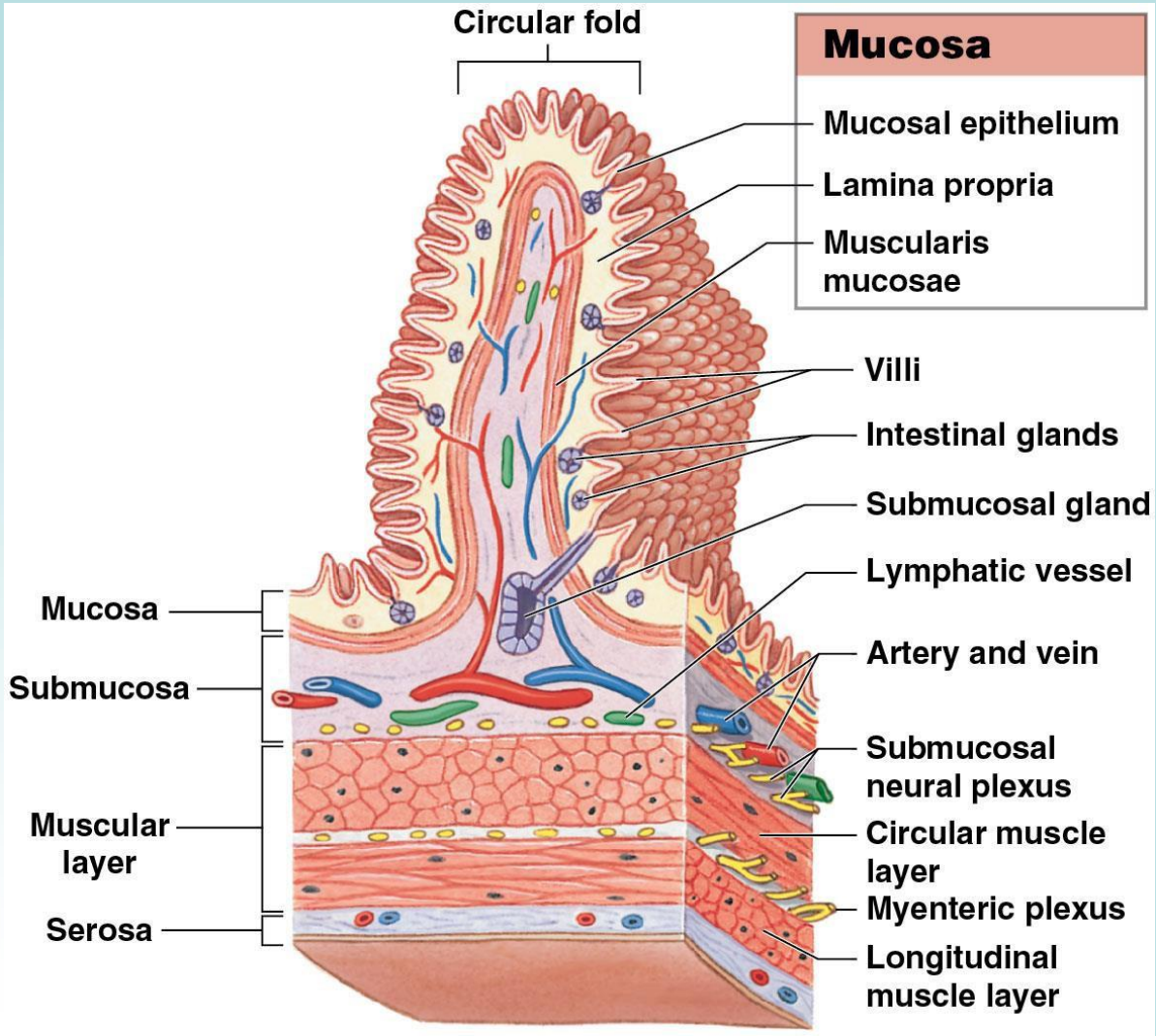
Figure 24-3
Histological Organization of the Digestive Tract (Part 1 of 2).



A diagrammatic view of a representative portion of the digestive tract. The features illustrated are typical of those of the small intestine.

Figure 24-3

Histological Organization of the Digestive Tract (Part 2 of 2).



A diagrammatic view of a representative portion of the digestive tract. The features illustrated are typical of those of the small intestine.

a. Epithelium: It is composed of simple columnar or stratified epithelium, according to the amount of physical and chemical stress endured regionally. Areas that experience strong stresses are lined by stratified squamous epithelium (mouth, pharynx, esophagus, and some areas of the anal canal). The areas of absorption, and other areas contain simple columnar epithelium with goblet cells that produce mucus, and other cells that may secrete enzymes and/or hormones. Hormone secreting cells are called enteroendocrine cells and their secretions help to coordinate the activities of the digestive tract and its accessory glands. In many areas of the epithelium there are temporary longitudinal folds that disappear as the GI tract fills and permanent transverse folds (circular folds) that increase the absorptive area.

b. The Lamina Propia: It is composed of loose areolar connective tissue with blood and lymphatic vessels, nerve endings and lymph nodules. In most areas the lamina propria contains a muscularis mucosae. This is formed by a band of smooth muscle and elastic fibers arranged in two concentric layers, one around the lumen to change its shape and the other longitudinal to move epithelial folds. Some areas of the lamina propria contain the secretory cells or mucous glands (mouth, pharynx, esophagus, stomach, and duodenum or first part of the small intestine).

2. **Submucosa:** it is composed of dense irregular connective tissue with large blood vessels lymphatic vessels, lymph nodules, nerves fibers and neurons. It surrounds the muscularis mucosae. In some areas this layer contains exocrine glands that secrete enzymes and buffers into the lumen of the GI tract.

The nerves fibers and neurons that innervate the mucosa and submucosa form the **submucosal plexus**, a group of sensory neurons, parasympathetic ganglionic neurons, and sympathetic postganglionic fibers. This plexus controls the smooth muscle and glands of the mucosa and submucosa.

3. **Muscularis Externa or Muscular Layer:** It includes an inner circular layer and an outer longitudinal layer of smooth muscle. These are responsible for mechanical processing and movements that mix and propel material along the GI tract. In some areas they thicken to form sphincters that control passage of substances. The movements of muscularis externa are coordinated by the enteric nervous system or ENS composed of sensory neurons, interneurons, and motor neurons. The ENS is primarily innervated by the parasympathetic nervous system.

The **Myenteric plexus** regulates the movements of the muscular layer and it is part of the enteric nervous system. It is found between the circular and longitudinal muscular layers. It consists of a network of neurons or parasympathetic ganglia that increase muscle tone and activity and sympathetic postganglionic fibers, which do the opposite.

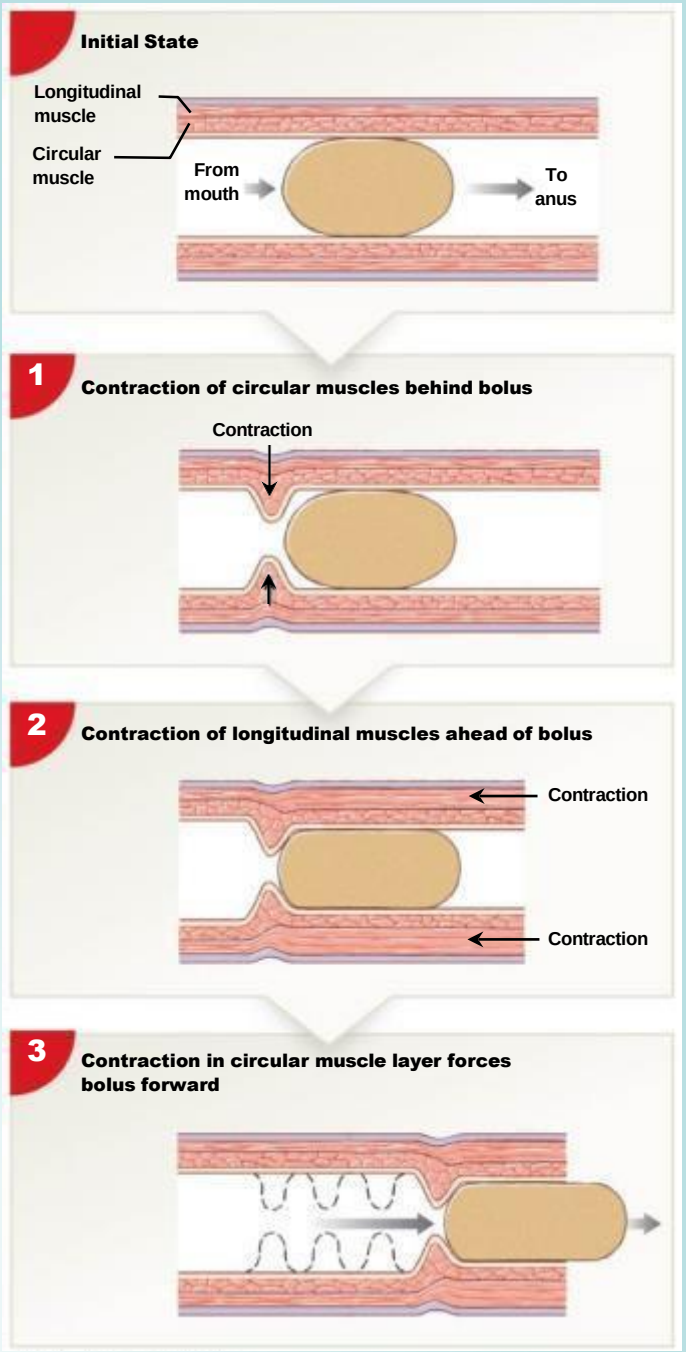
4. **Serosa or Visceral Peritoneum:** covers and protects the intraperitoneal organs. It is formed by areolar connective tissue and simple squamous epithelium called mesothelium. In the mouth, pharynx, esophagus, and rectum this is replaced by an adventicia, a dense network of collagen fibers. This sheath firmly attaches the digestive tract to adjacent structures.

Movements of Digestive Materials

The visceral smooth muscle along the GI tract has rhythmic cycles of activity that are controlled by pacesetter cells. These cells go spontaneous depolarization initiating a wave of contractions through the entire muscular sheet. The two most important patters of movement are: peristalsis and segmentation.

1. **Peristalsis:** it consists of a series of waves of muscular contractions that propel the digestive contents along the GI tract. It is produced by the muscular layer as the longitudinal muscles contract ahead of the GI tract contents shortening adjacent segments, the circular muscles contract behind the GI tract contents, forcing them forward.

Figure 24-4 Peristalsis.



The digestive material between the mouth and the esophagus is called bolus. The wave of contractions in the circular muscles forces the bolus forward.

2. Segmentation: it consists of cycles of contractions that churn and fragment the GI tract contents, mixing them with the intestinal secretions. These movements do not follow a set pattern and do not propel the materials in any one direction.

These movements occur in most of the small intestine, and some parts of the large intestine.

Control of Digestion

Digestion is controlled by local, neural, and hormonal mechanisms.

Local Mechanisms: involve local hormones such as prostaglandins, histamine, and other chemicals released into the interstitial fluid. They can affect nearby cells within a small segment of the GI tract . They coordinate responses to changes in local conditions such as pH changes, volume or degree of fullness, and chemical composition, (proteins, lipids or carbohydrates). For example stomach cells of the lamina propria release histamine, which triggers acid secretion by nearby epithelial cells.

They affect only a small area of the GI tract.

1. **Neural Mechanisms:** they are the most active in controlling the movements of materials through the GI tract, and glandular secretions that are necessary for digestion. Muscle contractions and glandular secretions are controlled by visceral motor neurons in the myenteric plexus and submucosal plexus, which are mostly considered to be parasympathetic fibers.

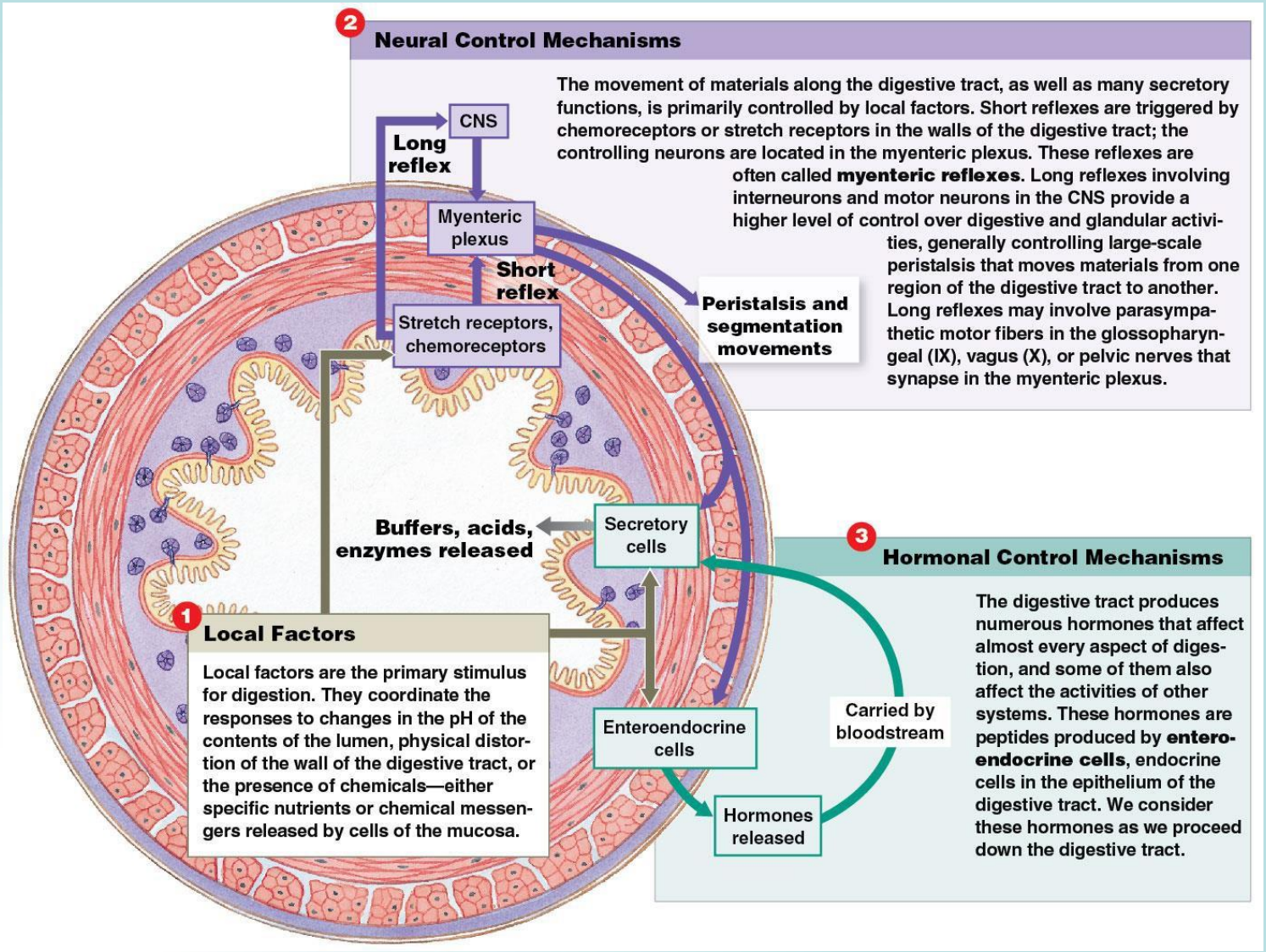
Short or local reflexes are responsible for local reflexes and control small segments of the GI tract. They are not under CNS control and include sensory neurons, motor neurons, and interneurons.

Long reflexes exert higher level of control over the digestive and glandular activities. They control large-scale peristalsis that include motor neurons and interneurons located in the CNS. They also can involve parasynpathetic motor fibers which synapse in the myenteric plexus.

These reflexes move materials from one region of the GI tract to another (from small intestine to the large intestine).

2. Hormonal Mechanisms: the GI tract produces at least 18 peptide hormones that influence almost every aspect of digestion and may influence the activities of other systems. For example the smooth muscle cells sensitivity to neural commands can be increased or decreased by digestive hormones. These hormones are peptides produced by the enteroendocrine cells of the GI tract. They are distributed by the bloodstream to their target organs and tissues.

Figure 24-5
The Regulation of Digestive Activities.



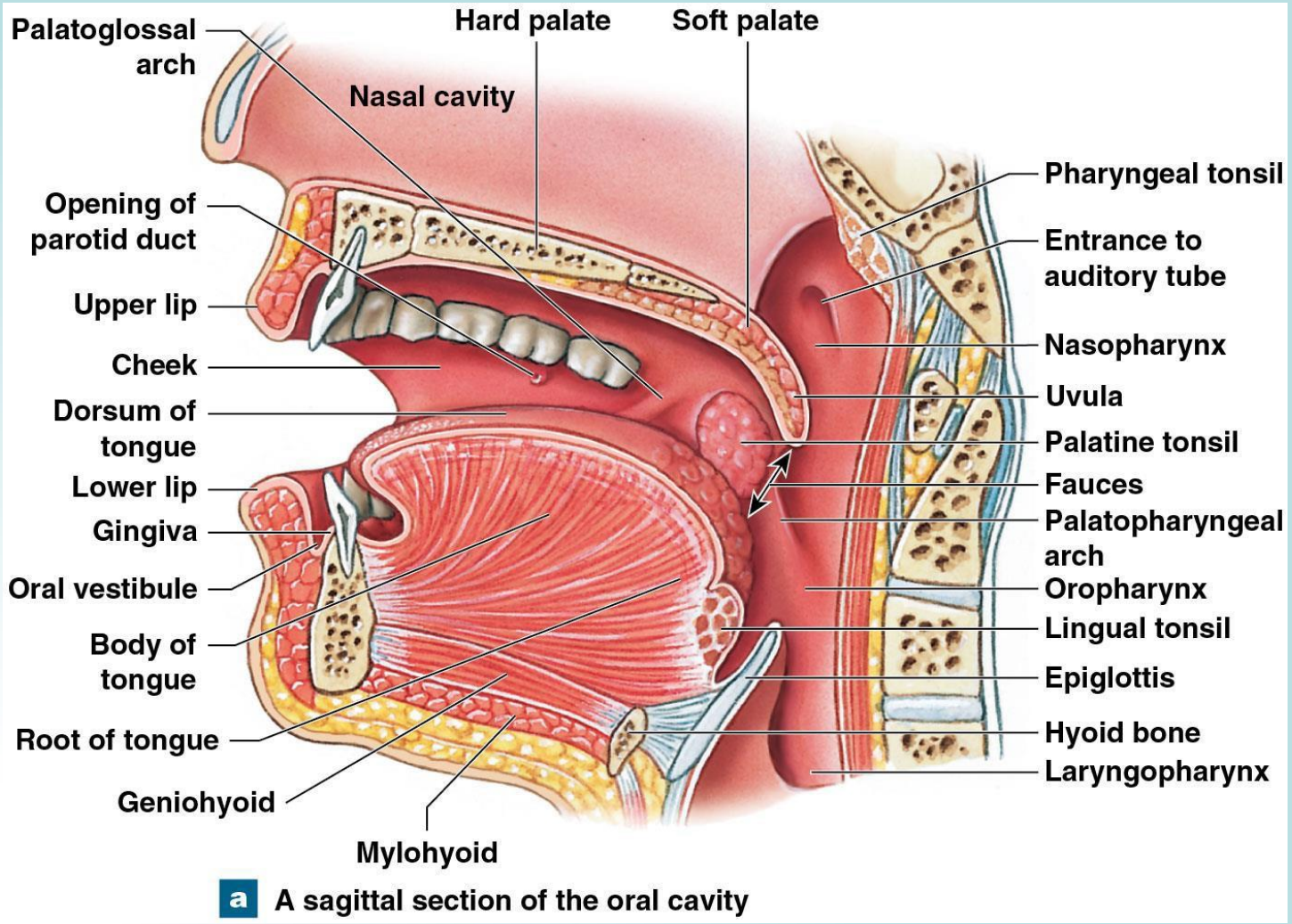
Functional Anatomy of the Digestive System

The Oral Cavity: The mouth is where ingestion takes place and mechanical and chemical digestion start. In the oral cavity ingested material is analyzed; mechanical activity by teeth, tongue, and palatal surfaces takes place; secretion from salivary glands and mucus mix to lubricate; and some carbohydrate and lipid digestion takes place. Lining is stratified non-keratinized squamous epithelium.

1- The Lips or Labia and The Cheeks: they hold and keep the food between the teeth and play a role in speech. The space between the lips or cheeks and the teeth is called the oral vestibule. The cheeks are supported by fat pads and muscles.

The Palate: It forms the roof of the oral cavity and it is composed of the hard palate and the soft palate.

Figure 24-6a
Anatomy of the Oral Cavity.



A sagittal section of the oral cavity

ATLAS: Plates 11a; 19

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The **uvula** is supported by the posterior margin of soft palate, which raises and closes the nasopharynx to prevent food or liquid from going into the nasal cavity when swallowing.

The Tongue: it is overt he floor of the oral cavity. The main functions of the tongue are :

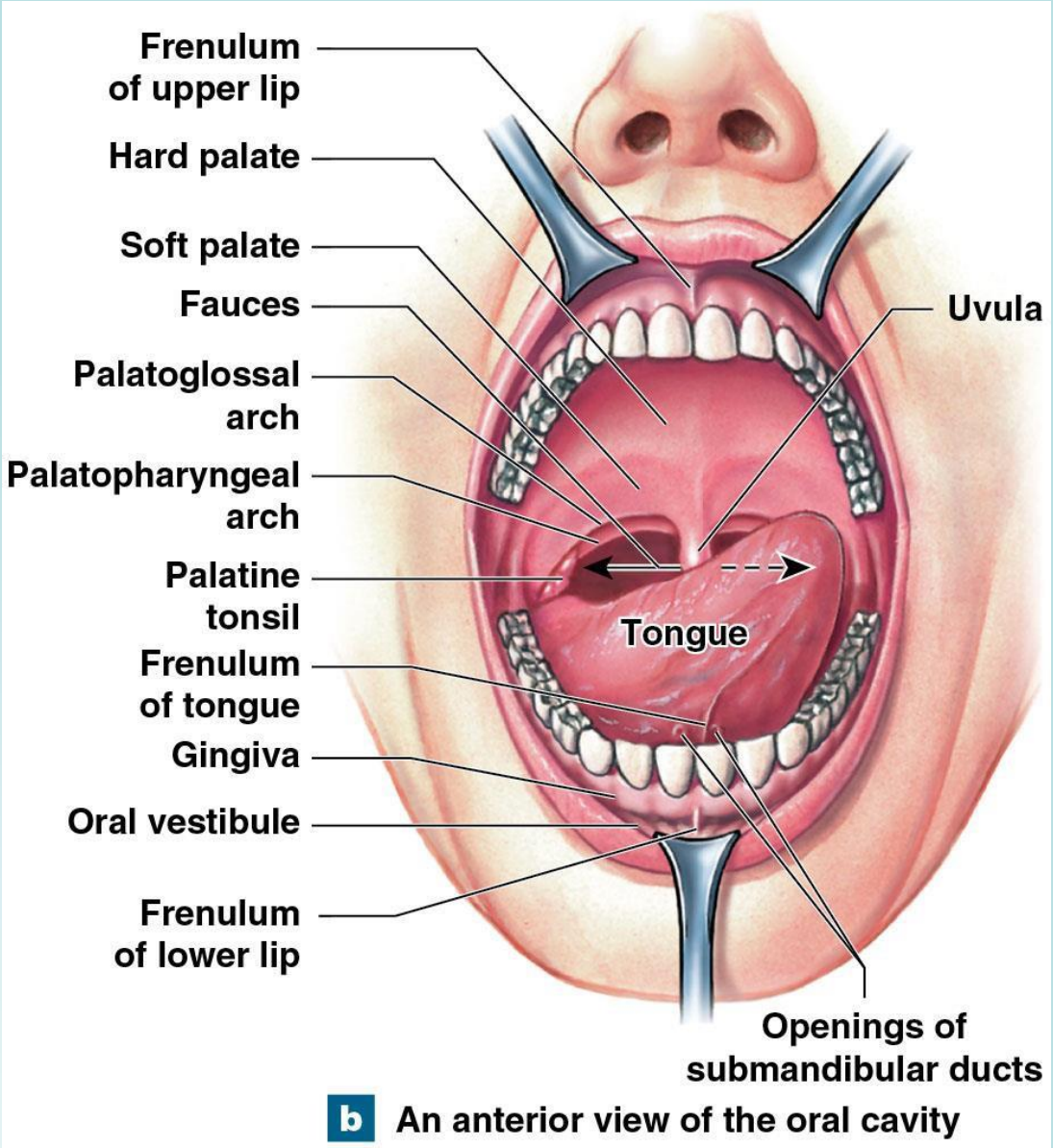
1 mechanical digestion by compacting, abrasion, and distorting ingested materials.

2 manipulation to help in keep the food against the teeth when chewing in preparation for swallowing.

3 Sensory analysis of food by touch, temperature and taste receptors.

4 secretion of mucus to moisten food, and of the enzyme lingual lipase to break down medium chain fatty acids.

Figure 24-6b
Anatomy of the Oral Cavity.



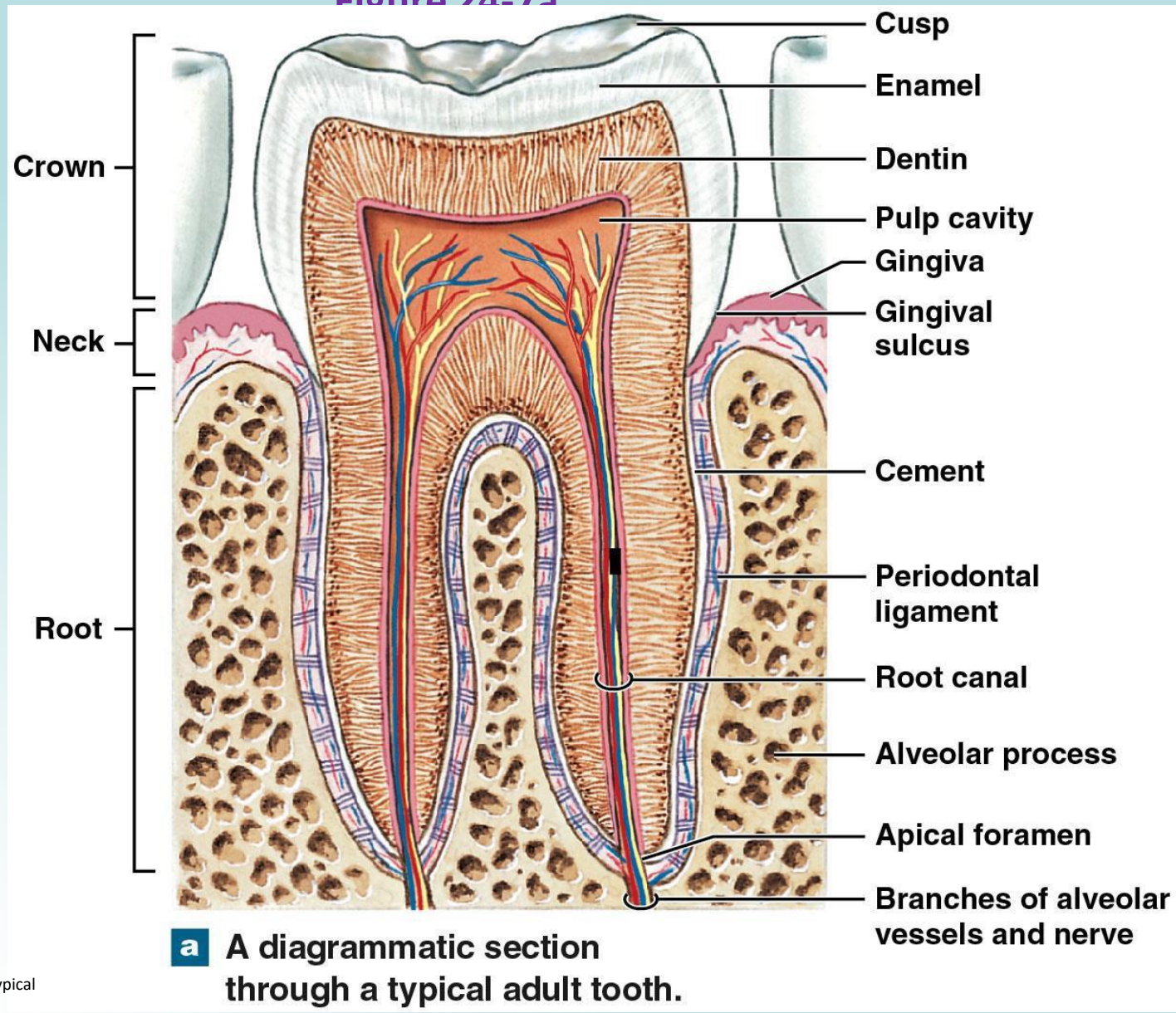
An anterior view of the oral cavity
ATLAS: Plates 11a; 19

Pearson

5- helping in speech to form consonants. Its surface has peg like projection called lingual papillae of 3 types, filiform, fungiform and circumvallate. The filiform are the most abundant and help to produce friction to manipulate and lick foods, but do not house taste buds. The other 2 house taste buds. The lingual frenulum connects the body of the tongue to the floor of the oral cavity.

5. **Teeth:** carried mechanical breakdown or chewing of food also called mastication. The tooth structure consists of an exposed surface or crown, a neck between the crown and the root or base. The crown is cover with enamel. Dentin is a mineralized matrix, similar to bone, without cells found under enamel that forms the bulk of the tooth and surrounds the pulp cavity. The root sits on a bony socket of alveolus. The dentin of the root is covered by a layer of cementum, that provides protection and attaches the tooth to periodontal ligament. The pulp cavity or inner chamber contains blood vessels and nerves coming through the root canal.

Figure 24-7a



a A diagrammatic section through a typical adult tooth.

A diagrammatic section through a typical adult tooth.

