The Digestive System

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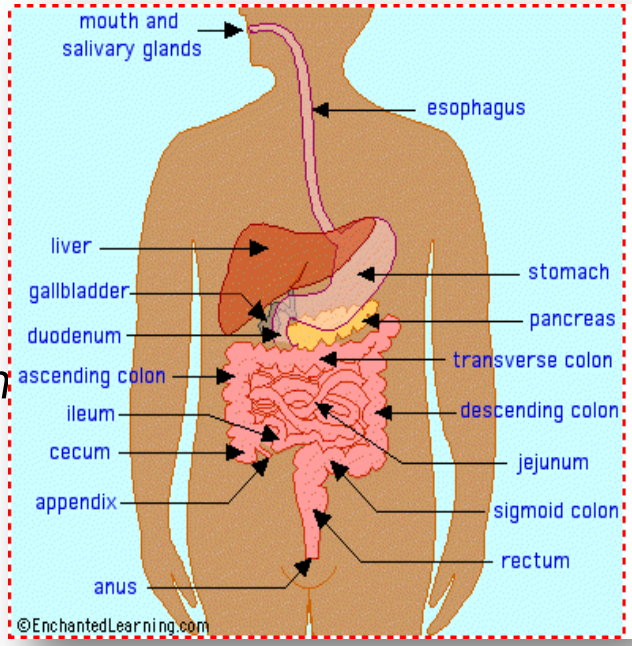
Digestive System = Digestive Tract + Accessory Organs

❖Digestive/Gastrointestinal (GI) tract organs:

- ✓ *mouth*
- ✓ *pharynx* (throat)
- ✓ *esophagus*
- ✓ *stomach*
- ✓ *small intestine* (*duodenum, jejunum, & ileum*)
- ✓ *large intestine* (*cecum, appendix, colon, & rectum*)
- ✓ *anus*

❖Accessory digestive organs:

- ✓ *salivary glands*
- ✓ *exocrine pancreas*
- ✓ *biliary system (liver and gallbladder)*



Primary function of the digestive system is to bring essential nutrients into the internal environment so they are available to cells of the body

Basic Digestive Processes

1. **Motility**: physically breaks down large food material & moves food along the tract
2. **Secretion**: digestive enzymes that allow chemical digestion
3. **Digestion**: breakdown of complex nutrients into simple nutrients
4. **Absorption**: taking nutrients into the internal environment through the mucosa

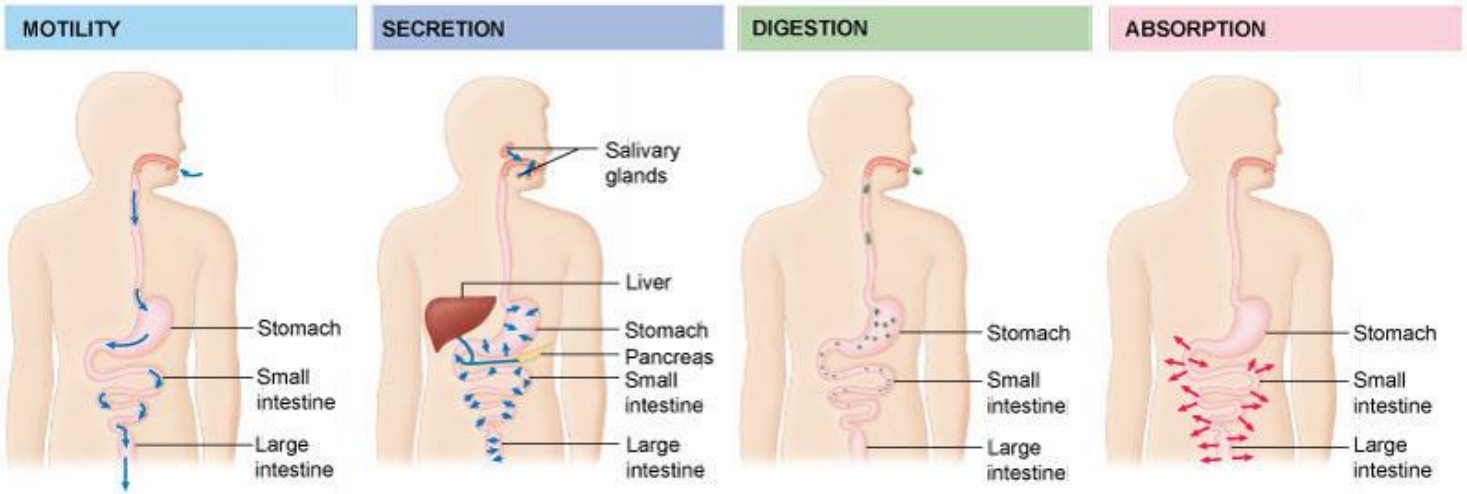


Fig. 26-1. **Overview of digestive functions.** Several important digestive functions are summarized in these diagrams. Note that the digestive tract is an extension of the external environment—extending like a tunnel through the body.

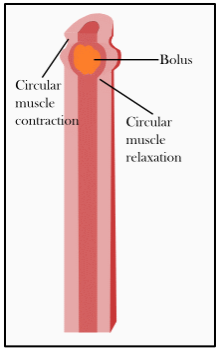
Basic Digestive Processes

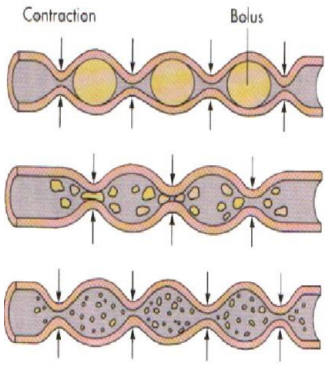
1. **MOTILITY**: the digestive tract's muscular contractions

- Two types:

  i. ***Propulsive movements:***
  - Propel/push the contents forward through the digestive tract (oral→anal)

  ii. ***Mixing movements:***
  - Facilitate digestion by mixing food with the digestive juices
  - Facilitate absorption by exposing all parts of the intestinal contents to the absorbing surfaces of the digestive tract





- The ends of the tract: motility involves skeletal muscle

Basic Digestive Processes

2. **SECRETION:**

- Digestive juices consist of water, electrolytes, enzymes, bile salts, and mucus.
- Energy-dependent process
- Requires neural/hormonal stimulation
- Reabsorbed back into the blood

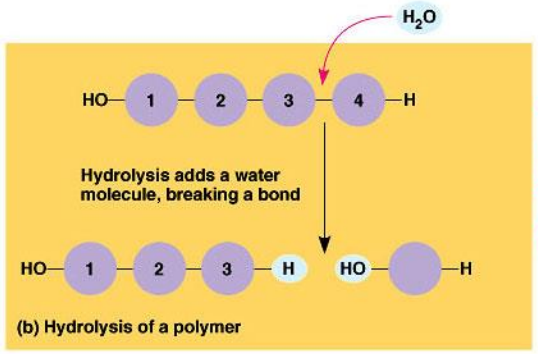
Basic Digestive Processes

3. DIGESTION:

Biochemical breakdown of the structurally complex foodstuffs of the diet into smaller, absorbable units by the enzymes produced within the digestive system.

- **Carbohydrates:**
  Polysaccharides/disaccharides → monosaccharides
- **Proteins:**
  Polypeptides → amino acids
- **Fat:**
  Triglycerides → monoglycerides and free fatty acids

- Hydrolysis



HYDROLYSIS...

the splitting of a polymer by adding water to a covalent bond;

catalyzed by a hydrolyase enzyme.

Kari, HL-1 Biology

Basic Digestive Processes

4. **ABSORPTION:**

The small absorbable units that result from digestion, along with water, vitamins, and electrolytes, are transferred from the digestive tract lumen into the blood or lymph.

- Most absorption occurs in the small intestine

The Digestive Tract Wall

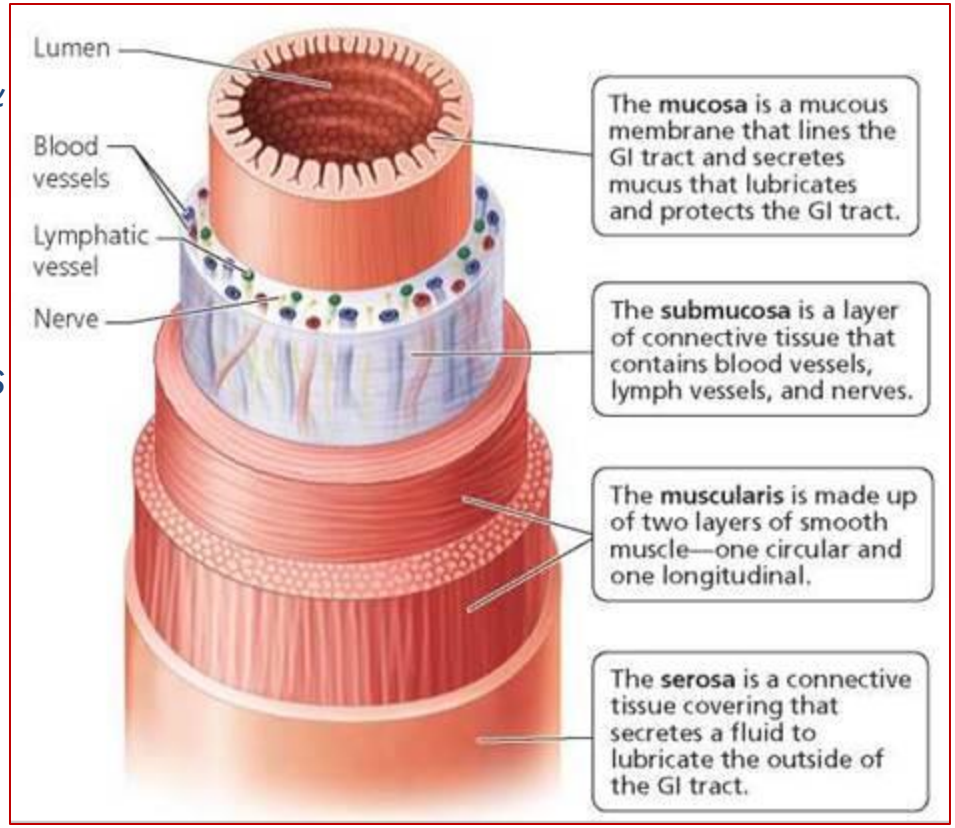
- From the innermost layer outward:

- ***Mucosa***, *protective role, secretion and absorption, contains exocrine, endocrine, & epithelial cells.*

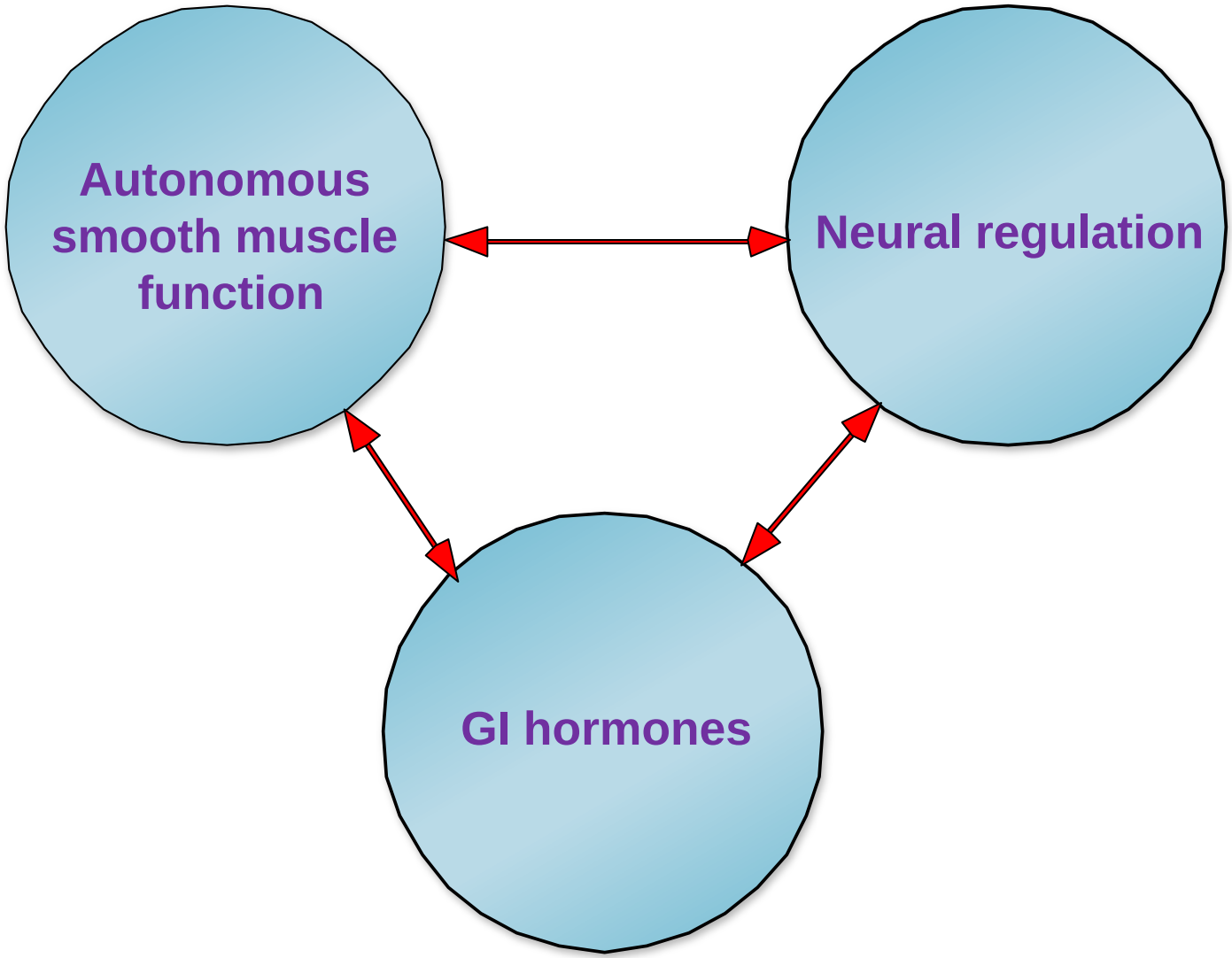
- ***Submucosa***, *thick layer of connective tissue, gives GI tract distensibility & elasticity, contains blood and lymph vessels*

- ***Muscularis externa,***
  - ✓ *inner circular layer: contraction constricts/decreases the diameter of the lumen*
  - ✓ *outer longitudinal layer: contraction shortens the tube*

- ***Serosa***, *outer connective tissue covering, secretes a watery, slippery fluid; lubricates and prevents friction with surrounding organs*

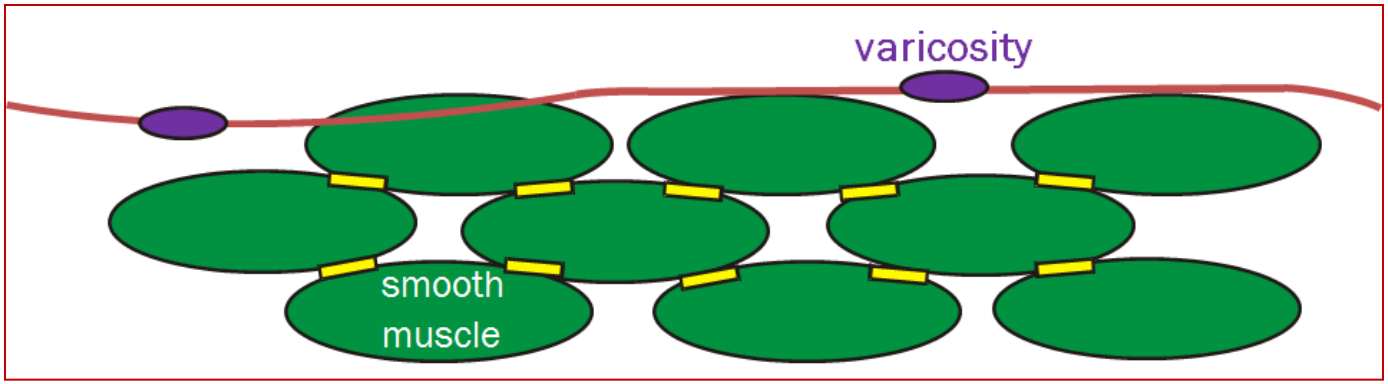


Regulation of GI function



Autonomous Smooth Muscle Function

Sheets of smooth muscle cells are connected by gap junctions (i.e., functional syncytium)



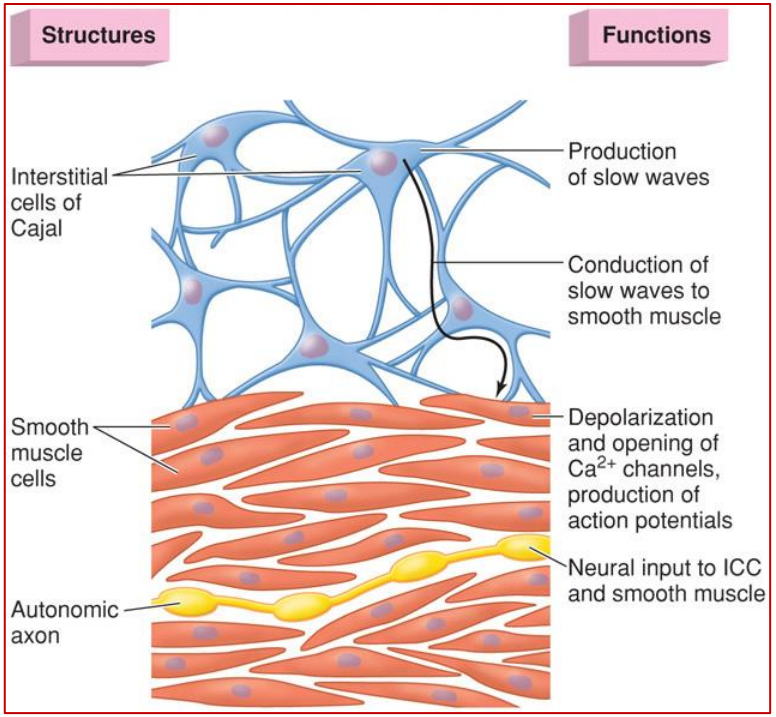
- ***Tonic smooth muscle:*** *contraction is maintained for prolonged periods of time. e.g. fundus, sphincters*

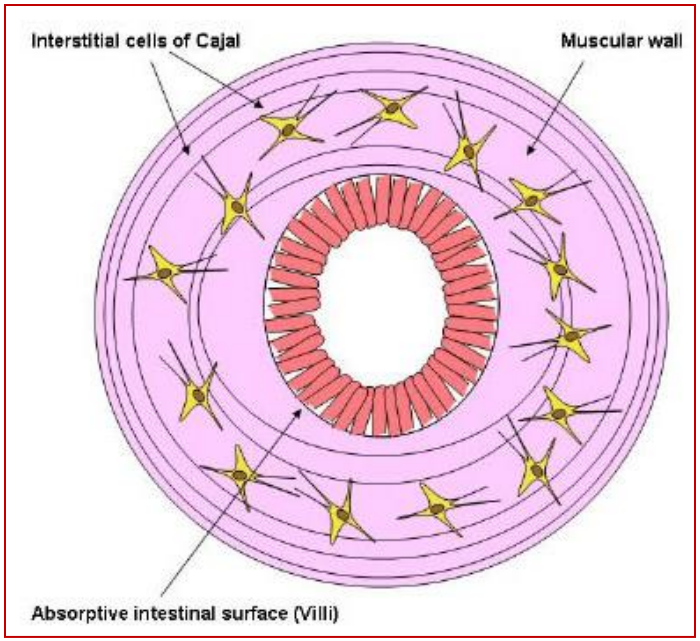
- ***Phasic smooth muscle:*** *"twitch-like" contraction evoked by action potentials. e.g. antrum, esophagus, intestine*

