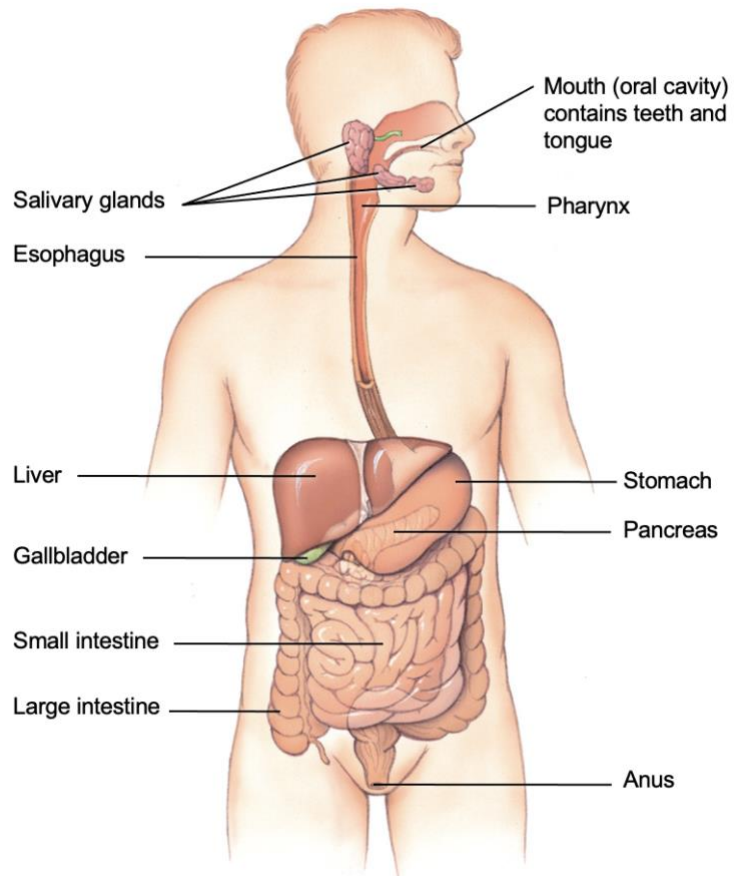


## Gastrointestinal Lab Supplemental Resource

### I. Overview of the Digestive System

#### A. Consists of the Gastrointestinal Tract and the Accessory Digestive Organs

- Gastrointestinal tract
  - a. Alimentary canal
  - b. Everything from mouth to anus
- Accessory digestive organs
  - a. Teeth
  - b. Tongue
  - c. Salivary glands
  - d. Pancreas
  - e. Liver
  - f. Gallbladder

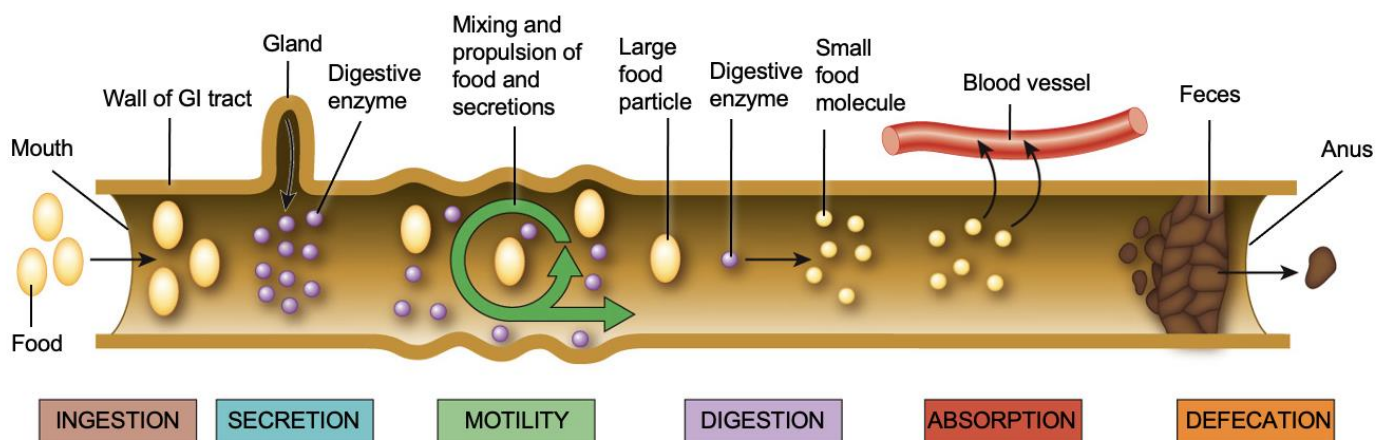


#### B. There are six basic digestive processes of digestion

- Ingestion – involves taking food and liquids into the mouth (eating)
- Secretion – each day, cells within the walls of the GI tract and accessory digestive organs secrete a total of about 7 liters of water, acid, buffers, and enzymes into the lumen (interior space) of the tract. This occurs in the mouth, esophagus, stomach, small intestine and large intestine.
- Motility – contractions of smooth muscle in the wall of the GI tract mix food and secretions, and propel them toward the anus. This capability to mix and move

material along its length is called motility. This occurs in esophagus, stomach, small intestine, and the large intestine.