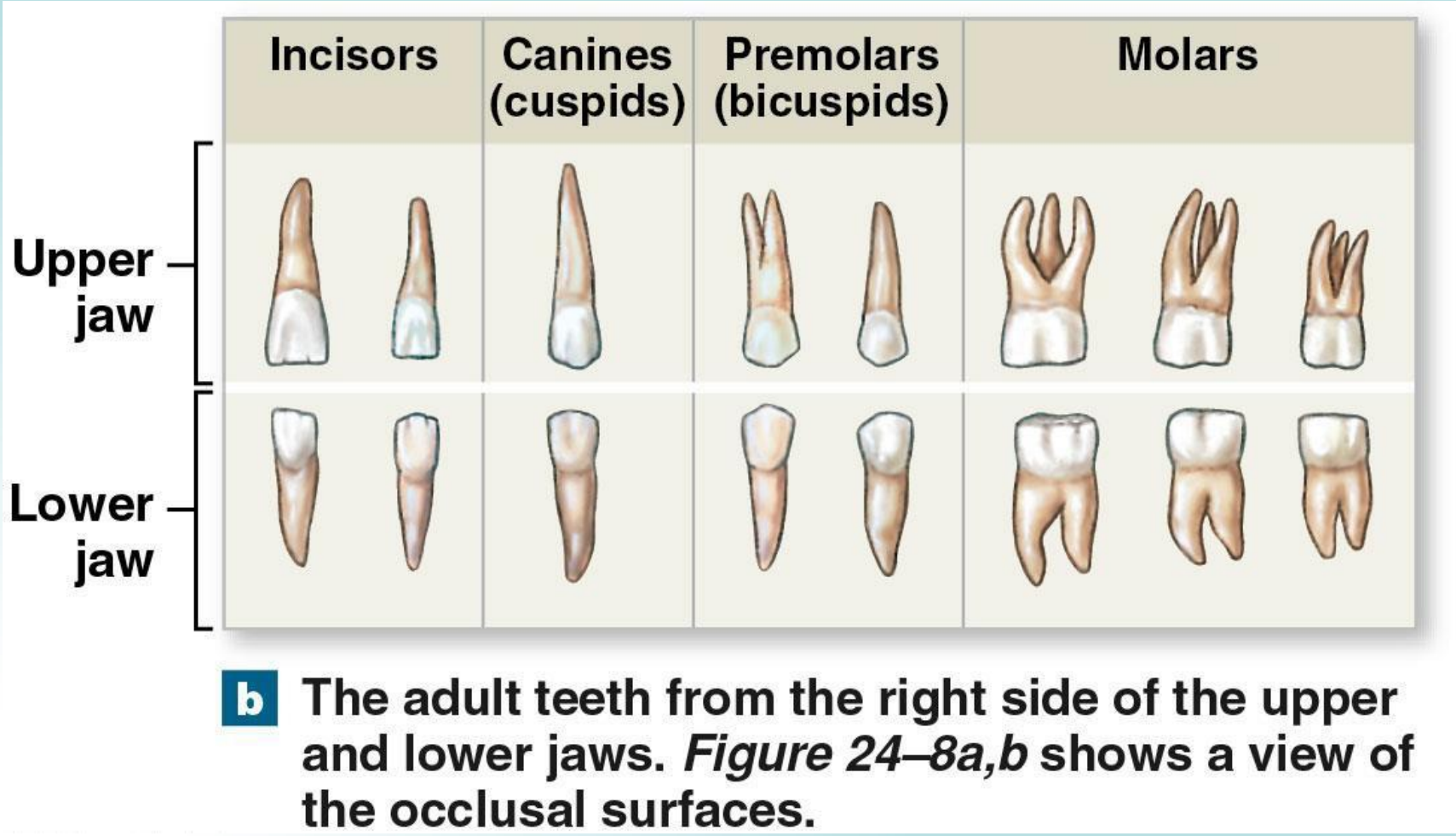
The periodontal ligament formed of collagen fibers that extend from the root dentin to the alveolar bone. The gingivae or gums surround the tooth they are ridges of oral mucose that surround the base of each tooth on the alveolar processes. The tooth nerve death causes darkening of tooth. It can be caused by a blow to the jaw. Tooth decay is caused by demineralization of the enamel and dentin by bacteria, which produce plaque. In gums bacterial plaque causes calculus that lead to gingivitis or gum infection.

a. Types of Teeth: there are four types of teeth:

1incisors (2 pairs) are blade shaped teeth in the front of the mouth, they have a single root, and cut or clip materials.

2canines or cuspids (1 pairs) are conical with a sharp ridgeline, and pointed tip. They are next to the incisors. They tear and slash. Also, they have a single root.

Figure 24-7b
The Teeth.



The adult teeth from the right side of the upper and lower jaws. Figure 24–8a,b shows a view of the occlusal surfaces.

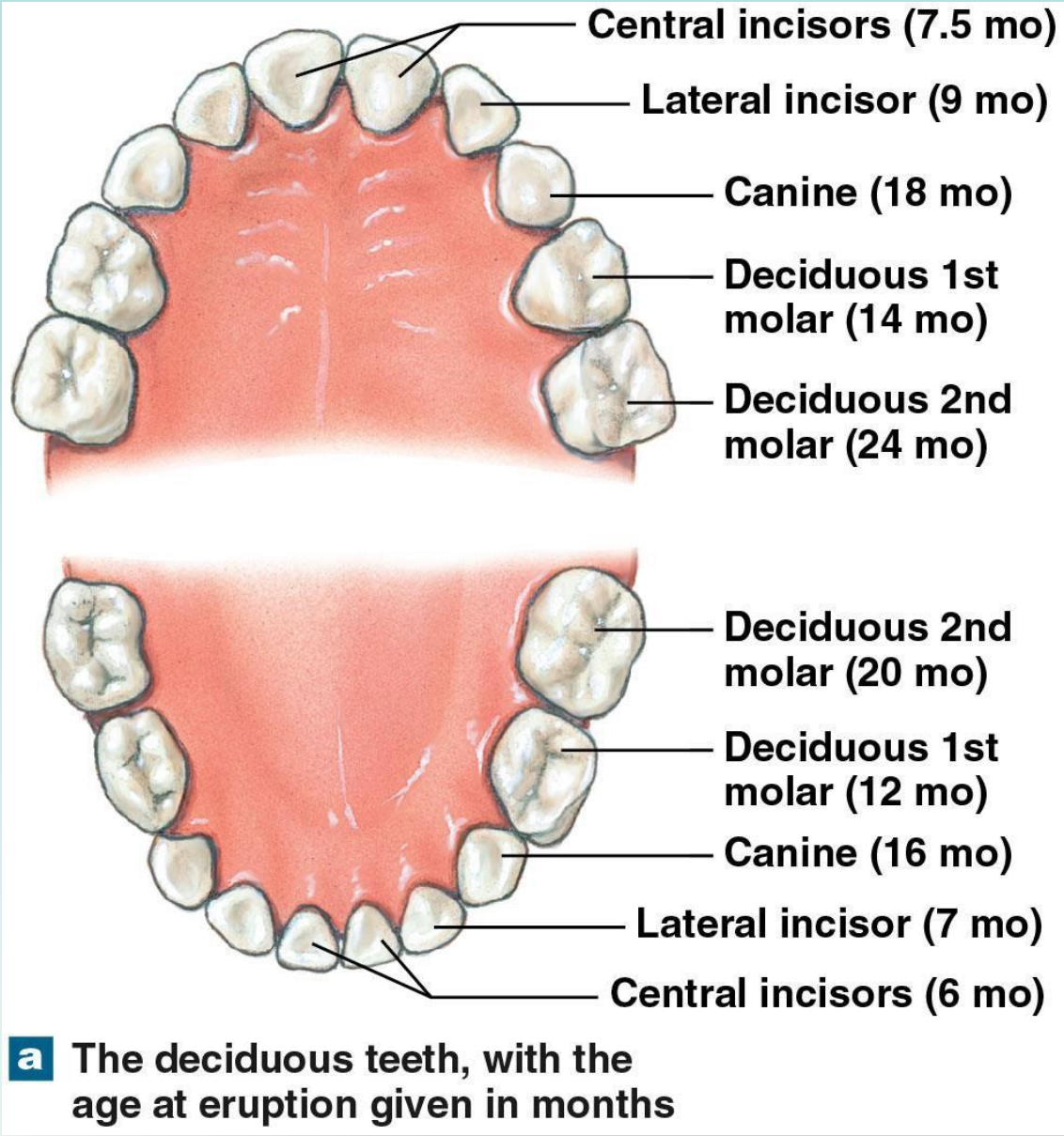
3- premolars (2 pairs) or bicuspids are next to canines, they have flat surfaces or crowns with prominent ridges. They are used to crush, mash and grind, and they can have one or two roots.

4- Molars (3 pairs) also have flat surfaces with prominent ridges, but they are larger than and next to the premolars, they grind and crush, and they can have 3 or more roots.

There are two sets of teeth: 1- primary, decidual, temporary, or baby (20) teeth of childhood; and 2- secondary or permanent (32) teeth of adulthood, which replace the decidual teeth.

b. Mastication: or chewing is the mechanical break down of food particles that also help to mix ingested materials with salivary secretions. The mastication muscles slide the lower jaw from side to side, and close the jaws. Muscles of the cheeks, lips, and tongue help in mastication. Chewing includes: elevation depression, protraction, retraction, and lateral movements.

Figure 24-8a
Deciduous and Permanent Dentitions.



The deciduous teeth, with the age at eruption given in months

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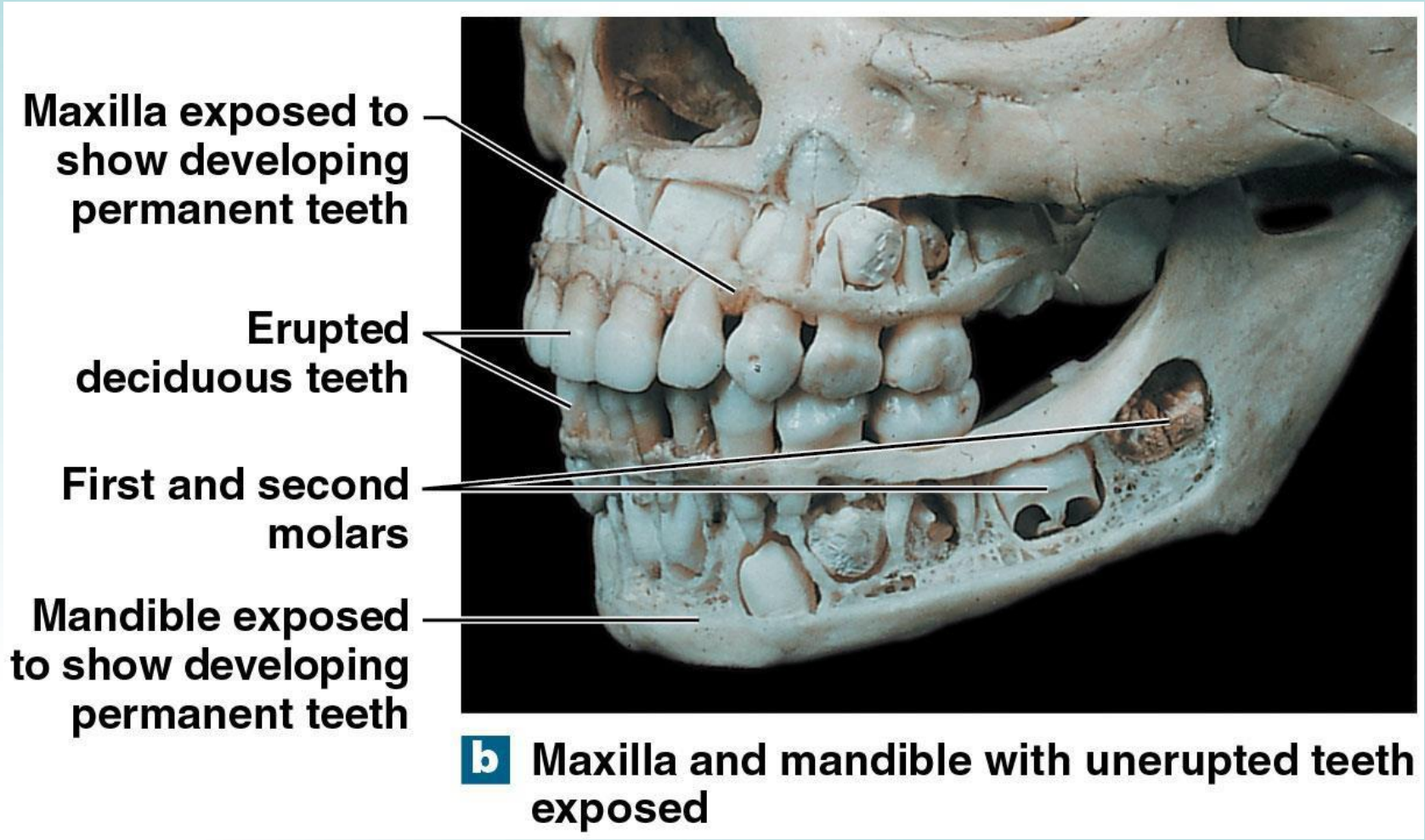
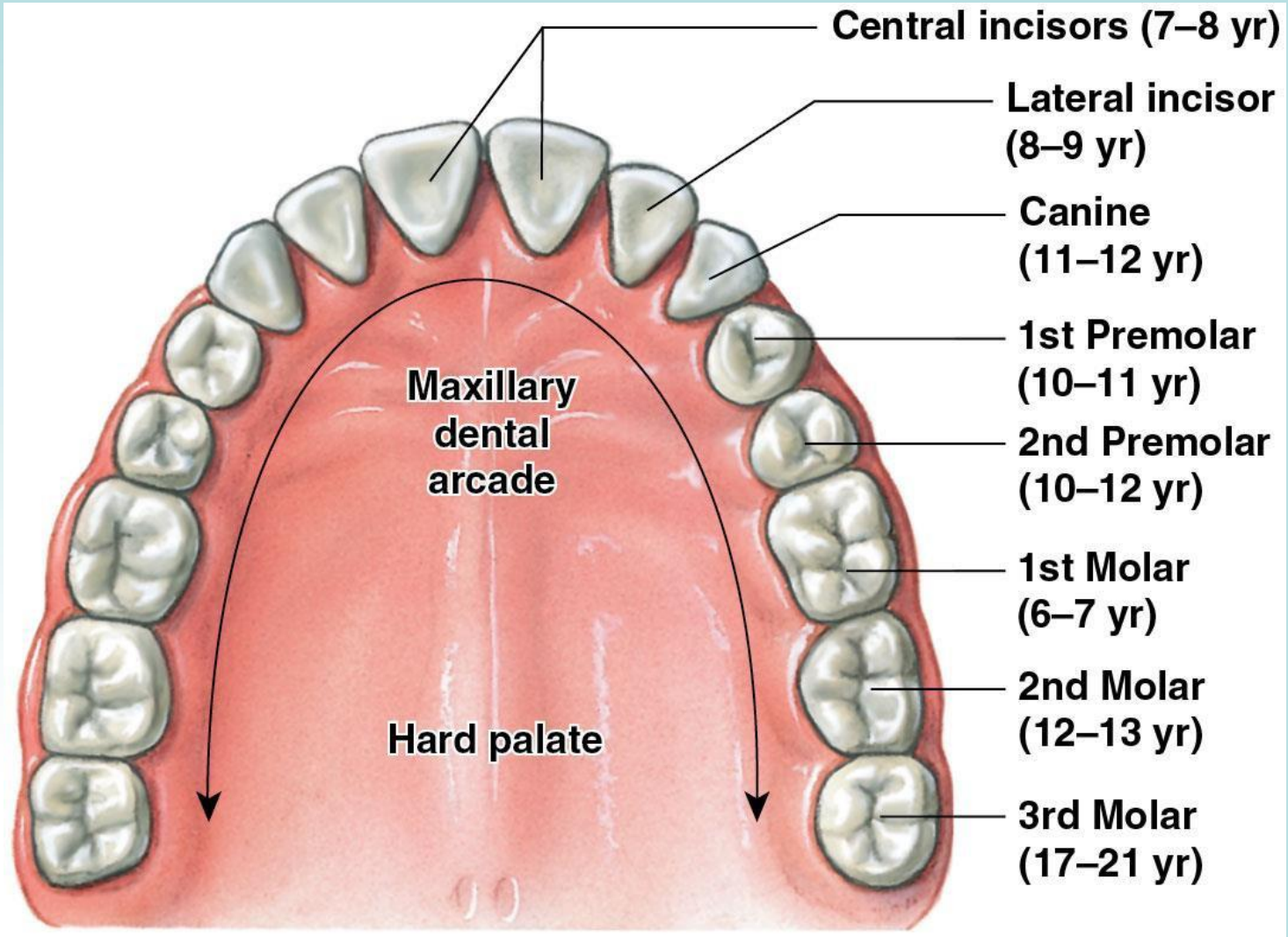
Figure 24-8b
Deciduous and Permanent Dentitions.



Maxilla and mandible with unerupted teeth exposed

Figure 24-8c

Deciduous and Permanent Dentitions (Part 1 of 2).



The permanent teeth, with the age at eruption given in years.

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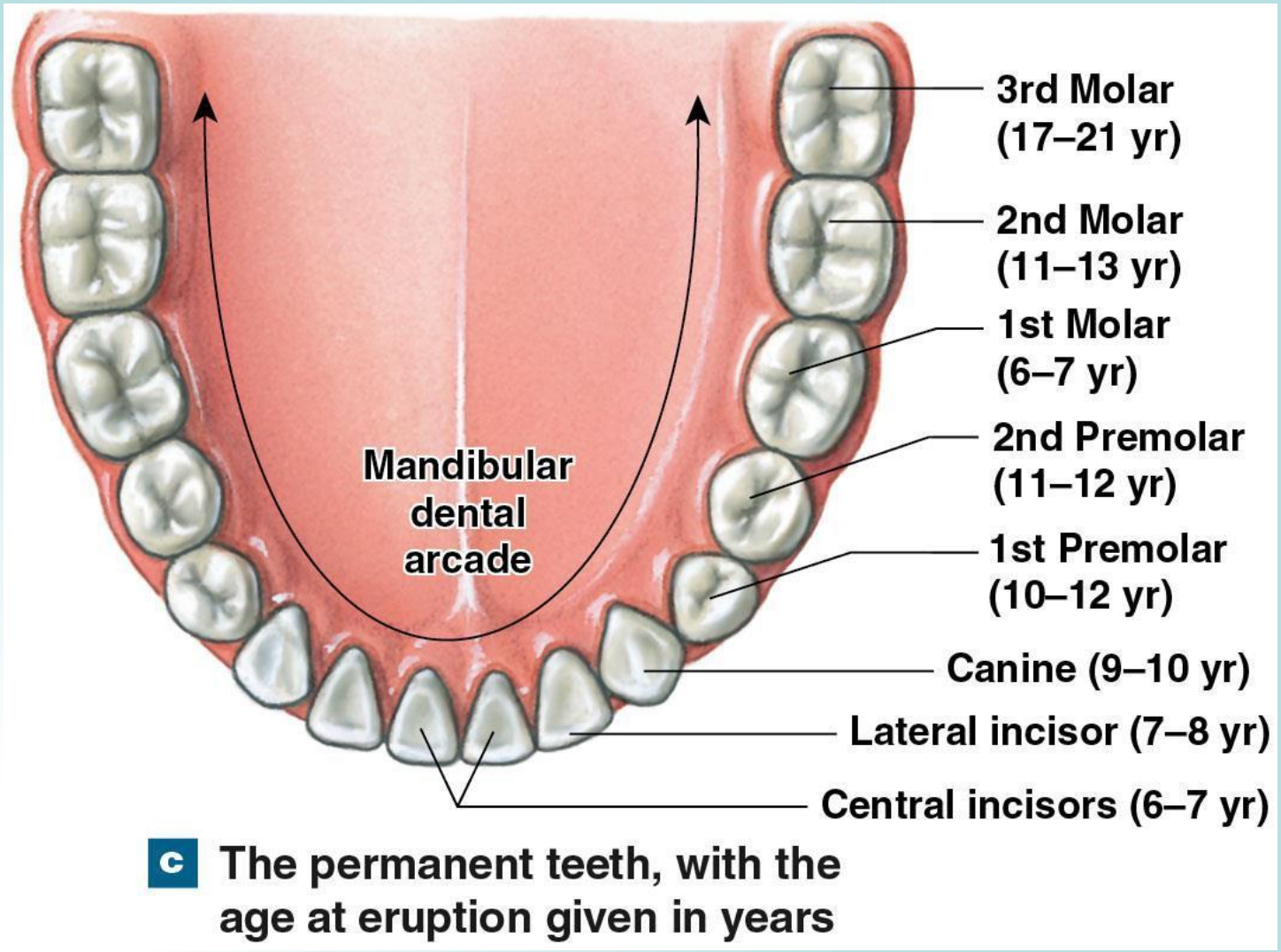
Figure 24-8c

Deciduous and Permanent Dentitions (Part 2 of 2).



The permanent teeth, with the age at eruption given in years.

4- Salivary Glands: secrete saliva, which cleanses the mouth, dissolves and moistens food, and contains enzyme that start the break down of carbohydrates.

There are 3 pairs of salivary glands:

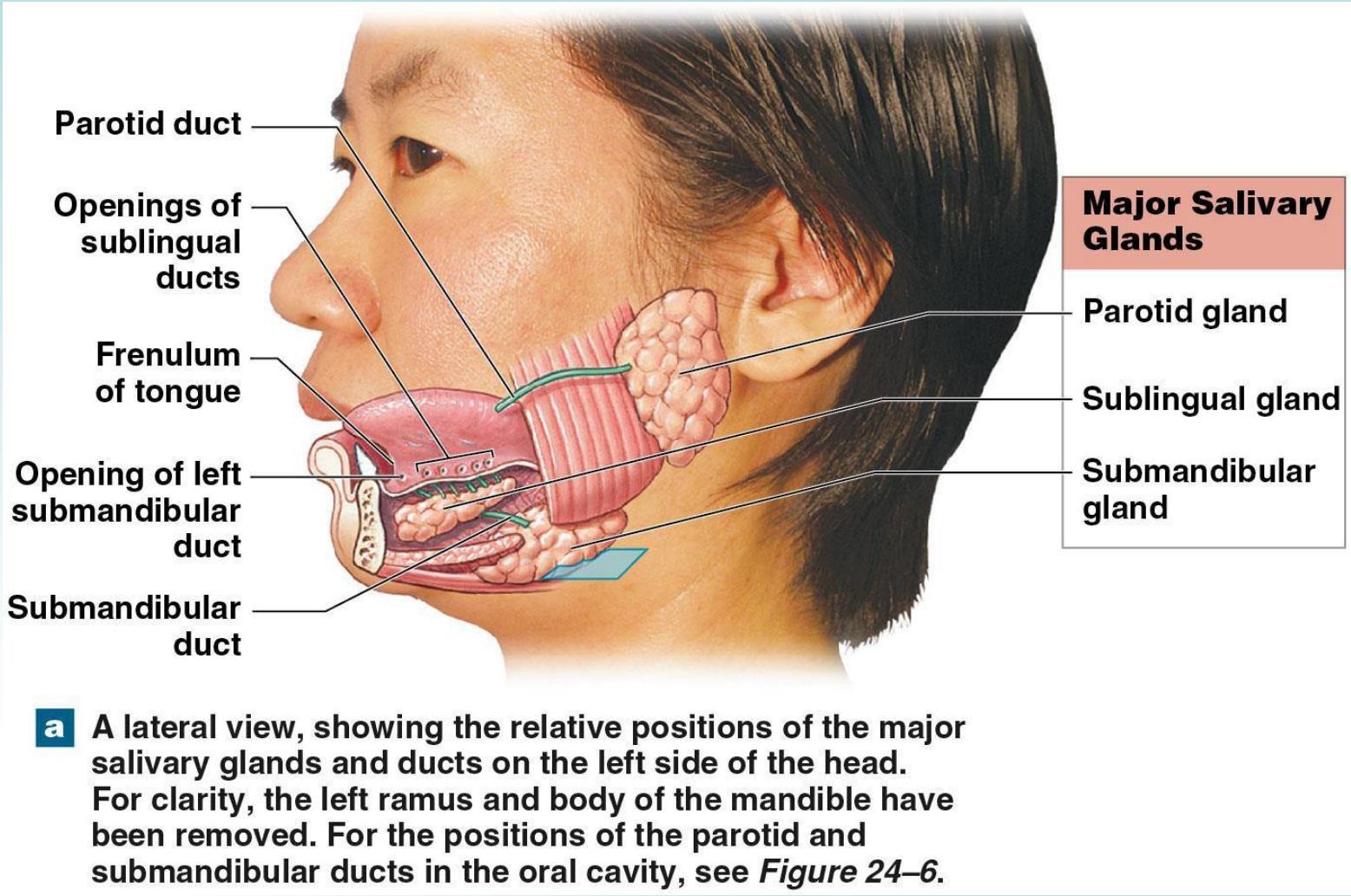
1 The large parotid glands are found along the mandible between the skin and the masseter muscle below the zygomatic arch. They secrete a thick serous fluid containing salivary amylase, an enzyme that breaks down starch. They drain their secretions through the parotid ducts into the vestibule by the second molars. They produce 25% of the saliva.

2 The sublingual glands are found covered by the mucous membrane of the floor of the mouth. They produce a watery, mucous secretion that buffers and lubricates (5% of saliva). They drain by the sublingual ducts along the lingual frenulum.

3- the submandibular glands are found within the mandibular groove in the floor of the mouth. They secrete a fluid that contain buffers, mucins, and salivary amylase, they drain by the submandibular ducts into the mouth posterior to the teeth, on either side of the lingual frenulum (produce 70% of saliva).

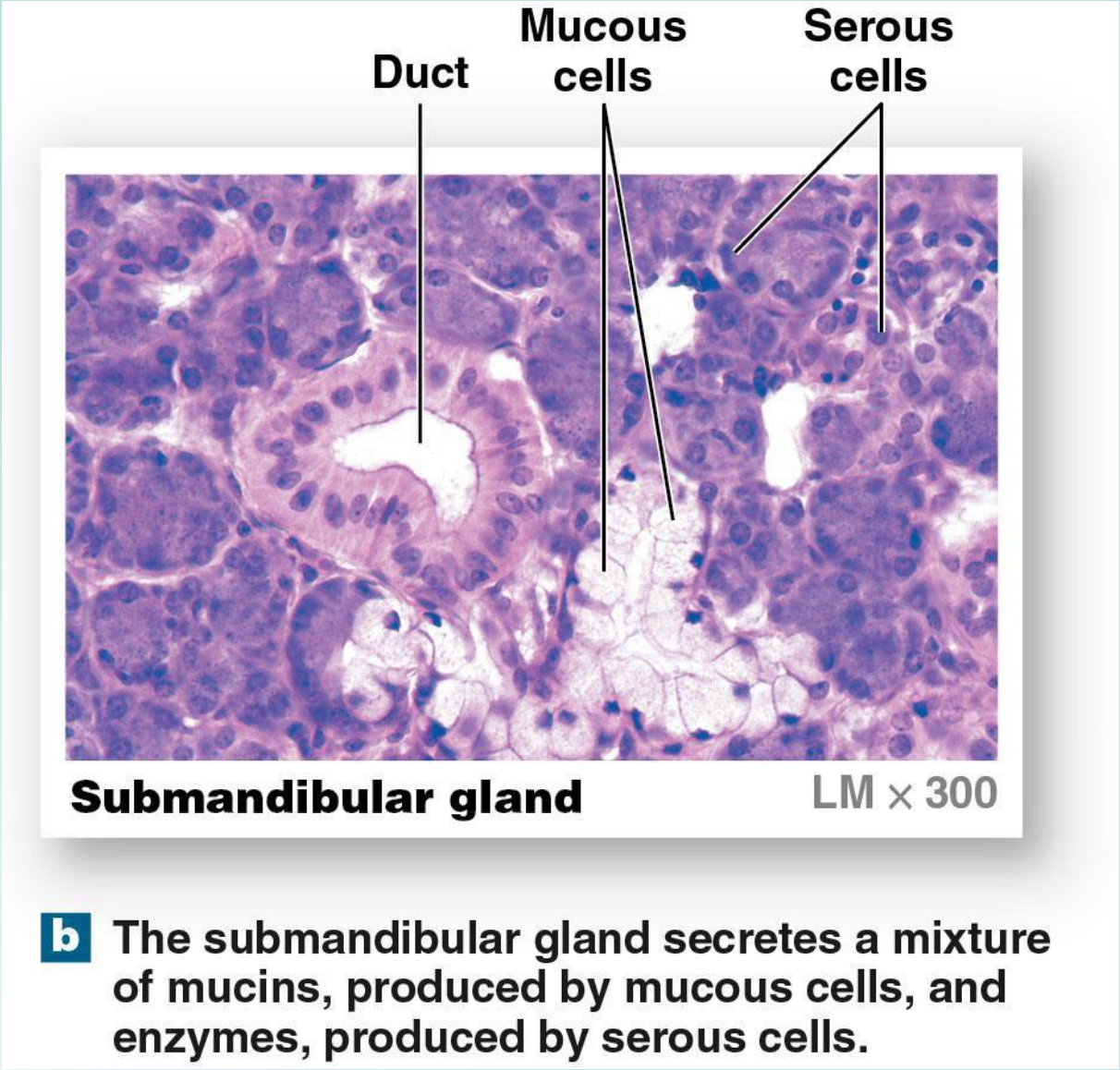
a. **Composition of Saliva:** the salivary glands produce 1.0 to 1.5 L of saliva a day. Saliva is a watery (99.4%) fluid containing other substances such as electrolytes (mostly Na, Cl, and HCO3), buffers, mucin, antibodies, enzymes, and metabolic waste such as urea and uric acid. Mucins are glycoproteins that help lubricate and moisten materials in the mouth. **Salivary amylase** starts starch digestion. The enzyme lysozyme and the antibodies (IgA) help to control bacterial growth. Saliva helps to clean oral surfaces.

Figure 24-9a
Anatomy of the Salivary Glands.



A lateral view, showing the relative positions of the major salivary glands and ducts on the left side of the head. For clarity, the left ramus and body of the mandible have been removed. For the positions of the parotid and submandibular ducts in the oral cavity, see Figure 24–6. ATLAS: Plates 3c,d; 18a,b

Figure 24-9b
Anatomy of the Salivary Glands.



The submandibular gland secretes a mixture of mucins, produced by mucous cells, and enzymes, produced by serous cells. ATLAS: Plates 3c,d; 18a,b

The buffers are important in preventing accumulation of bacterial acids, which can create dental caries, saliva keeps the mouth pH near 7.0. Dissolves chemicals to stimulate taste buds.

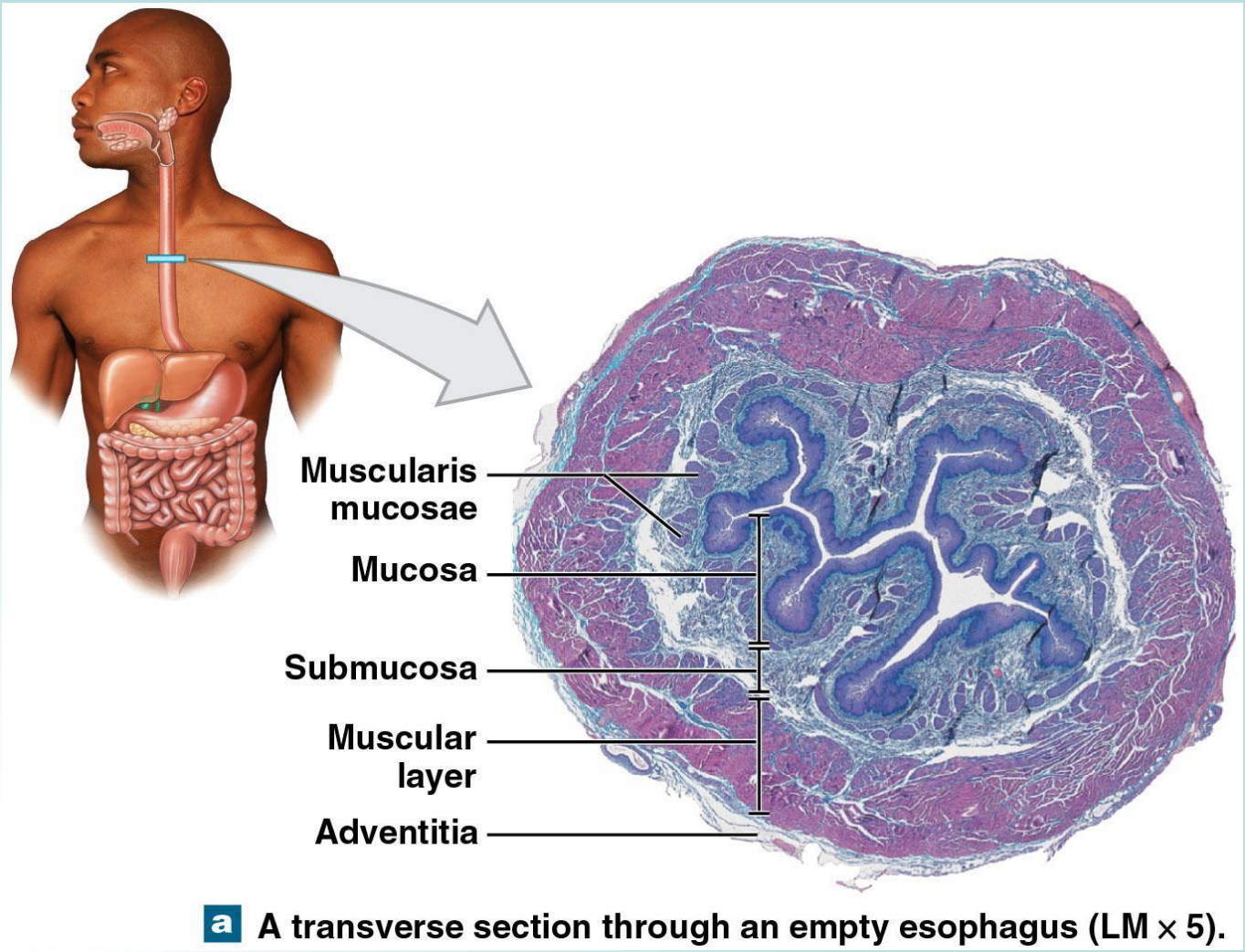
b. Control of Salivation: salivation can be triggered by visual and/or olfactory stimuli as well as chewing and food in the mouth. It is controlled by the PNS of the autonomic nervous system.