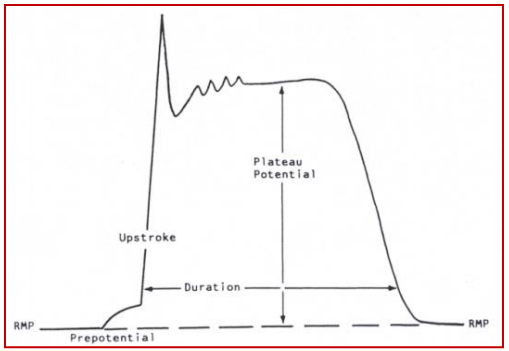
Autonomous Smooth Muscle Function

- Display rhythmic, spontaneous variations in membrane potential – **slow-wave potentials (basic electrical rhythm (BER)** or **pacesetter potential)**

- Slow waves are generated by **Interstitial Cells of Cajal "ICC"** (pacemaker cells)







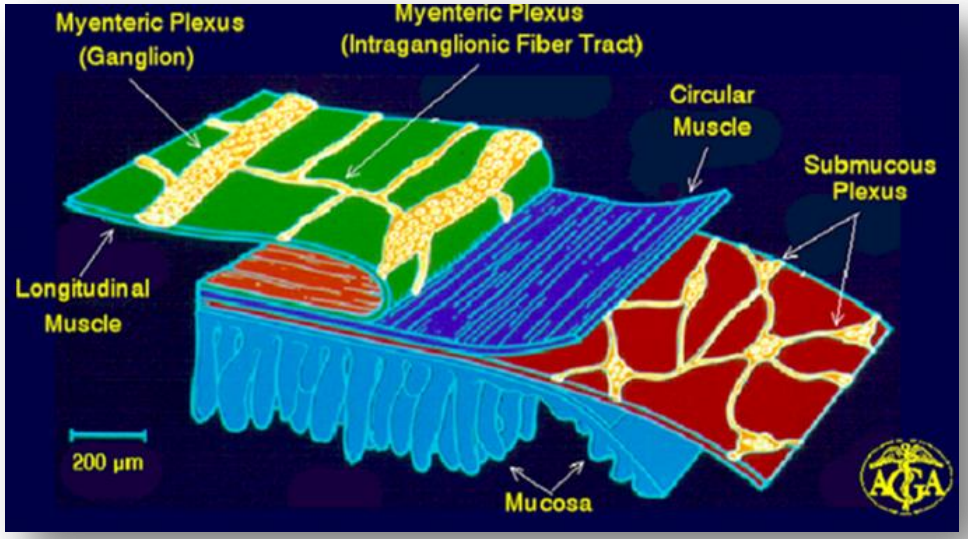
Neural Regulation of GI function

1. **Intrinsic nerve plexuses:**

- Digestive tract has its own intramural ("within-wall") nervous system
- Contains as many neurons as the spinal cord

- 2 major networks:
  - Submucous plexus
  - Myenteric plexus

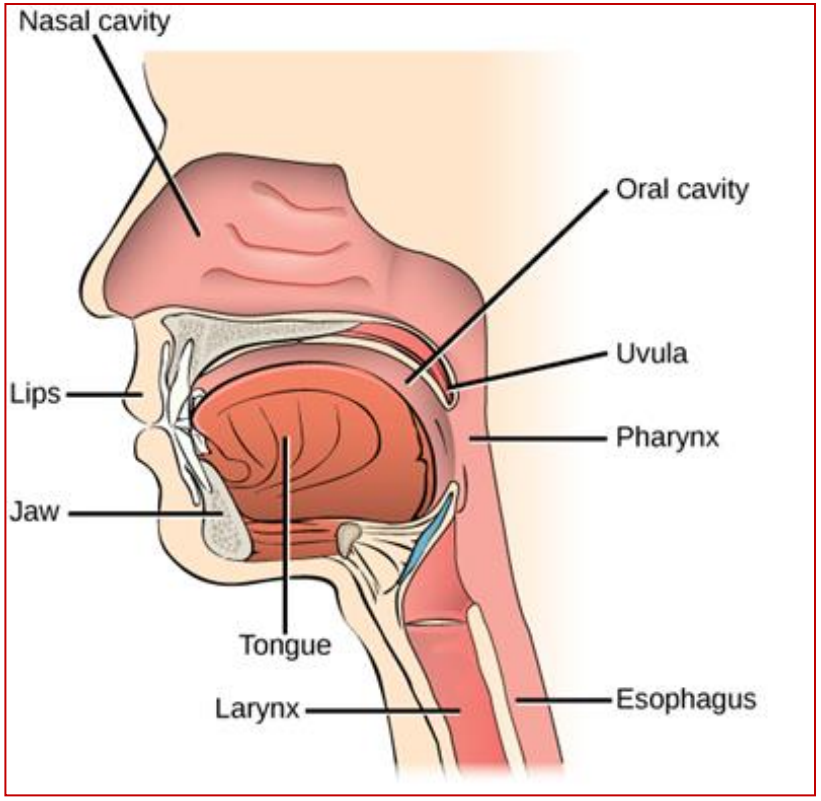
} **ENS**
Enteric Nervous System



2. **Extrinsic nerves:**
   - ✓ Sympathetic & parasympathetic of ANS
   - ✓ Either directly on the smooth muscle and glands or indirectly via ENS

Mouth

- Muscular **lips**:
  - ✓ Procure, guide, and contain the food in the mouth
  - ✓ Important in speech
  - ✓ Sensory receptor
- The **palate**:
  - ✓ Separates the mouth from the nasal passages
  - ✓ **Uvula;** sealing off the nasal passages during swallowing
- The **tongue**:
  - ✓ The floor of the oral cavity
  - ✓ Skeletal muscle
  - ✓ Guiding food within the mouth during chewing and swallowing
  - ✓ Role in speech
  - ✓ Contains taste buds



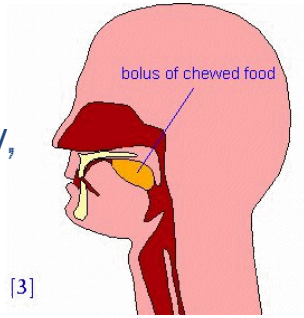
OPENStax "BIOLOGY"

Mouth

Chewing:

The motility of the mouth that involves the slicing, tearing, grinding, and mixing of ingested food by the **teeth**

- ✓ Grinding and breaking food up into smaller pieces to facilitate swallowing
- ✓ Mixing food with saliva
- ✓ Stimulating the taste buds; sensation of taste & reflexly increases salivary, gastric, pancreatic, and bile secretion
- ✓ After chewing, the food (now called a bolus) is swallowed.



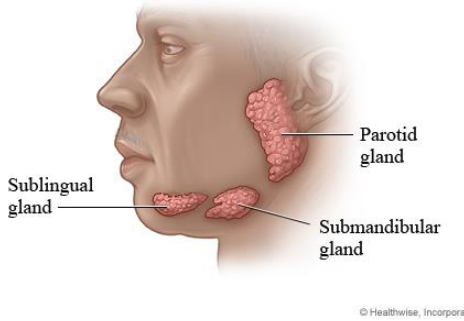
[3]

- Voluntary, but mostly a rhythmic reflex; activation of the skeletal muscles of the jaws, lips, cheeks, and tongue in response to the pressure of food against the oral tissues

Mouth

Saliva:

- **Components:**
  - ✓ 99.5% H_2O
  - ✓ 0.5% electrolytes and proteins (*amylase, mucus, & lysozyme)*
- **Functions:**
  - ✓ Begins digestion of carbohydrate (polysaccharide $\xrightarrow{\text{s.amylase}}$ maltose)
    - Gastric acid (in the stomach) inactivates amylase, except in the center of the food mass
  - ✓ Facilitates swallowing, providing lubrication through mucus
  - ✓ Antibacterial action via *lysozyme* & rinsing effect
  - ✓ Solvent for molecules that stimulate the taste buds
  - ✓ Aids speech
  - ✓ Oral hygiene (helping keep the mouth and teeth clean)
  - ✓ Contains bicarbonate buffers, which neutralize acids
  - ✓ Entirely under neural regulation (no hormonal regulation), **parasympathetic:** prompt and abundant flow of watery saliva, rich in enzymes. **sympathetic:** much smaller volume, thick saliva, rich in mucus



No absorption takes place in the mouth

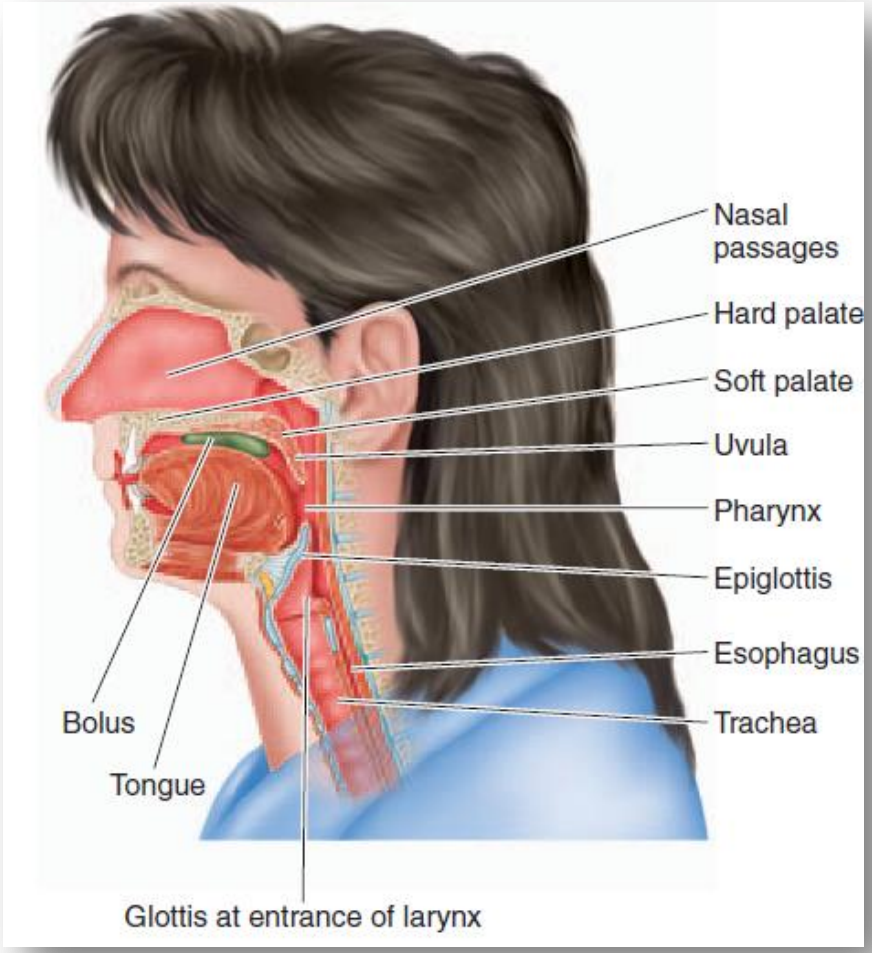
- **Nitroglycerin**

Pharynx & Esophagus

- **Swallowing (deglutition):** the process in the human or animal body that makes something pass from the mouth, to the pharynx, and into the esophagus

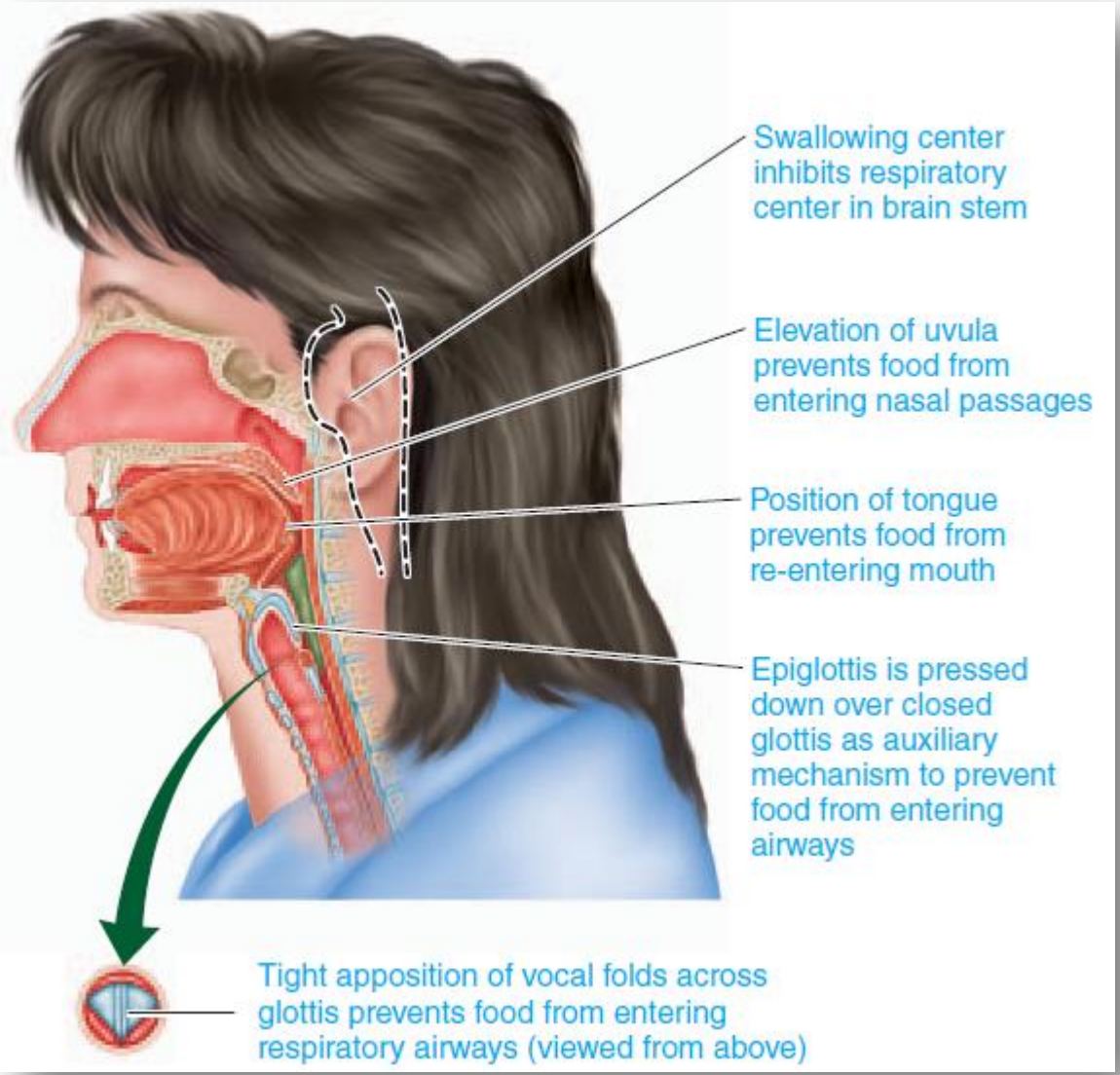
- **ALL or NON:** initiated voluntarily, but once begun it cannot be stopped
  - ✓ bolus distension stimulates pressure receptors, mediated by the intrinsic nerve plexuses at the level of the distension.

- **Two stages:**
  1. Oropharyngeal stage
  2. Esophageal stage



Swallowing Stages

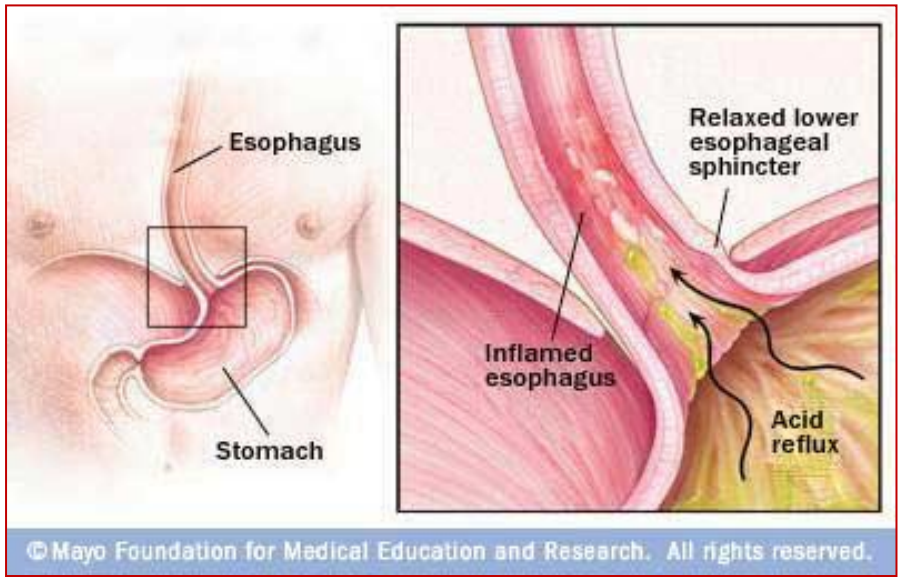
1. Oropharyngeal stage

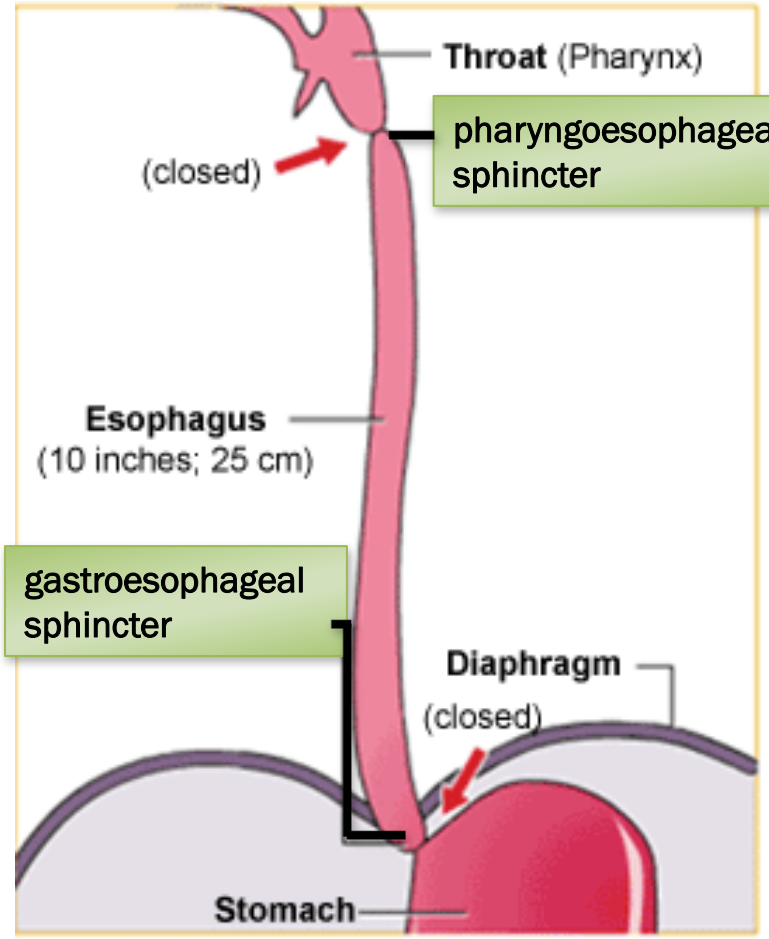


Swallowing Stages

2. Esophageal stage

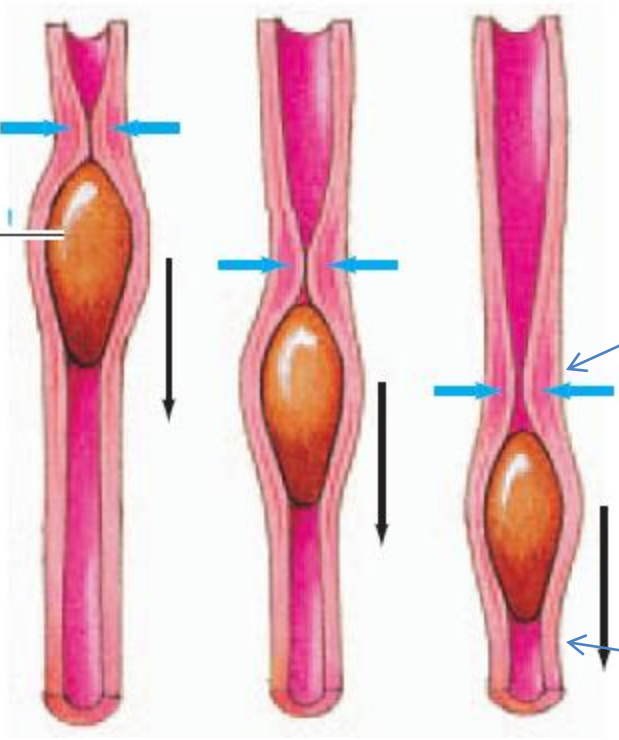
- Starts after food passes pharyngoesophageal sphincter
- Esophageal secretion is entirely mucus (for lubrication)
- **Peristalsis** starts here