- **Digestion** - Mechanical and chemical processes break down ingested food into small molecules. In mechanical digestion, the teeth cut and grind food before it is swallowed, and then smooth muscles of the stomach and small intestine churn the food. As a result, food molecules become dissolved and thoroughly mixed with digestive enzymes. In chemical digestion, the large carbohydrate, lipid, protein, and nucleic acid molecules in food are split into smaller molecules by hydrolysis. Digestive enzymes produced by the salivary glands, tongue, stomach, pancreas, and small intestine catalyze these catabolic reactions. This occurs in the mouth, stomach, small intestine, and large intestine.
- **Absorption** - The movement of the products of digestion from the lumen of the GI tract into blood or lymph is called absorption. Once absorbed, these substances circulate to cells throughout the body. A few substances in food can be absorbed without undergoing digestion. These include vitamins, ions, cholesterol, and water. This occurs in the mouth, stomach, small intestine, and large intestine.
- **Defecation** - Wastes, indigestible substances, bacteria, cells sloughed from the lining of the GI tract, and digested materials that were not absorbed in their journey through the digestive tract leave the body through the anus in a process called defecation. The eliminated material is termed feces. This occurs in the large intestine.

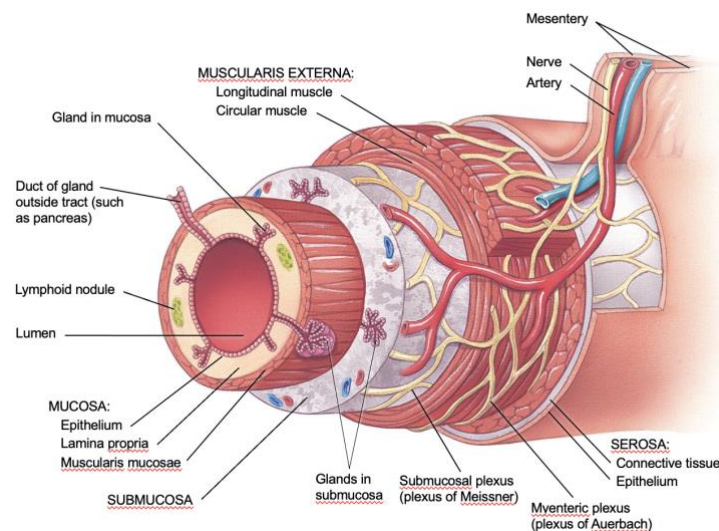


C. Wall of the GI tract is comprised of four functional layers

- Mucosa - The mucosa, or inner lining of the GI tract, is a mucous membrane. It is composed of (a) a layer of epithelium, (b) a lamina propria, and (c) a muscularis mucosae.
  - a. The epithelium of the mucosa is in direct contact with the contents of the GI tract. Several types of epithelial cells comprise the mucosal epithelium, and the types vary from one part of the GI tract to another. Some epithelial cells are exocrine cells that secrete fluids and other substances into the lumen of the GI tract. Other epithelial cells are endocrine cells, collectively known as enteroendocrine cells, that secrete hormones into the bloodstream. Still other epithelial cells are absorptive cells that transport nutrients from the lumen of the GI tract into the blood or lymph. Tight junctions firmly seal neighboring epithelial cells to one another to restrict leakage between the cells. The rate of renewal of GI tract epithelial cells is rapid: Every 5 to 7 days they slough off and are replaced by new cells.
  - b. The lamina propria is a layer of connective tissue that surrounds the epithelium of the mucosa. It contains small blood and lymphatic vessels, which are the sites where absorbed nutrients enter blood or lymph. Also located in the lamina propria is gut-associated lymphoid tissue (GALT). These prominent lymphoid nodules contain immune system cells that protect against disease. GALT is present all along the GI tract, especially in the small intestine, appendix, and large intestine.
  - c. The muscularis mucosae is a thin layer of smooth muscle fibers that surrounds the lamina propria. Contraction of the muscularis mucosae throws the mucous membrane of the stomach and small intestine into many small folds, which increase the surface area for digestion and absorption.
- Submucosa - The submucosa is a thick layer of connective tissue that provides the GI tract with distensibility and elasticity, allowing it to stretch as food passes through it and then to return to its original shape when food is no longer present. The submucosa contains relatively large blood and lymphatic vessels that receive absorbed food molecules from smaller vessels in the lamina propria. Also present in

the submucosa are exocrine glands and an extensive network of neurons known as the submucosal plexus.

- **Muscularis Externa** - The muscularis externa, or simply the muscularis, is the main muscle layer of the GI tract. The muscularis externa of the mouth, pharynx, and upper to middle parts of the esophagus contains skeletal muscle that produces voluntary swallowing. Skeletal muscle also forms the external anal sphincter, which permits voluntary control of defecation. Throughout the rest of the GI tract, the muscularis externa consists of smooth muscle that is arranged in two layers: an inner layer of circular muscle and an outer layer of longitudinal muscle. Involuntary contractions of the circular and longitudinal smooth muscles propel food along the GI tract and mix food with digestive secretions. Between the two smooth muscle layers is a second plexus of neurons—the myenteric plexus.
- **Serosa** - The serosa, the outermost layer of the GI tract, consists of connective tissue and epithelium. It forms part of the peritoneum, a membrane that lines the abdominal cavity and covers the organs within that cavity. Folds of the peritoneum known as mesenteries bind the digestive organs to one another and to the abdominal wall. The mesenteries hold the digestive organs in place and supply the organs with blood vessels and nerves.