All salivary glands are innervated by both parasympathetic and sympathetic nerves. Parasympathetic stimuli increase secretion by all salivary glands.

Pharynx or Throat: It is a common food, liquid, and air passageway. Food passes from the oropharynx into the laryngopharynx and finally, into the esophagus. It is covered by stratified squamous epithelium, and its lamina propria has mucous glands and the lymphoid tissue for the tonsils. It also has numerous muscles that propel food to the esophagus.

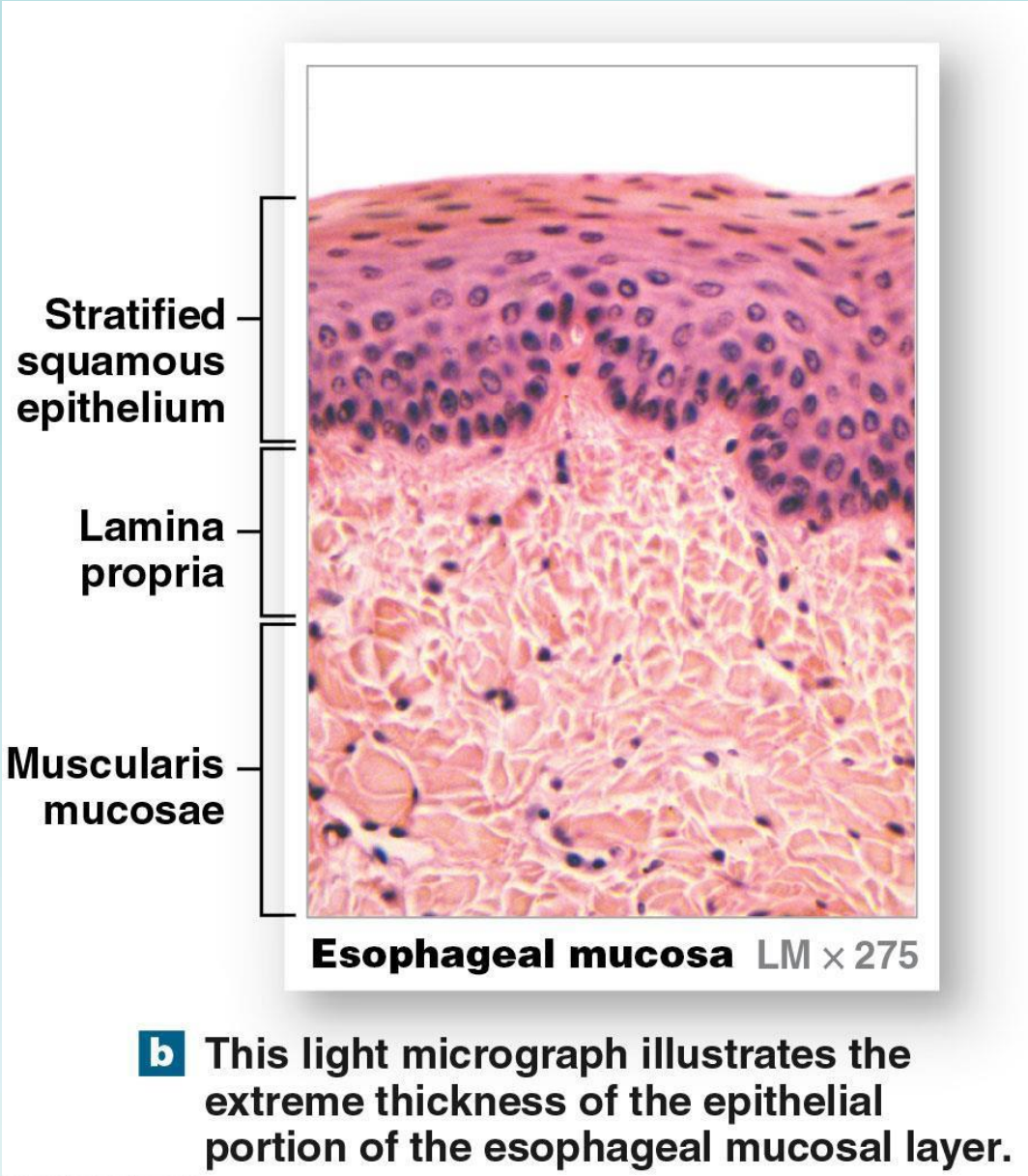
Esophagus: a muscle tube 10 in (25 cm) long that collapses when not propelling food to stomach. It carries food and liquids to the stomach. It is lined by stratified squamous epithelium with many esophageal glands that secrete lubricant mucus. It enters the abdominoplevic cavity at the **esophageal hiatus**, which is an opening in the diaphragm. It ends in the **cardiac sphincter**, which keeps gastric juices from backing up into esophagus. Its wall has 3 layers: mucosa, submucosa, and muscular layer. The exterior is covered by an adventicia.

Figure 24-10a
Anatomy of the Esophagus.



A transverse section through an empty esophagus (LM multiplied by 5).

Figure 24-10b
Anatomy of the Esophagus.



This light micrograph illustrates the extreme thickness of the epithelial portion of the esophageal mucosal layer.

Pearson

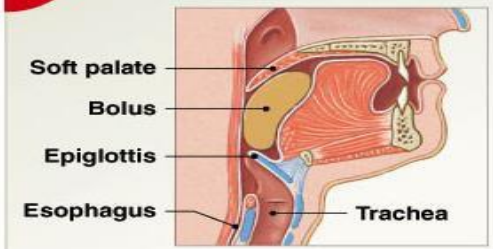
This is innervated by both parasympathetic and sympathetic fibers of the esophageal plexus. The circular muscle layer of the superiors 1/3 prevents air from entering the esophagus. The muscles propel the bolus by peristalsis to the stomach. The adventitia anchors the esophagus against the body wall.

Swallowing or Deglutition: It is part voluntary and part involuntary. It proceeds automatically in 3 phases buccal, pharyngeal, and esophageal.

1. Buccal phase: it begins in the mouth where the bolus is compressed against the hard palate, and then the tongue forces the bolus into the oropharynx and the soft palate elevates to isolate the nasopharynx. This phase is voluntary.

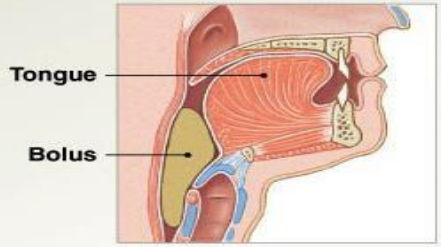
2. **Pharyngeal phase:** it starts with the **swallowing reflex** triggered by the tactile receptors on the oral arches and the uvula, which are stimulated by the passing of the bolus. It causes the elevation of the larynx and folding of the epiglottis, which direct the bolus past the closed glottis. At the same time the uvula and soft palate block the nasopharynx. This process is controlled by the **swallowing center** of the medulla, which is stimulated while the respiratory centers are inhibited to temporarily stop breathing.
3. **Esophageal phase:** it stars as the contraction of the esophageal muscles force the bolus through the esophagus. Once in the esophagus the bolus is automatically propelled by peristalsis toward the lower esophageal or cardiac sphincter which opens and bolus enters the stomach.

1 Buccal Phase



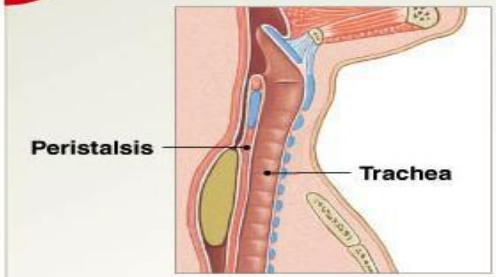
The **buccal phase** begins with the compression of the bolus against the hard palate. Subsequent retraction of the tongue then forces the bolus into the oropharynx and assists in the elevation of the soft palate, thereby sealing off the nasopharynx. Once the bolus enters the oropharynx, reflex responses begin and the bolus is moved toward the stomach.

2 Pharyngeal Phase



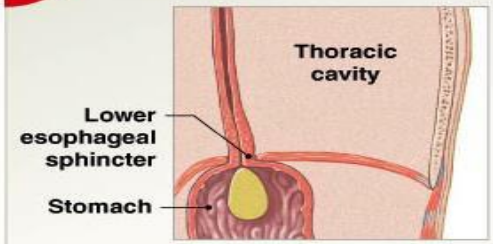
The **pharyngeal phase** begins as the bolus comes into contact with the palatoglossal and palatopharyngeal arches and the posterior pharyngeal wall. Elevation of the larynx and folding of the epiglottis direct the bolus past the closed glottis. At the same time, the uvula and soft palate block passage back to the nasopharynx.

3 Esophageal Phase



The **esophageal phase** begins as the contraction of pharyngeal muscles forces the bolus through the entrance to the esophagus. Once in the esophagus, the bolus is pushed toward the stomach by a peristaltic wave.

4 Bolus Enters Stomach



The approach of the bolus triggers the opening of the lower esophageal sphincter. The bolus then continues into the stomach.

Stomach: It is a storage tank where mechanical digestion continues, chemical digestion of proteins takes place, and the pasty bolus is turn into a watery **Chyme** made of partially digested food mixed with stomach secretions. The 4 primary functions of the stomach are: temporary storage, mechanical breakdown, and chemical breakdown of proteins by acids and enzymes and production of the intrinsic factor necessary for vitamin B12 absorption in the small intestine.

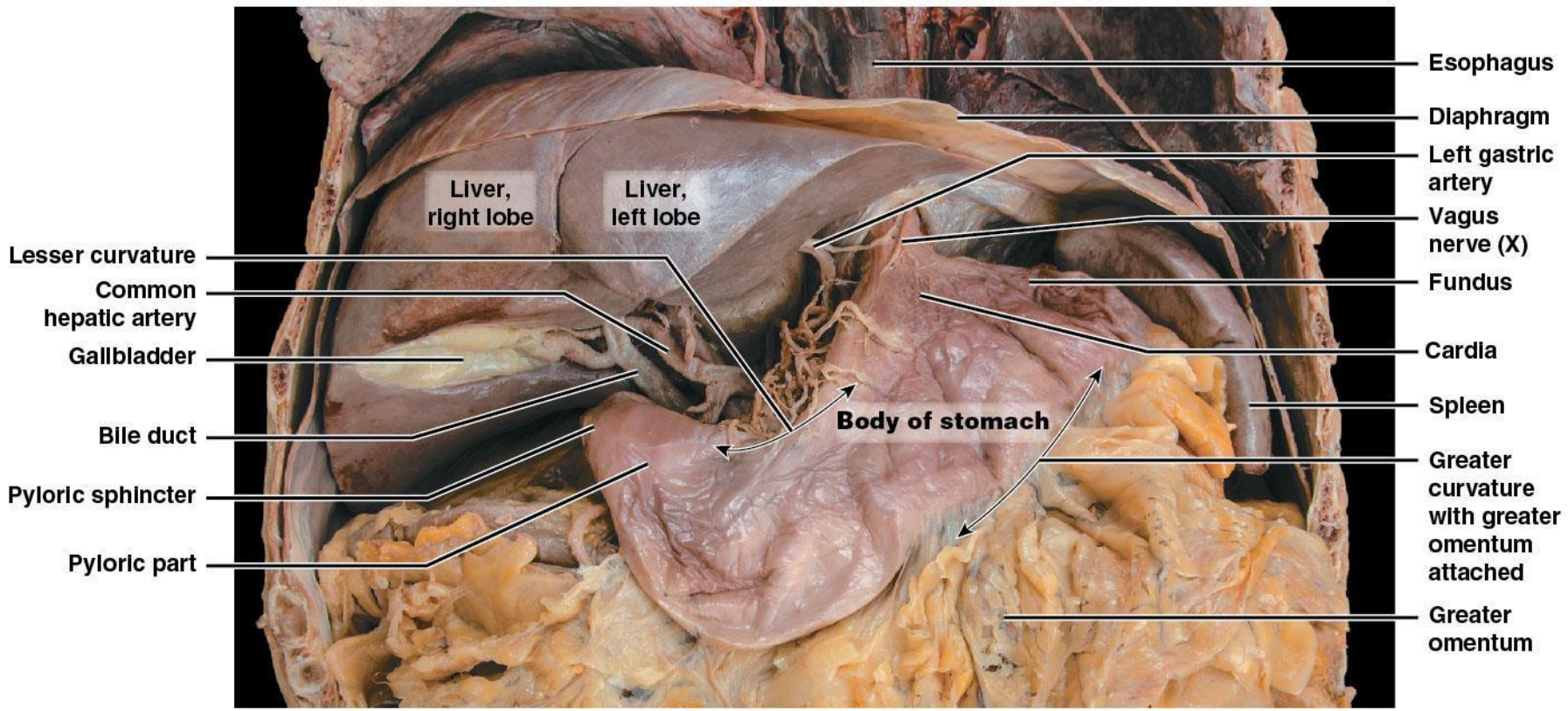
A. Gross Anatomy: Internally the mucosae and submucosa of the stomach form folds called rugae that allow the stomach to distend or increase its holding capacity. It has a J shape, and its medial surface forms a lesser curvature while its lateral surface forms a greater curvature. The anterior and posterior surfaces are rounded. It changes in shape and size vary person to person and form meal to meal. The stomach extends from T7 to L3.

It is divided into 4 regions the cardia (area closest to the esophagus), fundus (bump superior to junction with esophagus), body (area between fundus and pylorus), and pylorus (the curve of the J) with the pyloric sphincter which is a thick circular muscle within the pylorus. It is anchored to its surroundings by peritoneal folds called the omenta.

B. Microscopic Anatomy: The muscularis externa contains a unique internal oblique layer of muscle that helps in the churning of food.

1. **Surface Epithelium:** is simple columnar with many cells that secrete an alkaline protective mucus that covers the interior surface of the stomach to protect against acids and enzymes.
2. **Gastric Glands:** are found at the bottom of shallow depressions called **gastric pits** that open to the stomach lumen surface. They extends to the lamina propria.

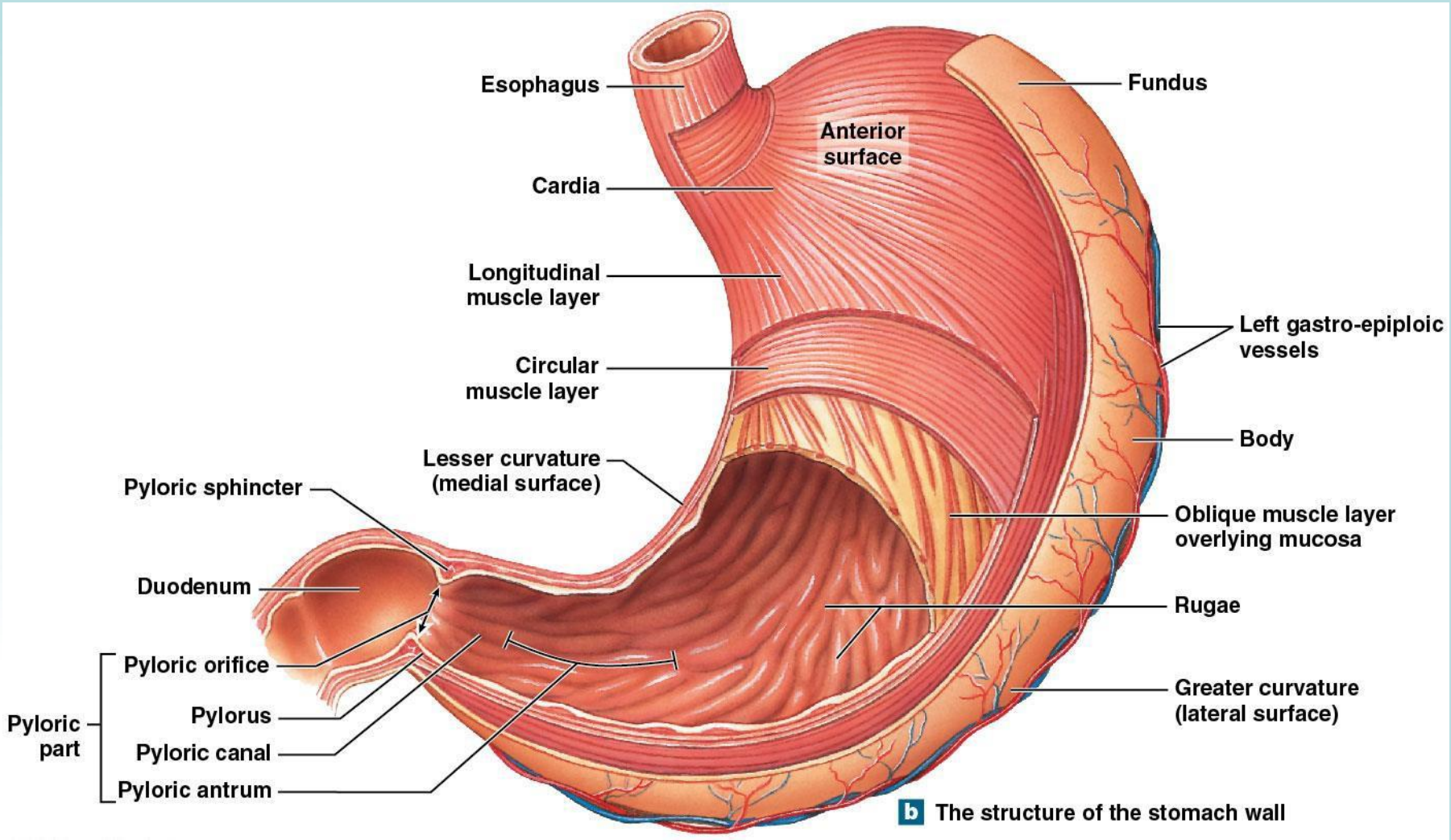
Figure 24-12a
Gross Anatomy of the Stomach.



a The position and external appearance of the stomach, showing superficial landmarks

The position and external appearance of the stomach, showing superficial landmarks
ATLAS: Plates 49a-c; 50a–c

Figure 24-12b
Gross Anatomy of the Stomach.



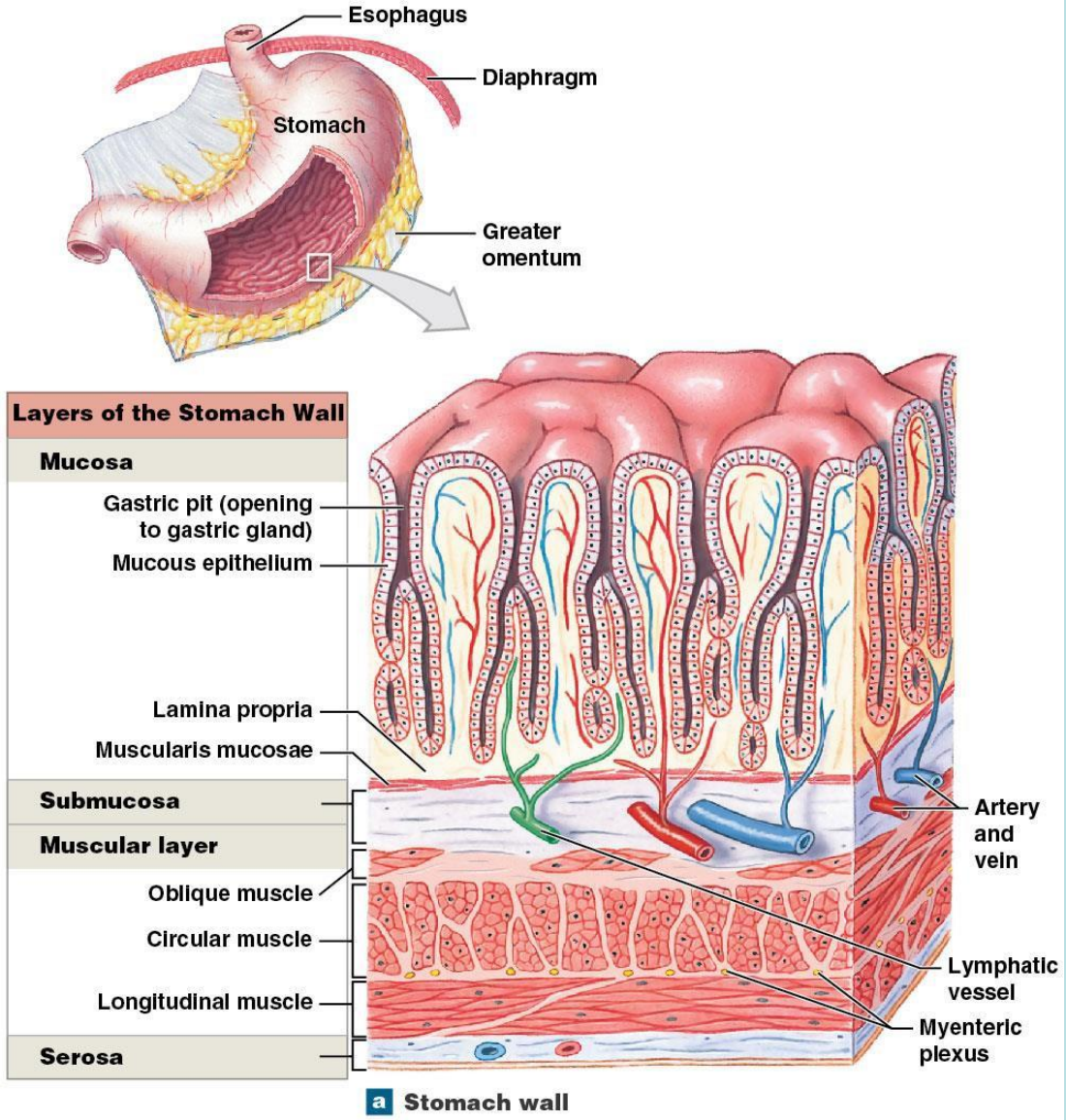
The structure of the stomach wall

ATLAS: Plates 49a–c; 50a–c

These are pockets in the stomach lining that contain secretory cells. They produce gastric juice, which is a mixture of the secretions of several glands, but the most important are the parietal cells and the chief cells.

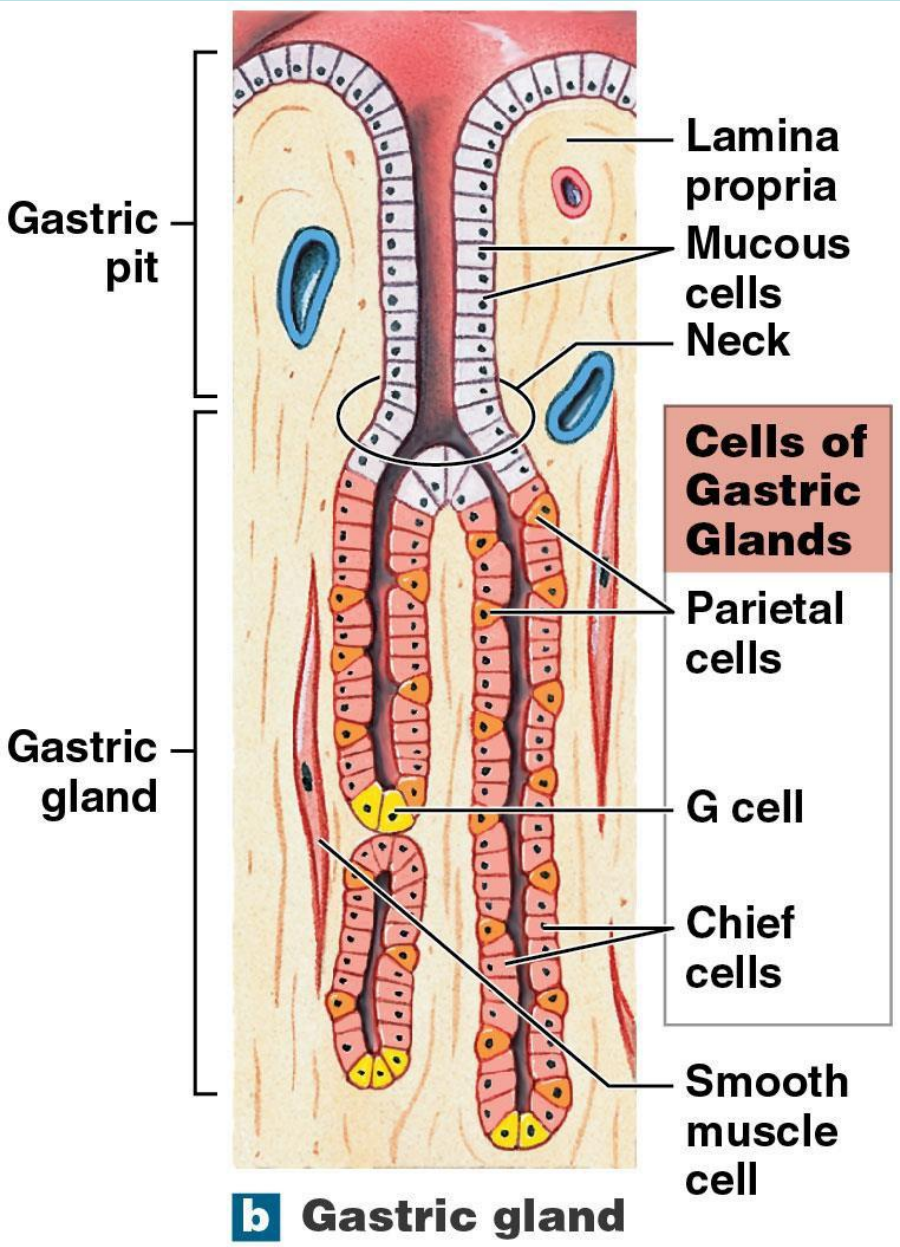
3. Secretory cells: throughout the stomach there are mucous cells, parietal cell that produce HCl and Intrinsic factor; chief cells that produce pepsinogen, and enteroendocrine cells that produce substances such as gastrin (by G cells), somatostatin (inhibits gastric secretion), histamin, and serotonin (reduces appetite). The HCl produced by the parietal cells maintain the stomach contents at a pH between 1.5 and 2.0. This acidity has several functions: a. To kill most microorganisms ingested with the food; b. To Denature proteins and inactivate food enzymes; c. To help breakdown plant materials and connective tissue in meet; and d. To activate the enzyme pepsin.

Figure 24-13a
Histology of the Stomach Lining.



Stomach wall

Figure 24-13b
Histology of the Stomach Lining.



Gastric gland

Pearson

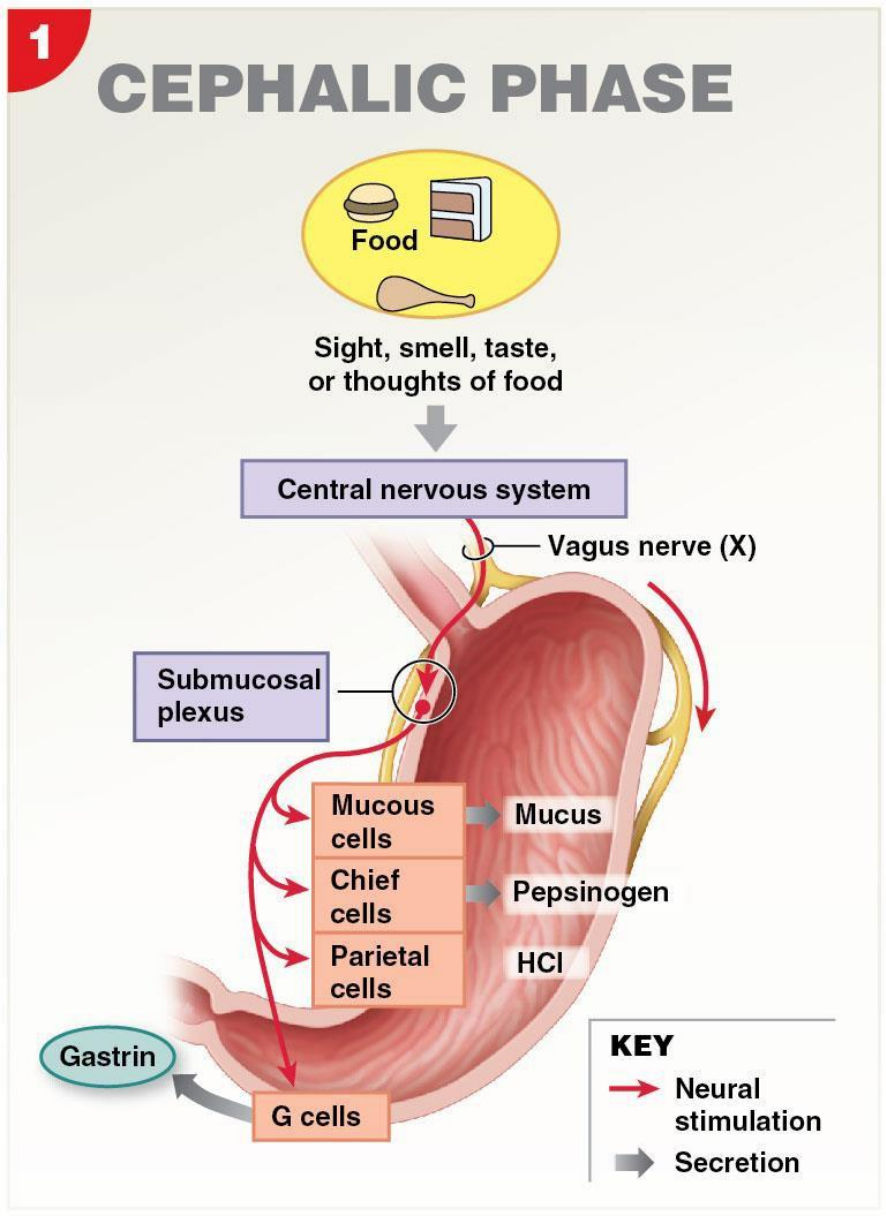
The chief cells secrete the proenzyme (inactive enzyme) pepesinogen, which is converted to pepsin by the HCl in the gastric lumen. In the pylorus G cells produce the hormone gastrin, which stimulates secretion by parietal and chief cells, and trigger muscular contractions of the stomach wall that churn its contents. The D cells of the pylorus secrete somatostatin, which inhibits gastrin release. Protein digestion is carried on by enzyme pepsin. In new born infants the stomach secretes the enzymes: renin , which acts on the milk protein casein; and gastric lipase, which starts milk fat breakdown.