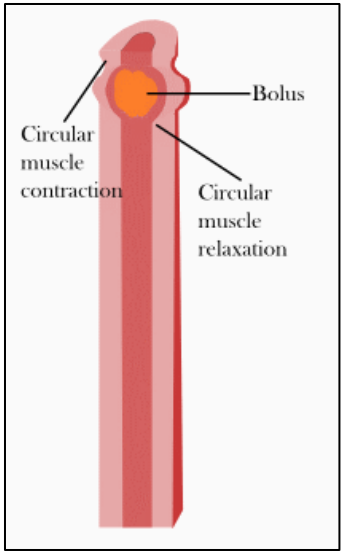
Esophageal Peristalsis

Ringlike peristaltic contraction sweeping down the esophagus



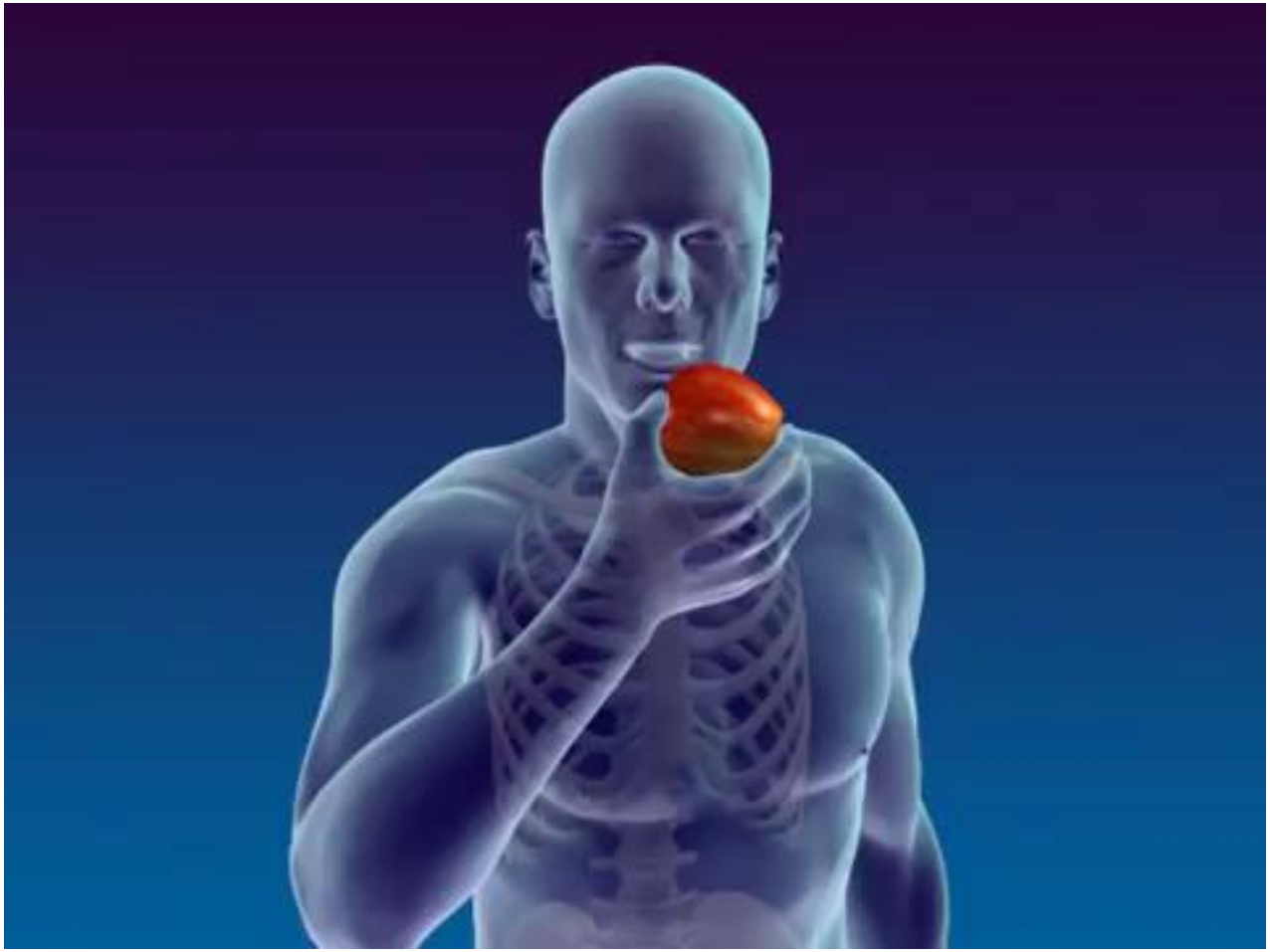
Circular muscle contraction

Circular muscle relaxation

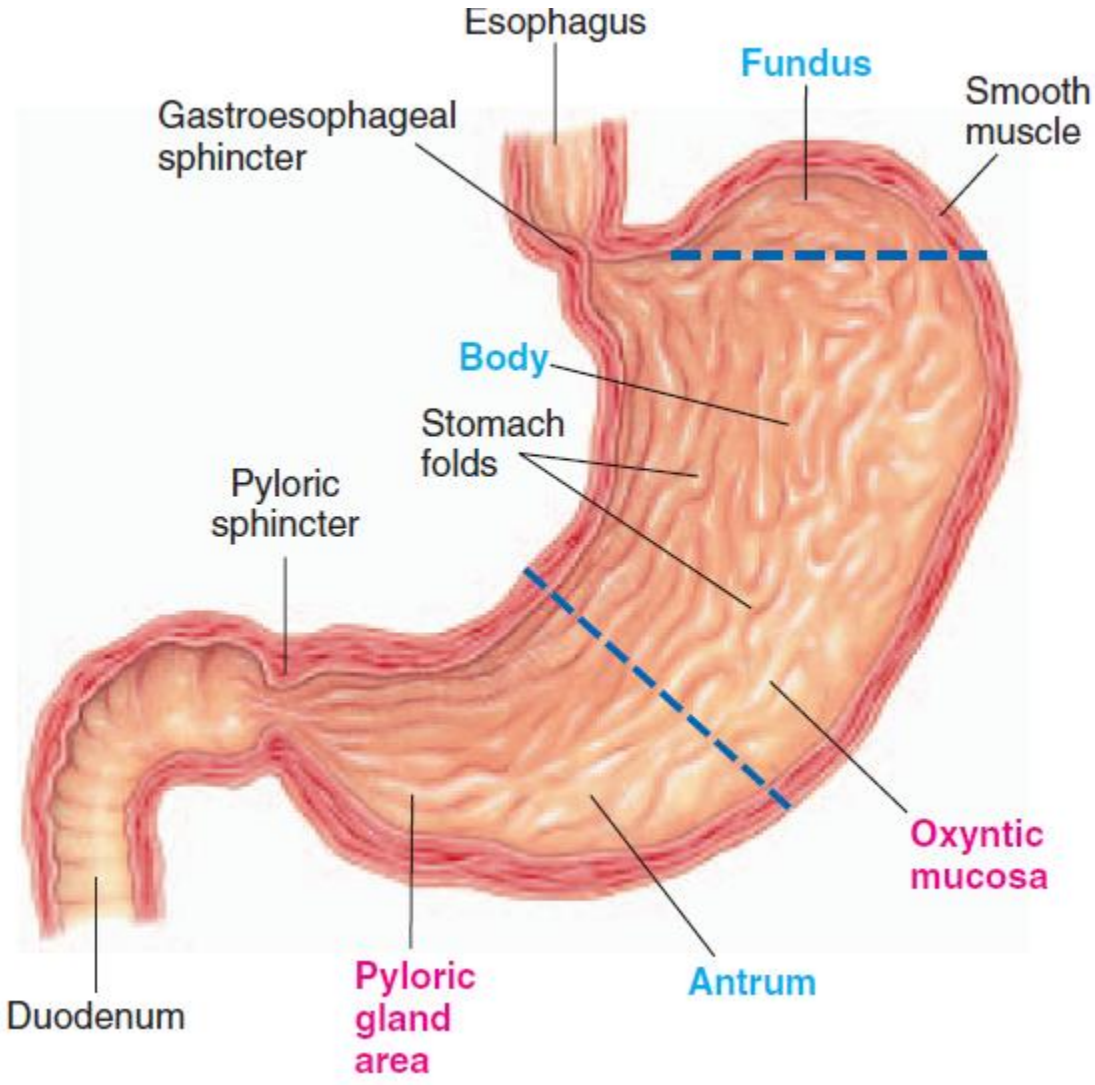


progressive motility that produces forward movement of matter along the GI tract

Swallowing Stages



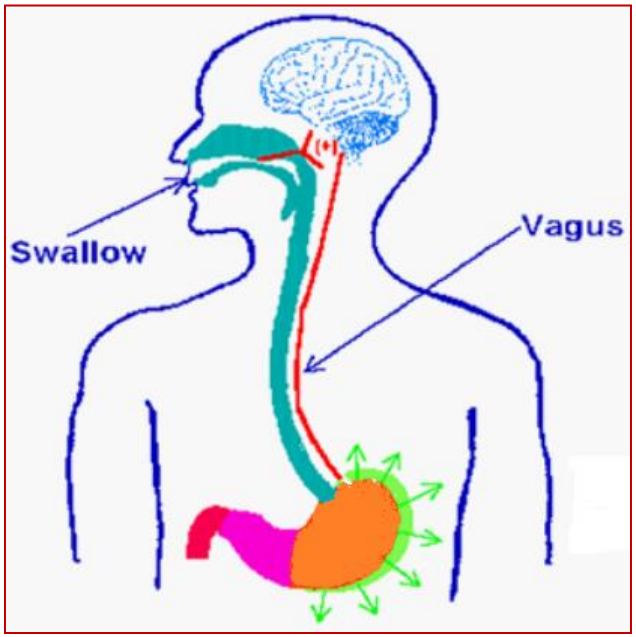
Stomach


Esophagus
Fundus
Smooth muscle
Gastroesophageal sphincter
Body
Stomach folds
Pyloric sphincter
Oxyntic mucosa
Duodenum
Pyloric gland area
Antrum

Gastric Motility

1. Gastric filling & storage

- Stomach volume; 50-1000mL
- Receptive relaxation:
  - ✓ Increase in stomach (Fundus) volume with little change in tension in its walls and little rise in intragastric pressure upon food reception
  - ✓ Stimulated by eating and is mediated by the **vagus** nerve
- Gastric storage takes place in the fundus of the stomach (**tonic** contraction)



Gastric Motility

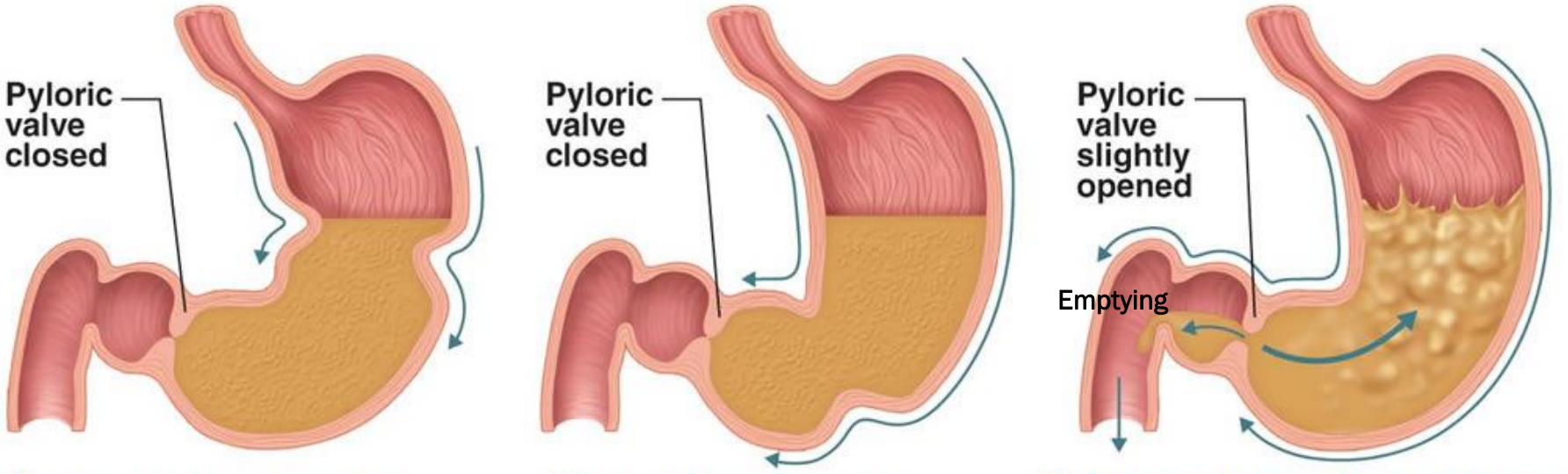
2. Gastric mixing & emptying

- Gastric mixing takes place in the thick-muscled antrum as a result of vigorous **peristaltic** contractions against the almost closed pyloric sphincter

- The amount of chyme that escapes into the duodenum with each peristaltic wave before the pyloric sphincter tightly closes depends largely on the strength of peristalsis

Chyme is what we call partly digested food as it leaves the stomach; it's full of good stuff…yum!

Gastric Motility



① **Propulsion:** Peristaltic waves move from the fundus toward the pylorus.

② **Grinding:** The most vigorous peristalsis and mixing action occur close to the pylorus.

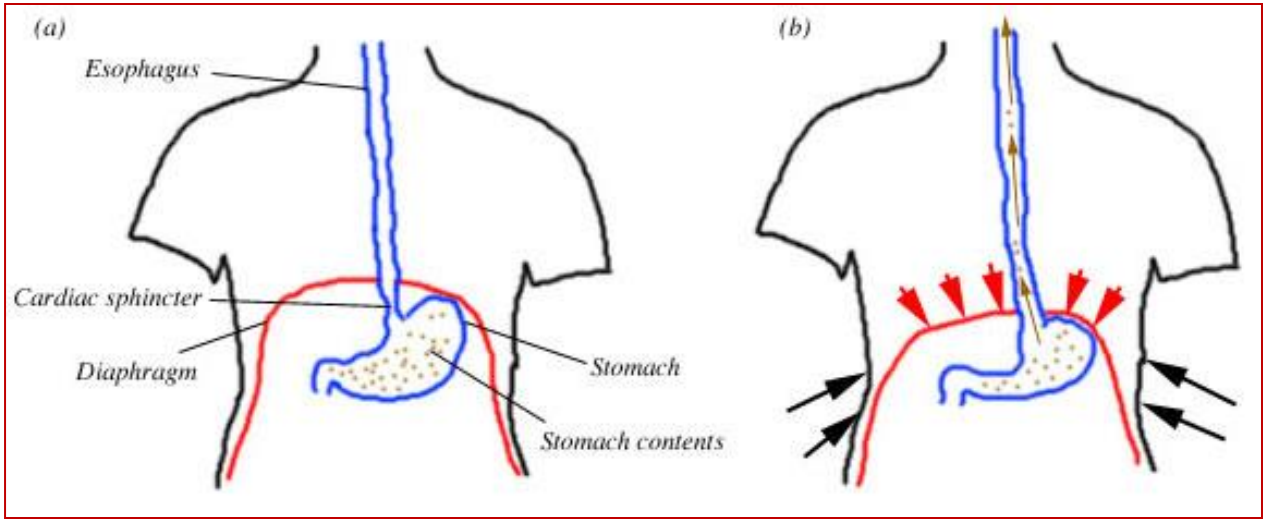
③ **Retropulsion:** The pyloric end of the stomach acts as a pump that delivers small amounts of chyme into the duodenum, simultaneously forcing most of its contained material backward into the stomach.

Factors Regulating Gastric Motility and Emptying

FACTORS	EFFECTS ON GASTRIC MOTILITY AND EMPTYING
Within the Stomach	
Volume of chyme	Increased volume stimulates motility and emptying
Degree of fluidity	Increased fluidity allows more rapid emptying
Within the Duodenum	
Presence of fat, acid, hypertonicity, or distension	These factors in the duodenum inhibit further gastric motility and emptying until the duodenum has coped with factors already present
Outside the Digestive System	
Emotion	Stimulates or inhibits motility and emptying
Intense pain	Inhibits motility and emptying

Vomiting

- **Vomiting** (or **emesis):** the forceful expulsion of gastric contents out through the mouth
- Vomiting is coordinated by a **vomiting center** in the medulla.
- The stomach, the esophagus, and associated sphincters are all relaxed during vomiting
- The major force for expulsion comes from contraction of the respiratory muscles; (diaphragm & abdominal muscles)
- Vomiting begins with a deep inspiration and closure of the glottis.