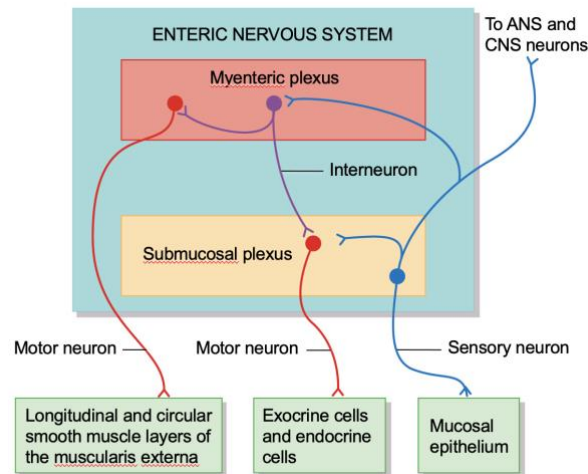


D. **Nervous innervation** - The gastrointestinal tract is regulated by an intrinsic set of nerves known as the enteric nervous system and by an extrinsic set of nerves that are part of the autonomic nervous system.

- **Enteric nervous system**

- a. Myenteric plexus
    - Controls smooth muscle contraction
  - b. Submucosal plexus
    - Controls endocrine and exocrine GI secretion
- Autonomic nervous system - Although the neurons of the ENS can function independently, they are subject to regulation by the parasympathetic and sympathetic divisions of the autonomic nervous system. The vagus (X) nerves supply parasympathetic fibers to most parts of the GI tract, with the exception of the last half of the large intestine, which is supplied with parasympathetic fibers in pelvic nerves from the sacral region of the spinal cord. The parasympathetic nerves that supply the GI tract form neural connections with the ENS. Parasympathetic preganglionic neurons of the vagus (X) nerves or pelvic nerves synapse with parasympathetic postganglionic neurons located in the myenteric and submucosal plexuses. Some of the parasympathetic postganglionic neurons in turn synapse with neurons in the ENS; others directly innervate smooth muscle and glands within the wall of the GI tract. In general, stimulation of the parasympathetic nerves that innervate the GI tract causes an increase in GI secretion and motility by increasing the activity of ENS neurons.
- Sympathetic nerves that supply the GI tract arise from the thoracic and upper lumbar regions of the spinal cord. Like the parasympathetic nerves, these sympathetic nerves form neural connections with the ENS. Sympathetic postganglionic neurons synapse with neurons located in the myenteric plexus and the submucosal plexus. In general, the sympathetic nerves that supply the GI tract cause a decrease in GI secretion and motility by inhibiting the neurons of the ENS. Emotions such as anger, fear, and anxiety may slow digestion because they stimulate the sympathetic nerves that supply the GI tract.
- Gastrointestinal reflex pathways - Many neurons of the ENS are components of gastrointestinal (GI) reflex pathways that regulate GI secretion and motility in response to stimuli present in the lumen of the GI tract. The initial components of a typical GI reflex pathway are sensory receptors (such as chemoreceptors and mechanoreceptors) that are associated with the sensory neurons of the ENS. The axons of these sensory neurons can synapse with other neurons located in the ENS, CNS, or ANS, informing these regions about the nature of the contents and the degree

of distension (stretching) of the GI tract. The neurons of the ENS, CNS, or ANS subsequently activate or inhibit GI glands and smooth muscle, altering GI secretion and motility. If the reflex pathway is confined entirely within the GI tract wall, then it is called a short reflex. If the reflex pathway involves not only the GI tract wall but also the CNS and autonomic nerves, then it is referred to as a long reflex.