Regulation of Gastric Activity: the production of acid and enzymes by the gastric mucosa is : 1- controlled by the CNS, 2- regulated by short reflexes of the ENS ; and 3- regulated by GI tract hormones.

3 phases of gastric control are identified: cephalic, gastric and intestinal phases.

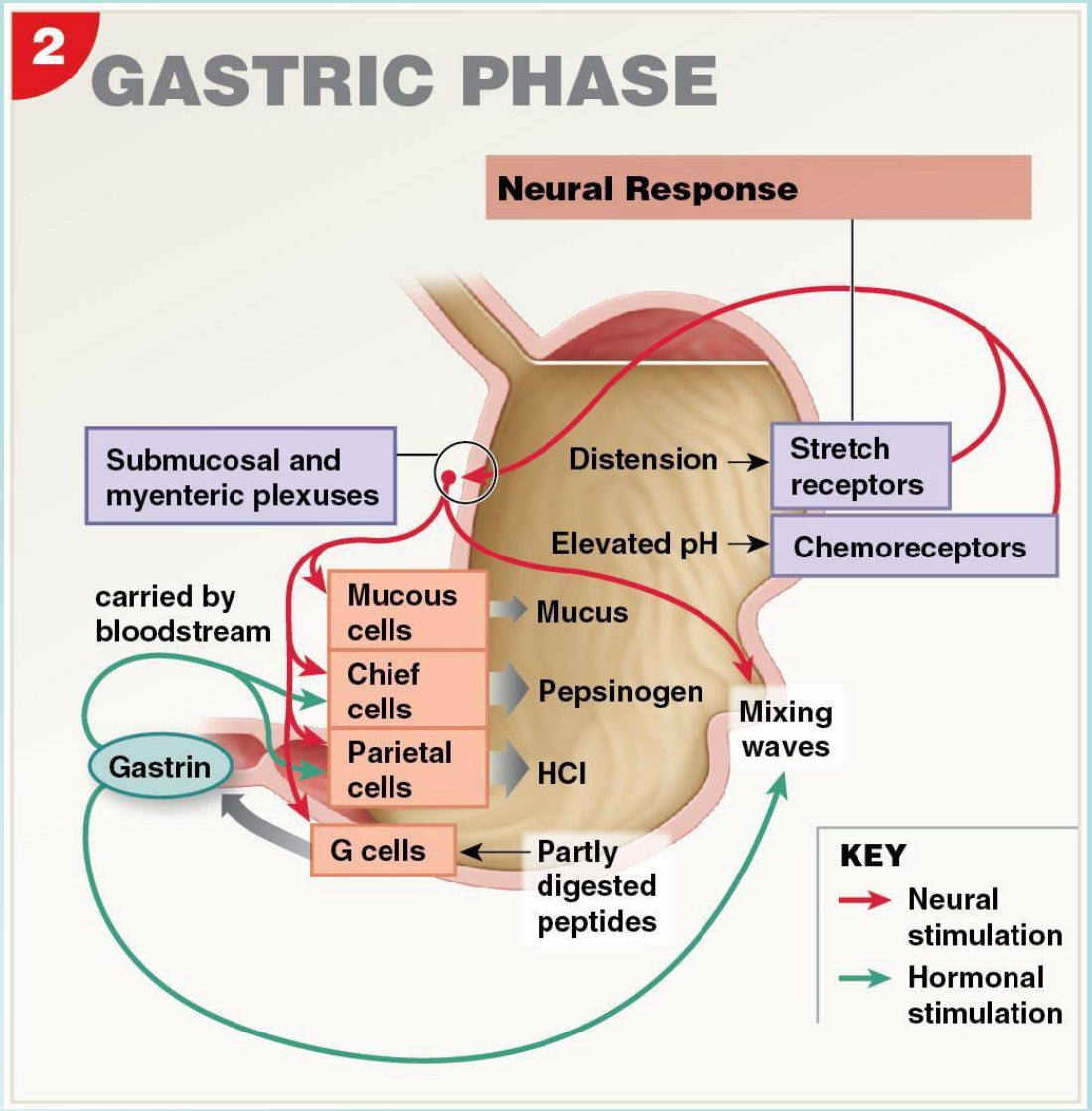
1. **Cephalic Phase:** or reflexive phase, it happens before foods enter the stomach and it is caused by sight, smell, taste or thinking of food. The brain through the hypothalamus initiates this reflex by the vagal nerve that innervates the submucosal plexus of the stomach. This is a short phase (minutes) that prepares the stomach for food arrival by stimulation of secretory activity (especially mucus secretion).
2. **Gastric Phase:** It is triggered by food entering the stomach. The stimuli that start this phase are: the stomach distension, increased acidity, the presence of undigested materials such as proteins and peptides. This phase is regulated by local, neural, and hormonal mechanisms.

Figure 24-15
The Regulation of Gastric Activity (Part 1 of 4).



Pearson

Figure 24-15
The Regulation of Gastric Activity (Part 2 of 4).



The neural mechanisms trigger myenteric reflexes that cause muscular contractions, and submucosal reflexes that cause ACh release, which stimulated output of gastric juice. The hormone gastrin plays the most important role in this phase. Gastrin release is stimulated by the presence of peptides and amino acids in chyme, and by neural stimulation. The local mechanisms involve the release of histamine by the lamina propia in response to stomach wall distortion. Histamine triggers acid secretion by the parietal cells. This phase can last 3 to 4 hours.

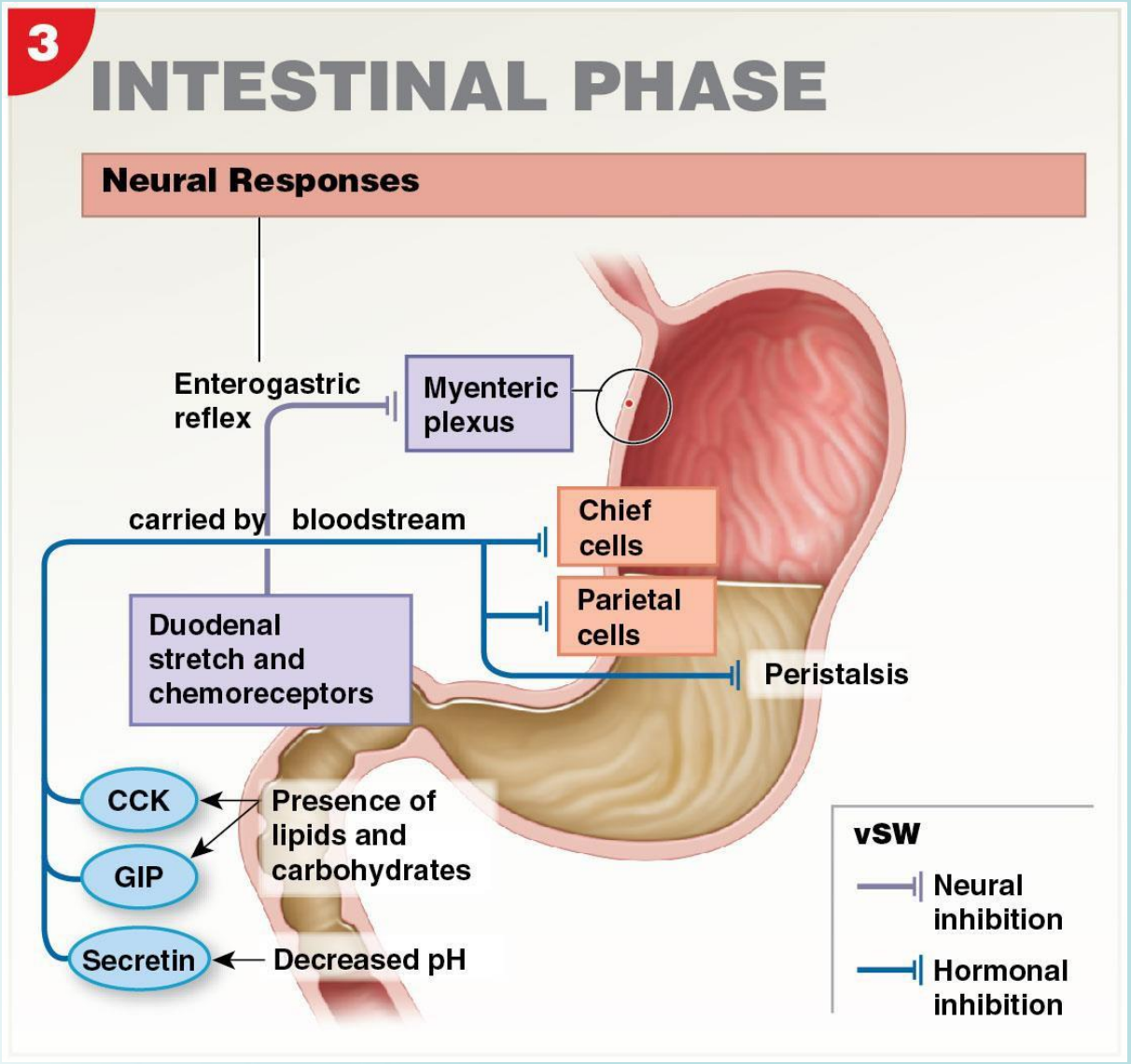
3. Intestinal Phase: it stars as chyme enters the intestine. The main function of this phase is to control the chyme rate of entry into the duodenum or to control stomach emptying.

This is in order to allow for efficient secretion, digestion and absorption in the small intestine.

This phase is regulated by neural and hormonal responses.

As the pylorus contracts the pyloric valve allows small amount of liquefied chyme to enter the duodenum, about 3 ml per wave. This triggers the enterogastric reflex, which causes tightening of pyloric sphincter to prevent more chyme from entering the duodenum, and inhibits central and local stimulation of gastric secretion and stomach contractions. Local reflexes stimulate mucus production in the duodenum. The hormonal responses depend in part to the chyme contents arriving to the duodenum. When lipids and carbohydrates arrive to the duodenum, the hormones cholecystokinin (CCK) and gastric inhibitory peptide (GIP) are released. In the stomach CCK and GIP inhibit gastric secretion, and GIP also reduces the rate and force of gastric contractions.

Figure 24-15
The Regulation of Gastric Activity (Part 3 of 4).



In the duodenum, when the pH goes below 4.5 secretin is released. This hormone inhibits the parietal and chief cells in the stomach, triggers pancreatic production of neutralizing buffers, and stimulate liver's bile secretion. Partially digested proteins entering with the chyme in the duodenum, stimulate the release of intestinal gastrin by duodenal G cells, this triggers acid and enzyme production in the stomach.

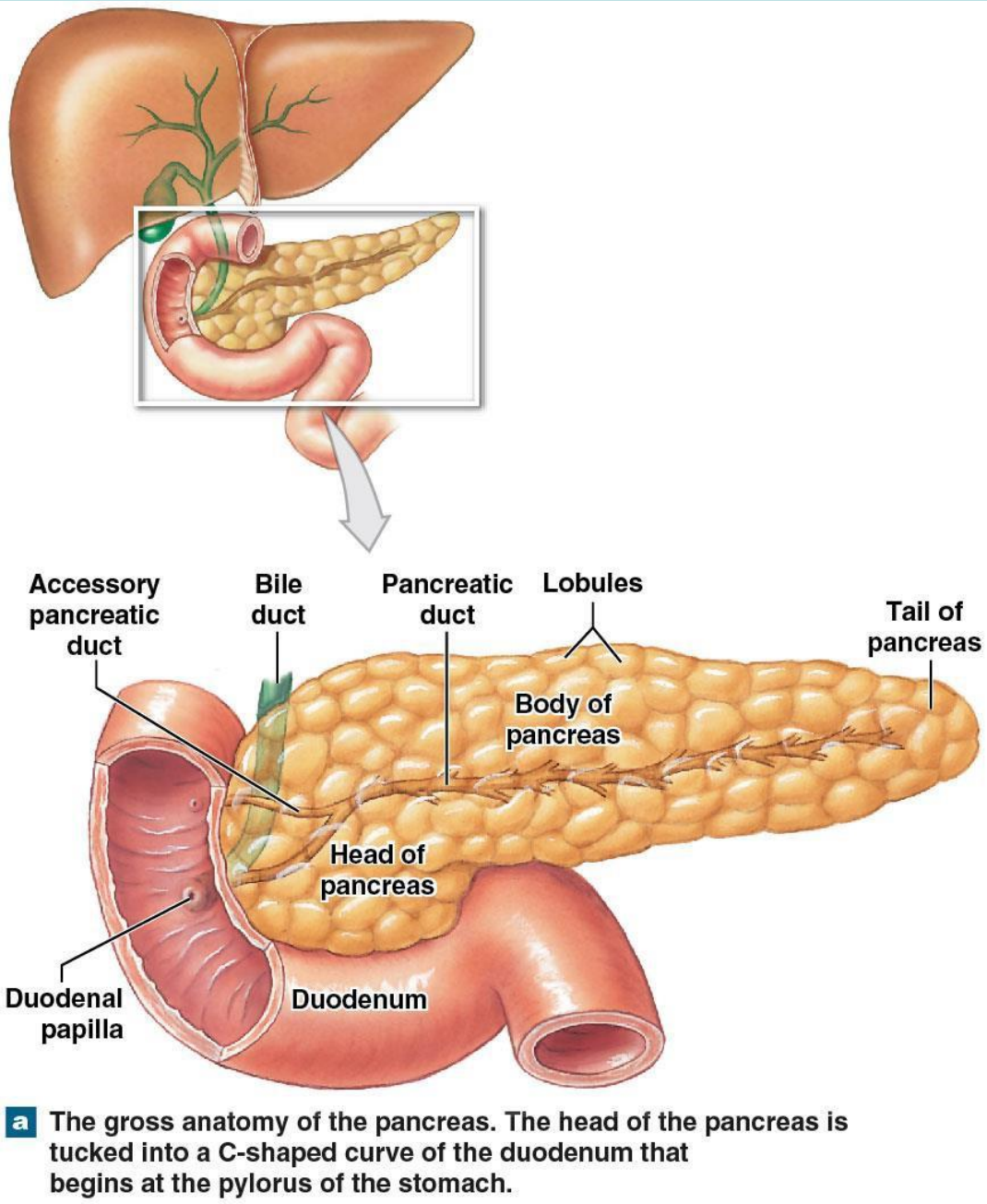
Pancreas: soft gland with a head, body and tail mostly retroperitoneal posterior to the stomach, and extending from the duodenum to the spleen. It is attached to the posterior wall and wrapped in a connective tissue capsule. It produces numerous digestive enzymes, and buffers. The pancreatic juice exits through the pancreatic duct and the accessory pancreatic duct, which both empty into the duodenum. The pancreatic duct joins the bile duct at the duodenal ampulla or ampulla of Vater.

Histology of the Pancreas : The pancreas is divided into lobules by connective tissues called septa, which contain branches of the pancreatic duct and blood vessels. The ducts end on blind pockets called **pancreatic acini** that form clusters of exocrine secretory cells that secrete proenzymes, which are activated into digestive enzymes.

The pancreatic ducts are lined by exocrine epithelial cells, which produce water and alkaline pancreatic juice. The pancreas also contains endocrine glands or cells (1% of pancreatic cells) scattered among the pancreatic acini which are called the Islets of Langerhans. They produce primarily the hormones insulin and glucagon into the blood.

Composition of the Pancreatic Juice: The exocrine cells produce pancreatic juice which is mostly water, enzymes and electrolytes, mainly bicarbonate ions at a rate of 1000 ml a day. The acinar cells produce enzymes and the ductal cells produce bicarbonate ions. The enzymes include proteases that break down protein, lipases that break down lipids, amylase that break down carbohydrates and nucleases that break down nucleic acids.

Figure 24-16a
Anatomy of the Pancreas.



a The gross anatomy of the pancreas. The head of the pancreas is tucked into a C-shaped curve of the duodenum that begins at the pylorus of the stomach.

The gross anatomy of the pancreas. The head of the pancreas is tucked into a C-shaped curve of the duodenum that begins at the pylorus of the stomach.
ATLAS: Plates 54d; 55; 57a

Pearson

Figure 24-16b
Anatomy of the Pancreas.

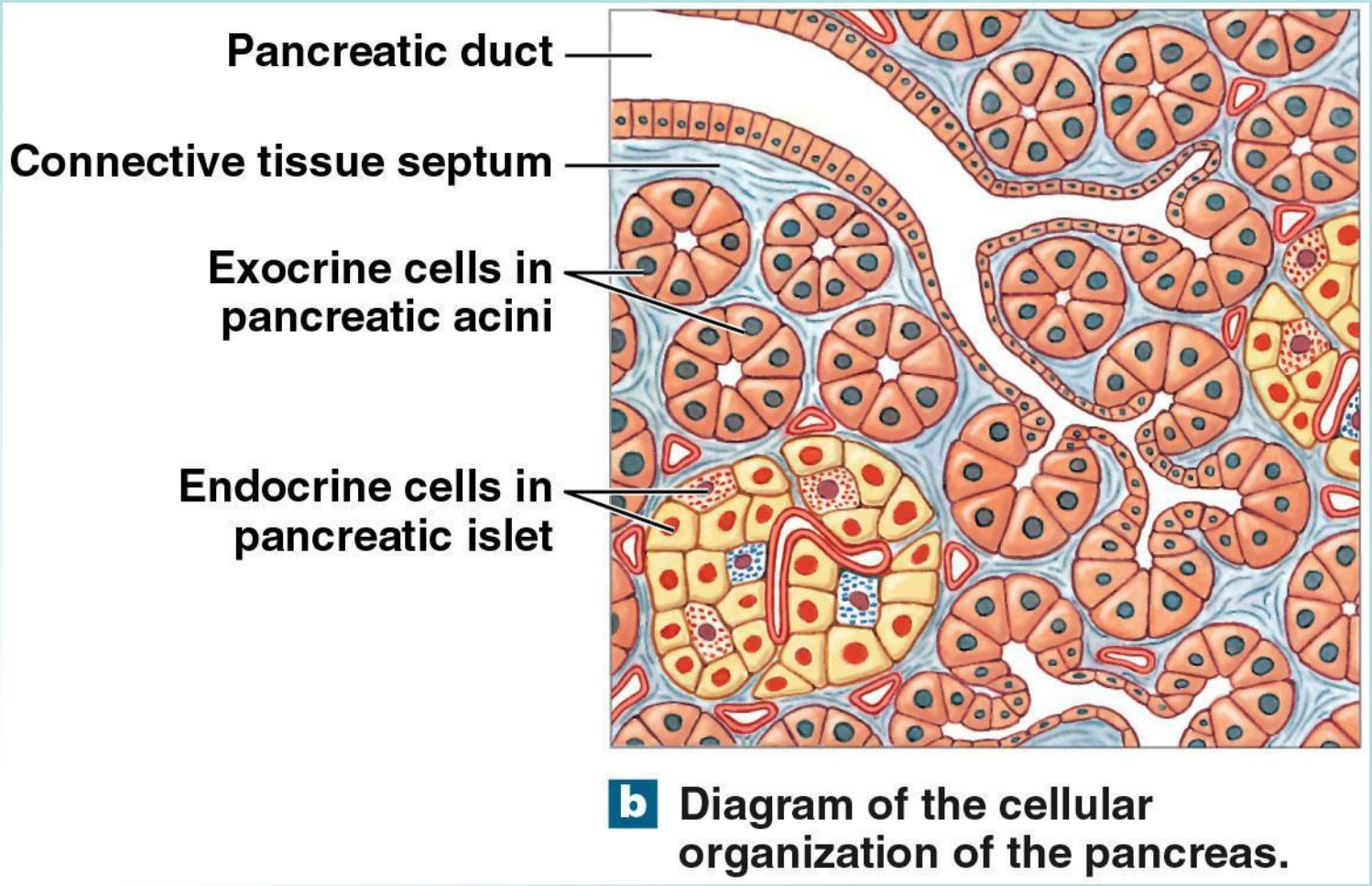
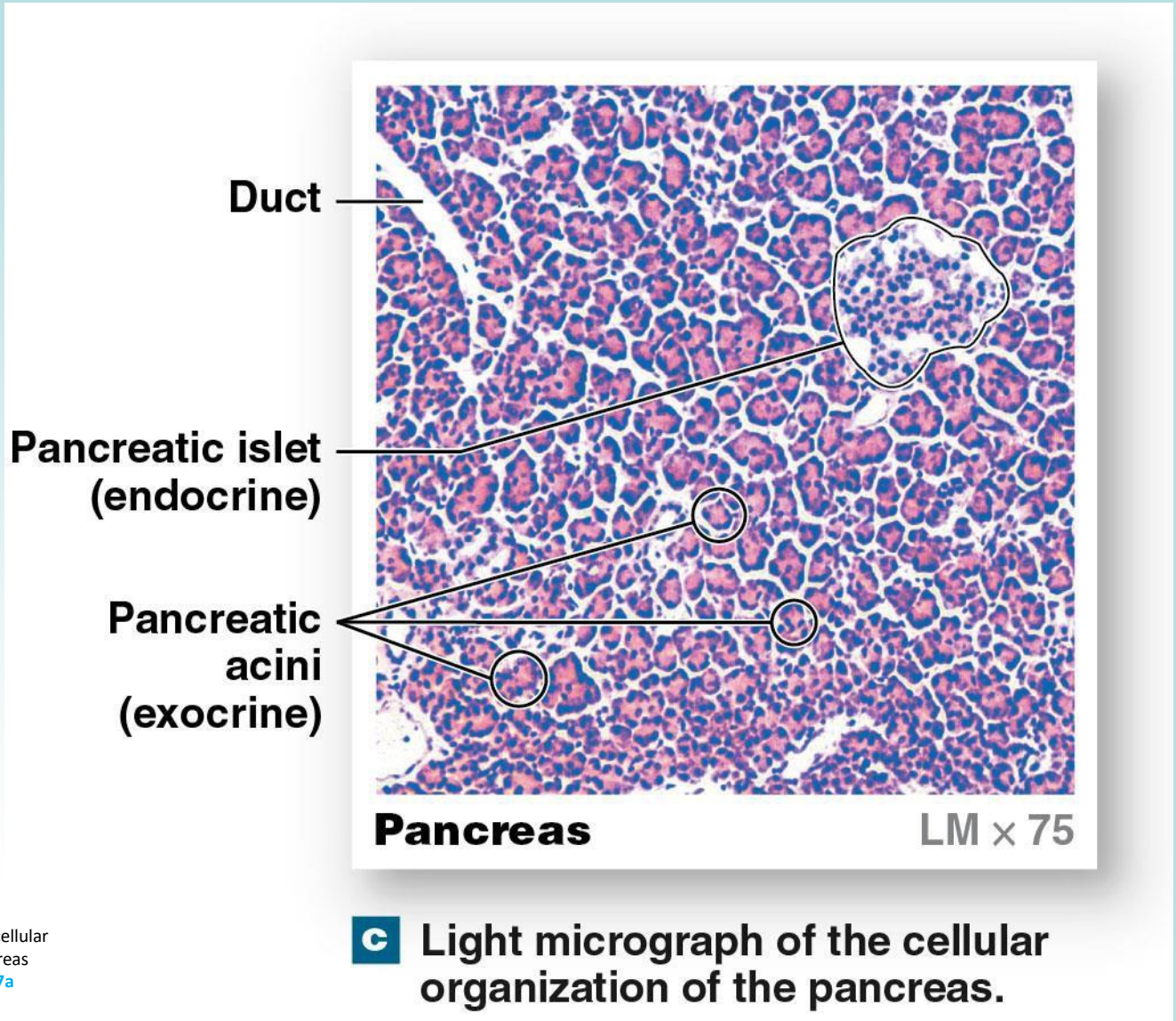


Diagram of the cellular organization of the pancreas.
ATLAS: Plates 54d; 55; 57a

Figure 24-16c

Anatomy of the Pancreas.



Light micrograph of the cellular organization of the pancreas
ATLAS: Plates 54d; 55; 57a

C Light micrograph of the cellular organization of the pancreas.

Pearson

Regulation of Pancreatic Secretion

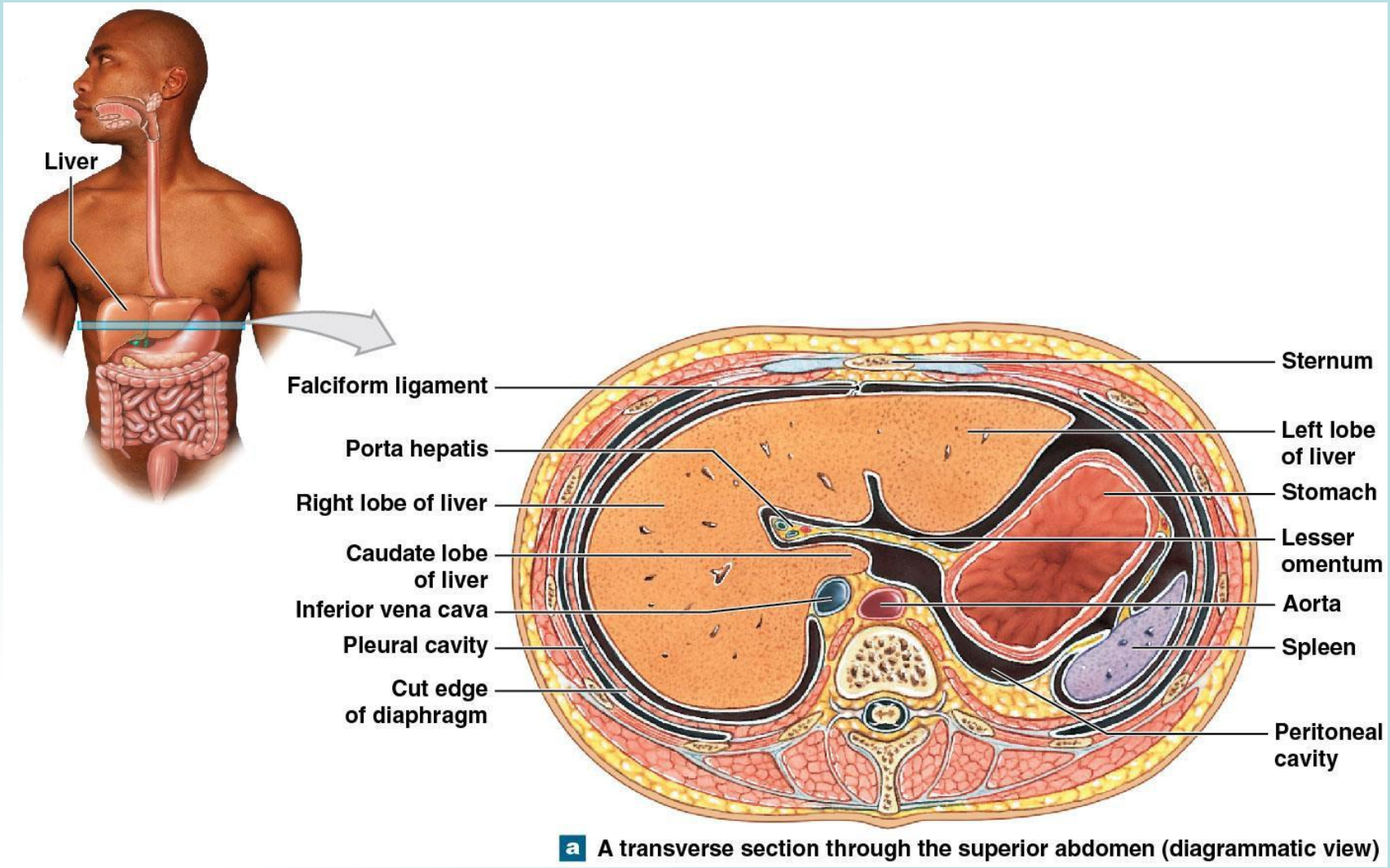
Secretion of pancreatic juice is controlled mainly by duodenal or local hormones, and by parasympathetic stimulation. The hormone secretin released in response to presence of acidic chyme in the duodenum. Secretin triggers the release of watery buffers containing bicarbonate and phosphate ions. The hormone CCK is released in response to presence of proteins and fats and triggers the secretion of pancreatic enzymes. These include: pancreatic alpha-amylase, pancreatic lipase several proteases or proteolytic enzymes, and nucleases. These enzymes release is also triggered by vagal stimulation. GIP stimulates insulin secretion by the pancreas.

The Liver: The digestive function of the liver is to produce **bile** to emulsify fats. The liver also processes nutrients from the blood and it has many metabolic and synthetic functions. The liver is located in the right side of the abdominal cavity somewhat protected by the ribcage.

A. Gross Anatomy of the Liver

The liver is the largest visceral organ in the body. It is enclosed in a tough fibrous capsule and covered by visceral peritoneum. It is composed of four lobes: 1- right, 2- left, 3- **Caudate** and 4- **Quadrate**. The **falciform ligament** separates the right and left lobes anteriorly. The round ligament or ligamentum teres is a thickening of the falciform ligament. This is a remnant of the umbilical cord. Posteriorly the liver has a groove where the inferior vena cava rests. This marks the separation between the right and caudate lobes.

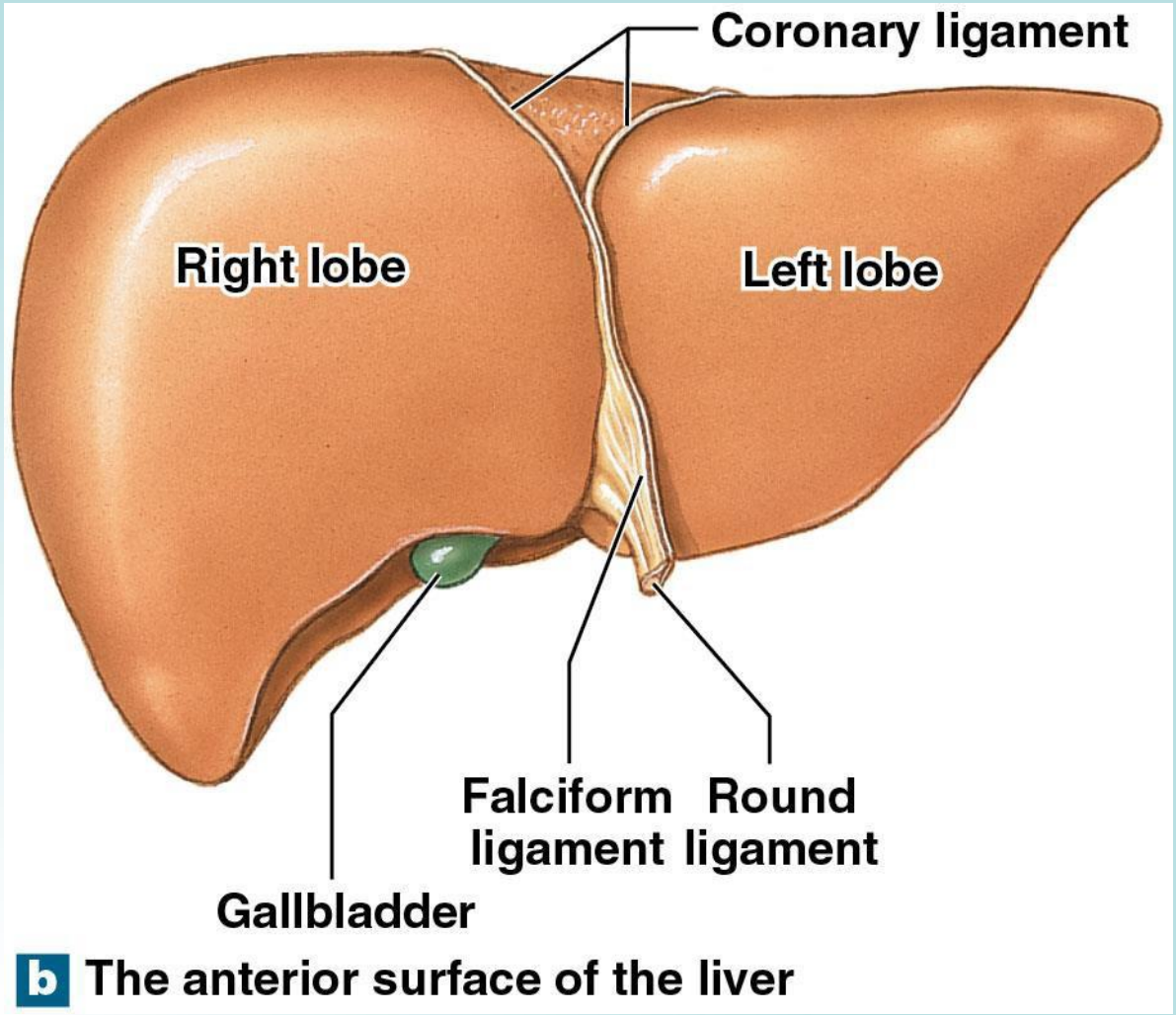
Figure 24-17a
Gross Anatomy of the Liver.