Gastric Secretion

The Stomach Mucosa and the Gastric Glands

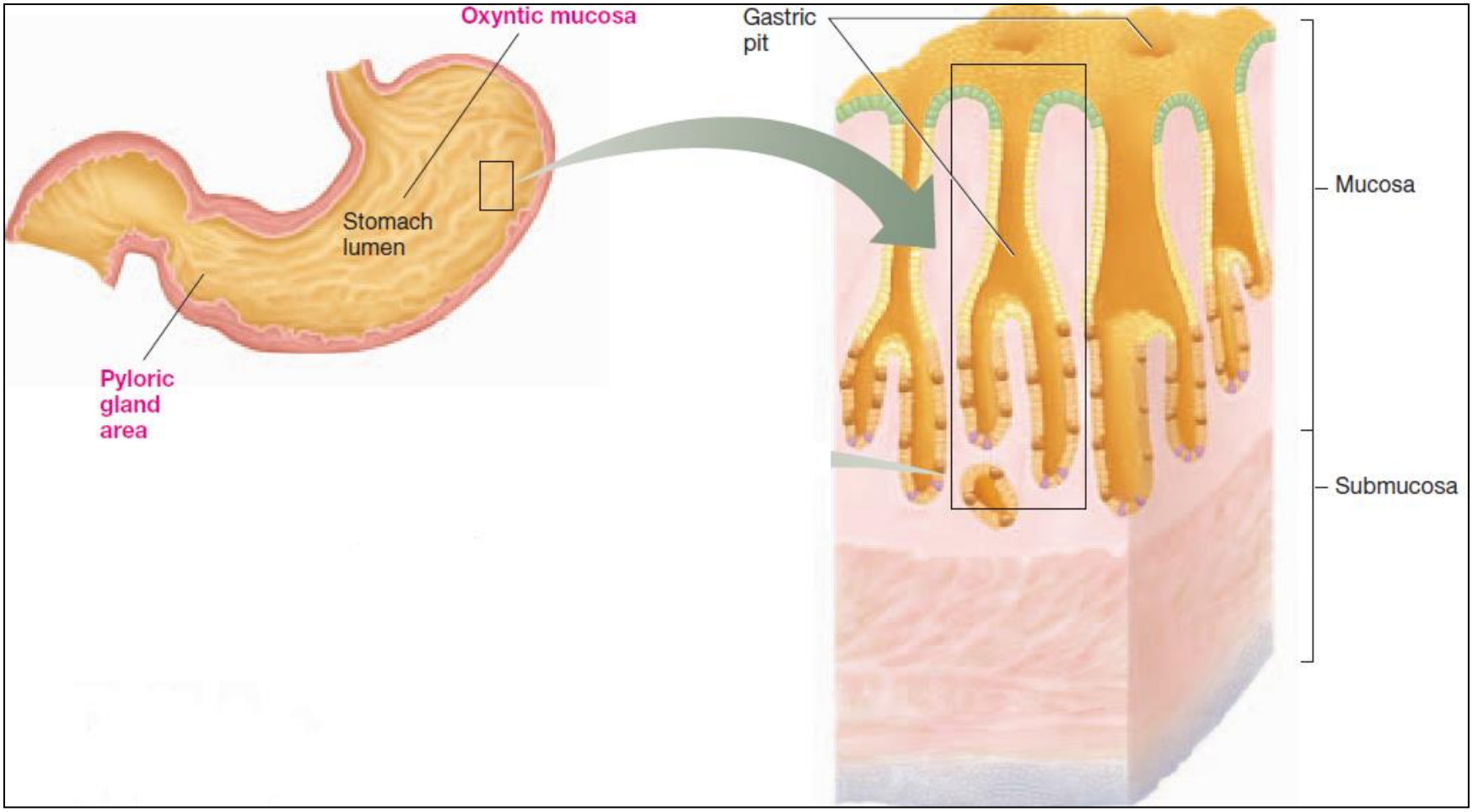


TABLE 15-3

The Stomach Mucosa and the Gastric Glands

TYPE OF SECRETORY CELL	PRODUCT SECRETED	STIMULI FOR SECRETION	FUNCTION(S) OF SECRETORY PRODUCT
Exocrine cells			
Mucous cells	Alkaline mucus	Mechanical stimulation by contents	Protects mucosa against mechanical, pepsin, and acid injury
Chief cells	Pepsinogen	ACh, gastrin	When activated, begins protein digestion
Parietal cells	Hydrochloric acid	ACh, gastrin, histamine	Activates pepsinogen, breaks down connective tissue, denatures proteins, kills micro-organisms
	Intrinsic factor		Facilitates absorption of vitamin B_{12}

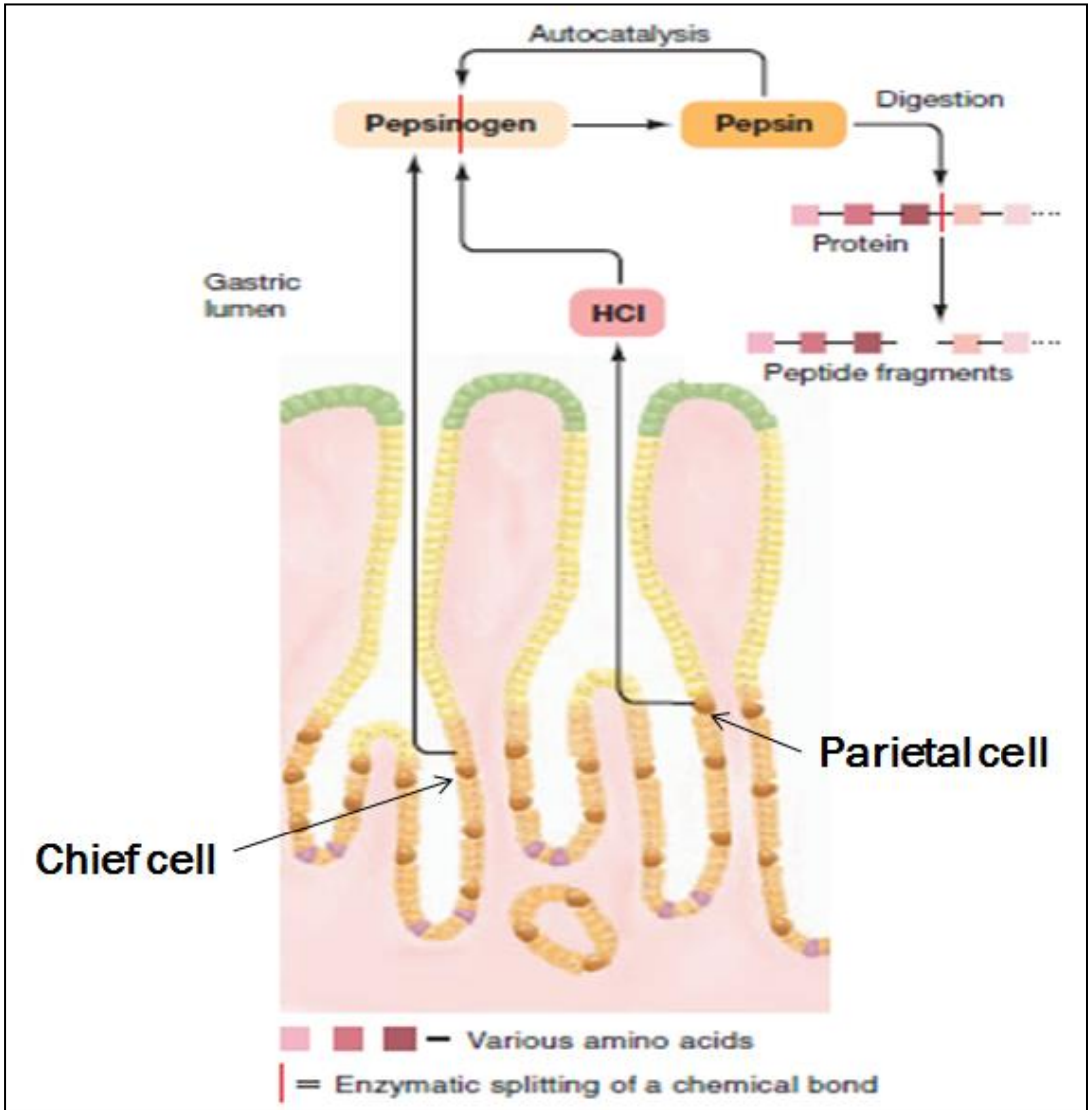
TABLE 15-3

The Stomach Mucosa and the Gastric Glands

TYPE OF SECRETORY CELL	PRODUCT SECRETED	STIMULI FOR SECRETION	FUNCTION(S) OF SECRETORY PRODUCT
Endocrine/Paracrine cells			
Enterochromaffin-like (ECL) cells	Histamine	ACh, gastrin	Stimulates parietal cells
G cells	Gastrin	Protein products, ACh	Stimulates parietal, chief, and ECL cells
D cells	Somatostatin	Acid	Inhibits parietal, G, and ECL cells

Pepsinogen Activation & Protein Digestion

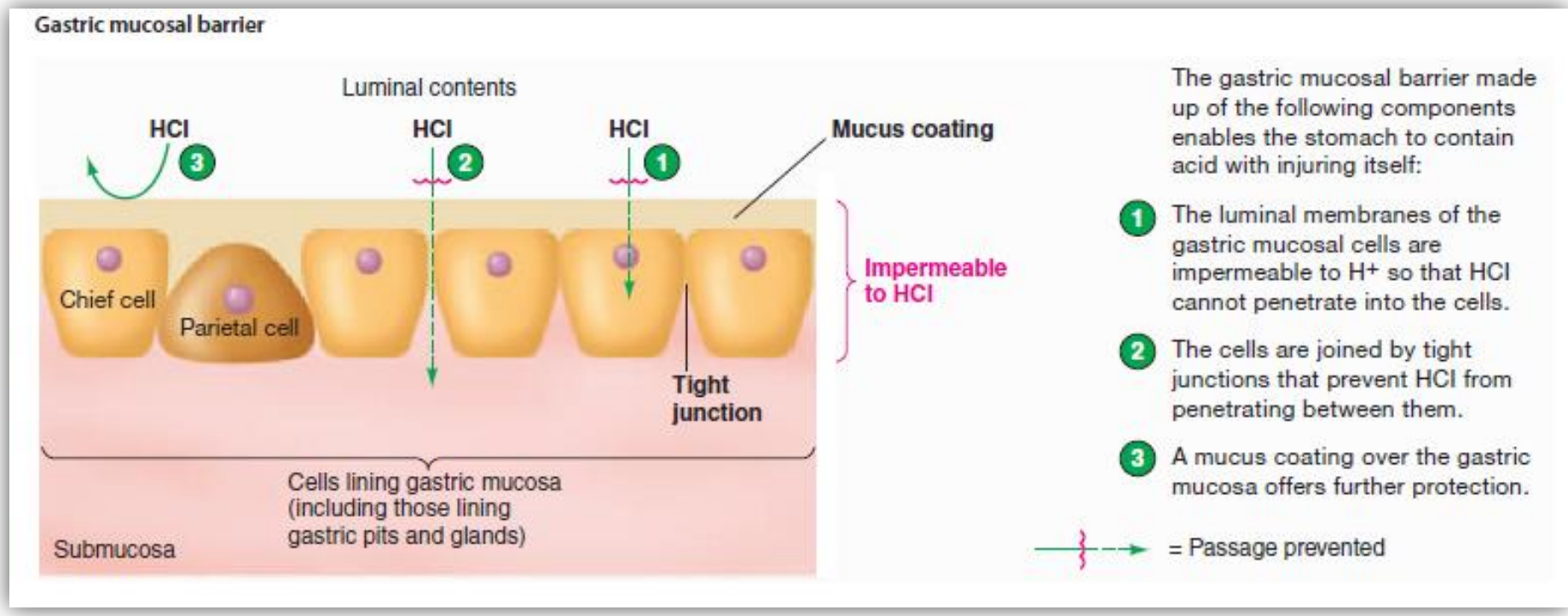
Protein digestion starts in stomach



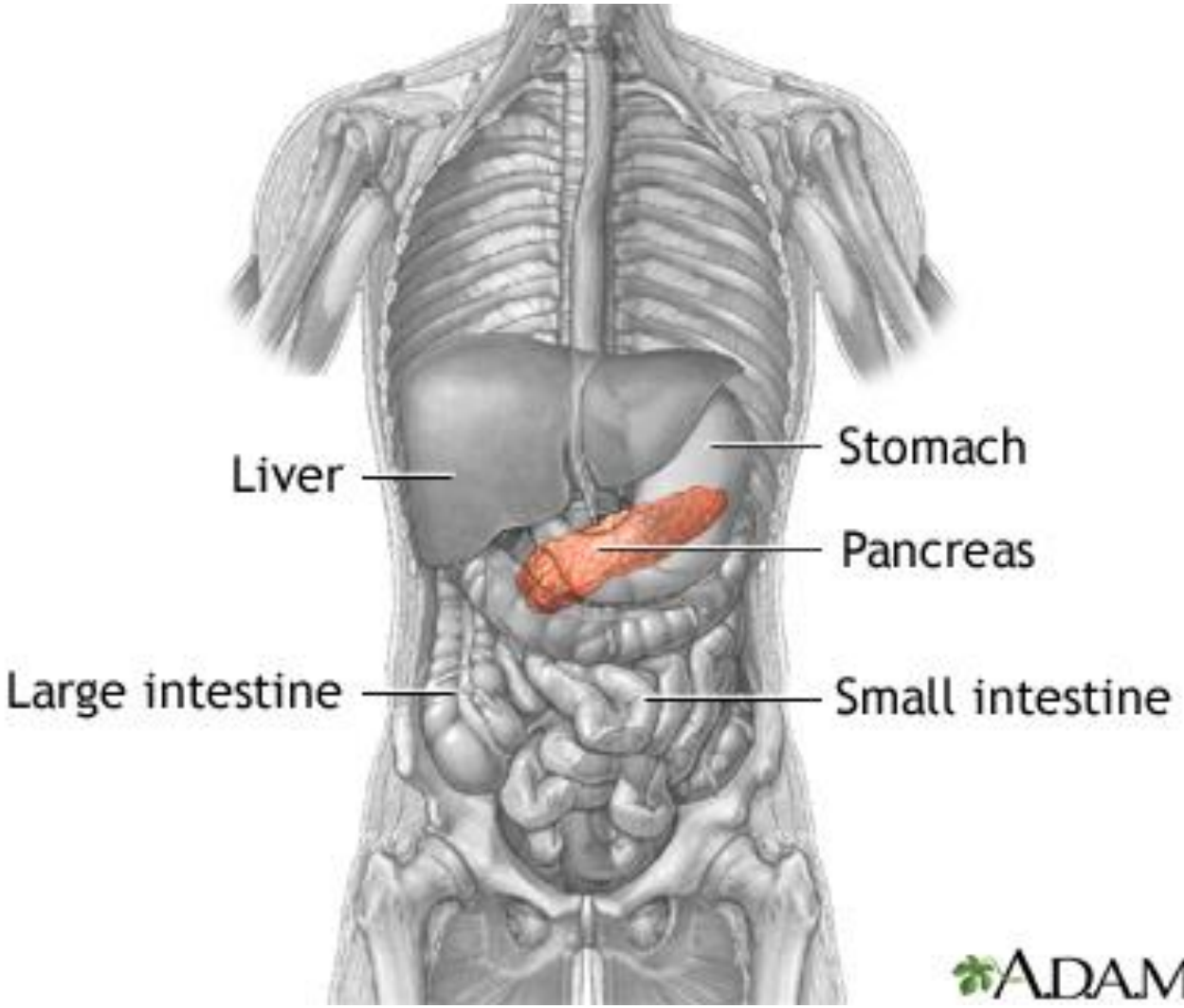
Phases of Gastric Secretion

PHASE	STIMULI	
Cephalic Phase of Gastric Secretion	Stimuli in the head—seeing, smelling, tasting, chewing, swallowing food	Stimulatory
Gastric Phase of Gastric Secretion	Stimuli in the stomach—protein, (peptide fragments), distension, caffeine, alcohol	Stimulatory
Intestinal phase of gastric secretion	Fat, acid, hypertonicity, distention	Inhibitory

Protecting Stomach Lining From Gastric Secretions



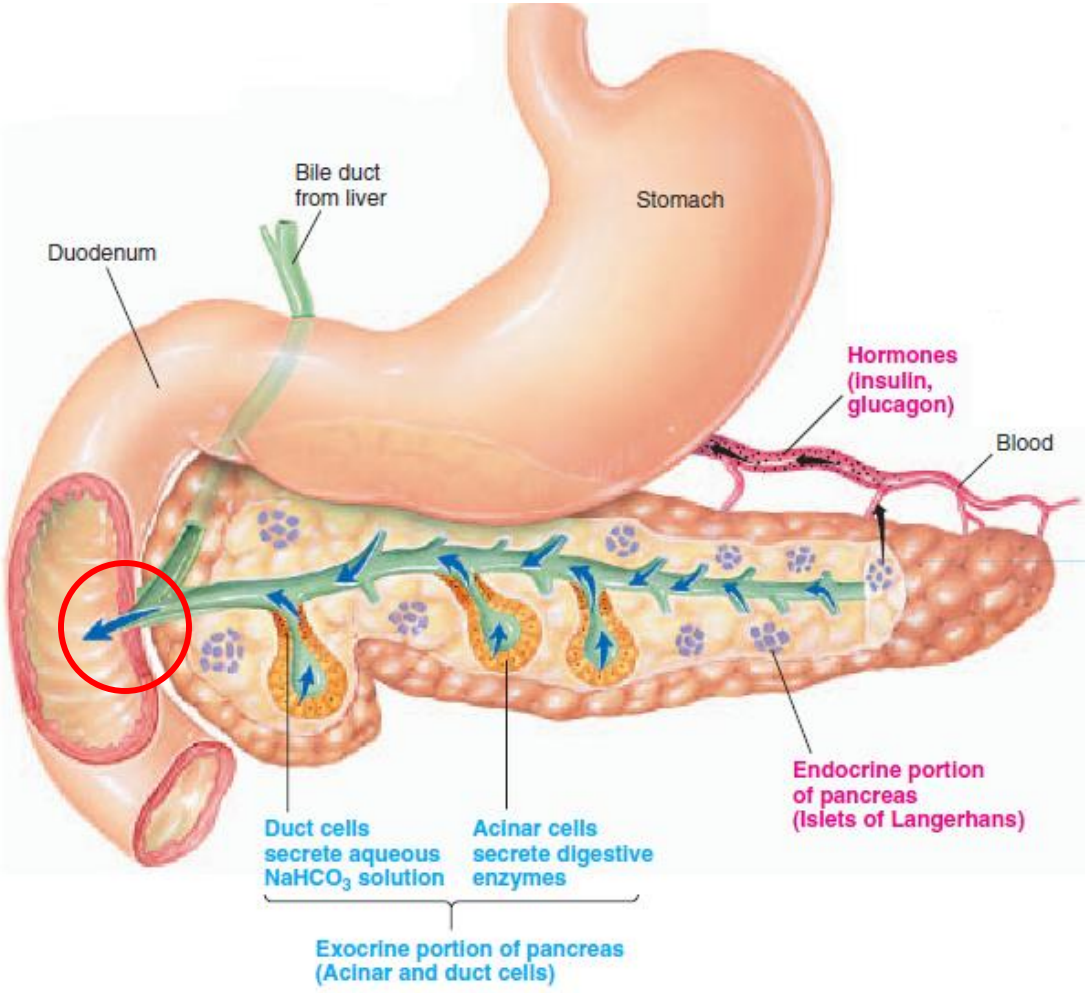
Pancreas


Liver
Stomach
Pancreas
Large intestine
Small intestine
A.D.A.M.