#### E. GI smooth muscle displays autorhythmicity and promotes two major patterns of motility

- Autorhythmicity

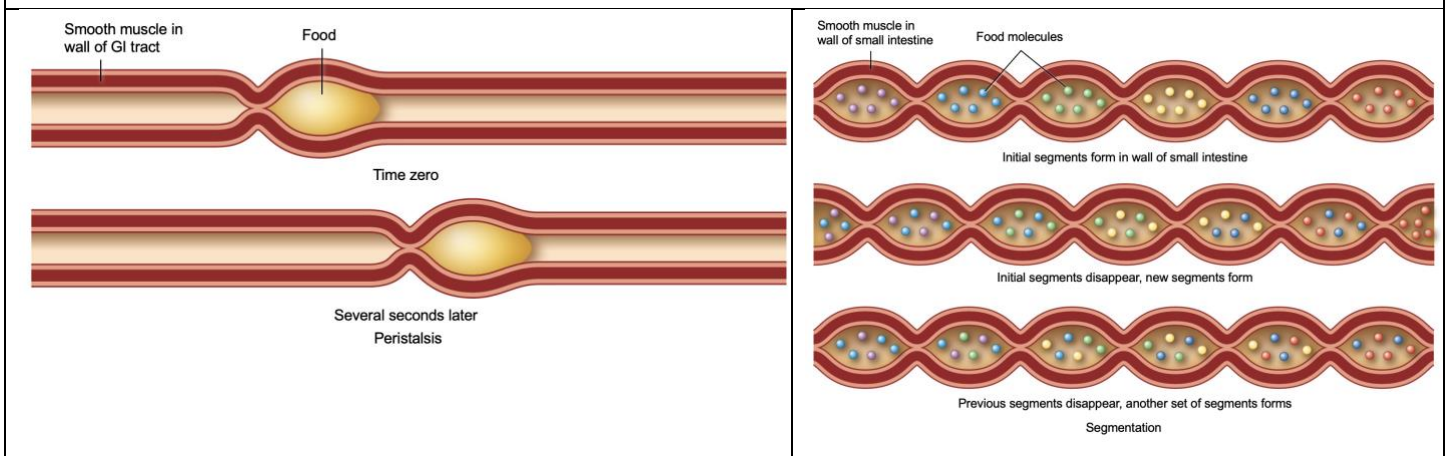
- Due to interstitial cells of Cajal (ICCs) – located in the muscularis externa
- Cause depolarizations that don't necessarily make it to threshold
- Slow wave potentials or GI tract's basic electrical rhythm (BER)
- Patterns of motility

- Peristalsis - successive muscular contractions along the wall of a hollow muscular tube that propel the luminal contents in a forward direction. It occurs throughout the GI tract, from the esophagus to the anus, and in other parts of the body, including the ureters, bile ducts, and uterine (fallopian) tubes. In the GI tract, peristalsis involves successive contractions of the circular and longitudinal layers of the muscularis externa and occurs mainly in response to distension of the wall by luminal contents. In the segment of the GI tract wall just behind a mass of food, the circular layer contracts while the longitudinal layer relaxes; this shortens the wall, causing the food to move forward. Meanwhile, in the segment of the GI tract wall just in front of the food mass, the circular muscle layer relaxes while the longitudinal layer contracts; this



causes the wall to push outward so that it can receive the food. As the circular and longitudinal layers undergo repeated cycles of contraction and relaxation, the food is moved along the GI tract toward the anus.

- Segmentation - refers to alternating muscular contractions that mix luminal contents. It occurs in the small intestine in response to distension and involves contractions of the circular muscle fibers of the muscularis externa. Segmentation begins with the contraction of the circular muscle fibers at various intervals along the small intestine, an action that constricts the intestine into segments. When the circular muscle fibers relax, the segments disappear. Then circular muscle fibers at other points along the intestinal wall contract, causing new segments to form. As this sequence of events repeats, the intestinal contents slosh back and forth. Segmentation mixes food with digestive juices and brings the molecules of food into contact with the mucosa for absorption.



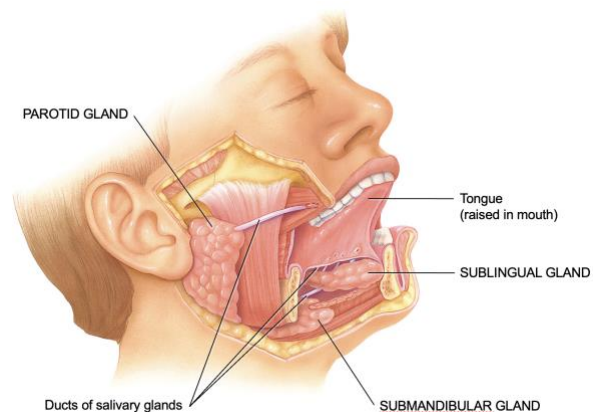
## II. Mouth

### A. Oral cavity

- Formed by
  - a. Cheeks
  - b. Lips
  - c. Soft palate
  - d. Tongue

### B. Other structures

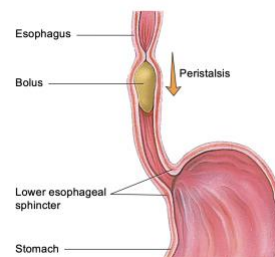
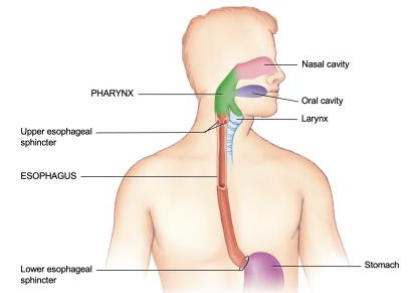
- Teeth



- Salivary glands
- C. Cheeks and lips keep food in the mouth during chewing
- D. Palate prevents food from entering nasal cavity
- E. Tongue moves food toward the pharynx and produces lingual lipase
- F. Salivary glands secrete saliva
  - Saliva:
    - i. Dissolves and lubricates food for taste, initial digestion, and swallowing
    - ii. Secretion of salivary amylase (carbohydrate digestion)
    - iii. Buffers ingested acid food
- Three large glands that produce saliva: parotid, submandibular, sublingual
- G. Teeth allow for initiation of mechanical digestion
  - Grind and tear apart food
- H. Chemical digestion initiates in mouth