A transverse section through the superior abdomen (diagrammatic view) ATLAS: Plates 49a,b,e; 54a–c; 57a,b

Figure 24-17b

Gross Anatomy of the Liver.

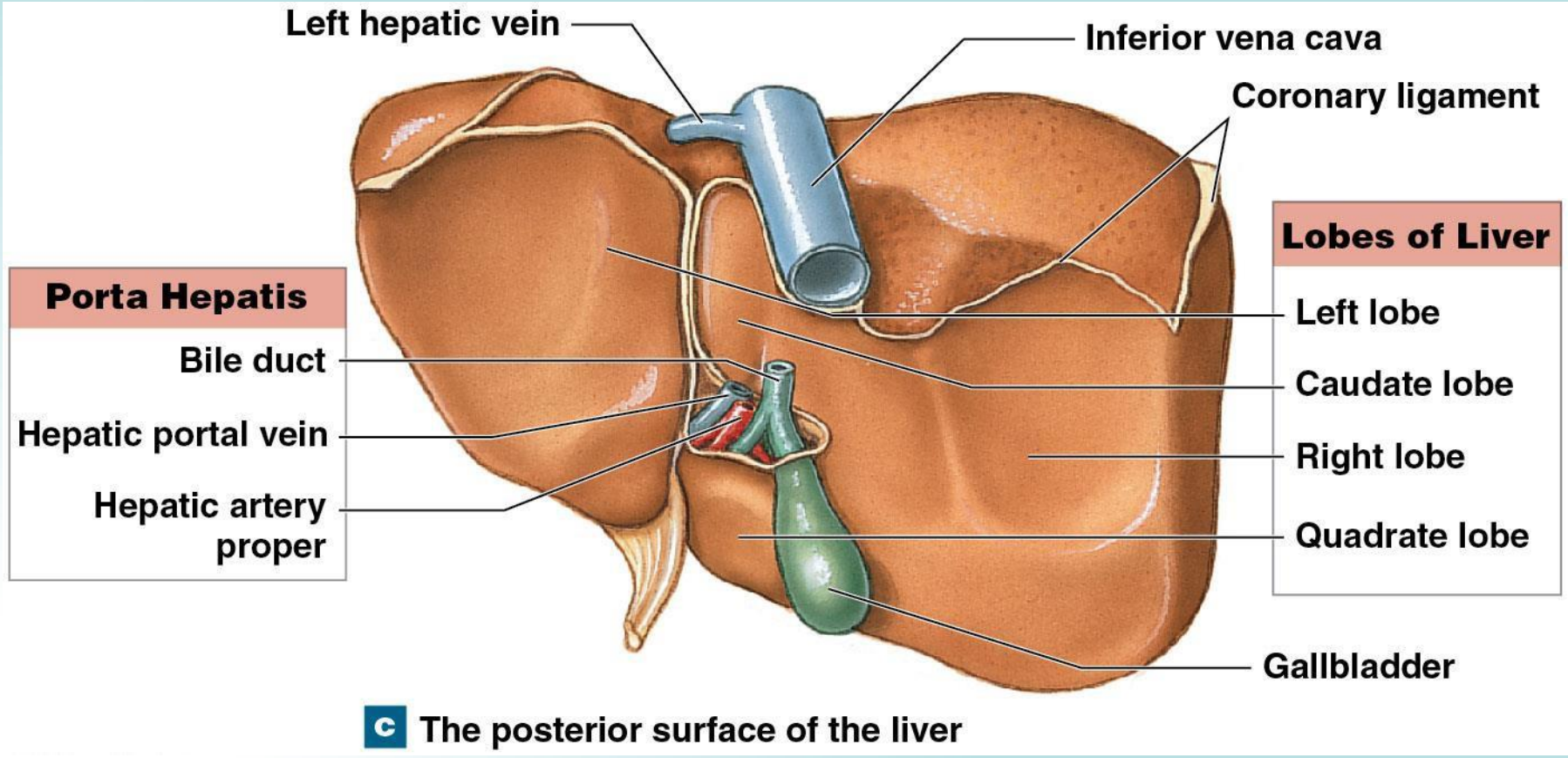


The anterior surface of the liver

ATLAS: Plates 49a,b,e; 54a–c; 57a,b

Pearson

Figure 24-17c
Gross Anatomy of the Liver.



The posterior surface of the liver
ATLAS: Plates 49a,b,e; 54a–c; 57a,b

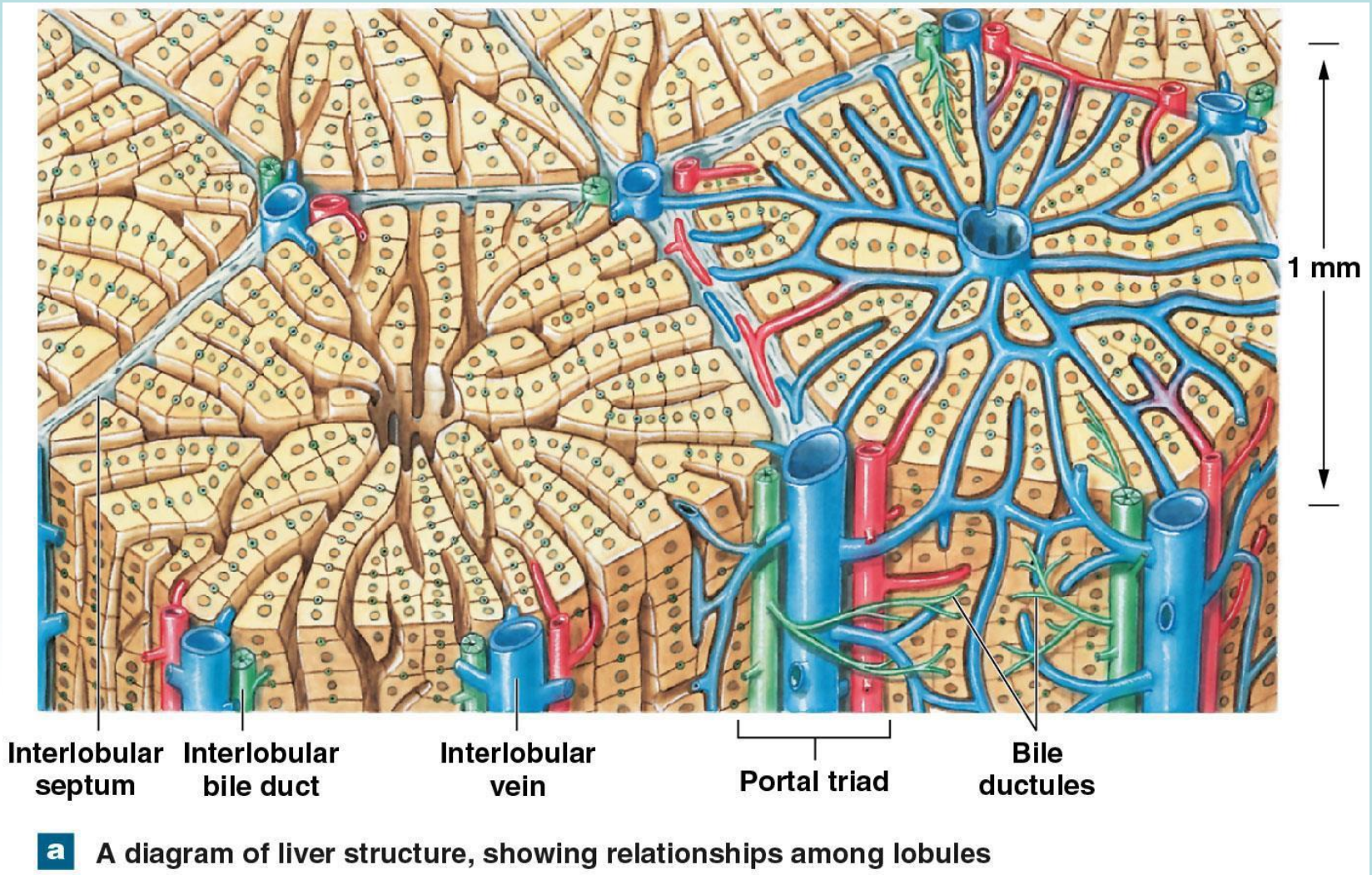
Pearson

The quadrate lobe is located below the caudate and between the gallbladder and the left lobe. The blood vessels and bile duct converge at the porta hepatis or hilus.

B. Histological Organization of the Liver

The liver is divided into functional units called liver **lobules** by connective tissue interlobular septa. They have a hexagonal shape. The liver cells or hepatocytes are separated by sinusoids and radiate from the **central vein** in which the sinusoids empty. At the corners of each lobule there is a **portal triad**, composed of an interlobular artery, intrlobular vein and interlobular bile duct, so there are six portal triads or areas. Hepatocytes adjust the levels of circulating nutrients by selective absorption of solutes from the plasma and secretion of materials such as plasma proteins. The portal vein carries nutrient rich blood from the digestive viscera.

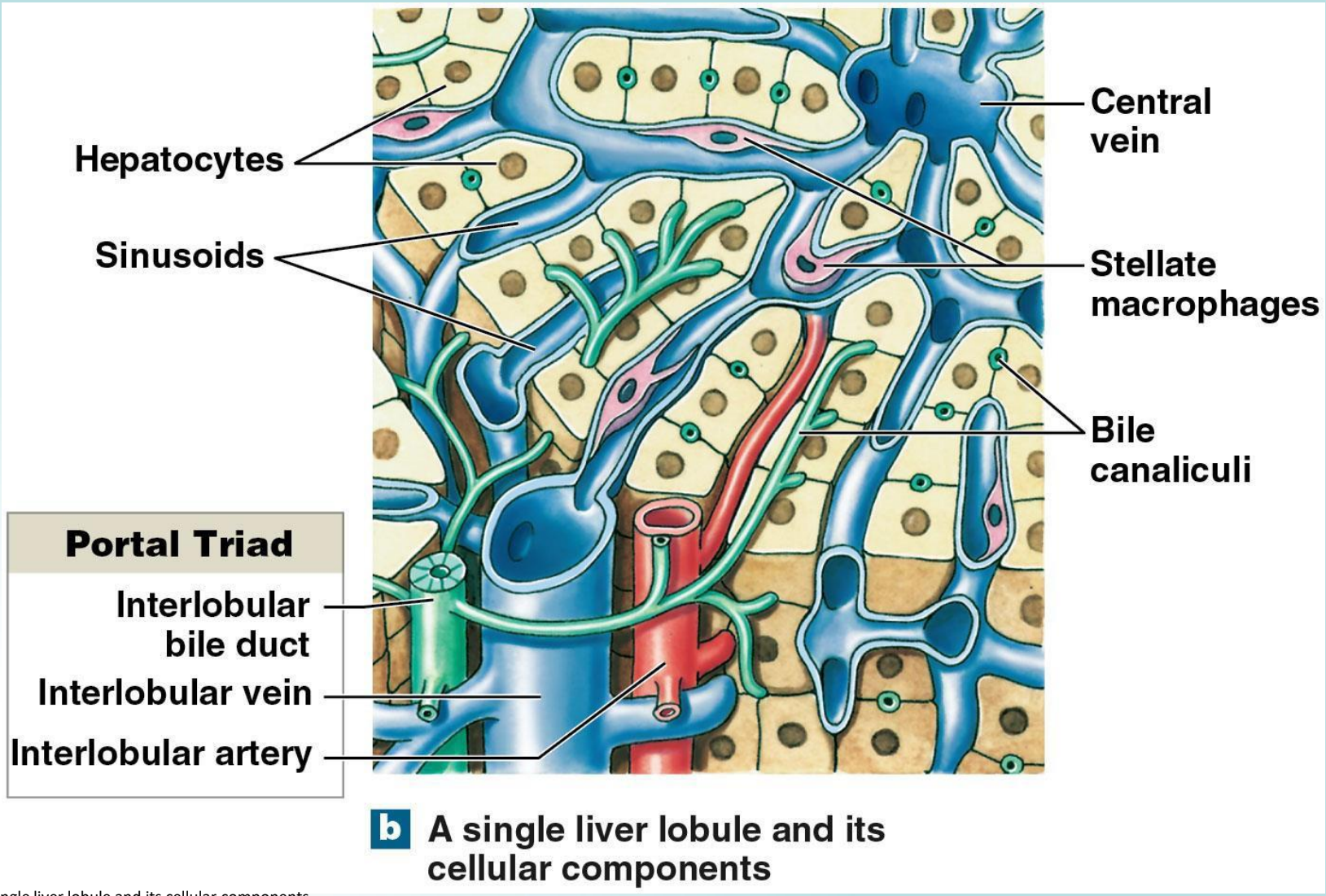
Figure 24-18a
Histology of the Liver.



A diagram of liver structure, showing relationships among lobules

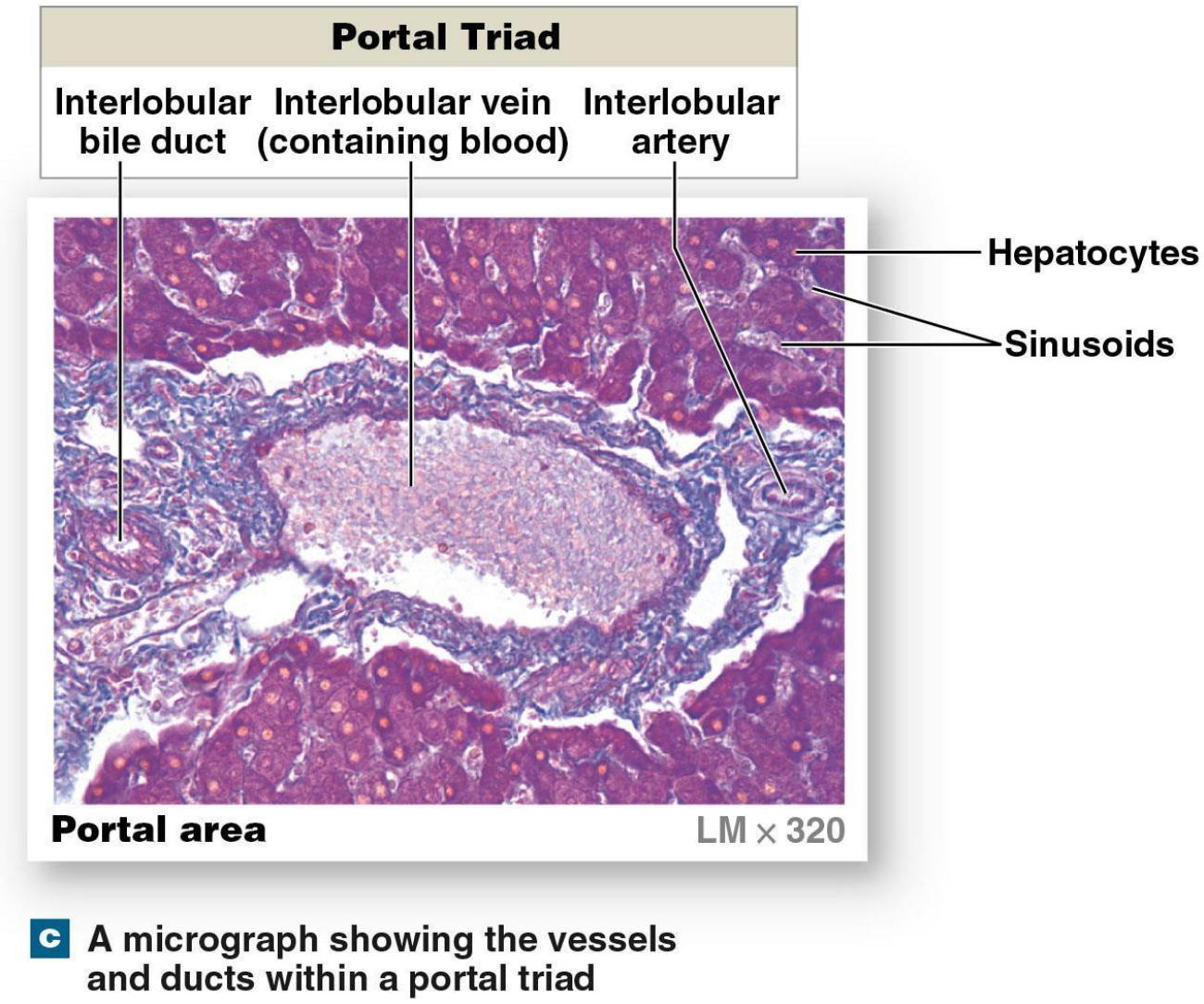
Figure 24-18b

Histology of the Liver.



A single liver lobule and its cellular components

Figure 24-18c
Histology of the Liver.



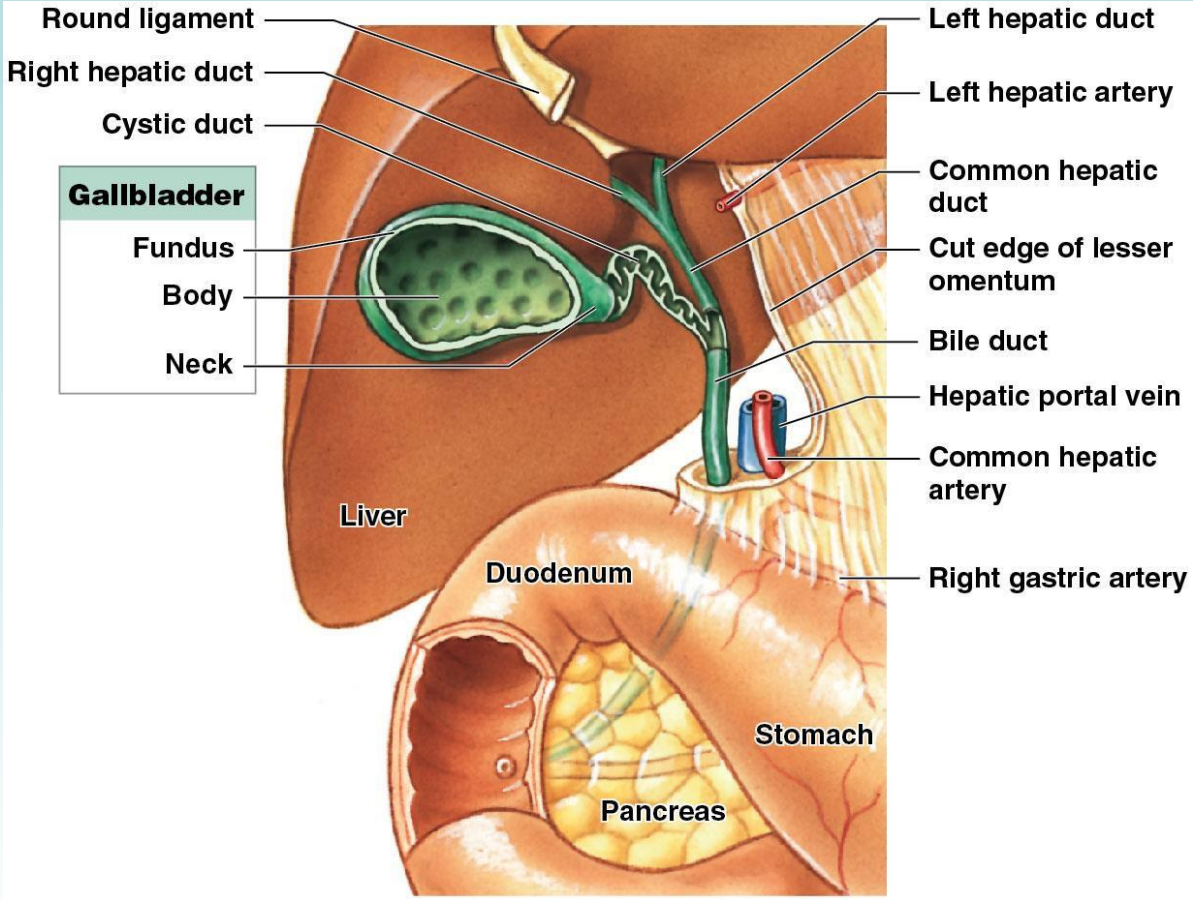
A micrograph showing the vessels and ducts within a portal triad

The liver sinusoids are lined with **stellate macrophages** called kupffer cells. They engulf pathogens, remove debris and worn out blood cells, store iron, lipids and heavy metals.

Bile Duct System, Bile Composition, and Functions: Bile is secreted by the liver into a network of channels called **bile canaliculi**. They extend outward away from the **central vein** and carry bile in the opposite direction to the blood in the sinusoids. They empty into bile ductules that empty into the bile ducts at the portal triad. These then empty into the **right and left hepatic ducts**, which join to form the **common hepatic duct**. Bile leaves the liver and empties into either the **bile duct** or the **cystic duct**. The bile duct, formed by the joining of the cystic duct and common hepatic duct, carries bile to the duodenum at the duodenal ampulla, and the cystic duct carries bile to the gallbladder.

Figure 24-19a

Anatomy and Physiology of the Gallbladder and Bile Ducts.



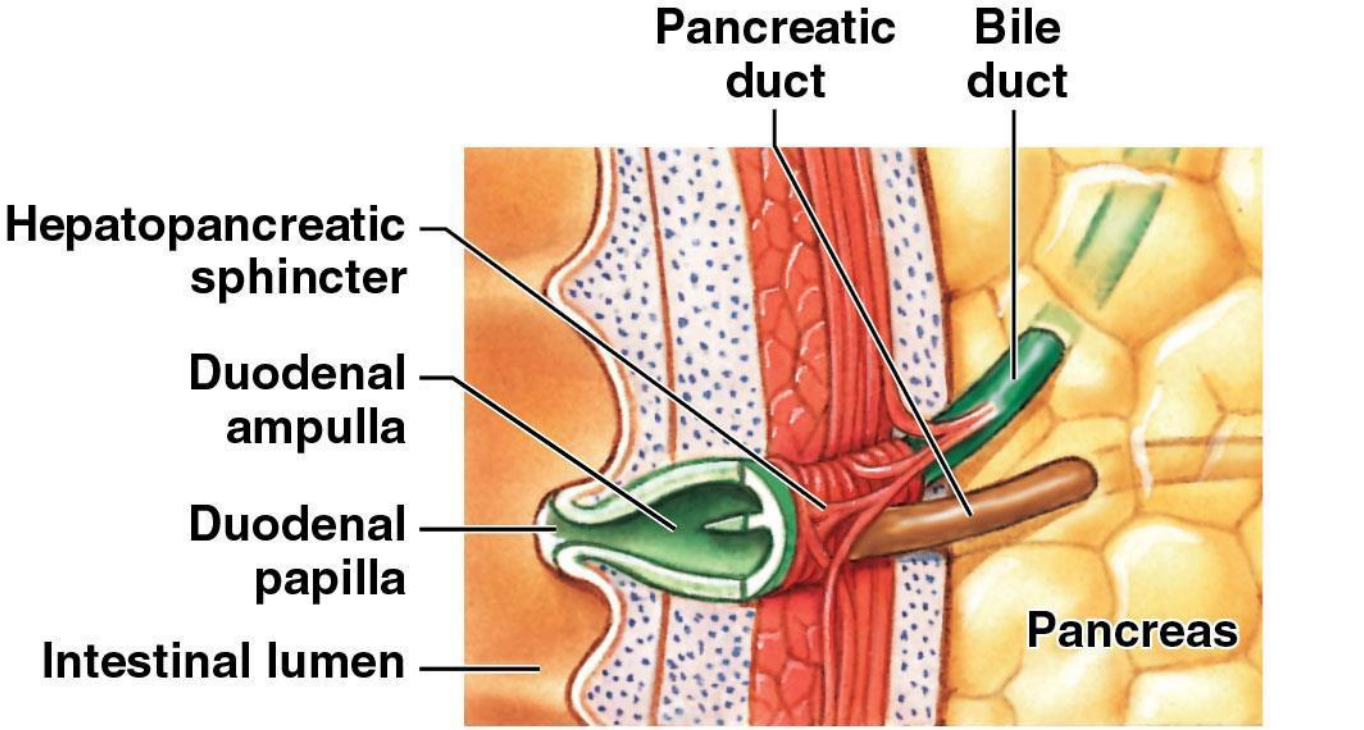
a A view of the inferior surface of the liver, showing the position of the gallbladder and ducts that transport bile from the liver to the gallbladder and duodenum. A portion of the lesser omentum has been cut away.

A view of the inferior surface of the liver, showing the position of the gallbladder and ducts that transport bile from the liver to the gallbladder and duodenum. A portion of the lesser omentumhas been cut away. ATLAS: Plates 49c,e; 51a; 54b–d

Pearson

Figure 24-19b

Anatomy and Physiology of the Gallbladder and Bile Ducts.

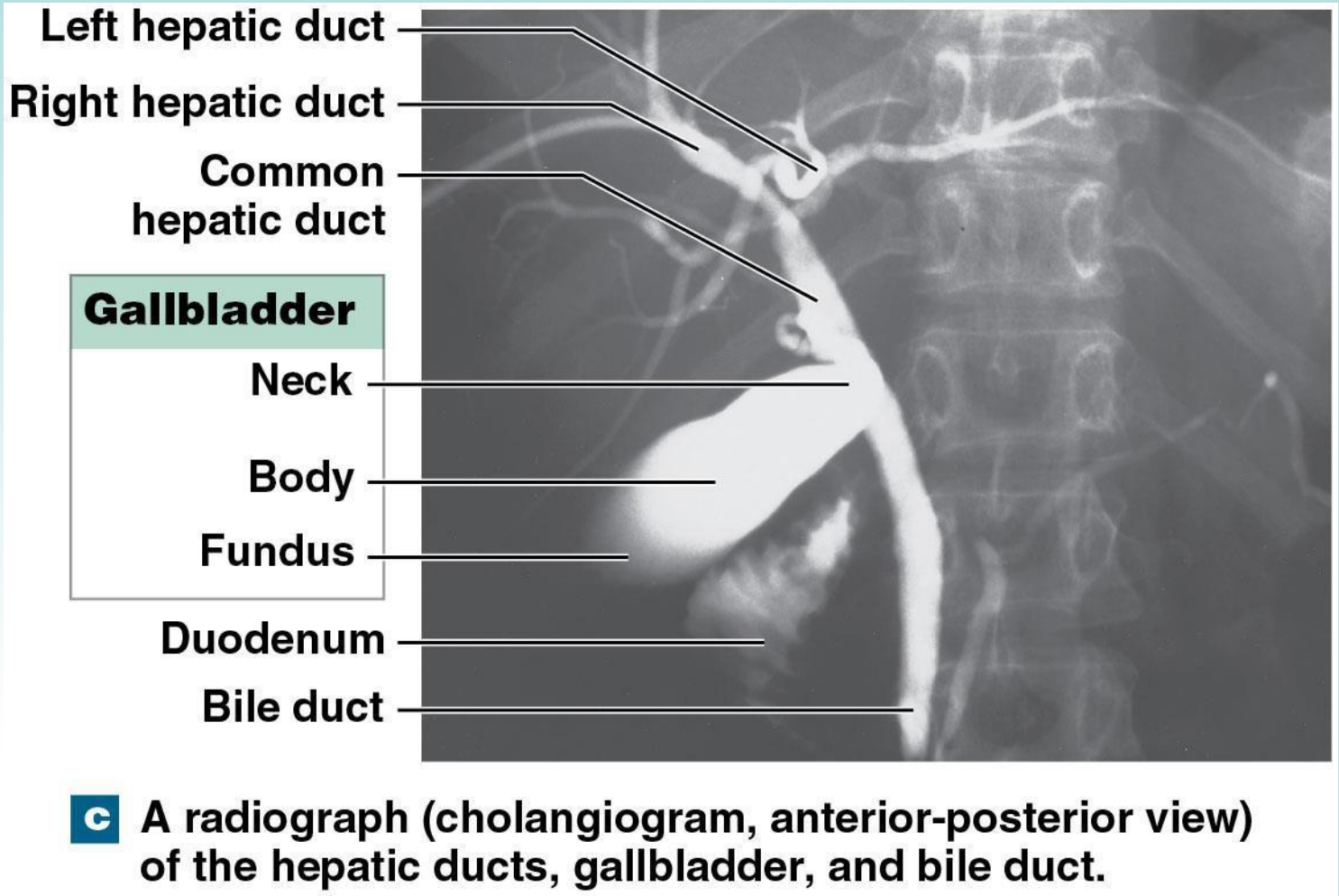


b A sectional view through a portion of the duodenal wall, showing the duodenal ampulla and related structures.

A sectional view through a portion of the duodenal wall, showing the duodenal ampulla and related structures. ATLAS: Plates 49c,e; 51a; 54b–d

Figure 24-19c

Anatomy and Physiology of the Gallbladder and Bile Ducts.