Pancreas is a Mixture of Exocrine and Endocrine Tissue

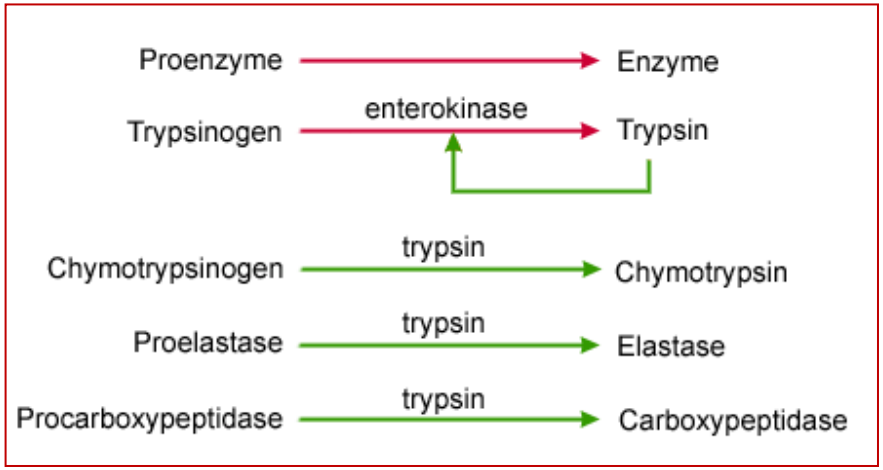
- Secretes into the duodenum

1. **Pancreatic enzymes**
   - ✓ By the acinar cells
2. **Aqueous alkaline solution**
   - ✓ By the duct cells
   - ✓ Rich in sodium bicarbonate ($NaHCO_3$)
     - to allow optimal functioning of the pancreatic enzymes
     - to prevent acid (from stomach) damage to the duodenal mucosa



Pancreatic Enzymes

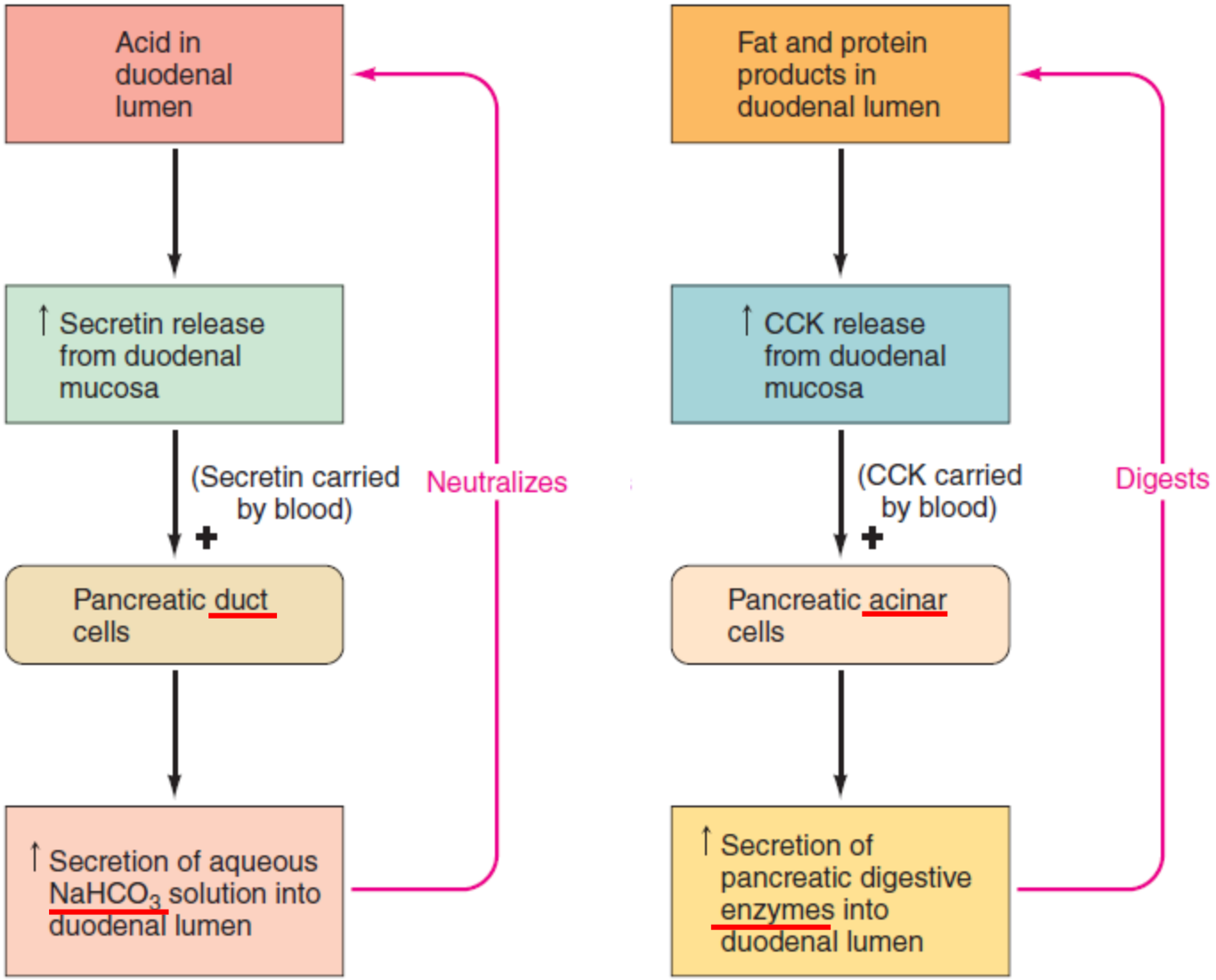
1. **Proteolytic enzymes**
   - ✓ trypsin, chymotrypsin, elastase, carboxypeptidase
   - ✓ Secreted in an inactive form
   - ✓ Trypsin inhibitor



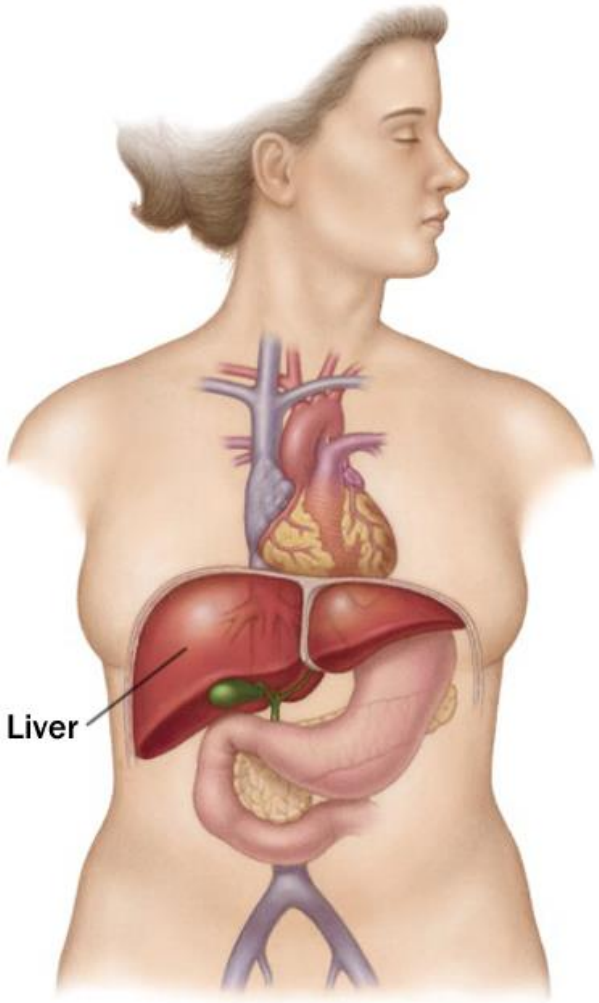
2. **Pancreatic amylase:**
   - ✓ Secreted in the pancreatic juice in an active form
   - ✓ Polysaccharides ⟶ disaccharide maltose

3. **Pancreatic lipase**
   - ✓ Secreted in its active form
   - ✓ The only enzyme secreted throughout the entire digestive system that can digest fat
   - ✓ Triglycerides ⟶ monoglycerides + free fatty acids

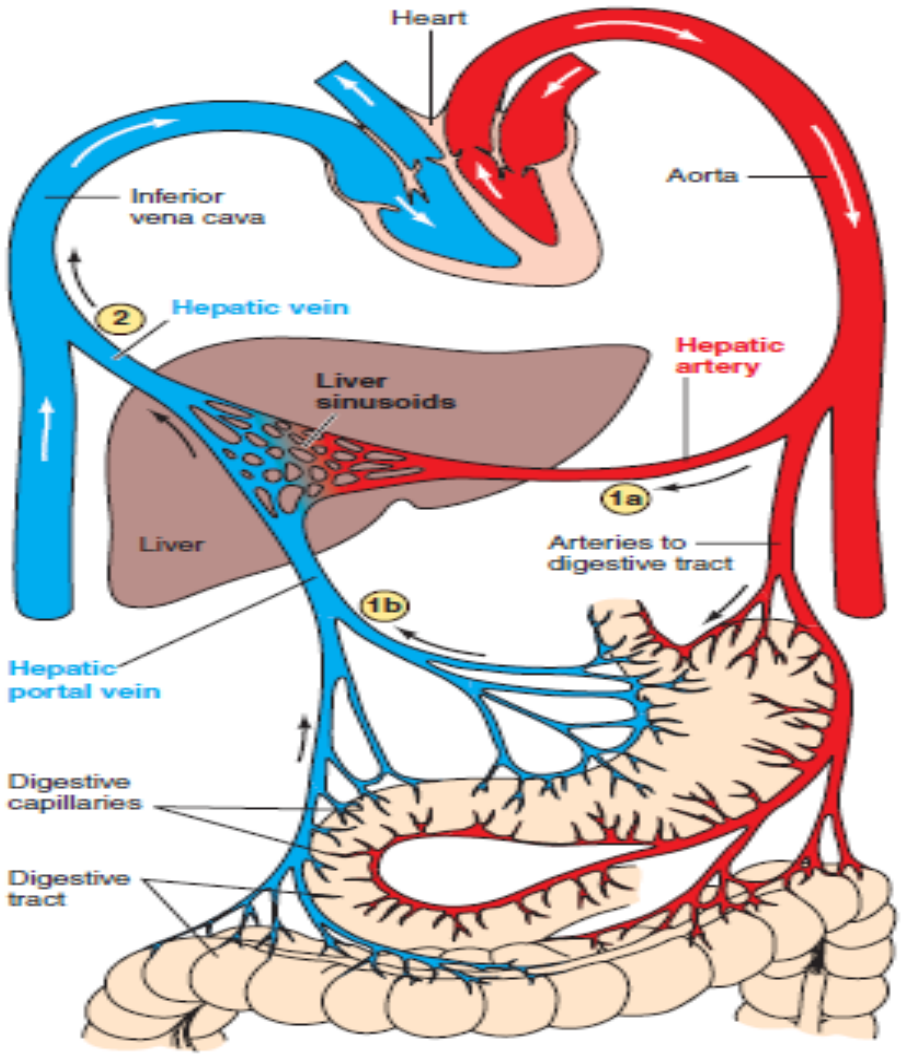
Regulation of Exocrine Pancreatic Secretion



Liver

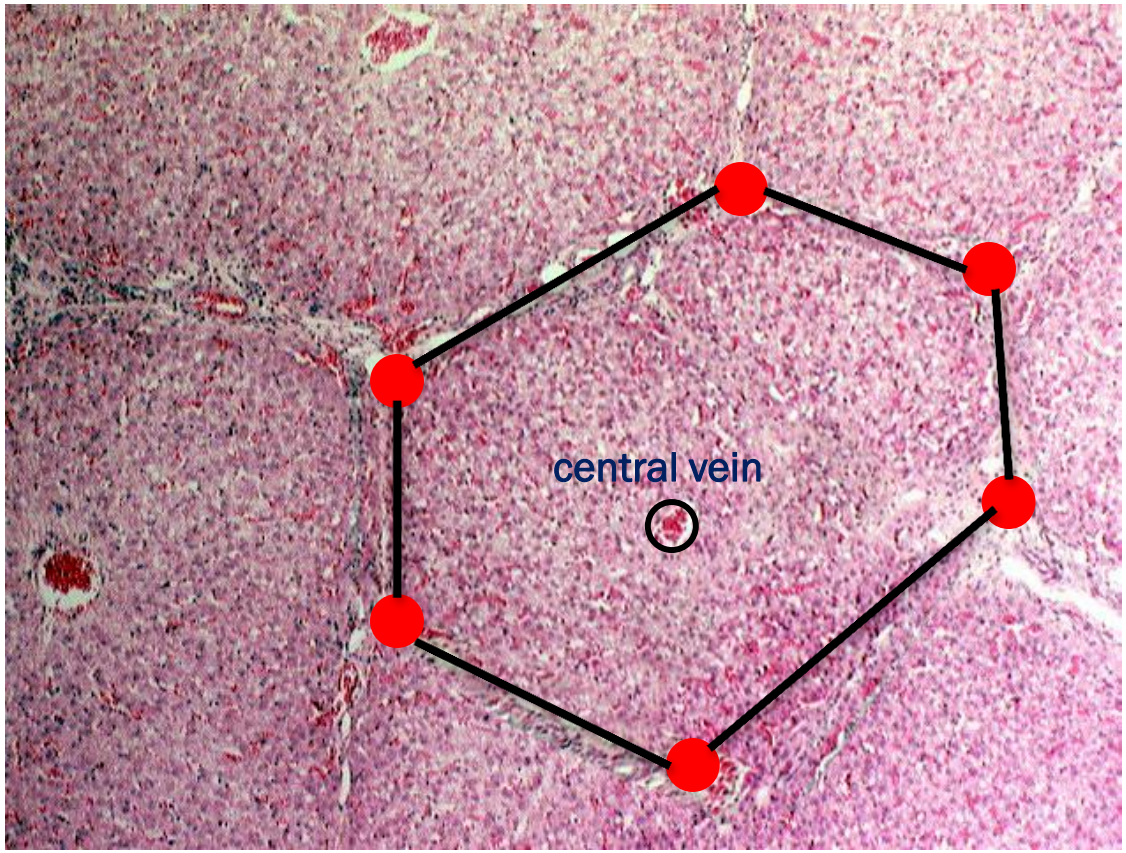


Liver Blood Flow

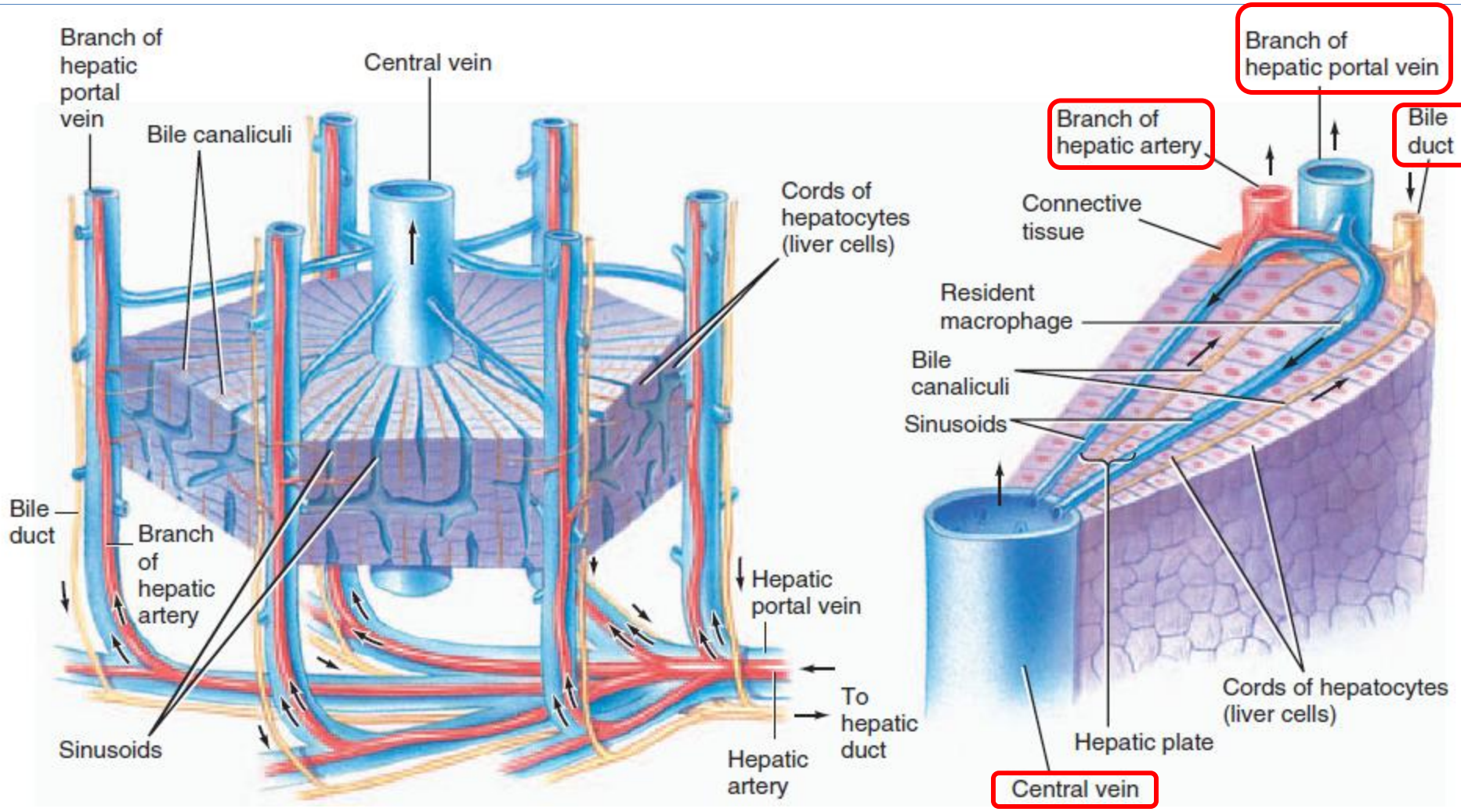


The Liver is Organized into Functional Units Known as Lobules

- Liver lobules: hexagonal arrangements of tissue surrounding a central vein



The Liver is Organized into Functional Units Known as Lobules



Each hepatocyte is in contact with a sinusoid on one side and a bile canaliculus on the other side

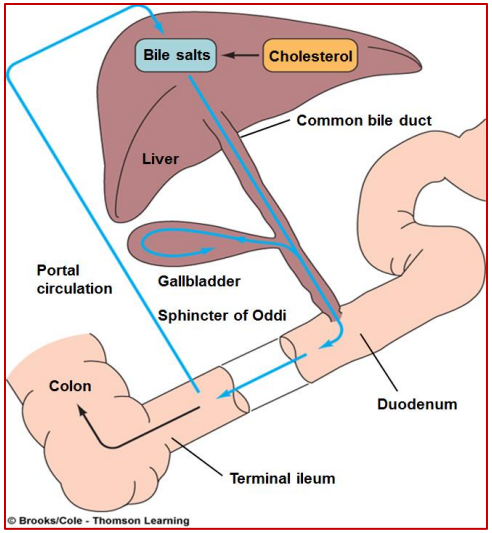
Bile

- **Bile constituents:**

1. Bile salts (derivatives of cholesterol)
2. Cholesterol
3. Lecithin
4. Bilirubin (heme waste product excreted in the bile)

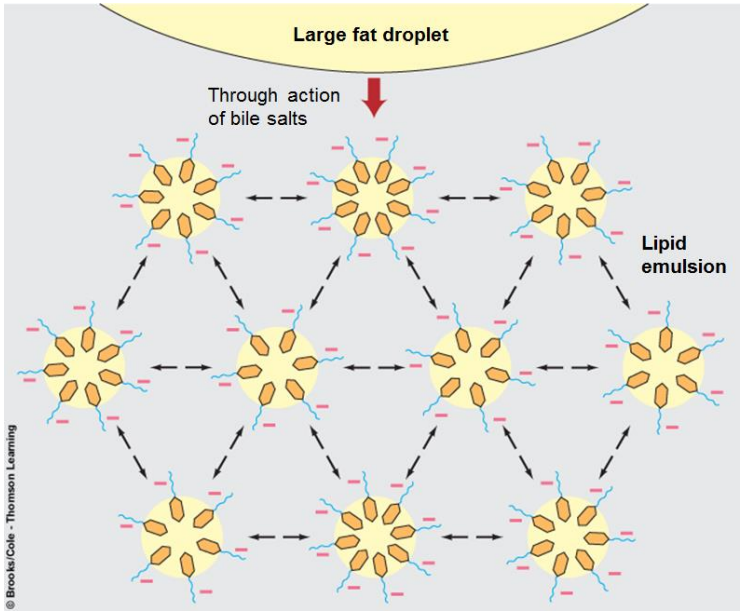
All in an aqueous alkaline fluid (added by the duct cells) similar to the pancreatic $NaHCO_3$

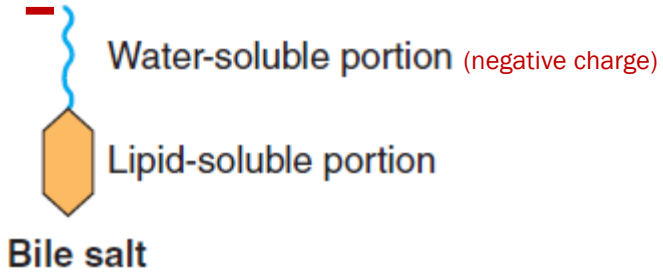
- No digestive enzymes
- Gallbladder stores and concentrates bile (5-10 times)
- CCK stimulates contraction of the gallbladder and relaxation of the sphincter of oddi; so releasing bile into duodenum

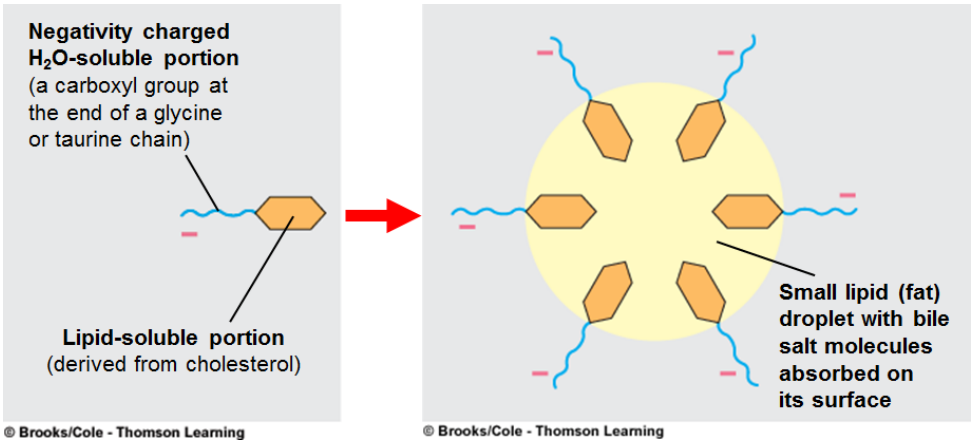


1. Detergent Action of Bile Salts Facilitates Fat Digestion

- Bile salts' ability to convert large fat globules into a lipid emulsion consisting of many small fat droplets suspended in the aqueous chyme, thus increasing the surface area available for attack by pancreatic lipase.