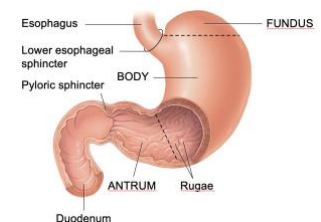
### III. Pharynx and Esophagus

- A. Pharynx conveys food from the mouth to the esophagus
- B. Esophagus transports food into the stomach
  - Requires relaxation of two sphincters
    - a. Upper esophageal sphincter
    - b. Lower esophageal sphincter
- C. Deglutition
  - Swallowing of food (bolus)



### IV. Stomach

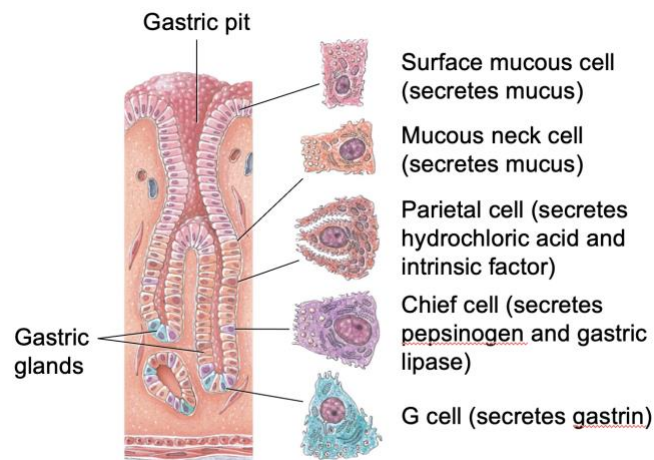
- A. J – shaped enlargement of the GI tract
- B. Connects esophagus to the small intestine
- C. Serves as a mixing chamber and a temporary holding reservoir
- D. Can accommodate up to 2 liters of food
- E. Main regions : fundus, body and antrum





## F. Stomach wall

- Four basic layers- each with specific functions
  - a. Mucosa
    - The mucosa is thick to prevent the organ from autodigestion.
    - Consists of folds called rugae: these folds increase surface area. Rugae are visible when the stomach is empty but disappear when the stomach is distended (full).
    - Contains different cell types
      - i. Parietal cells (also known as oxyntic cells) = secrete HCl
      - ii. Chief cells (also known as zymogen cells) = secrete pepsinogen and gastric lipase
        - Pepsinogen (a zymogen = inactive form of enzyme) is then converted into its active form, pepsin, in the presence of HCl
      - iii. Surface Mucus cells and Mucus Neck Cells = secrete mucus which provides a layer of protection for the stomach
    - Arranged in pits and glands
  - b. Muscularis externa contains 3 layers
    - Extra layer = oblique (allows for churning)



## G. Mechanical digestion in the stomach involves propulsion and retropulsion

- Propulsion
  - a. Forward movement
- Retropulsion
  - a. Splash back of gastric contents when they hit against pyloric sphincter

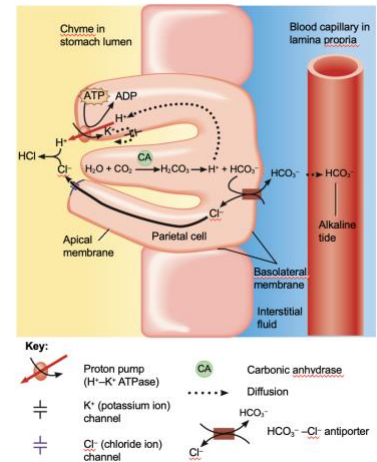
H. Chemical digestion in the stomach occurs as food mixes with gastric juice

- Gastric juice
  - a. Includes many different gastric secretions
    - Mostly HCl
      - i. Produced by parietal cells
  - b. Also includes enzymes
    - Mostly to digest proteins

I. Reflexes

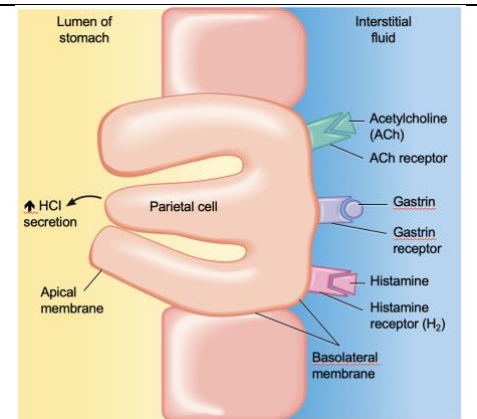
- Vomiting
  - a. Rapidly expels contents of the GI tract