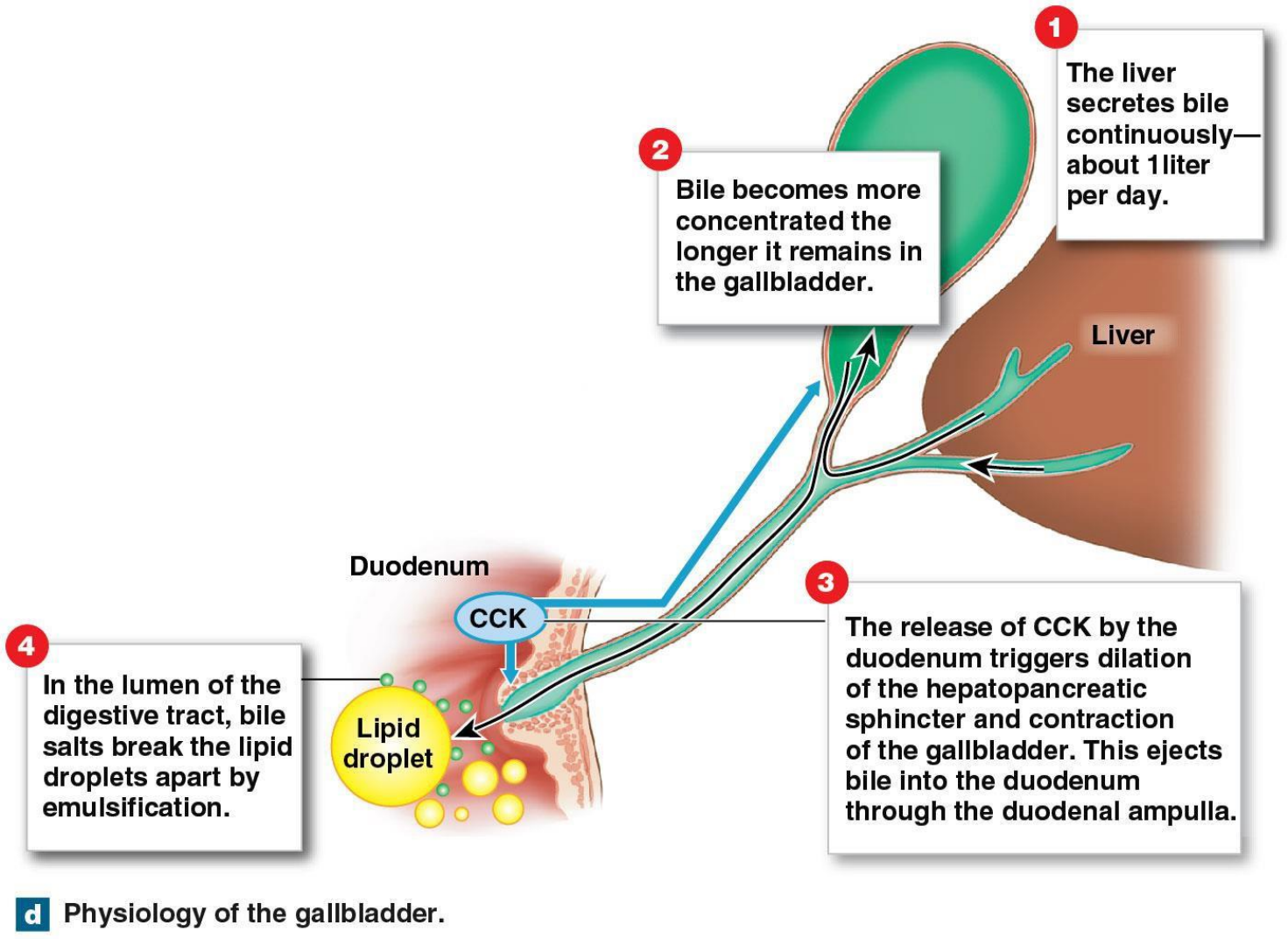
C A radiograph (cholangiogram, anterior-posterior view) of the hepatic ducts, gallbladder, and bile duct.

A radiograph (cholangiogram, anterior-posterior view) of the hepatic ducts, gallbladder, and bile duct. ATLAS: Plates 49c,e; 51a; 54b–d

Pearson

Figure 24-19d

Anatomy and Physiology of the Gallbladder and Bile Ducts.



Physiology of the gallbladder. ATLAS: Plates 49c,e; 51a; 54b–d

Bile is a yellow-green alkaline fluid composed of water, ions, bile salts, pigments, and cholesterol. Bile salts aid in the lipid digestive process by emulsifying or breaking down large lipid droplets into tiny emulsion droplets that can be attacked by enzymes. These droplets have a coating of bile salts that help lipid-enzyme interaction, and lipid absorption. The **enteropancreatic circulation** recycles bile salts. The main bile pigment is bilirubin a by product of heme group from the break down of hemoglobin.

Other Liver Functions

Besides bile production and secretion, the liver has metabolic and hematological regulatory functions. The metabolic regulation of the liver includes: the composition of circulating blood, nutrient metabolism, waste removal, nutrient storage, and drug inactivation.

The liver is involved in carbohydrate metabolism such as stabilizing glucose levels in the blood; lipid metabolism by regulating triglycerides, fatty acid, and cholesterol levels in circulation; amino acid metabolism; removal of waste products such as nitrogenous waste by formation of urea, and of circulating toxins and drugs; storage of vitamins such as A, D, E, K and B12, minerals such as iron, and glycogen and lipids; and Inactivation of toxins and drugs. The liver removes and stores excess nutrients. The hematological functions include: phagocytosis and antigen presentation by Kupffer cells; synthesis of most plasma proteins; removal of circulating hormones; removal of antibodies; and removal or inactivation of toxins.

The Gallbladder: It is a thin green muscular pear shaped sac on a shallow fossa of the posterior surface of the liver's right lobe. It is divided into fundus, body, and neck.

The gallbladder stores bile (40 to 70 ml) that is not immediately needed for digestion and it concentrate it by absorbing excess water and ions. It contracts to spell bile into the cystic duct, which empties into the bile duct. This meets the pancreatic duct at **the duodenal ampulla**, a chamber that opens into the duodenum at the **duodenal papilla**, which is a small mouth protruding into the duodenum. The release of bile and pancreatic juice is controlled by the **Hepatopancreatic sphincter**.

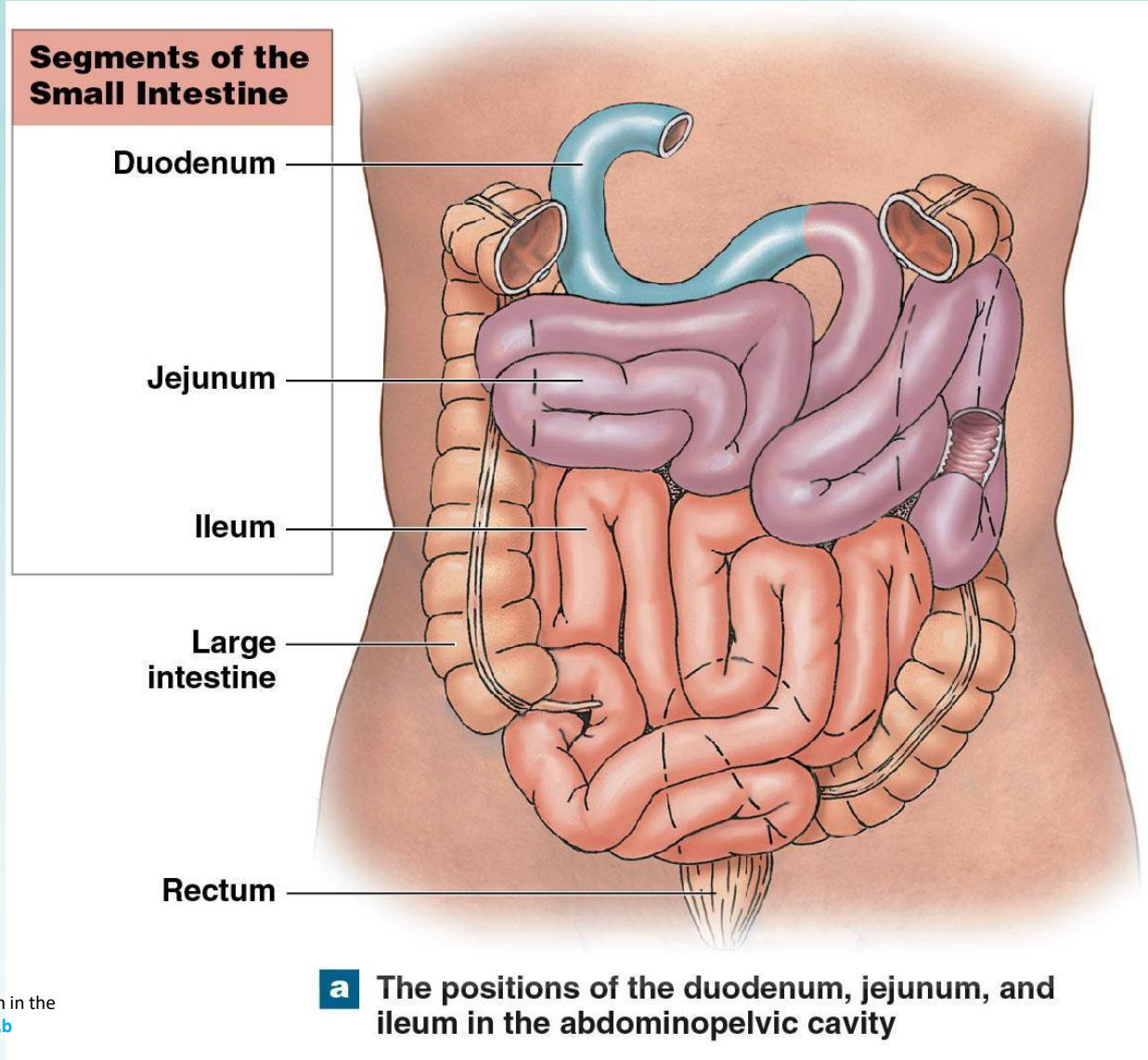
Regulation of Bile Release into the Small Intestine: The intestinal hormone CCK is the major stimulant for gallbladder contraction. Bile is release when chime rich in fats enters the duodenum as CCK produces the relaxation of the sphincter and the contraction of the gallbladder walls. The amount of bile released depends on the amounts of fat in the chyme.

Small Intestine: The small intestine is a long, muscular tube where chemical digestion is completed and 90% of the digested nutrients are absorbed.

Gross Anatomy: It extends from the pyloric sphincter to the ileocecal valve. It is the longest part of the GI tract and occupies most abdominal regions. It is divided in 3 parts. The first part is **Duodenum** (25 cm long), that receives the chyme form the stomach and pancreas and liver digestive secretions all of which mix here. It is also where acid from the stomach is neutralized. Next, the **Jejunum** (2.5 m long) has small villi and few circular folds. This is where most chemical digestion and nutrient absorption takes place. The last part is the **Ileum** (3.5 m long), which ends at the **ileocecal valve** that controls the passage of undigested materials to the large intestine. The jejunum and ileum are suspended from the posterior wall by mesenteries and are surrounded by the large intestine.

Figure 24-20a

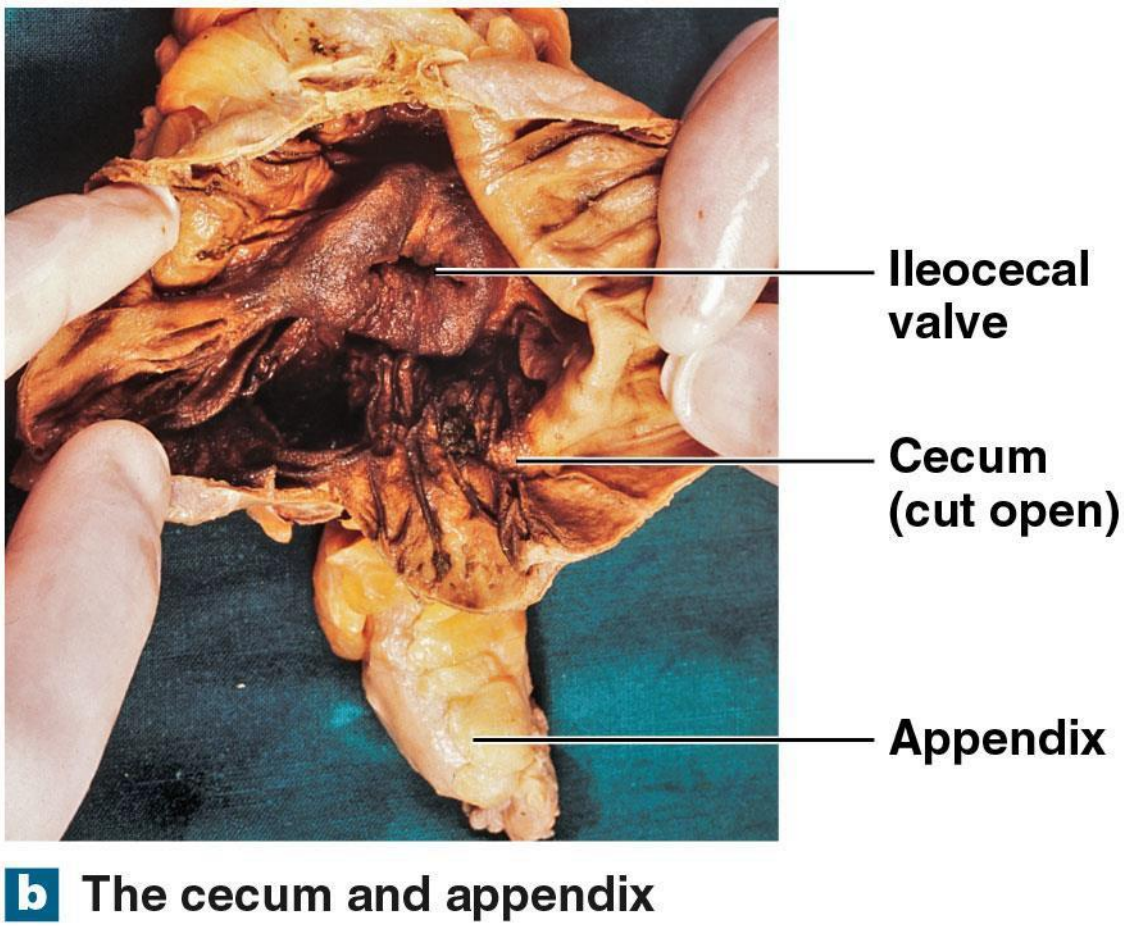
Gross Anatomy and Segments of the Intestine.



The positions of the duodenum, jejunum, and ileum in the abdominopelvic cavity. ATLAS: Plates 49a,b,d; 51a,b

Pearson

Figure 24-24b
Anatomy of the Large Intestine.



The cecum and appendix
ATLAS: Plates 49a,b,d; 51a,b

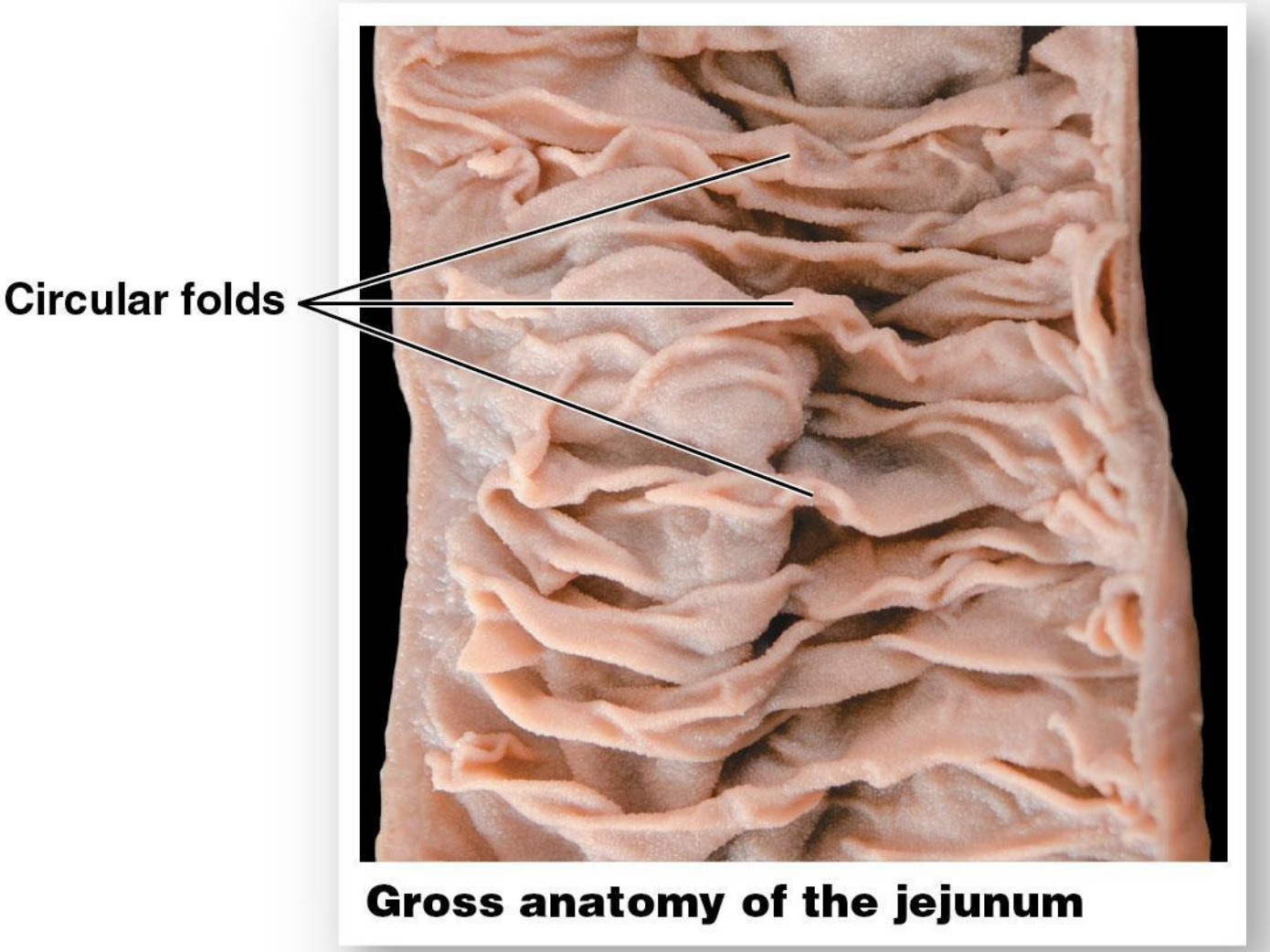
Pearson

B. Histology of the small Intestine: The SI is adapted for nutrient absorption with several structures to increase surface area and slow chyme mixing and passage. These structures are:

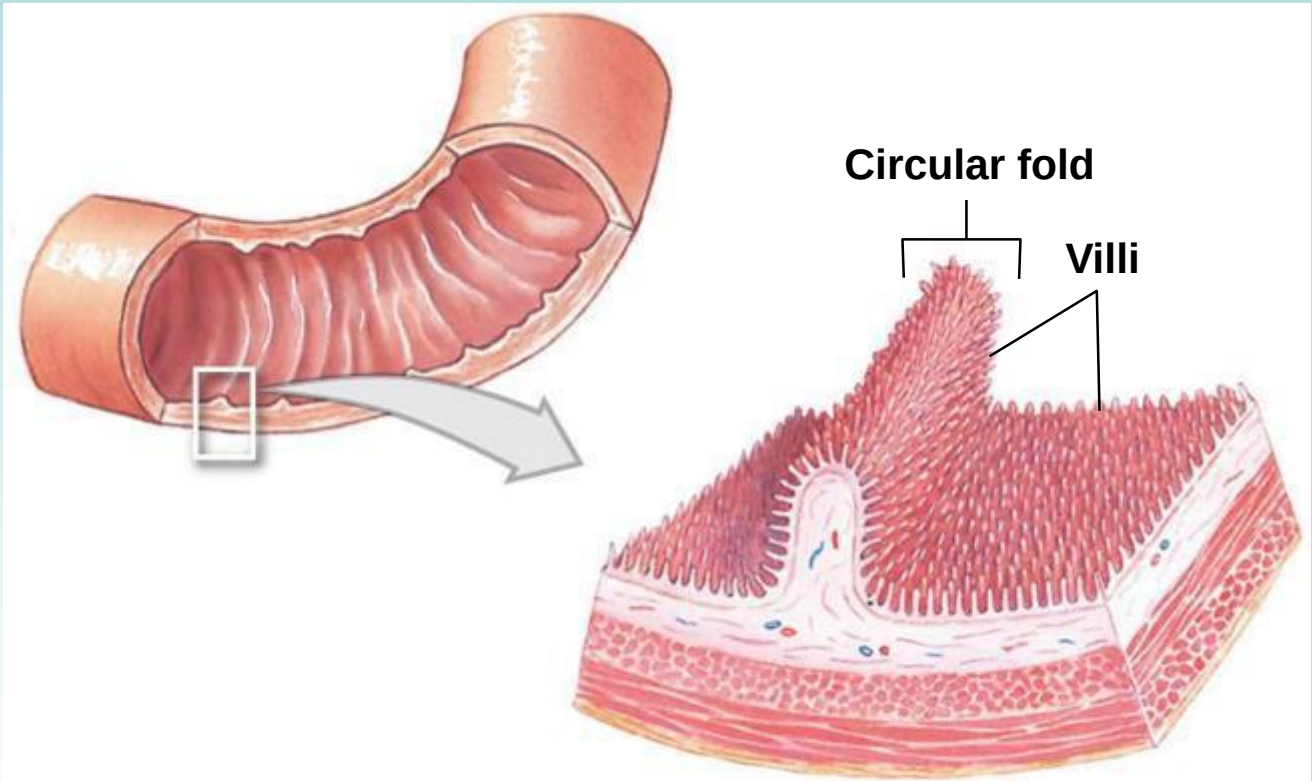
1. **8Circular folds:** they are deep transverse permanent folds of mucosa and submucosa that greatly increase the surface area for absorption and make chyme spiral through the lumen to mix with intestinal juice and slows movement to allow time for absorption.
2. **The Intestinal Villi:** they are finger like projections that give a velveti texture to the intestinal mucosa. They are formed by a single layer of columnar epithelium covered with **microvilli**. They also increase the surface area for absorption. They contain blood capillaries and the **lacteals**, which are lymphatic capillaries that transport the lipids and lipid soluble vitamins that cannot enter the blood capillaries and give a milky appearance to the fluid.

Figure 24-20b

Gross Anatom
Segments
the Intesti



A representative view of the jejunum
ATLAS: Plates 49a,b,d; 51a,b

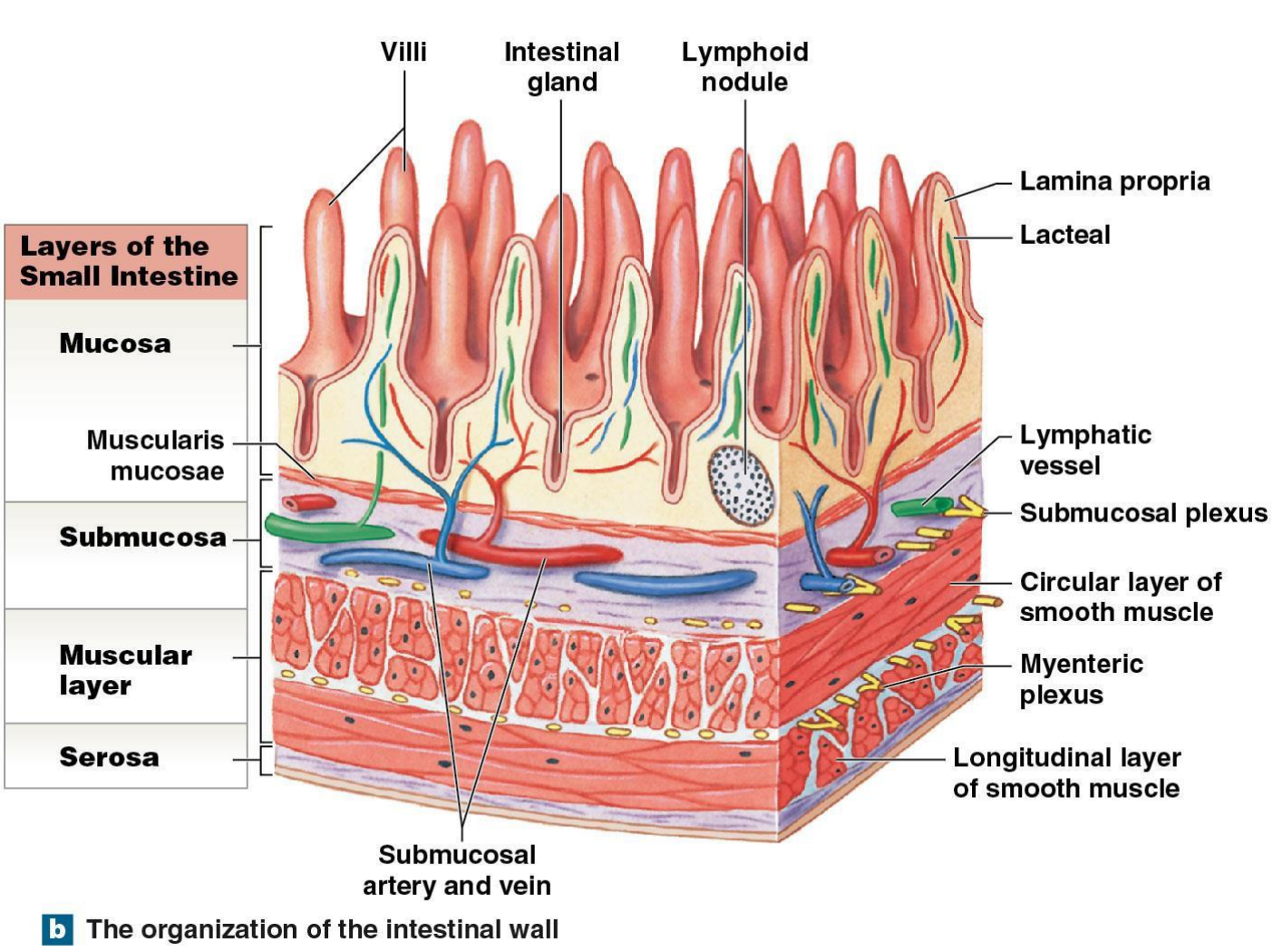


a A single circular fold and multiple villi

3. Microvilli: they are tiny projection of plasma membrane of absorptive cells that form the brush border. They increase the surface area for absorption, and contain bound enzymes such as disaccharidases and peptidases for carbohydrate and protein digestion.

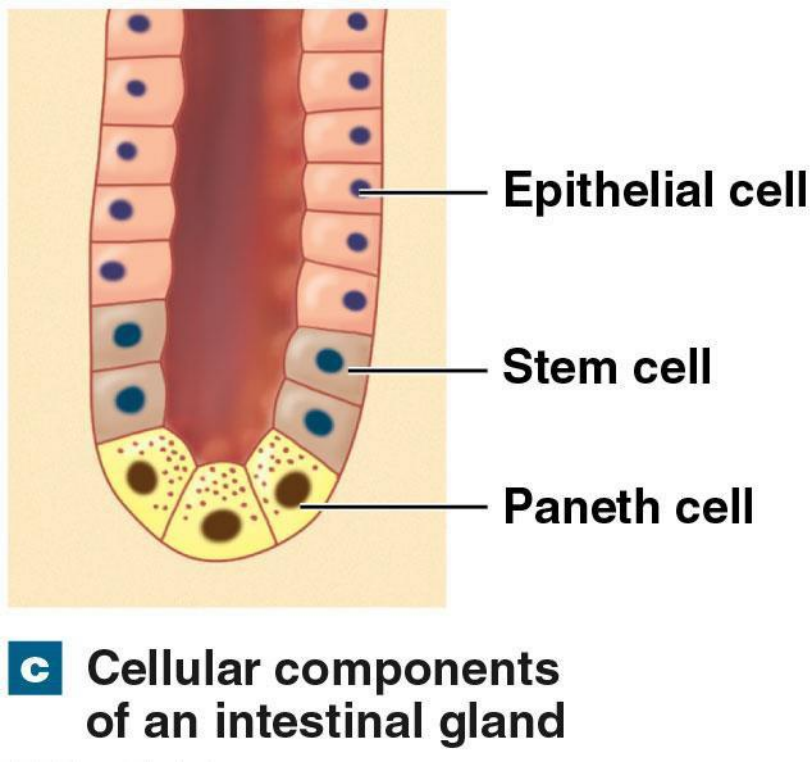
Intestinal Glands: The absorptive cells are part of the single columnar epithelium with enteroendocrine cells that release hormones, and mucous or goblet cells that secrete mucins onto the intestinal surface. This surface has numerous pits or openings at the base of the villi that lead to intestinal glands called intestinal crypts that extend into the lamina propria. They have stem cells near the base to produce new epithelial cells and Paneth cells at the base that provide innate immunity . The duodenal glands called submucosal or Brunner's glands produce a abundant of mucus when chyme arrives from the stomach.

Figure 24-21b
Histology of the Intestinal Wall.



The organization of the intestinal wall. ATLAS: Plates 51a–d

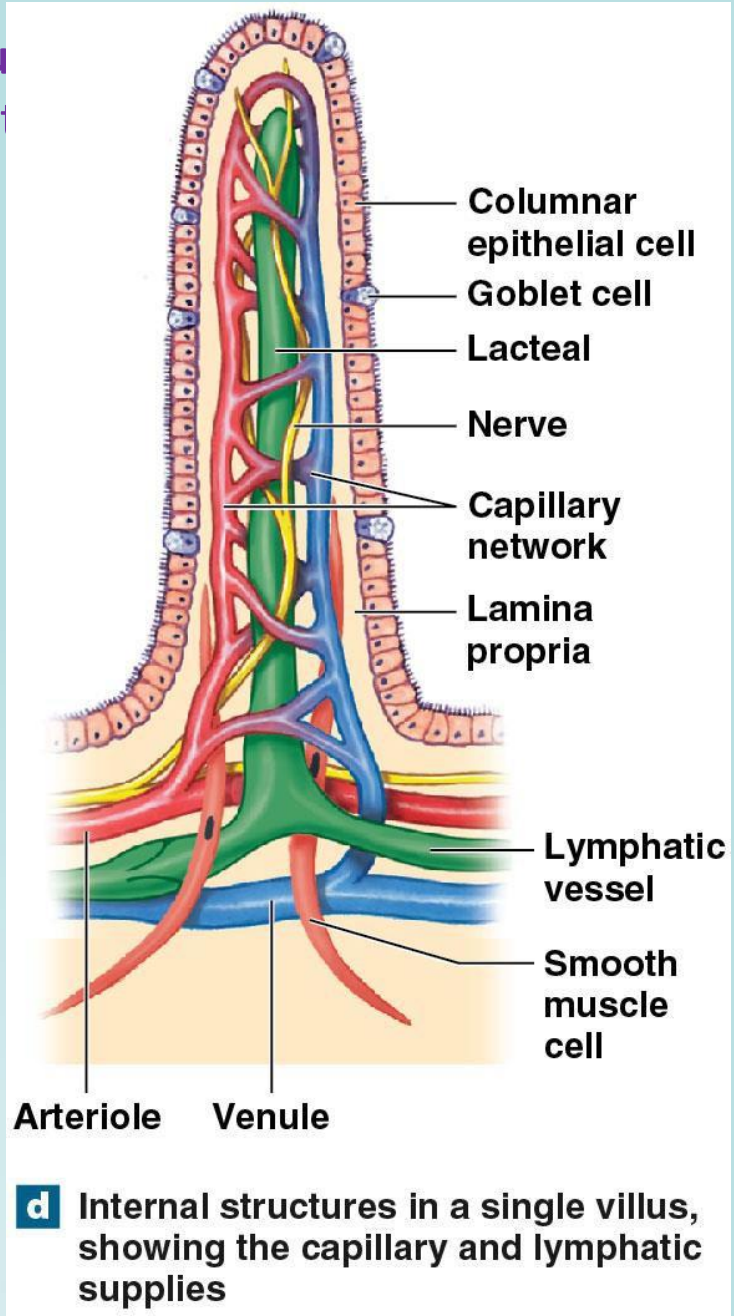
Figure 24-21c
Histology of the Intestinal Wall.