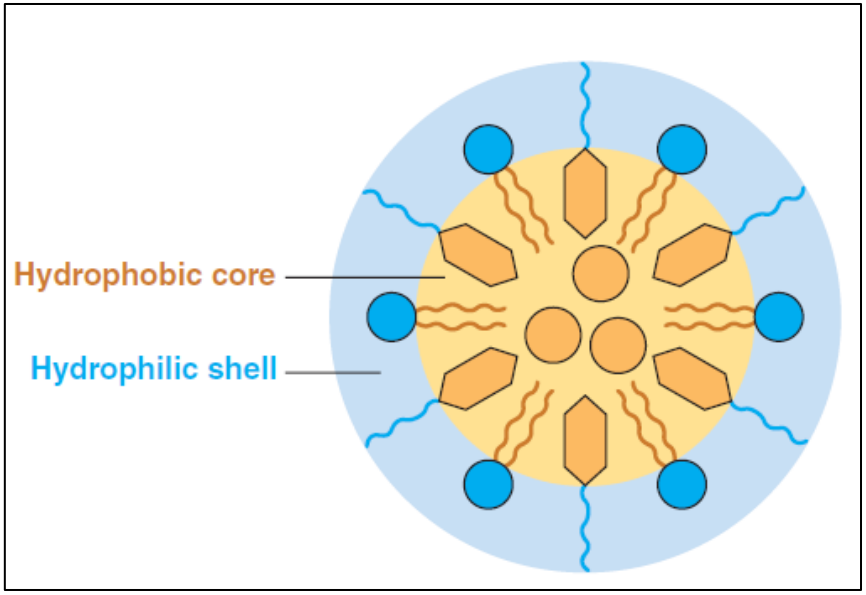


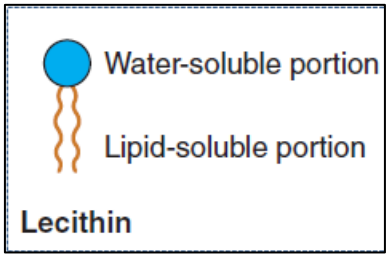


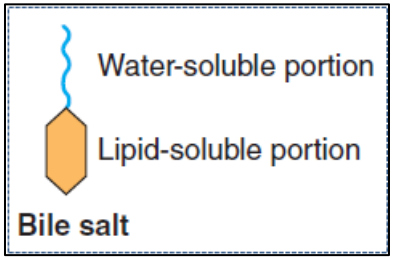


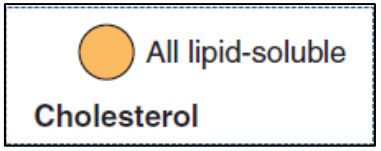
2. Bile Salts Facilitate Fat Absorption Through Formation of Micelles

- Micelles are lipid molecules that arrange themselves in a spherical form in aqueous solutions
- Can dissolve water-insoluble substances in their lipid soluble cores
- Vehicle for carrying water insoluble substances (monoglycerides, free fatty acids, & fat-soluble vitamins) through the watery luminal contents







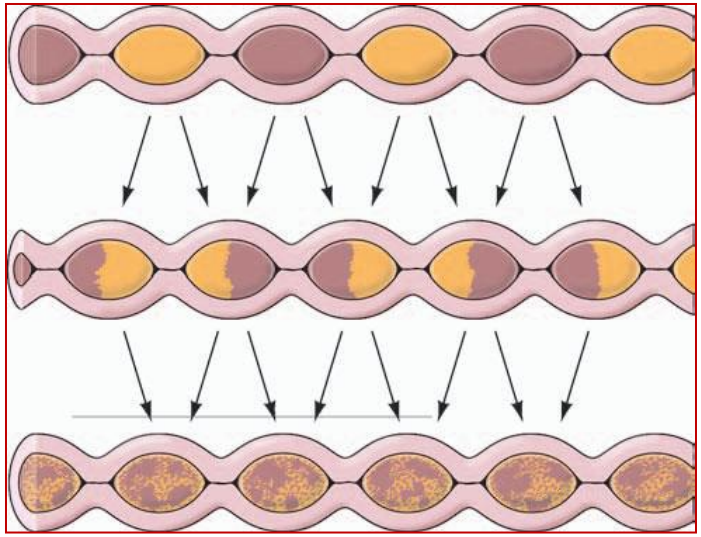


Small Intestine

Small Intestine Motility

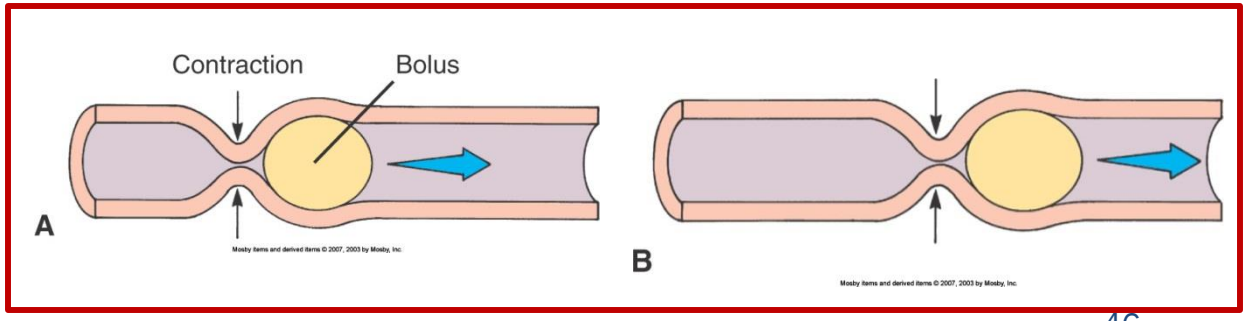
1. **Segmentation:**

- Oscillating, ring-like contractions of the circular smooth muscle along the small intestine's length
  - ✓ Between the contracted segments are relaxed areas containing a small bolus of chyme



2. **Peristalsis**

- Progressive motility that produces forward movement of matter along the GI tract



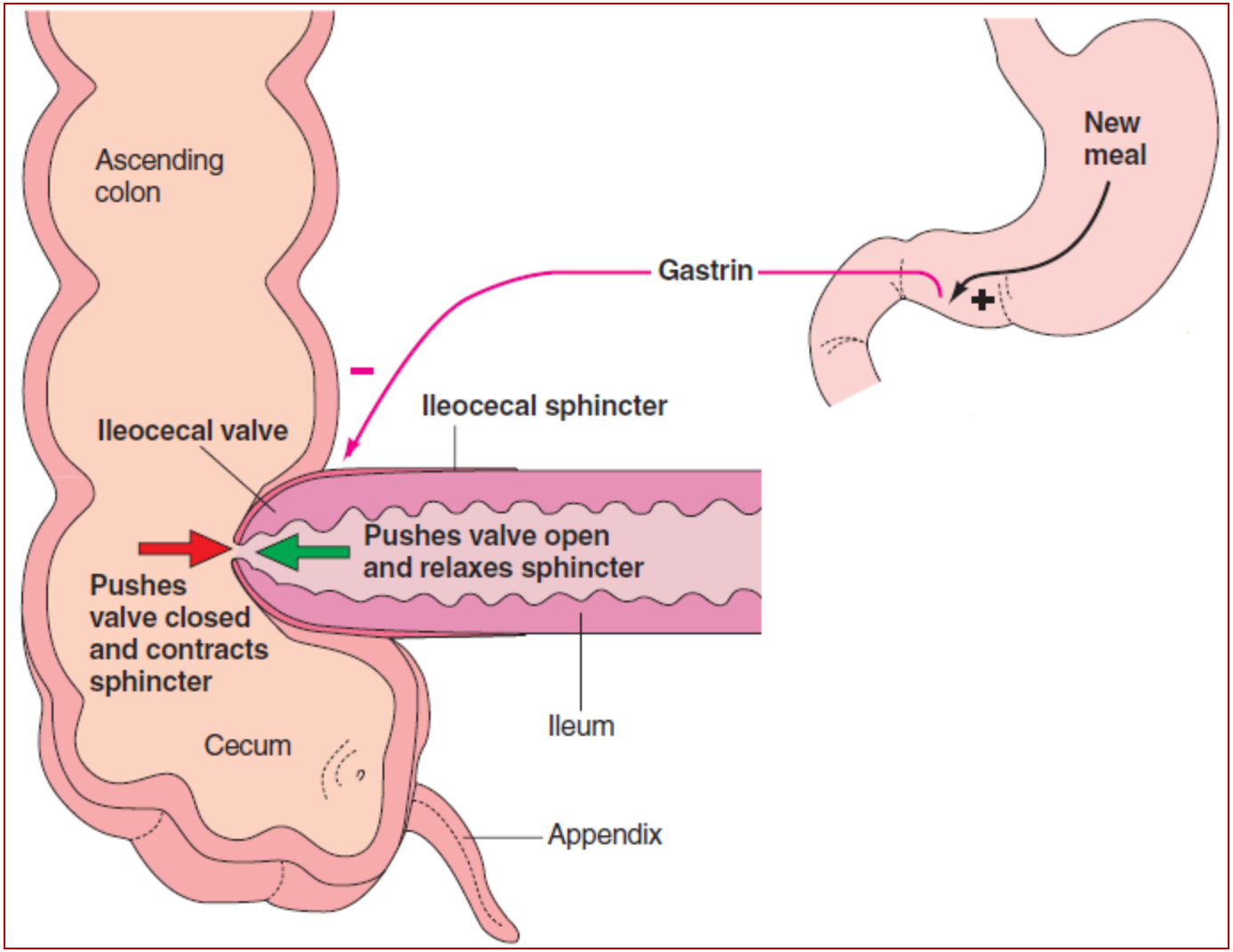
Small Intestine Motility

3. The migrating motility complex

- Between-meal (interdigestive) motility
- Consists of weak, repetitive peristaltic waves that move a short distance down the intestine before dying out.
- Starts in the stomach and migrates down the intestine
- Each new peristaltic wave is initiated at a site a little farther down the small intestine
- **Intestinal housekeeper**; sweeping any remnants of the preceding meal plus mucosal debris and bacteria forward toward the colon
- Regulated by the hormone **motilin**

Gastroileal Reflex

- Increase in ileal motility and opening of the ileocecal valve when food enters the empty stomach
- Mediated by gastrin



Small Intestine Secretions

- **Brush border enzymes**
  - Inserted into microvilli covering
  - Enzymatic digestion occurs at surface rather than in the lumen
    - ✓ **Enterokinase** [activation of trypsin]
    - ✓ **Disaccharidases** (maltase, sucrase, and lactase) [disacharides→monosccharides]
    - ✓ **Aminopeptidases** [protein digestion]

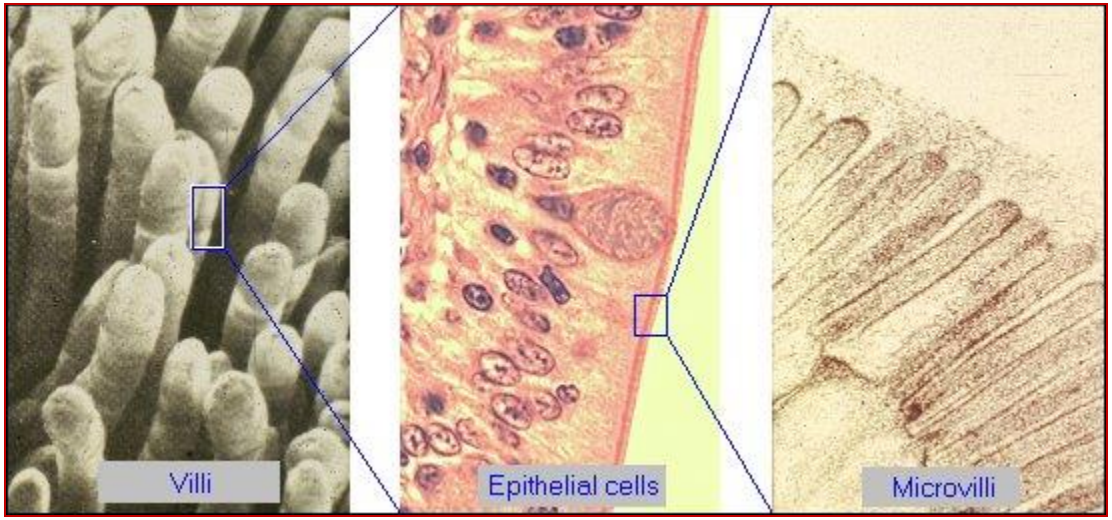


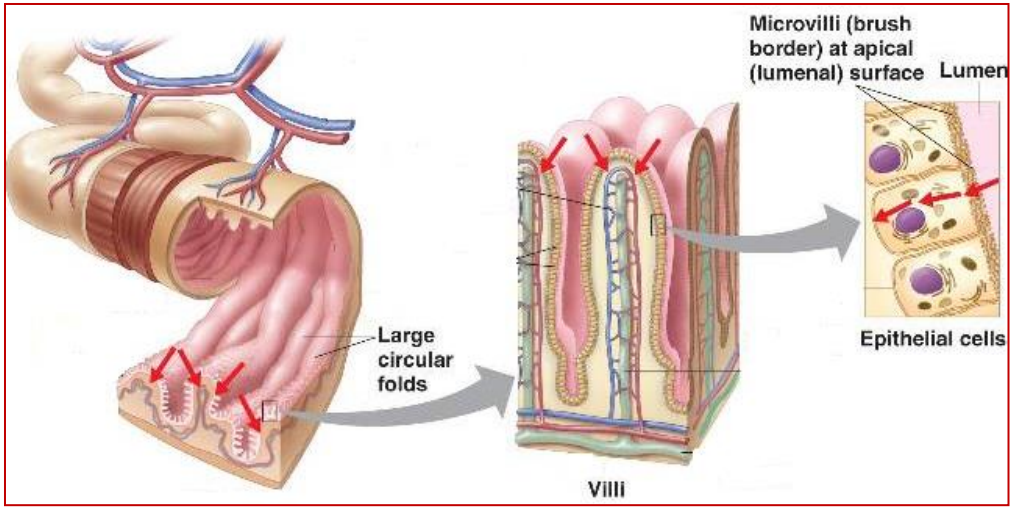
Table 18.1 Brush Border Enzymes Attached to the Cell Membrane of Microvilli in the Small Intestine

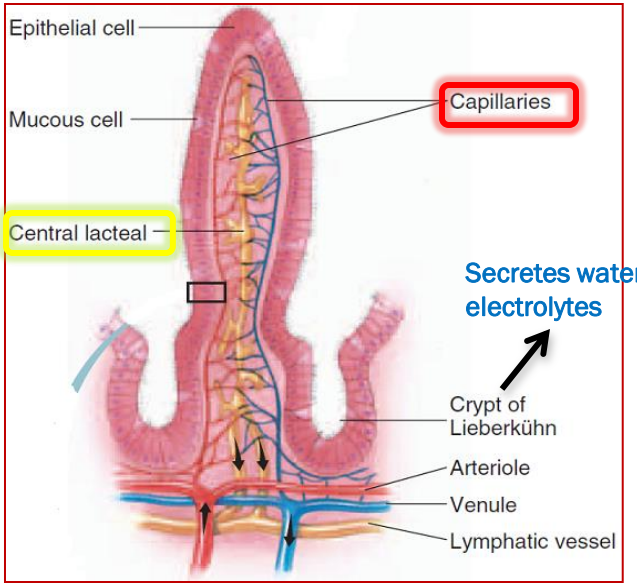
Category	Enzyme	Comments
Disaccharidase	Sucrase	Digests sucrose to glucose and fructose; deficiency produces gastrointestinal disturbances
	Maltase	Digests maltose to glucose
	Lactase	Digests lactose to glucose and galactose; deficiency produces gastrointestinal disturbances (lactose intolerance)
Peptidase	Aminopeptidase	Produces free amino acids, dipeptides, and tripeptides
	Enterokinase	Activates trypsin (and indirectly other pancreatic juice enzymes); deficiency results in protein malnutrition
Phosphatase	Ca^{2+}, Mg^{2+}-ATPase	Needed for absorption of dietary calcium; enzyme activity regulated by vitamin D
	Alkaline phosphatase	Removes phosphate groups from organic molecules; enzyme activity may be regulated by vitamin D

Small Intestine Absorption

- Most absorption occurs in the duodenum and jejunum
- Adaptations that increase the small intestine's surface area:

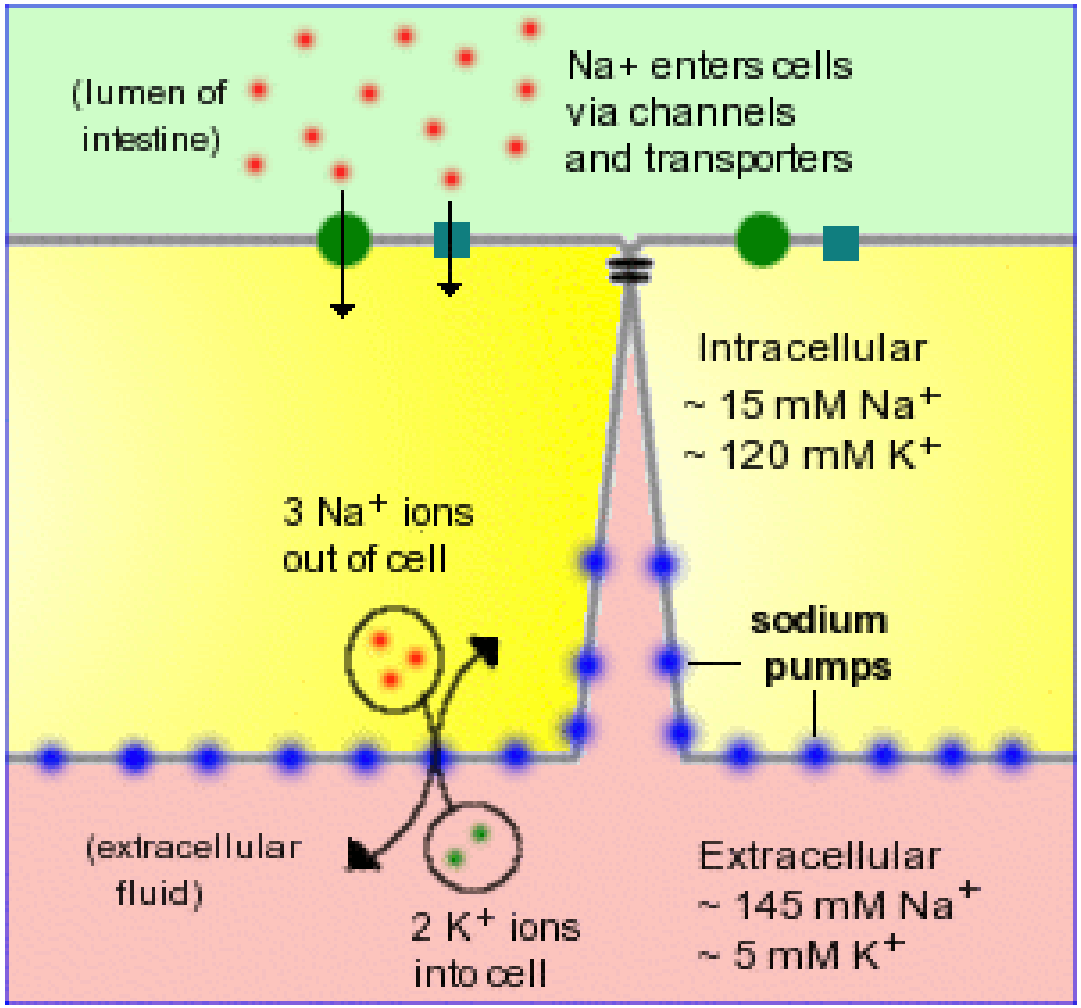
circular folds → villi → microvilli





Na^+ & H_2O Absorption

- Passive diffusion of Na^+ can occur between the intestinal epithelial cells through the leaky tight junctions
- Energy dependent movement of Na^+ through the cells (driven by the Na^+–K^+ ATPase pumps located at the cells' basolateral borders)
- Chloride passively follows down the electrical gradient created by Na^+ absorption and can be actively absorbed as well if needed.
- Water is reabsorbed passively down the osmotic gradient produced by active reabsorption of Na^+

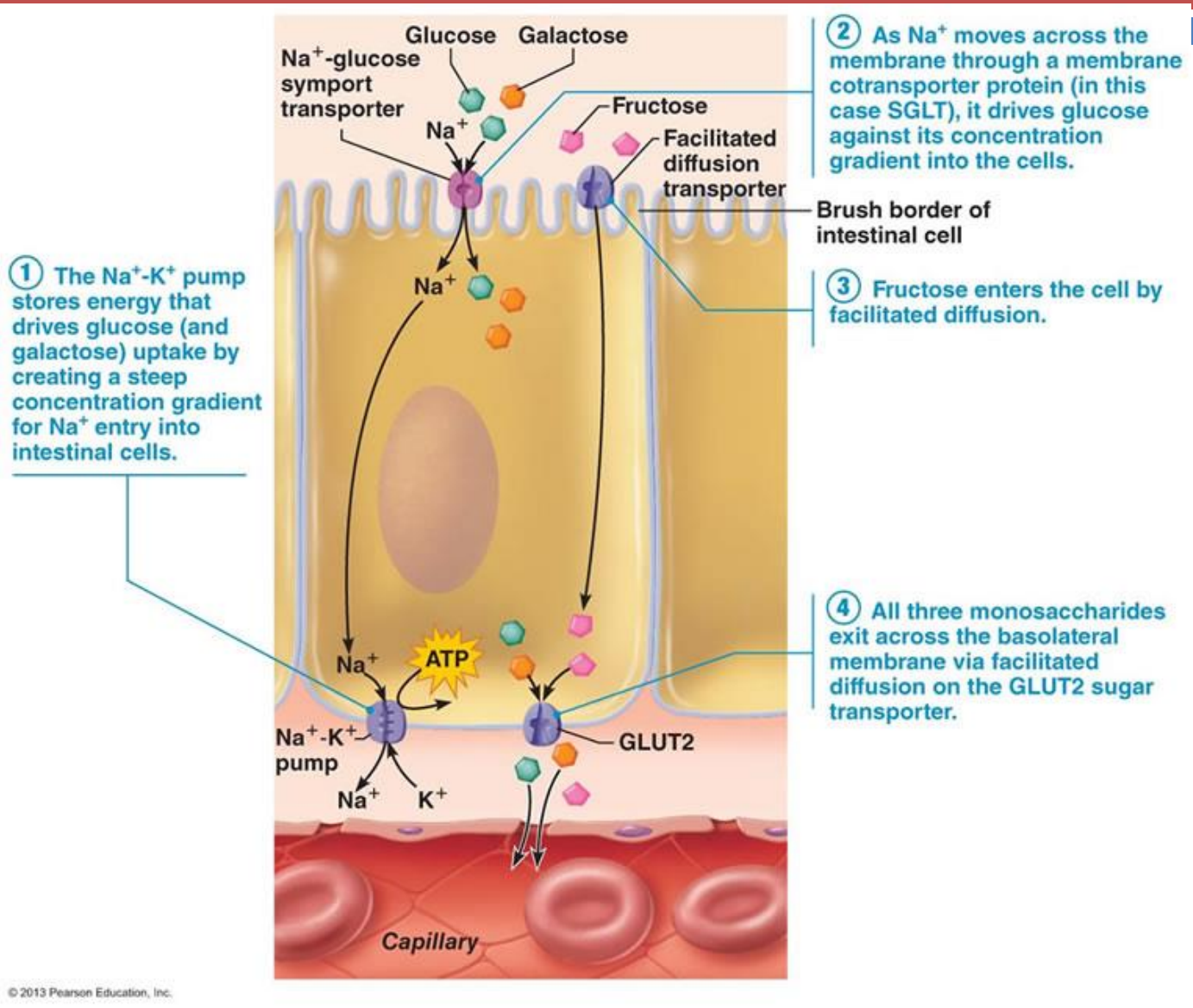


Carbohydrate & protein absorption

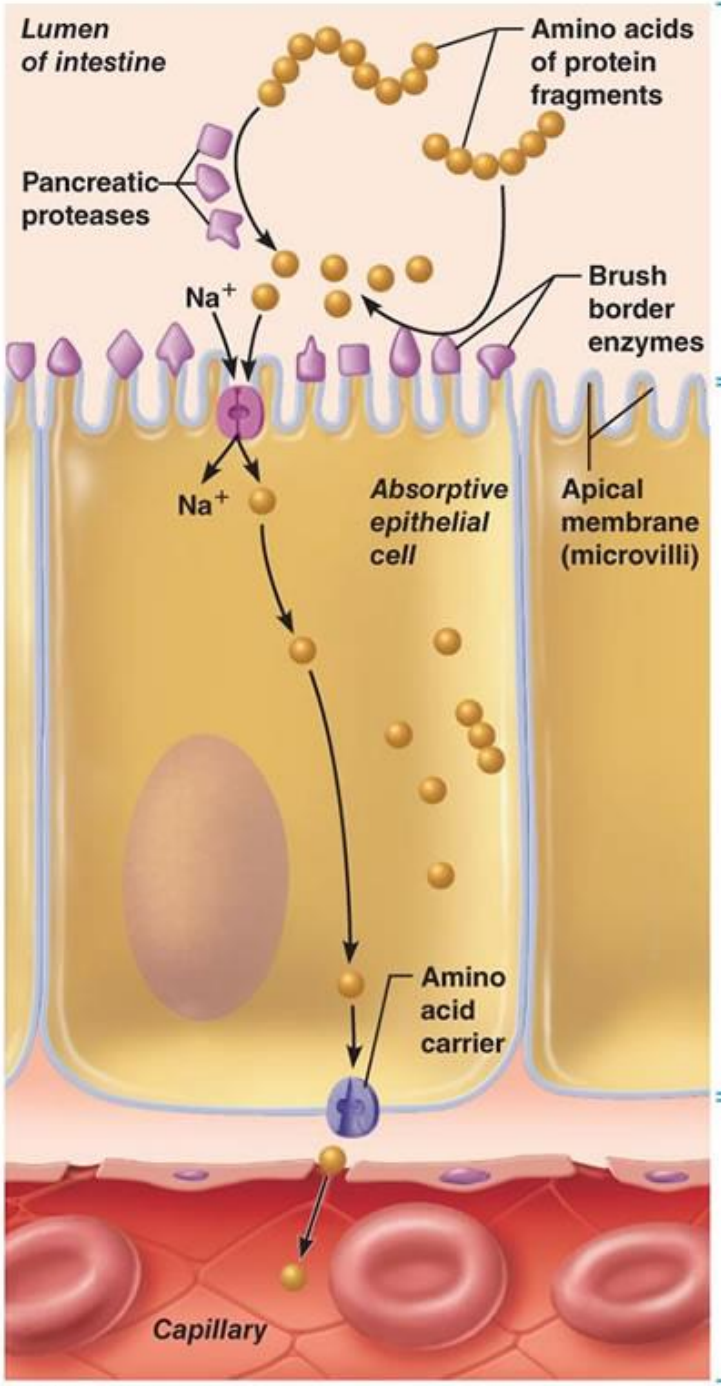
- Glucose, Galactose, and amino acids → linked to Na^+– secondary active transport

- Fructose is absorbed into the blood solely by facilitated diffusion

Carbohydrate Absorption



Protein Absorption



① Proteins and protein fragments are digested to amino acids by pancreatic proteases (trypsin, chymotrypsin, and carboxy- peptidase), and by brush border enzymes (carboxypeptidase, aminopeptidase, and dipeptidase) of mucosal cells.

② The amino acids are then absorbed by active transport into the absorptive cells, and move to their opposite side.

③ The amino acids leave the villus epithelial cell by facilitated diffusion and enter the capillary via intercellular clefts.

Fat Absorption

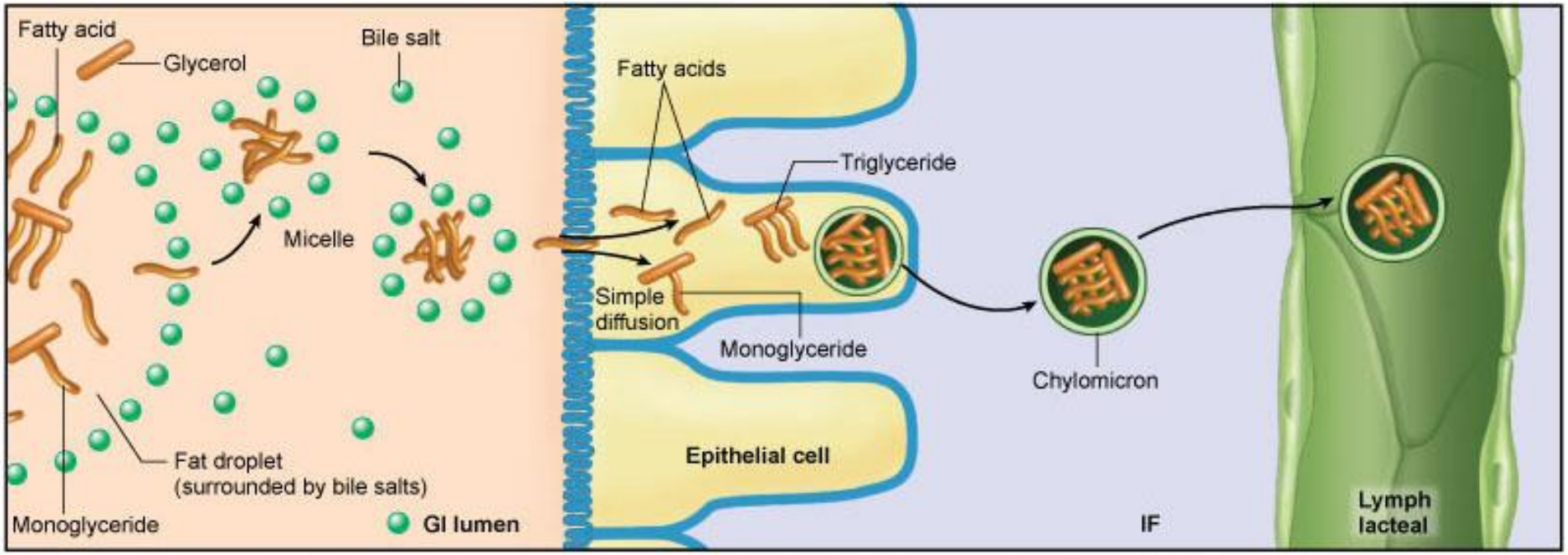


Fig. 26-21. **Absorption of fats.** Fats such as triglycerides are chemically digested within emulsified fat droplets, yielding fatty acids, monoglycerides, and glycerol *(left)*. Fatty acids and other lipid-soluble compounds (such as cholesterol) leave the fat droplets in small spheres coated with bile salts (micelles). When a micelle reaches the plasma membrane of an absorptive cell, individual fat-soluble molecules diffuse directly into the cytoplasm. The endoplasmic reticulum of the cell resynthesizes fatty acids and monoglycerides into triglycerides. A Golgi body within the cell packages the fats into water-soluble micelles called chylomicrons, which then exit the absorptive cell by exocytosis and enter a lymphatic lacteal. *IF,* Interstitial fluid.

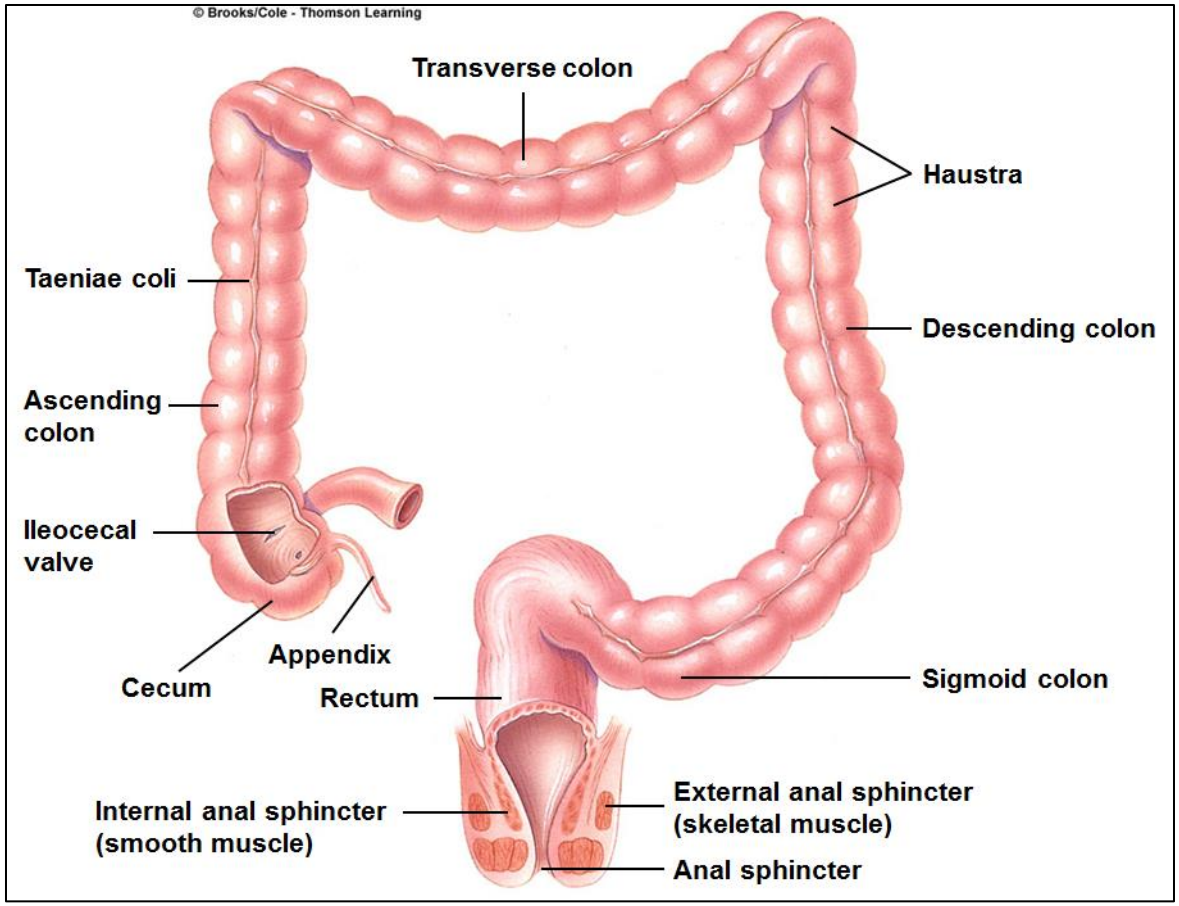
Vitamin Absorption

- **Water-soluble** vitamins (A, D, E, & K): passively with water
- **Fat-soluble** vitamins (B & C): carried in micelles & absorbed passively
  - **Vitamin B12**: needs gastric intrinsic factor for absorption

Large Intestine

Large Intestine

- To store feces before defecation
- Absorption of H_2O, salts, & vitamin K (no villi)
- Secretes alkaline ($NaHCO_3$) mucus solution

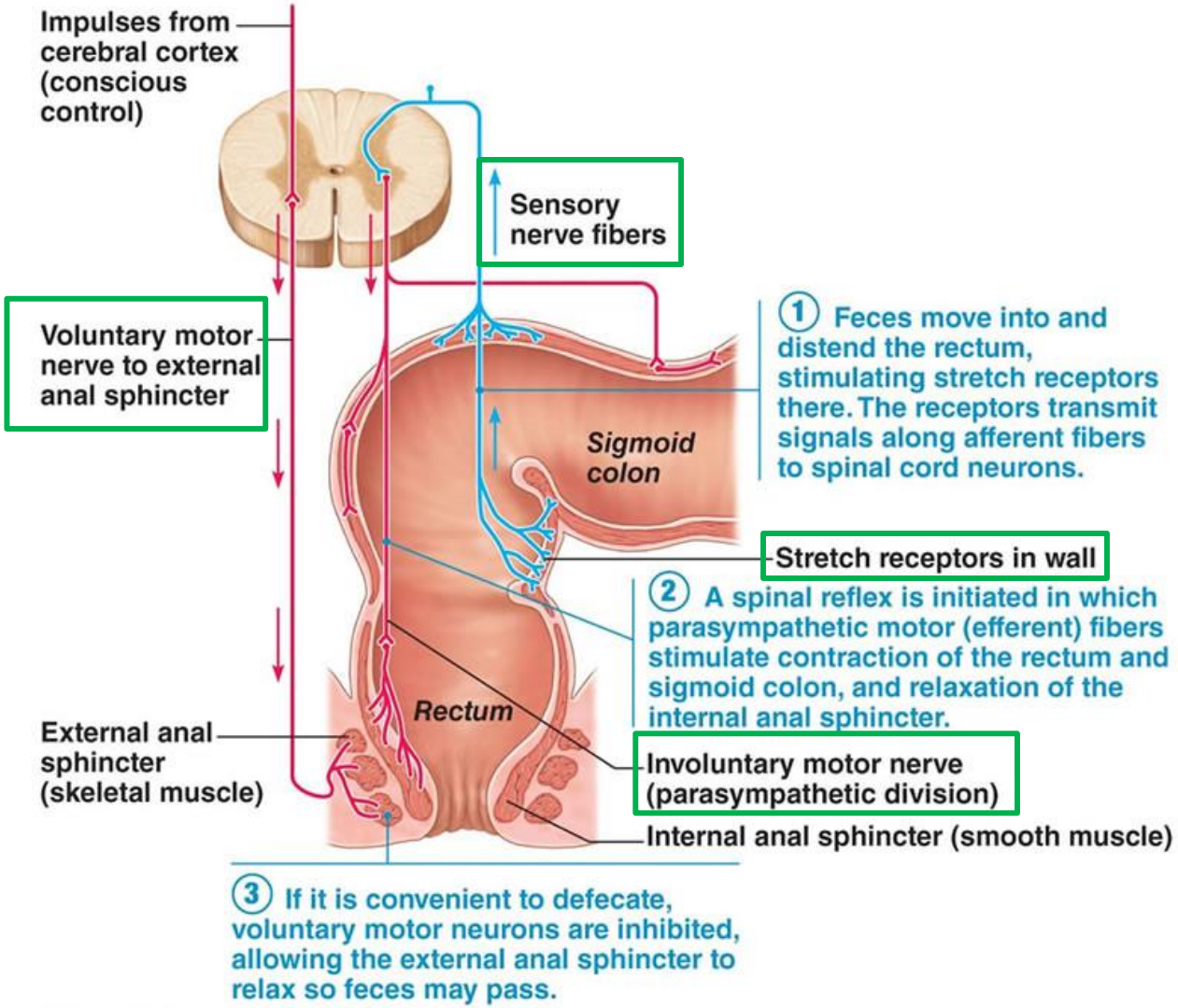


Large Intestine Movements

- **Haustral contractions**
  - Slow and non-propulsive, shuffle the contents in a back-and-forth mixing movement
  - Similar to small-intestine segmentations but occur much less frequently