- J. Parietal cell secretion - Food may remain in the fundus for about an hour without becoming mixed with gastric juice. During this time, digestion by salivary amylase continues. Soon, however, the churning action mixes food with acidic gastric juice, inactivating salivary amylase and activating lingual lipase, which starts to digest triglycerides into fatty acids and diglycerides.
- K. Although parietal cells secrete hydrogen ions ( $H^+$ ) and chloride ions ( $Cl^-$ ) separately into the stomach lumen, the net effect is secretion of hydrochloric acid (HCl). Proton pumps powered by  $H^+/K^+$  ATPases actively transport  $H^+$  into the lumen while bringing potassium ions ( $K^+$ ) into the cell. At the same time,  $Cl^-$  and  $K^+$  diffuse out into the lumen through  $Cl^-$  and  $K^+$  channels in the apical membrane. The enzyme carbonic anhydrase, which is especially plentiful in parietal cells, catalyzes the formation of carbonic acid ( $H_2CO_3$ ) from water ( $H_2O$ ) and carbon dioxide ( $CO_2$ ). As carbonic acid dissociates, it provides a ready source of  $H^+$  for the proton pumps but also generates bicarbonate ions ( $HCO_3^-$ ). As  $HCO_3^-$  builds up in the cytosol, it exits the parietal cell in exchange for  $Cl^-$  via  $Cl^-/HCO_3^-$  antiporters in the basolateral membrane (next to the lamina propria).  $HCO_3^-$  diffuses into nearby blood capillaries. This “alkaline tide” of bicarbonate ions entering the bloodstream after a meal may be large enough to elevate blood pH slightly.



HCl secretion by parietal cells can be stimulated by several sources: acetylcholine (ACh) released by parasympathetic neurons; gastrin secreted by G cells; and histamine, which is a paracrine substance released by mast cells in the nearby lamina propria. Acetylcholine and gastrin stimulate parietal cells to secrete more HCl in the presence of histamine. In other words, histamine acts synergistically,

enhancing the effects of acetylcholine and gastrin. Receptors for all three substances are present in the plasma membrane of parietal cells. The histamine receptors on parietal cells are called H<sub>2</sub> receptors; they mediate different responses than do the H<sub>1</sub> receptors involved in allergic responses.



## V. Small Intestine

A. Made up of three different regions: duodenum, jejunum and ileum

B. Functions

- Digestion (mainly in the duodenum)
- Absorption (mainly in the jejunum and ileum)

C. Secretes intestinal juice

- Contains: Enzymes, Mucus, Water, Ions

D. Contains brush border enzymes

- Attached to the villi of cells

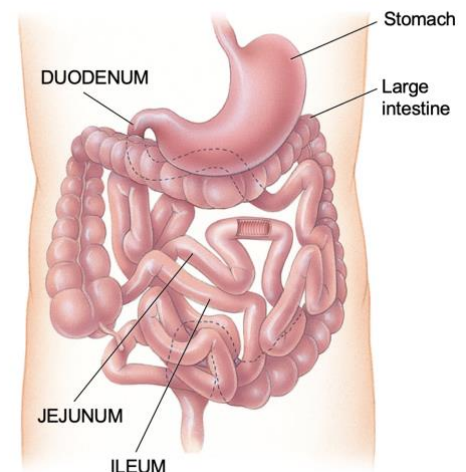
E. Mechanical digestion

- Involves segmentation

F. Chemical digestion

- Occurs as chyme mixes with pancreatic juice, intestinal juice and bile
  - a. Along with digestive enzymes, pancreatic juice also contains Bicarbonate-rich fluid that helps protect the duodenum against the corrosive action of acidic chyme coming from the stomach.

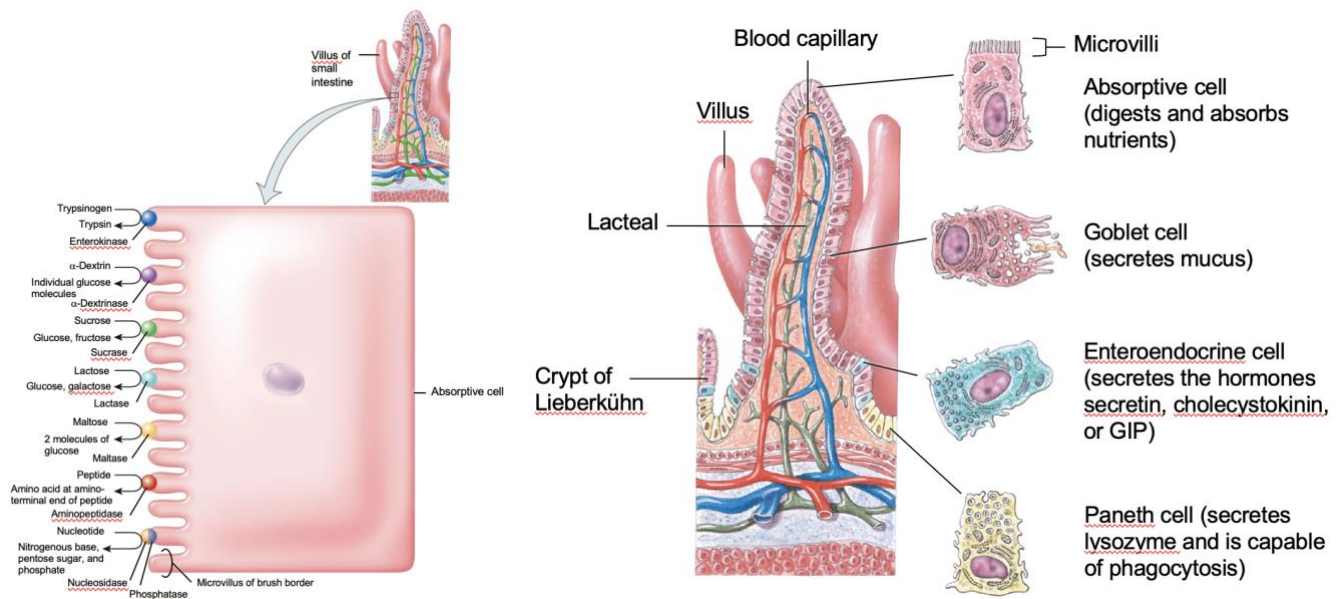
G. Absorptive brush border - The absorptive cells of the small intestine synthesize several digestive enzymes, called brush-border enzymes, and insert them in the plasma membrane of the microvilli. You have already learned about one brush-border enzyme, namely enterokinase, which converts trypsinogen (a zymogen = inactive form of enzyme) into trypsin. Among the other brush-border enzymes are four carbohydrate-digesting enzymes called  $\alpha$ -dextrinase, sucrase, lactase, and maltase; a protein-digesting enzyme called aminopeptidase; and two types of nucleotide-digesting enzymes, nucleosidase and phosphatase. Thus, some enzymatic digestion occurs at the surface of the absorptive cells