Cellular components of an intestinal gland. ATLAS: Plates 51a–d

Figu

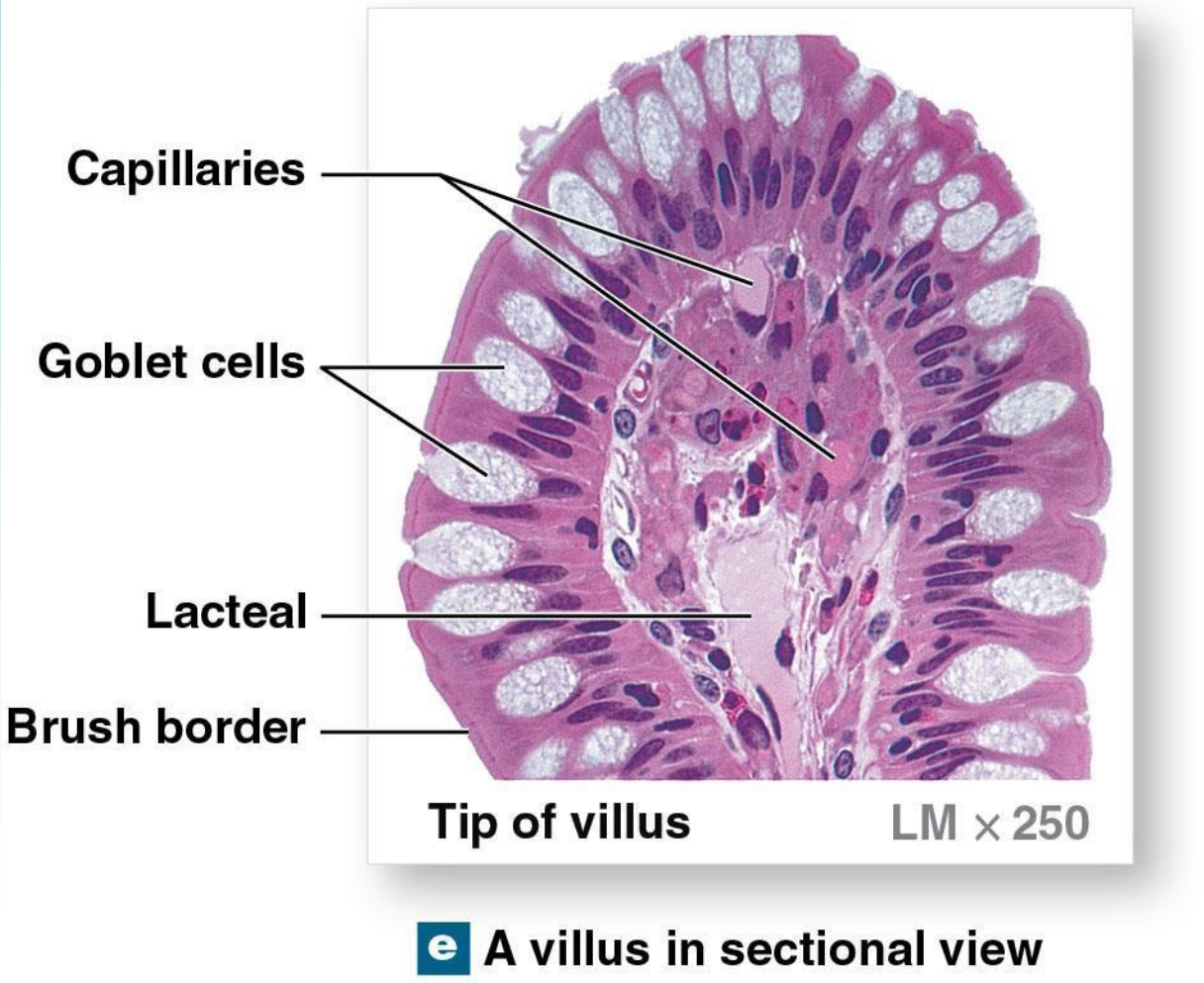
Histology of t



Internal structures in a single villus, showing the capillary and lymphatic supplies. ATLAS: Plates 51a–d

Pearson

Figure 24-21e
Histology of the Intestinal Wall.



A villus in sectional view. ATLAS: Plates 51a–d

The intestinal epithelium regenerates itself continuously, and in the process releases the brush border enzymes important in digestion which are integral membrane proteins. They are found on the surfaces of the microvilla and break down materials in contact with the brush border. The enteroendocrine cells secrete the hormones intestinal gastrin, secretin and CCK. The duodenal glands secrete bicarbonate rich mucus to neutralize the acidic chyme. The lamina propia of the ileum contains Peyers's patches, a type of lymph nodules that protect the SI against large intestine bacteria. The last layer in the duodenum is adventicia and in the rest of the SI is the serosa or visceral peritoneum.

Intestinal secretion and Control: 1.8 L of intestinal juice are produced per day. This is an enzyme poor alkaline fluid mostly water, and mucus. It assists in moistening chyme; buffering acids; and keeping enzymes and digestive products in solution . Its production is stimulated by distension or irritation of the intestinal wall. Intestinal gland secretion is controlled by local reflexes, the duodenal hormone enterocrinin, and parasympathetic stimulation. Sympathetic stimulation inhibits duodenal glands secretion, which may produce duodenal ulcers in conditions such as chronic stress.

Regulation of Intestinal Digestive Activity: It depends on proper activity of liver and pancreas, and proper function of brush border enzymes and slow delivery of chime by the stomach pylorus. It takes 3 to 6 hours through the small intestine for digestion and absorption of the nutrients in chyme to take place.

Motility of the Small Intestine: Chyme entering the duodenum is moved by peristalsis toward the jejunum. This peristalsis is controlled by local myenteric and submucosal reflexes. Parasympathetic stimulation increases sensitivity of myenteric reflexes increasing peristalsis and segmentation. The activities along the entire length of the SI are coordinated by complex reflexes. One example of these reflexes is the gastroenteric reflex that stimulates motility and secretion along the entire length of the small intestine. This reflex is activated when food enters the stomach again as peristalsis stops in the small intestine segmentation begins. Another example is those reflexes is the gastroileal reflex that triggers the relaxation or opening of the ileocecal valve, which allows materials to pass from the SI into the LI. This reflex is initiated by the increased mobility of the ileum and by gastrin released by the stomach.

Figure 24-15
The Regulation of Gastric Activity (Part 4 of 4).

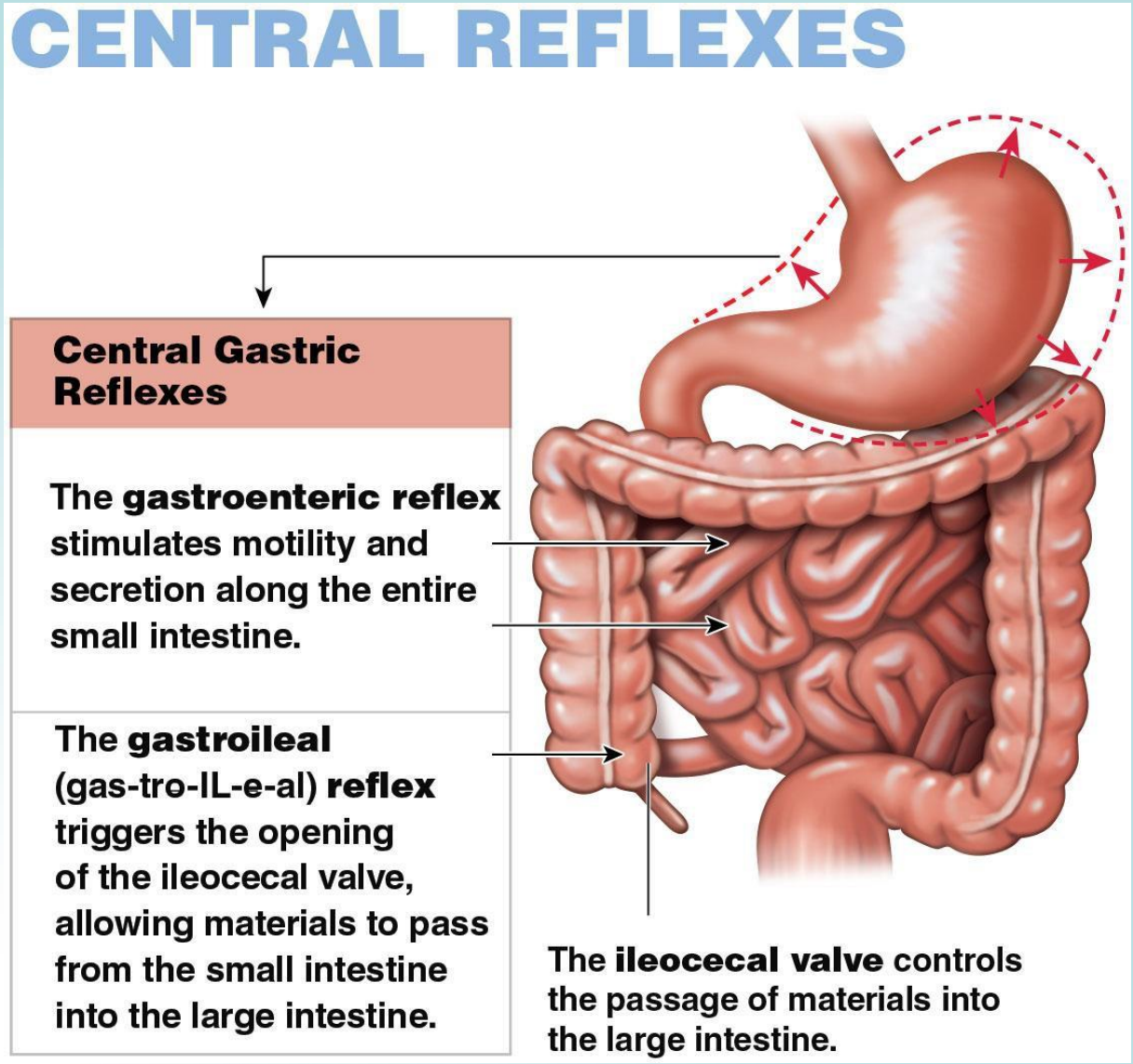
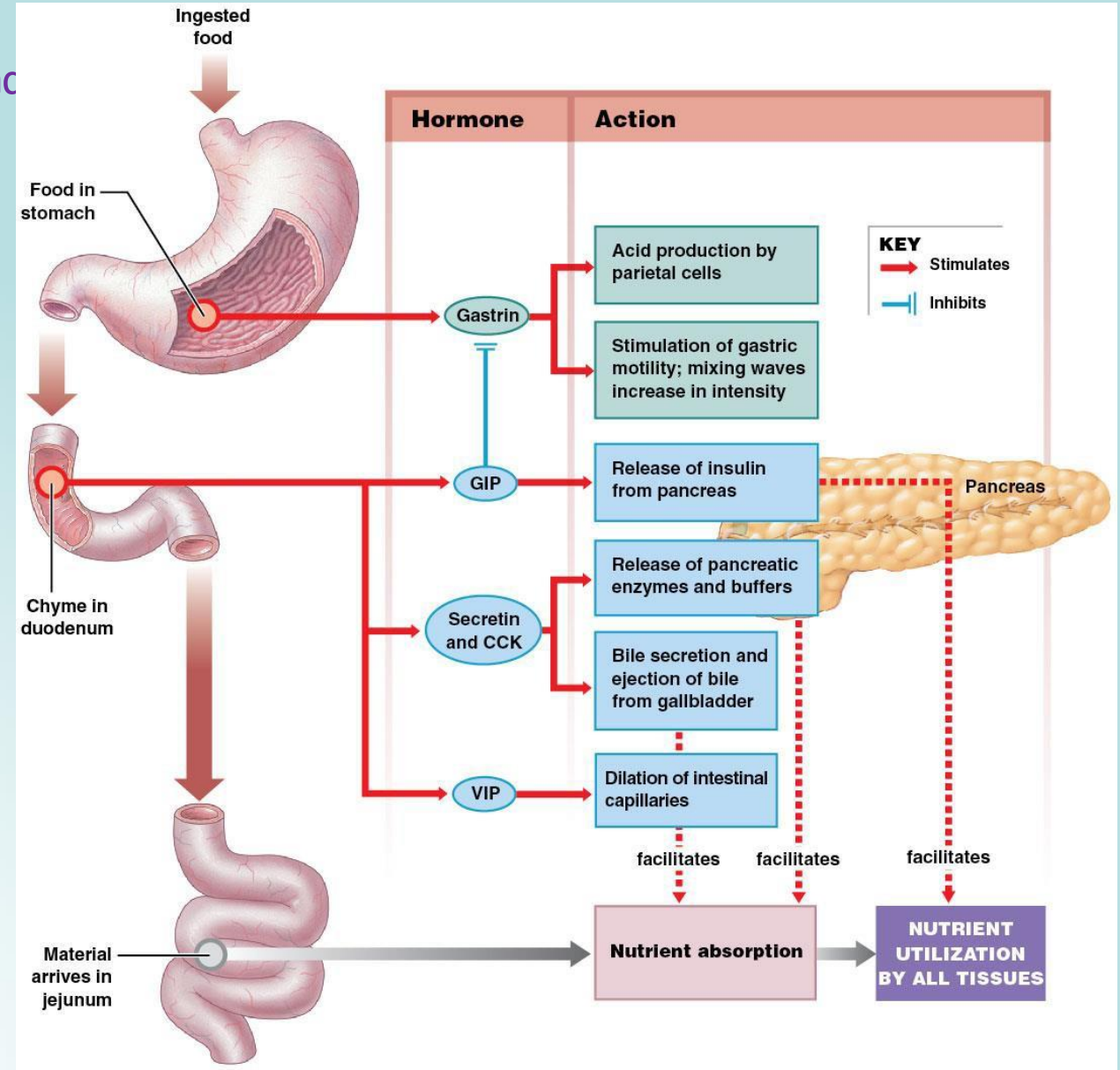


Figure 24-23
The Secretion and Effects of Major Digestive Tract Hormones.



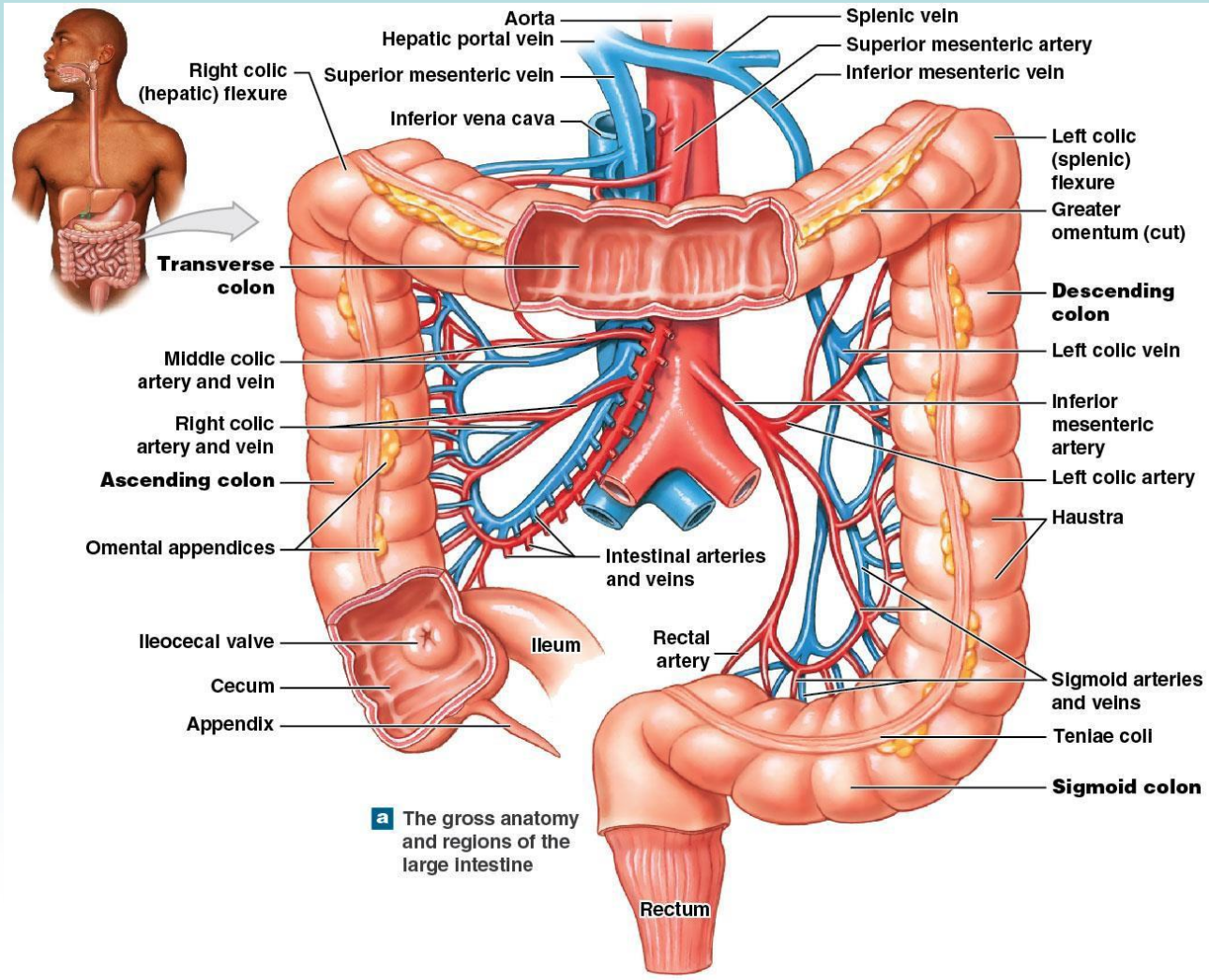
The primary effects of gastrin, GIP, secretin, CCK, and VIP are shown.

Large Intestine: this horseshoe shaped organ is found under the stomach and liver surrounding the small intestine and extending from the ileocecal valve to the anus (4.9 ft long and 3 in wide). Its major functions are: 1- to reabsorb water, 2- to compact undigested food stuff into feces, 3- to eliminate the feces, 4- to absorb bacterial vitamins, and 5- to store fecal matter until defecation. It has a larger diameter in lumen than the small intestine and that is why is called the large intestine. Even though in length is shorter.

A. Gross Anatomy: The large intestine is subdivided into 3 parts: the pouch like cecum; the largest portion or colon; and the rectum (last 6 inches). The **cecum**, a pouch like structure, lies below the **ileocecal valve**, which allows passage of undigested material into the cecum form the small intestine.

Here this material is stored and compactation starts. The cecum has the worm like **appendix** attached to it in its posterior medial surface (9 cm long). In the **colon** the longitudinal muscularis is reduced to 3 bands of smooth muscles called the **teniae coli**, their tone causes the formation of **haustra** or external pouches like sacs. Hanging from serosa of the colon along the teniae coli are numerous small sacs of fat or fatty appendices called **omental appendages**. The colon is divided into the **ascending**, **transverse**, **descending** and **sigmoid** colon. The bends of the ascending and transverse colon form the **right colic flexure** and **left colic flexure** receptively. Mesenteries called mesocolons attach the transverse and sigmoid colon to the posterior abdominal wall. The sigmoid colon stars at the sigmoid flexure. The rectum has 3 rectal valves that separate feces from gas.

Figure 24-24a
Anatomy of the Large Intestine.

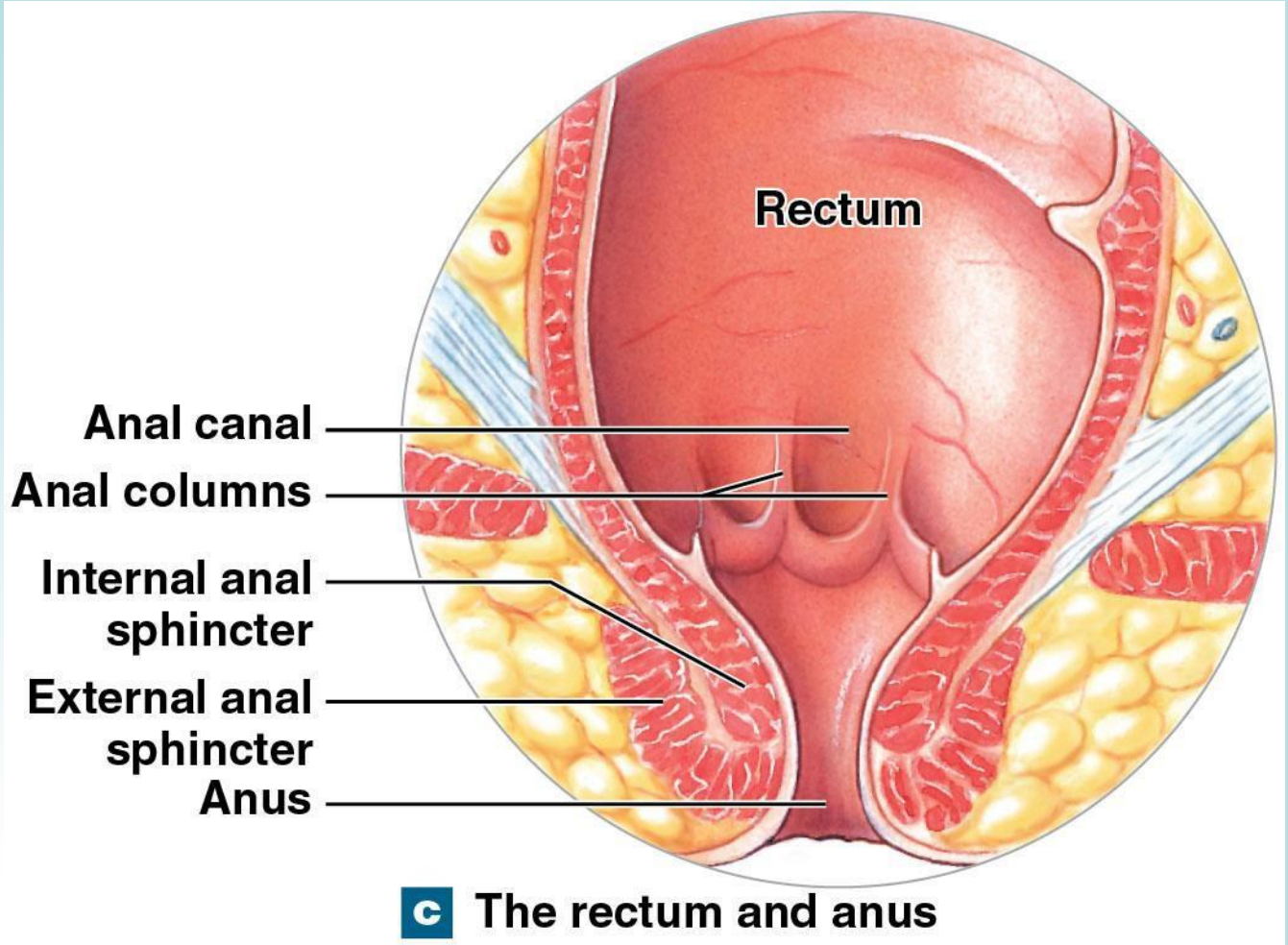


The gross anatomy and regions of the large intestine. ATLAS: Plates 49a–c; 58a–c; 59; 64; 65

The **anal canal** contains longitudinal folds called **anal columns**. The **rectum** opens at the anus or anal orifice and stores feces temporarily. This has 2 sphincters, one is the involuntary **internal anal sphincter**, and the other is the voluntary **external anal sphincter**, formed by skeletal muscle.

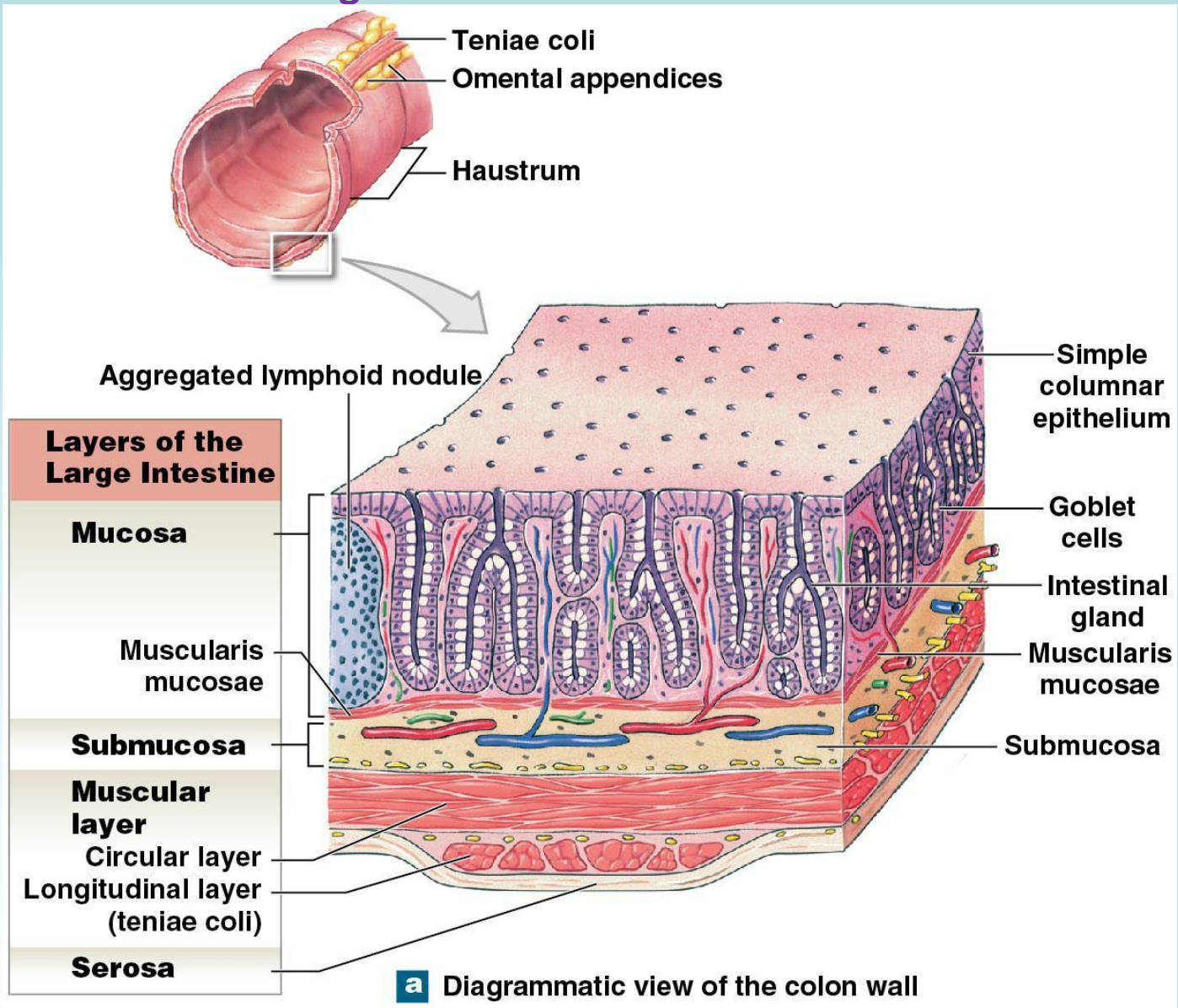
B. Large Intestine Histology: its mucosa is composed of simple columnar epithelium, except for the anal canal. There in no villi, but there are many goblet cells and intestinal glands that produce lubricating mucus to ease the passage of feces and protect the intestinal wall from bacterial acids and gases. Anal canal contains stratified squamous epithelium. The lamina propria and submucosa contain scattered lymphoid nodules. Two superficial venous plexuses form the hemorrhoidal veins that can become inflamed and itchy forming varicosities called hemorrhoids by increased intraabdominal pressure due to trying to defecate when constipated.

Figure 24-24c
Anatomy of the Large Intestine.



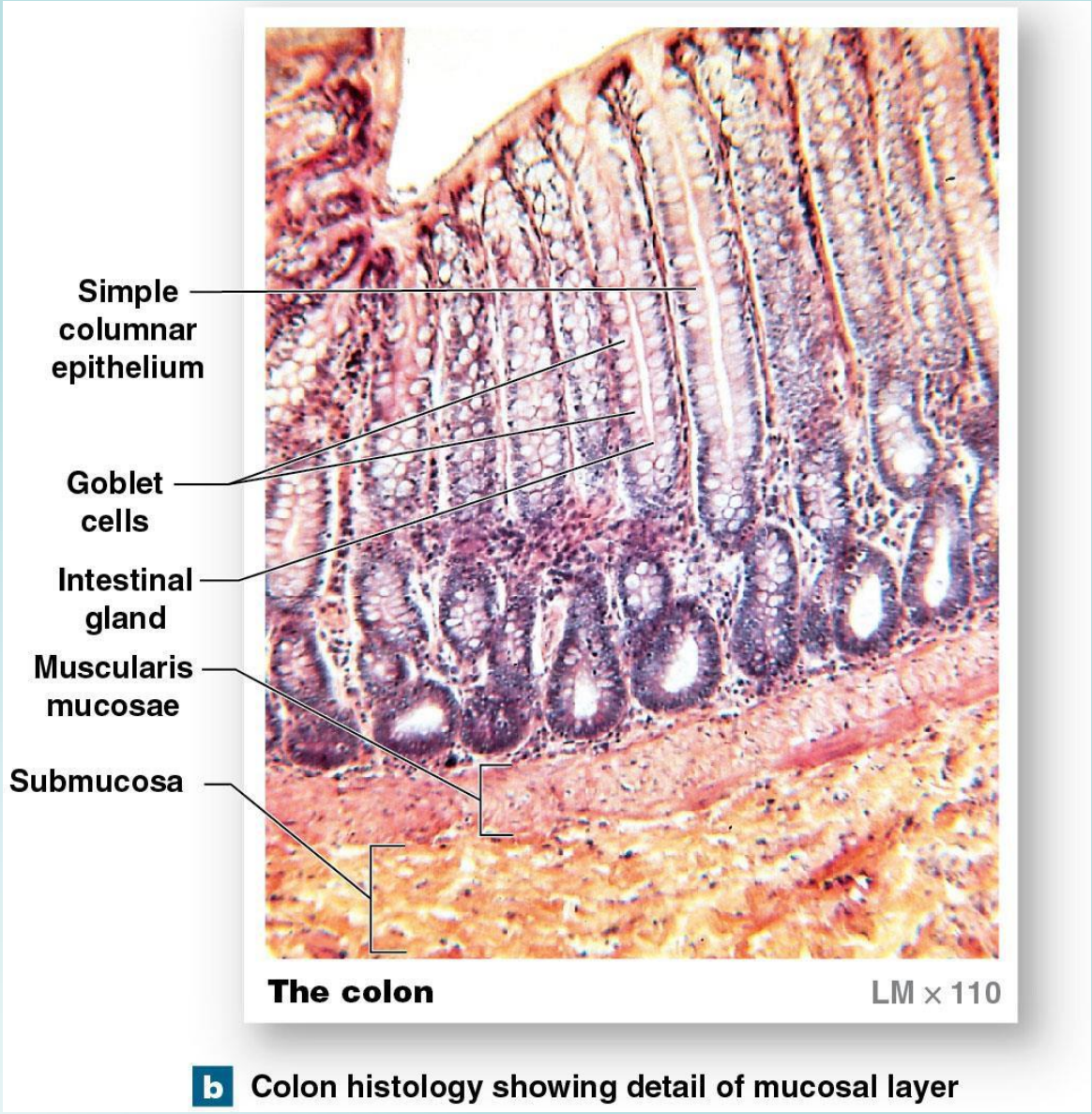
The rectum and anus. ATLAS: Plates 49a–c; 58a–c; 59; 64; 65

Figure 24-25a



Diagrammatic view of the colon wall

Figure 24-25b
Histology of the Colon.



Colon histology showing detail of mucosal layer

The functions of the large intestine: 1- compaction of intestinal contents into feces and elimination of feces. 2- storage of feces from 12 to 24 hours. 3- absorption water, and useful nutrients that remain in the feces or are secreted along its length such as bile salts, vitamins formed by bacteria, organic waste products, and toxins produced by bacterial action. The large intestine bacterial flora forms 5% of the feces. These originate from bacteria left alive after waste enter into large intestine and the bacteria that enter through the anus. These bacteria form colonies that ferment mostly undigested carbohydrates and release acids and gases (flatus) such as H_2, N_2, CO_2, CH_4, and H_2S. These bacteria are beneficial, because they synthesize vitamin K, Biotin and Vitamin B5 or pantothenic acid which supplement the diet.