- **Mass movements**
  - Stimulated by presence of food in stomach (gastrocolic reflex)
  - Push the colonic contents into the distal part of the large intestine
  - 3 to 4 times a day

Defecation Reflex

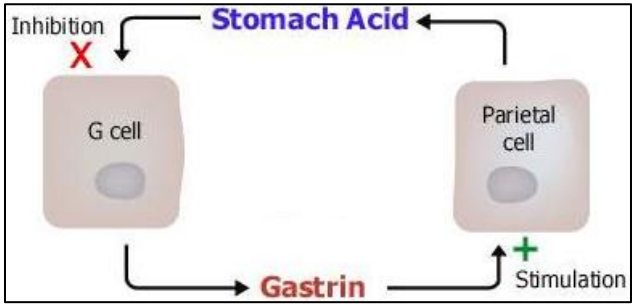


Gastrointestinal Hormones

- Gastrin
- Secretin
- CCK
- GIP

GASTRIN

- Release is stimulated by protein in the stomach



- Functions:
  1. ↑ secretion of HCl and pepsinogen.
  2. ↑ gastric motility, ↑ ileal motility, relaxes ileocecal sphincter, & induces mass movements

- Secretion is inhibited by an accumulation of acid in the stomach/duodenum

SECRETIN

- Secretion is stimulated by presence of acid in the duodenum

- Functions:

  1. inhibits gastric emptying

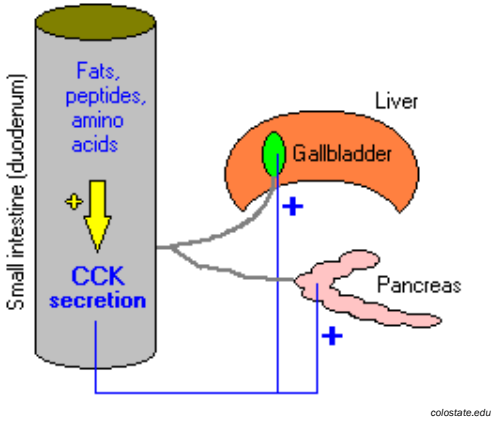
  2. inhibits gastric secretion

  3. stimulates the pancreatic duct cells to produce a large volume of aqueous $NaHCO_3$ secretion,

  4. stimulates secretion by the liver of a $NaHCO_3$-rich bile,

CCK

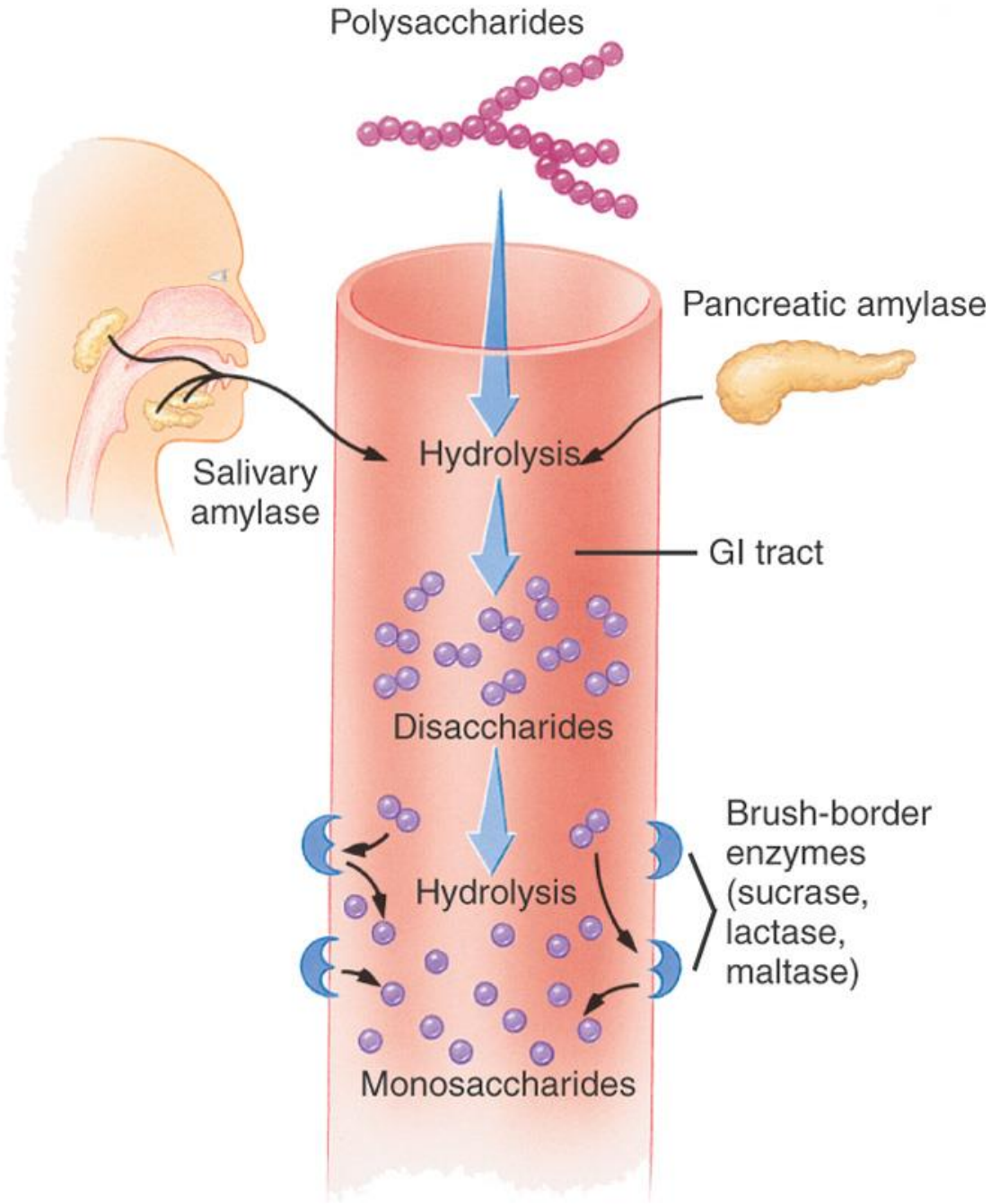
- Release is stimulated by chyme in duodenum (esp. fat and to a lesser extent protein products)
- Functions:

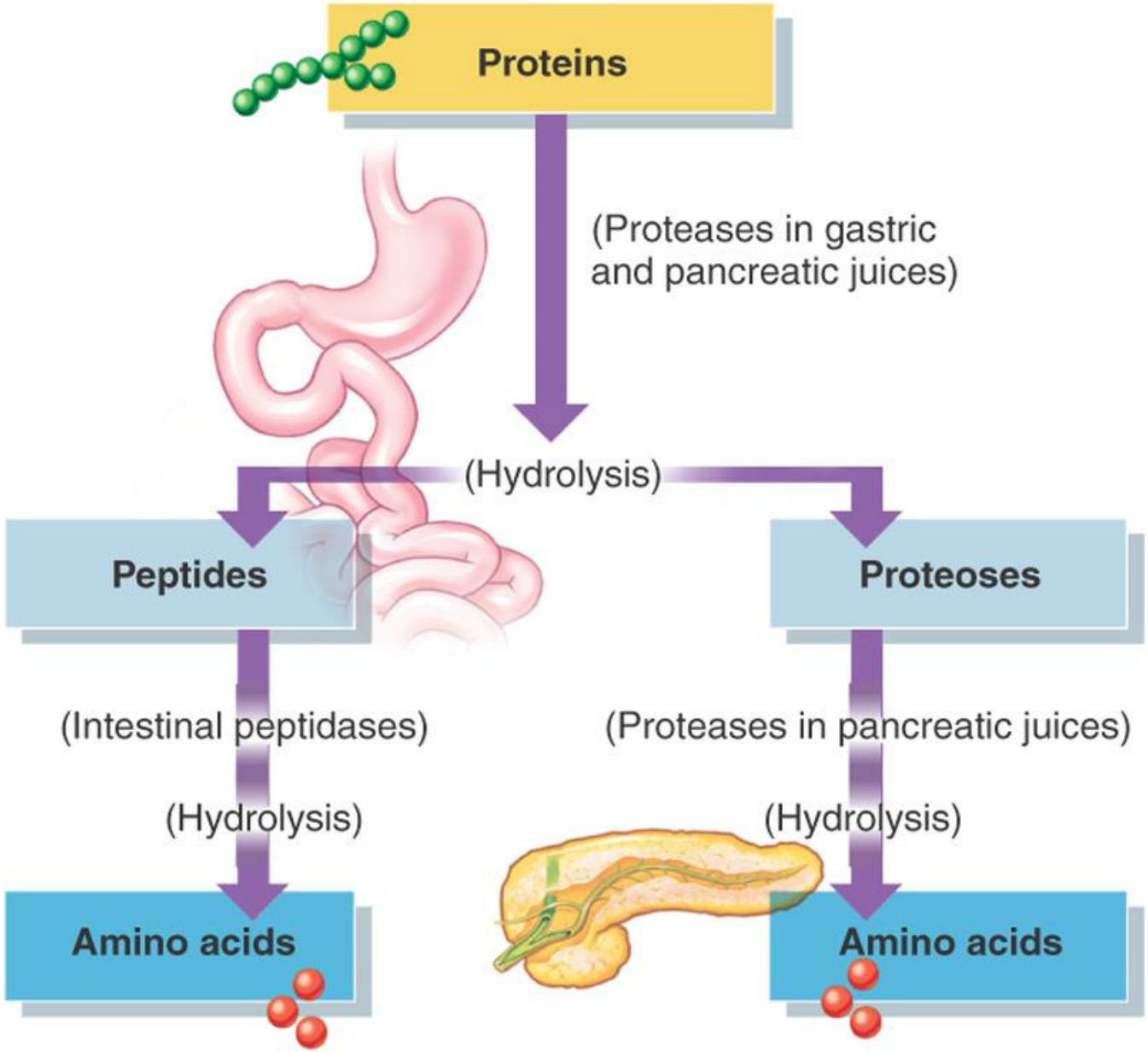


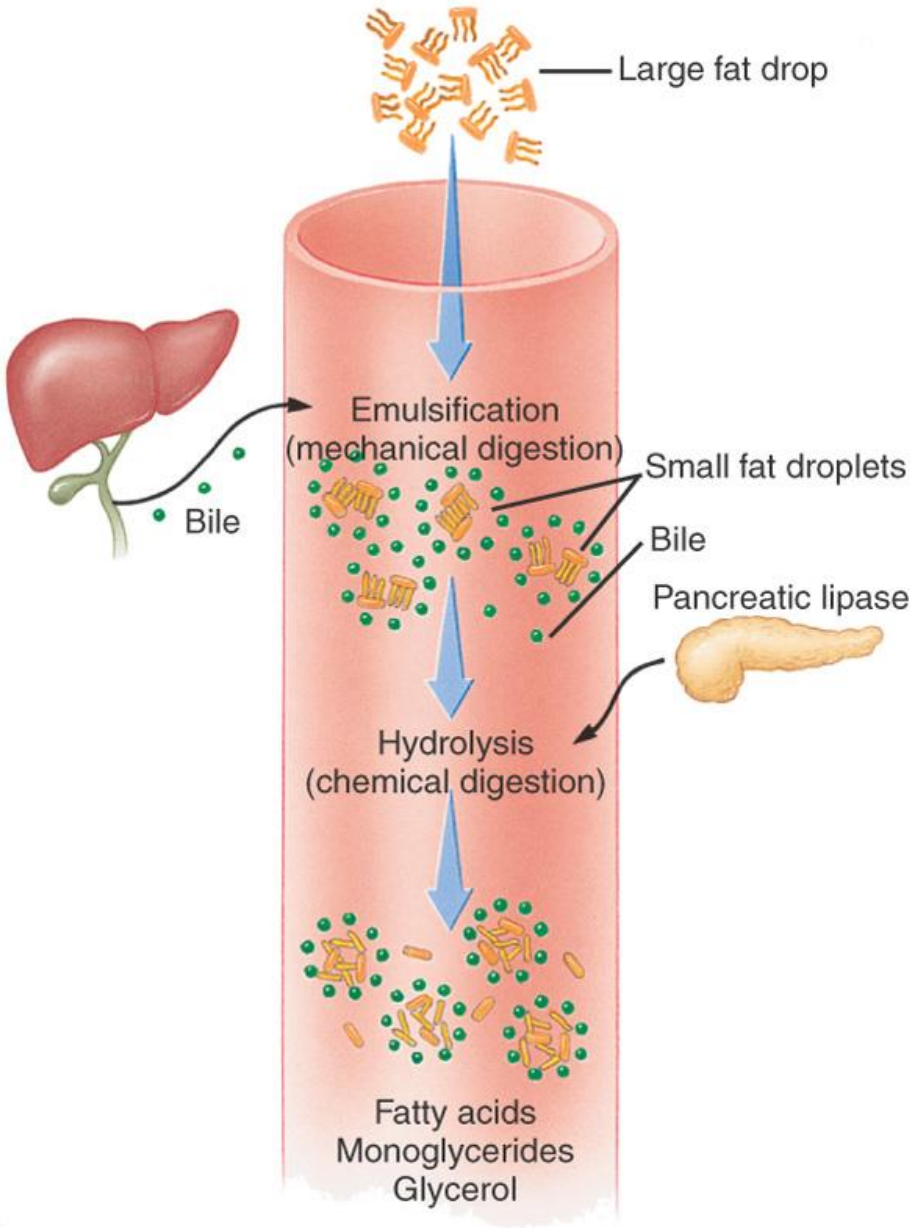
1. inhibits gastric motility and secretion,
2. stimulates the pancreatic acinar cells to increase secretion of pancreatic enzymes,
3. causes contraction of the gallbladder and relaxation of the sphincter of Oddi
4. plays a key role in satiety (the sensation of having had enough to eat)

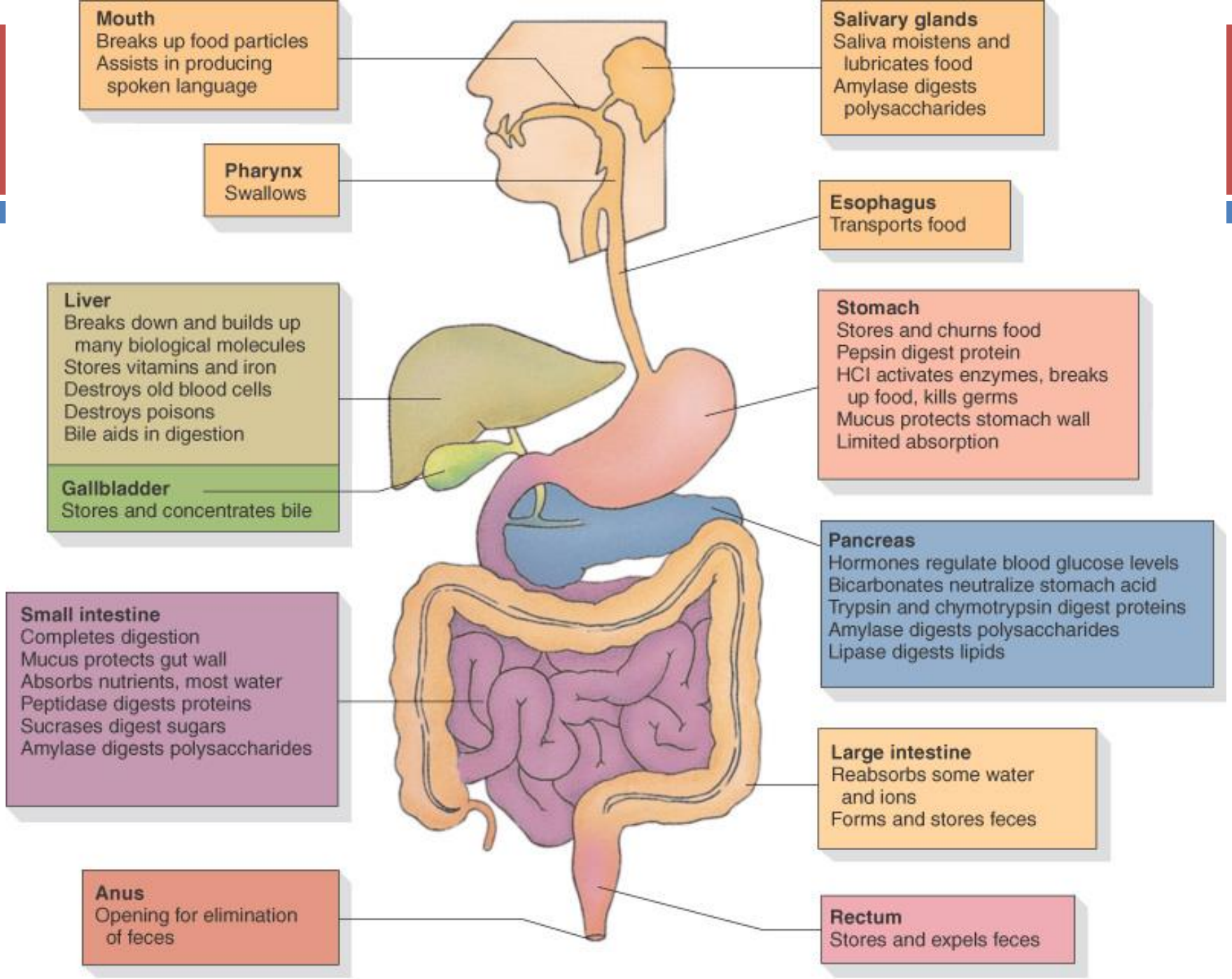
GIP - glucose-dependent insulinotropic peptide

- Stimulates insulin release by the pancreas in anticipation of absorption of the meal (feed-forward mechanism)
- Esp. glucose in the duodenum ↑ GIP secretion.









The END