that line the villi, rather than in the lumen exclusively, as occurs in other parts of the GI tract. Also, as absorptive cells slough off into the lumen of the small intestine, they break apart and release enzymes that help digest nutrients in chyme.

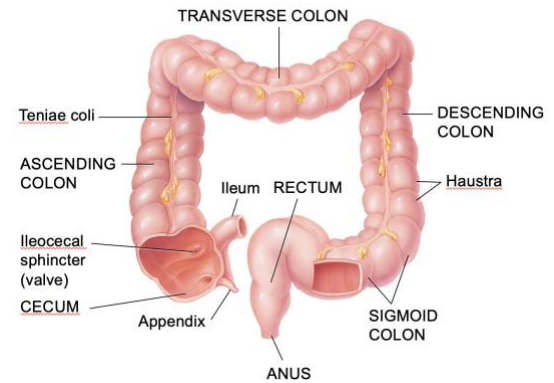
Even though the action of salivary amylase may continue in the stomach for a while, the acidic pH of the stomach destroys salivary amylase and ends its activity. Thus, only a few starches are broken down by the time chyme leaves the stomach. Those starches not already broken down into maltose, maltotriose, and  $\alpha$ -dextrins are cleaved by pancreatic amylase, an enzyme in pancreatic juice that acts in the small intestine. Although pancreatic amylase acts on both glycogen and starches, it has no effect on another polysaccharide called cellulose, an indigestible plant fiber that is commonly referred to as “roughage” as it moves through the digestive system. After amylase (either salivary or pancreatic) has split starch into smaller fragments, a brush-border enzyme called  $\alpha$ -dextrinase acts on the resulting  $\alpha$ -dextrins, clipping off one glucose unit at a time.

Ingested molecules of sucrose, lactose, and maltose—three disaccharides—are not acted on until they reach the small intestine. Three brush-border enzymes digest the disaccharides into monosaccharides. Sucrase breaks sucrose into a molecule of glucose and a molecule of fructose; lactase digests lactose into a molecule of glucose and a molecule of galactose; and maltase splits maltose and maltotriose into two or three molecules of glucose, respectively. Digestion of carbohydrates ends with the production of monosaccharides, which the digestive system is able to absorb.



## VI. Large Intestine

- A. Terminal part of the GI tract - The cecum is the initial portion of the large intestine. At the junction of the ileum and cecum is the ileocecal sphincter (valve), which allows materials from the small intestine to pass into the large intestine. The colon is the longest portion of the large intestine. It is further subdivided into an ascending colon, transverse colon, descending colon, and sigmoid colon. The rectum is the terminal portion of the large intestine. The opening of the rectum to the exterior is known as the anus. The anus is guarded by an internal anal sphincter of smooth muscle (involuntary) and an external anal sphincter of skeletal muscle (voluntary). Normally these sphincters keep the anus closed except during the elimination of feces.



- B. Involved in water and ion absorption
- C. Where feces are formed
- Feces is stored within the sigmoid colon
- D. Mechanical digestion
- Involves haustral churning - the haustra remain relaxed and become distended while they fill up. When the distension reaches a certain point, the walls contract and squeeze the contents into the next haustrum.
  - Peristalsis - occurs in the large intestine but at a slower rate than in more proximal portions of the tract.
  - Mass movement - a strong wave of contraction that begins at about the middle of the transverse colon and quickly drives the contents of the colon into the rectum. Mass movement is similar to peristalsis, except that the contraction lasts for a longer period of time. Mass movements usually take place three or four times a day, during or immediately after a meal. Hence, the presence of food in the stomach triggers mass movement in the large intestine, an event known as the gastrocolic reflex.
- E. Chemical digestion
- Occurs via bacteria
- F. Large intestine concentrates feces
- Defecation reflex expels feces from the body