The organic waste products include: urobolinogen and stercobilinogens produced by bacteria from bilirubin, ammonium ions, indole and skatole, which gives the peculiar odor to feces, and hydrogen sulfide (H_2S) that is a smelly gas.

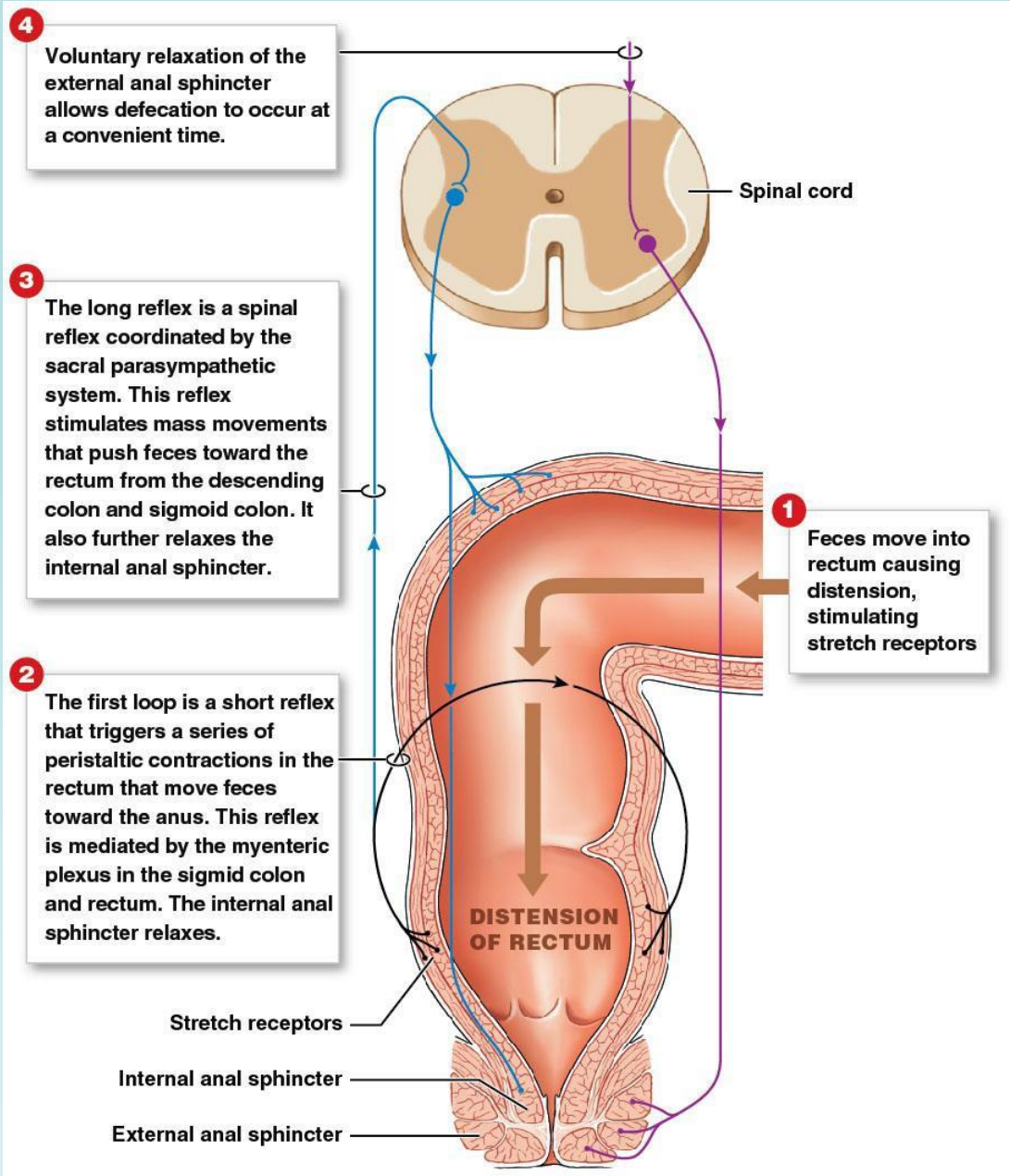
1. Movements of the Large Intestine: haustral churning or segmentation is stimulated by distention when haustra fill with food residue. These contractions mix and propel the residue to next haustra. The gastroileal and gastroenteric reflexes move material into the cecum while food is eaten.

Mass movements are strong peristaltic contractions that occur 3 to 4 times a day usually after eating (only in the large intestine). They force the feces into the rectum and produce the urge to defecate. Bulk or fiber in the diet strengthen colon contractions, and soften the stools to produce smooth passage of feces.

2. Defecation: The **defecation reflex,** which is a parasympathetic reflex occurs when feces are forced into the rectum. This reflex is composed of two positive feedback loops triggered by stretch receptors in the rectum.

The reflex causes the walls of the sigmoid colon and rectum to contract (short reflex) and the internal anal sphincter to relax (long reflex). Muscles of rectum strongly contract to expel the feces, but generally the external sphincter of skeletal muscle relaxes only by voluntary command (motor command by pudendal nerves). We usually close the glottis and contract the diaphragm and abdominal wall to increase intra-abdominal pressure to force hard stool to exit.

Figure 24-26
The Defecation Reflex.



Pearson

Chemical Digestion: It is the break down of the organic molecules in foods into building blocks that can be absorbed. This process is carried out by enzymes. Many ingested organic molecules are complex chains or polymers of simpler molecules or monomers. Digestive enzymes are secreted by intrinsic and accessory glands and they break the bonds between the component molecules of carbohydrates, proteins, lipids and nucleic acids by a process called enzymatic *hydrolysis*. There are specific enzymes for specific food groups or substrates and for specific molecules within those food groups. For example, carbohydrases break the bonds between simple sugars, but lactase breaks down the bond between glucose and galactose in lactose, which is a simple sugar. Proteases break the bonds between amino acids. Lipases separate fatty acids from glycerides.

Carbohydrate Digestion

Polysaccharide or complex carbohydrates such as starch and glycogen are broken first into oligosaccharides and then into disaccharide. Starch digestion starts in the mouth. Disaccharide such as lactose, sucrose and maltose are broken into monosaccharies. The enzymes involved in carbohydrate digestion include:

1 **Salivary amylase:** it is released in the mouth by the salivary glands, when food enters the mouth. This enzyme breaks down starches into disaccharides (Maltose) and trisaccharides.

2 **Pancreatic alpha-amylase:** it is released in the small intestine by the pancreas when chyme enters the SI. This enzyme breaks down the complex carbohydrates not broken down in the mouth to disaccharide and trisaccharides.

Table 24-1 Digestive Enzymes and Their Functions (Part 1 of 3).

Table 24–1 Digestive Enzymes and Their Functions

Enzyme (proenzyme)	Source	Optimal pH	Target	Products	Remarks
CARBOHYDRASES					
Maltase, sucrase, lactase	Brush border of small intestine	7–8	Maltose, sucrose, lactose	Monosaccharides	Found in membrane surface of microvilli
Pancreatic alpha-amylase	Pancreas	6.7–7.5	Complex carbohydrates	Disaccharides and trisaccharides	Breaks bonds between simple sugars
Salivary amylase	Salivary glands	6.7–7.5	Complex carbohydrates	Disaccharides and trisaccharides	Breaks bonds between simple sugars

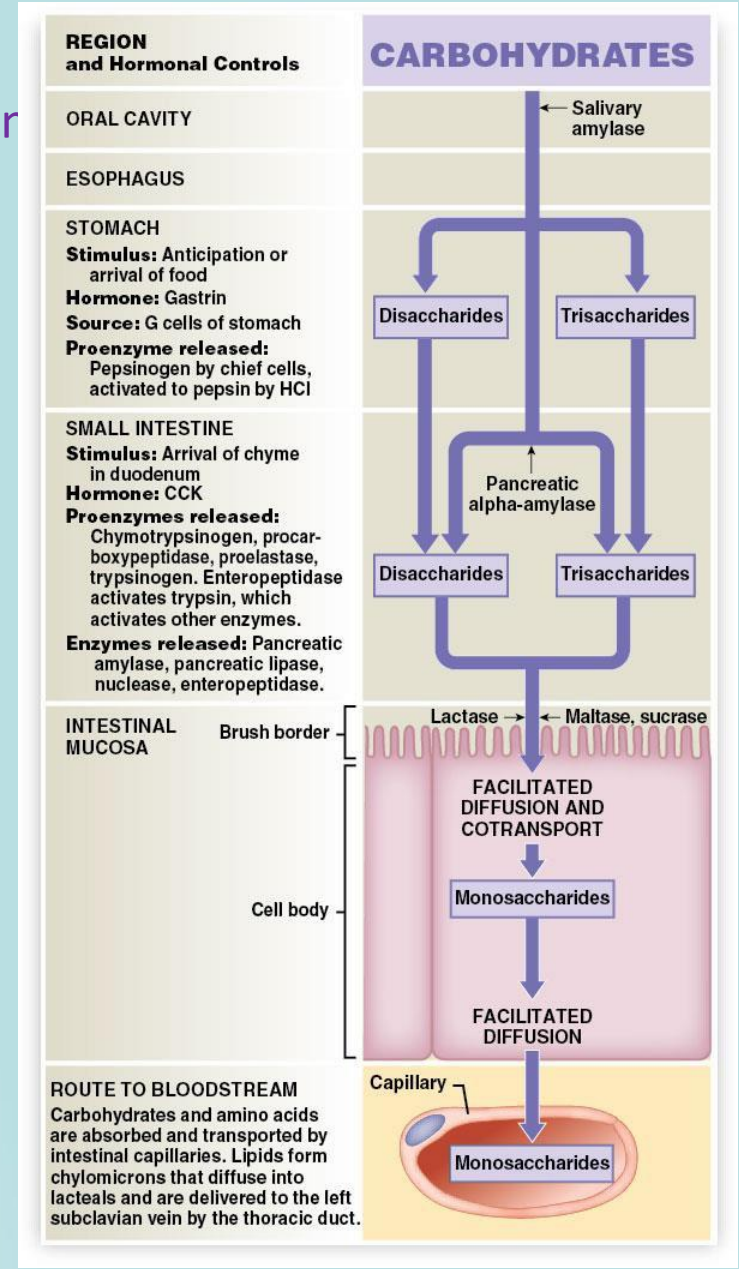
3- Maltase, Sucrase, and Lactase (disaccharases): they are part of the brush border enzymes of the small intestine microvilli, which become active when chyme enters the SI. They break down the simple sugars or disaccharides into monosaccharides. Maltase breaks down maltose into 2 glucoses, lactase breaks down lactose into glucose and galactose, and sucrase digests sucrose into fructose and glucose.

Protein Digestion

They are broken down into polypeptides, which then are broken down into smaller peptides and finally, these are broken into amino acids. Mechanical digestion of proteins stars in the mouth during mastication, but chemical digestion stars in the stomach through the actions of HCl and the enzyme Pepsin.

Figure 24-27

The Chemical Events of Digestion



Pearson

The enzymes involved in protein digestion include:

1. **Pepsin:** pepsinogen the proenzyme that forms pepsin is release by the chief cells of the gastric glands. Pepsin is activated and works only at the very low pH of the stomach. It breaks down proteins and polypeptides into short-chains polypeptides. It only digests 10% to 15% of proteins.
2. **Renin:** it is released by the gastric glands in the stomach. It breakdown or coagulates the milk protein casein. It is secreted only by infants.
3. **Trypsin and Chymotrysin:** they are released by the pancreas as proenzymes in the small intestine when chyme enters the SI. Chymotrypsin is released as chymotrypsinogen and it is activated by trypsin. Trypsin is released as trypsinogen, and it is activated by the enzyme enterokinase.

Table 24-1 Digestive Enzymes and Their Functions (Part 2 of 3).

Table 24–1 Digestive Enzymes and Their Functions

Enzyme (proenzyme)	Source	Optimal pH	Target	Products	Remarks
PROTEASES					
Carboxypeptidase (procarboxypeptidase)	Pancreas	7–8	Proteins, polypeptides, amino acids	Short-chain peptides	Activated by trypsin
Chymotrypsin (chymotrypsinogen)	Pancreas	7–8	Proteins, polypeptides	Short-chain peptides	Activated by trypsin
Dipeptidases, peptidases	Brush border of small intestine	7–8	Dipeptides, tripeptides	Amino acids	Found in membrane surface of brush border
Elastase (proelastase)	Pancreas	7–8	Elastin	Short-chain peptides	Activated by trypsin
Enteropeptidase	Brush border and lumen of small intestine	7–8	Trypsinogen	Trypsin	Reaches lumen through disintegration of shed epithelial cells
Pepsin (pepsinogen)	Chief cells of stomach	1.5–2.0	Proteins, polypeptides	Short-chain polypeptides	Secreted as proenzyme pepsinogen; activated by H^1 in stomach acid
Rennin	Stomach	3.5–4.0	Milk proteins		Secreted only in infants; causes protein coagulation
Trypsin (trypsinogen)	Pancreas	7–8	Proteins, polypeptides	Short-chain peptides	Proenzyme activated by enteropeptidase; activates other pancreatic proteases

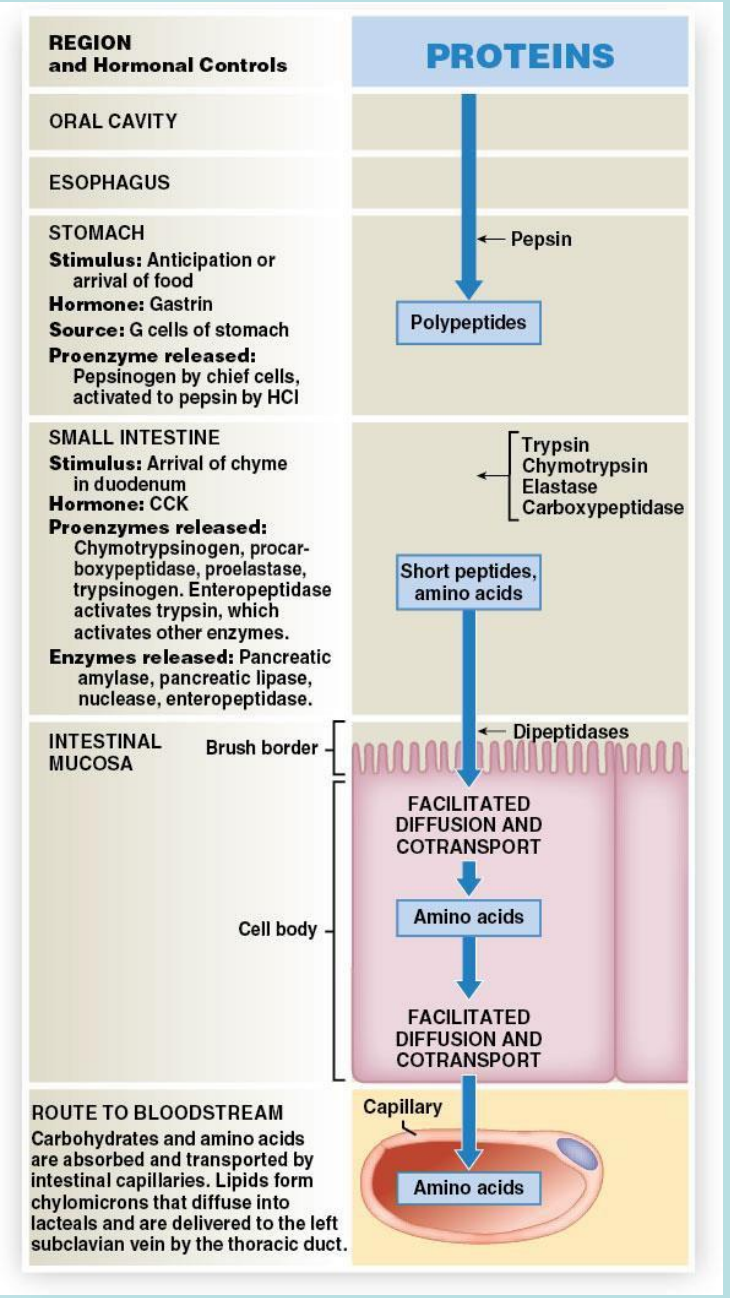
They digest proteins into smaller polypeptides and then polypeptides into short-chain peptides.

4 **Carbopeptidase:** it is part of the pancreatic enzymes, and it is present as the proenzyme procarbopeptidase. This enzyme is activated by trypsin. It digests proteins, and polypeptides into free amino acids by splitting one amino acid at a time from the carboxylic end.

5 **Dipeptidases and Peptidases:** they are part of the brush border enzymes. They break down tripeptides and dipeptides into amino acids.

6 **Elastase:** it is released by the pancreas into the SI as proelastase, and activated by trypsin. It breaks down elastin into short-chain peptides.

Figure 24-27
The Chemical Events of Digestio



Pearson

Lipid Digestion

Most digestion occurs in the small intestine, but some digestion takes place in the mouth and stomach. The most abundant dietary lipids or tryglycerides are broken down into fatty acids and monoglycerides or glycerol.

1. **Lingual Lipase:** lingual lipase is released by the lingual glands when fats enter the mouth. It breaks down triglycerides into fatty acids and monoglycerides.
2. **Gastric Lipase:** it is release in the stomach, but it only breaks down 5% of the fats in the stomach.
3. ***Pancreatic Lipase:** it is released by the pancreas into the small intestine when chyme enters the SI. It breaks down triglycerides by cleaving off the fatty acid chains into monoglycerides, free fatty acids, and glycerol. Fat soluble vitamins do not require digestion, but ride with products of digested fats. This enzyme does most of the fat break down

Nucleic acids

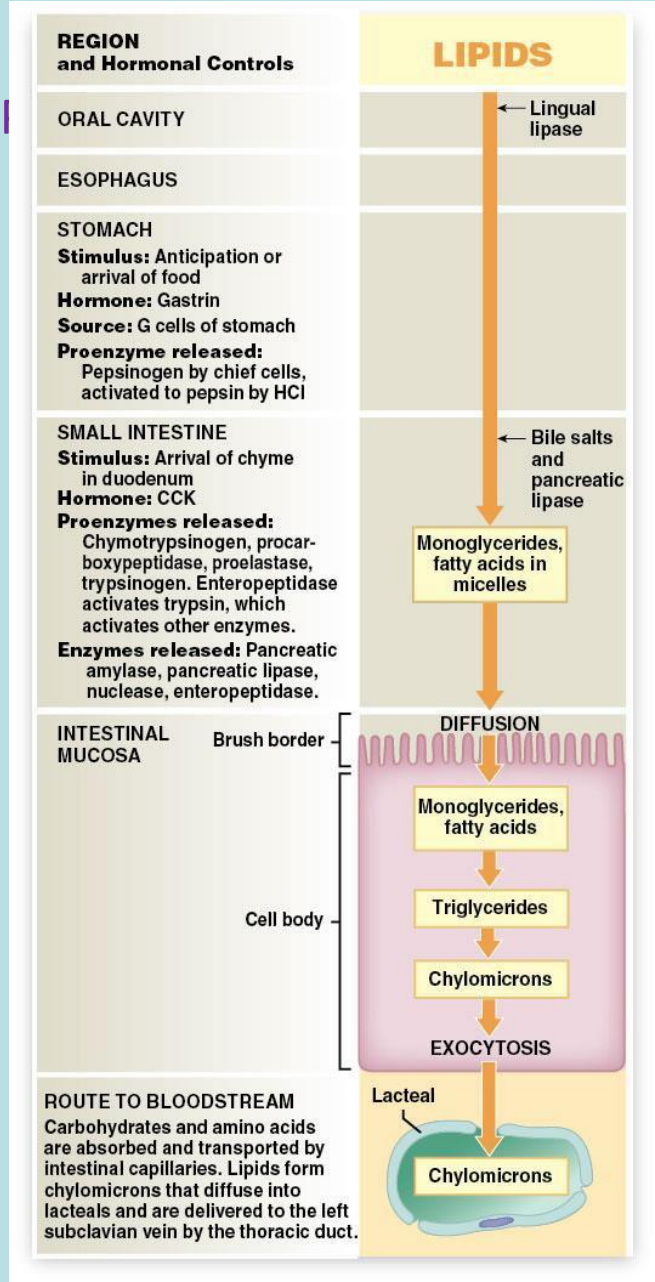
Their digestion takes place in the small intestine. Both nucleic acids, DNA and RNA are hydrolyzed to nitrogenous bases, simple sugars and a phosphate group. The enzymes involved in nucleic acid break down include:

1 **Pancreatic Nucleases:** they are released by the pancreas into the SI when chyme enters it. They digest DNA and RNA into nucleotides.

2 **Nuclosidases and Phosphatases:** they are part of the brush border enzymes, which are activated when chyme enters the SI. They brake down nucleotides into nitrogenous bases, simple sugars and phosphates.

Figure 24-27

The Chemical Events of Digestion (I



Pearson

Absorption: Most food stuff, 90% of water and 80% of electrolytes are absorbed in the small intestine. Most nutrient are absorbed through the mucosa of the intestinal epithelium by active transport, facilitated diffusion, or cotransport. This transport is called transepithelial, because it is through the epithelial cell cytoplasm and into the interstitial fluid. From the interstitial fluid the molecules move into the villus capillaries and then they are transported through the hepatic portal vein into the liver.

Table 24-1 Digestive Enzymes and Their Functions (Part 3 of 3).

Table 24–1 Digestive Enzymes and Their Functions

Enzyme (proenzyme)	Source	Optimal pH	Target	Products	Remarks
LIPASES					
Lingual lipase	Glands of tongue	3.0–6.0	Triglycerides	Fatty acids and monoglycerides	Begins lipid digestion
Pancreatic lipase	Pancreas	7–8	Triglycerides	Fatty acids and monoglycerides	Bile salts must be present for efficient action
NUCLEASES					
	Pancreas	7–8	Nucleic acids	Nitrogenous bases and simple sugars	Includes ribonuclease for RNA and deoxy-ribonuclease for DNA

Lipids and lipid soluble vitamins move into the lacteals by simple diffusion.

Carbohydrate Absorption

The end product of carbohydrate digestion, glucose, fructose, and galactose are absorbed into the small intestine epithelium by protein carries. Glucose and galactose are transported by secondary active transport or cotransport with sodium. Fructose moves in by facilitated diffusion.

Protein Absorption

The products of proteins digestion, amino acids, are absorbed into the small intestine epithelium by protein carries. There are different carriers for different amino acids. They are transported by cotransport and facilitated diffusion.

After crossing the epithelial cells the amino acids are released into the interstitial fluid by facilitated diffusion and cotransport , then, they are transported through the hepatic portal vein into the liver.

Lipid Absorption: It requires bile salts to be absorbed at the small intestine. Bile salts facilitate lipid digestion by emulsifying or breaking down large lipid drops into tiny droplets those enzymes can have access to. They then form micelles. and are transported in the lymph as chylomicrons.

1- Micelles: they are clusters of lipid droplets (fatty acids and monoglycerides) associated with bile salts. The lipid hydrophilic end is directed toward the outside watery environment, and the hydrophobic end toward the inside, forming a center core that also contain cholesterol and the lipid soluble vitamins.

They move across the intestinal epithelium by simple diffusion into the cytoplasm. Inside epithelial cells fatty acids and monoglicerides reform to triglycerides, which are then incorporated into chylomicrons. These chylomicrons cross into the interstitial fluid by exocytosis.

2- Chylomicrons: they are formed from the reformed triglycerides, small amounts of phospholipids, and cholesterol. Triglycerides are coated with water soluble lipoproteins. They diffuse from the interstitial fluid into the lymphatic capillaries or lacteals in the intestinal villi. Then they travel with the lymph to enter the blood at the exit of the thoracic duct. In the blood, the triglycerides in the chylomicrons are broken into fatty acids and glycerol by the enzyme lipoprotein lipase produced by the endothelial cells of the capillaries, then they are absorbed from the blood into the body cells.

The rest of the chylomicrons are converted to new lipoproteins that carry cholesterol.

Nucleic Acid Absorption: Nitrogenous bases, sugars and phosphates are carried through the epithelium by protein carries in the intestinal villi into the capillary blood.

Vitamin Absorption: The large intestine bacteria produced the vitamins K and B vitamins biotin and pantothenic acid, which are absorbed by simple diffusion in to the intestinal epithelium. Dietary fat soluble vitamins A, D, E, and K that enter the duodenum are incorporated into micelles and are also transported by simple diffusion across the intestinal epithelium. The water soluble vitamins, C, and most B vitamins, are absorbed across the intestinal epithelium by diffusion. However, vitamin B12 binds to the intrinsic factor and is absorbed by active transport or endocytosis in the ileum .

Electrolyte Absorption: They are actively absorbed along the length of the small intestine. Sodium is absorbed by facilitated diffusion, cotransport, or active transport across the intestinal epithelium into the interstitial fluid. Calcium absorption is regulated by the parathyroid hormone (PTH) and calcitriol or vitamin D, which acts as cofactor to facilitate its absorption. Calcium is transported by active transport at the intestinal epithelial surface. Iron and Magnesium are absorption involves specific carrier proteins, and ATP is used to transport them into the interstitial fluid. Iron is absorbed from the intestinal epithelium into the blood bound to ferritin, a carrier protein, and then transported by transferritin. Iron and calcium are absorbed according to the body needs, and based on their levels in the blood. Potassium ions are transported by diffusion into the epithelial cells.

Table 24-2 The Absorption of Ions and Vitamins.

Table 24–2 The Absorption of Ions and Vitamins

Ion or Vitamin	Transport Mechanism	Regulatory Factors
Na^+	Channel-mediated diffusion, cotransport, or active transport	Increased when sodium-linked cotransport is under way; stimulated by aldosterone
Ca^{2+}	Active transport	Stimulated by calcitriol and PTH
K^+	Channel-mediated diffusion	Follows concentration gradient
Mg^{2+}	Active transport	
Fe^{2+}	Active transport	
Cl^-	Channel-mediated diffusion or carrier-mediated transport	
I^-	Channel-mediated diffusion or carrier-mediated transport	
HCO_3^-	Channel-mediated diffusion or carrier-mediated transport	
NO_3^-	Channel-mediated diffusion or carrier-mediated transport	
PO_4^{3-}	Active transport	
SO_4^{2-}	Active transport	
Water-soluble vitamins (except B_{12})	Channel-mediated diffusion	Follows concentration gradient
Vitamin B_{12}	Active transport	Must be bound to intrinsic factor prior to absorption
Fat-soluble vitamins	Diffusion	Absorbed from micelles along with dietary lipids

Anions such as chloride, iodide, bicarbonate, and nitrate move into the intestinal epithelium by diffusion or carrier mediated transport. Phosphate and sulfate ions move into the epithelial cells by active transport.

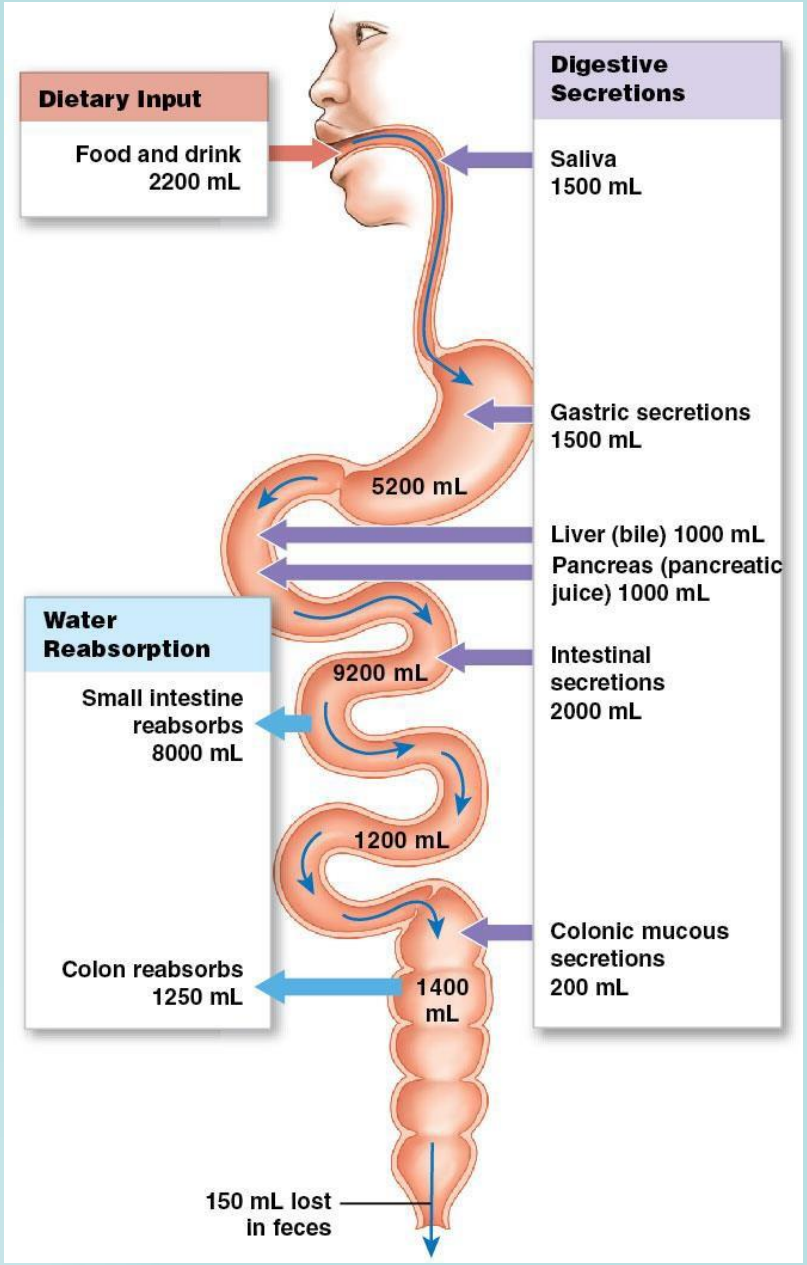
Water Absorption: Water moves by osmosis or simple diffusion along osmotic gradients. Most water is absorbed in the small intestine, some is lost with the feces, and the rest is absorbed in the large intestine.

Malabsorption of Nutrients: Impaired nutrient absorption can be the result of lack of bile or pancreatic juice, or damaged intestinal mucosa.

Gluten Enteropathy: Adult celiac disease. Gluten, a grain protein damages the intestinal villi by reducing length of microvilli in the brush border. This results in diarrhea and malnutrition.

Figure 24-28

Digestive Secretion and Water Reabsorption in the Digestive Tract.



The purple arrows indicate secretion, and the blue arrows show water ingestion and reabsorption.

Pearson

Homeostatic Imbalances of the Digestive System

As we age divisions of the epithelial stem cells decline and the digestive epithelium becomes more susceptible to damage by abrasion, acids, or enzymes which can lead to ulcers. The smooth muscle tone and motility decrease causing weaker peristaltic contractions which can lead to conditions such as irritable bowel disease. There is cumulative damage from toxins produce by bacteria or from alcohol, and other chemicals.

The rates of colon cancer and stomach cancer increase with age and oral and pharyngeal cancers are common among elderly smokers.

Digestive system movies and animations

http://www.youtube.com/watch?v=yEKdLqEB7gE&feature=related
http://www.youtube.com/watch?v=ZfVEJ50rdIA&feature=related
http://www.youtube.com/watch?v=XxvRbxhqoZk&feature=related
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