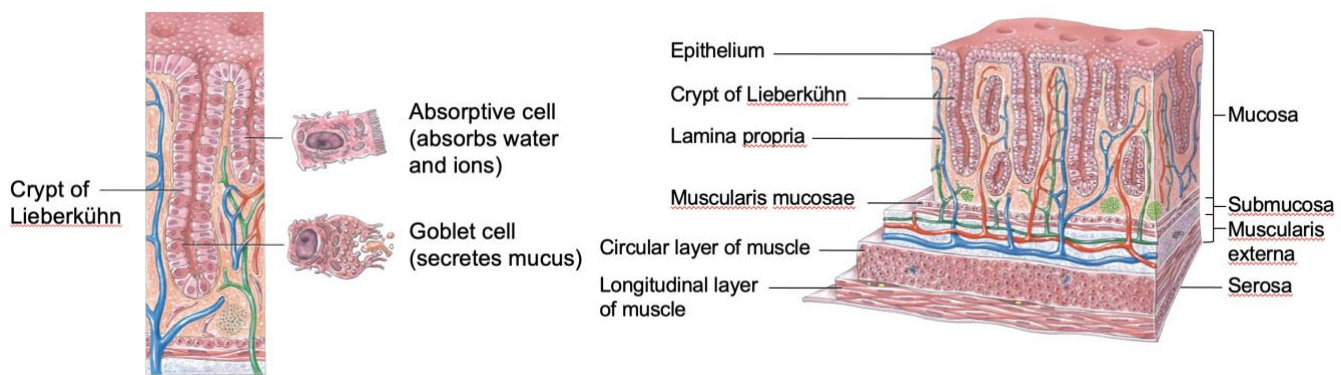
- Assisted by the valsalva maneuver
  - a. Involves voluntary contractions of the abdominal muscles

#### G. Disorders associated with feces

- Diarrhea
- Constipation

#### H. Large intestinal wall - The wall of the large intestine contains the typical four layers found in the rest of the GI tract, with certain modifications:

- The surface of the large intestinal mucosa consists of two types of epithelial cells: absorptive cells and goblet cells. The absorptive cells absorb water and ions; the goblet cells secrete mucus that lubricates the contents of the colon.
- As in the small intestine, the epithelium of the large intestinal mucosa extends downward from the surface to form intestinal glands called crypts of Lieberkühn. Recall that the crypts of Lieberkühn of the small intestine contain several types of cells. In the large intestine, however, the crypts of Lieberkühn contain only absorptive cells and goblet cells.
- Compared to the small intestine, the wall of the large intestine does not have as many structural features that increase surface area. There are no circular folds or villi; however, microvilli are present on the absorptive cells. Consequently, much more absorption occurs in the small intestine than in the large intestine.
- Unlike other parts of the GI tract, the outer longitudinal layer of smooth muscle of the muscularis externa is bundled into three bands called the teniae coli that run most of the length of the large intestine. Contractions of these bands gather the colon into a series of pouches called haustra (singular is haustrum), which give the colon a puckered appearance.





## VII. Phases of Digestion

### A. Digestive activities occur in overlapping phases

- Cephalic phase
  - a. Prepares the mouth and stomach for food that's about to be eaten
- Gastric phase
  - a. Promotes gastric juice secretion and gastric motility
- Intestinal phase
  - a. Promotes digestion in small intestine and slows the digestion in the stomach

### B. Under significant hormonal control

#### a. CCK

- Produced in the duodenum
- Stimulates secretion of pancreatic juice
- Causes ejection of bile (bile is a non-enzymatic substance that aids in mechanical digestion of fats. It does so by dispersing fat globules, increasing the surface area available for lipases to chemically digest these fats) from the gallbladder in the presence of fat in the duodenum
- Induces satiety - slows gastric emptying by promoting contraction of the pyloric sphincter

#### b. Secretin

- Produced in duodenum when acidic chyme comes from the stomach
- Stimulates secretion of pancreatic juice due to high acidic coming from the stomach
- Inhibits secretion of gastric juice
- Promotes normal growth and maintenance of the pancreas, and
- Enhances the effects of CCK, by acting on the liver

#### c. Gastrin

- Secreted in the stomach in response to:
  - i. distension of the stomach by chyme,
  - ii. partially digested proteins in chyme,
  - iii. the high pH of chyme due to the presence of food in the stomach,
  - iv. caffeine in gastric chyme, and
  - v. acetylcholine released from parasympathetic neurons.

- Promotes secretion of gastric juice
- Increases gastric motility
- Strengthens the contraction of the lower esophageal sphincter to prevent reflux of acid chyme into the esophagus
- Increases motility of the stomach; and relaxes the pyloric sphincter, which promotes gastric emptying
- Promotes the gastroileal and gastrocolic reflexes.
- Gastrin secretion is inhibited when the pH of gastric juice drops below 2.0 and is stimulated when the pH rises. This negative feedback mechanism helps provide an optimal low pH for the functioning of pepsin, the killing of microbes, and the denaturing of proteins in the stomach.

## VIII. Transport of Lipids by Lipoproteins

### A. Most lipids are very hydrophobic

- Makes it difficult to transport in blood
- Use lipoproteins
- Different classes of lipoproteins
  - a. Chylomicron
  - b. Very low-density lipoproteins
  - c. Low-density lipoproteins
  - d. High-density lipoproteins