Digestive System

The digestive system consists of the digestive tract, a tube extending from the mouth to the anus, and its associated accessory organs, primarily glands, which secrete fluids into the digestive tract. The digestive tract is also called the alimentary tract, or alimentary canal.

The regions of the digestive tract include:

1. The Mouth or oral cavity, which has salivary glands and tonsils as accessory organs;
2. The Pharynx, or throat, with tubular mucous glands;
3. The Esophagus, with tubular mucous glands;
4. The Stomach, which contains many tube-like glands;
5. The Small intestine, consisting of the duodenum, jejunum and ileum, with the liver, gallbladder, and Pancreas as major accessory organs.
6. The Large intestine, including the cecum, colon, rectum, and anal canal, with mucous glands.
7. The anus.

The major functions of the digestive system are as follows:

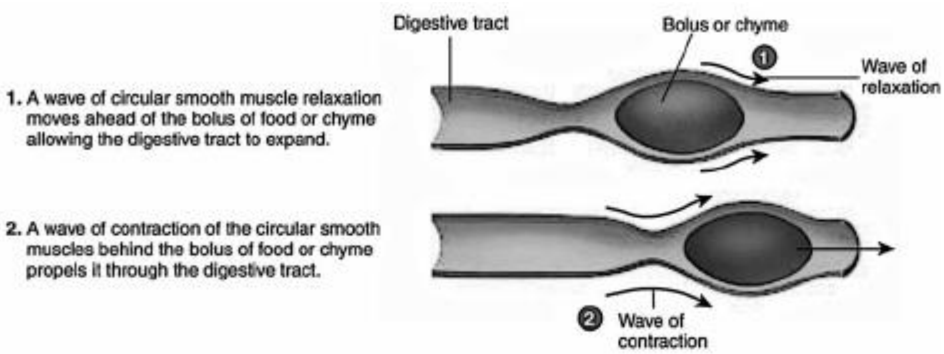
1. Ingestion is the introduction of solid or liquid food into the stomach.

2. Mastication is the process by which food taken into the mouth is chewed by the teeth. Digestive enzymes cannot easily penetrate solid food particles and can only work effectively on the surfaces of the particles. It's vital, therefore, to normal digestive function that solid foods be mechanically broken down into small particles. Mastication breaks large food particles into many smaller particles, which have a much larger total surface area than do a few large particles.

3. Propulsion in the digestive tract is the movement of food from one end of the digestive tract to the other. The total time that it takes food to travel the length of the digestive tract is usually about 24-36 hours. Each segment of the digestive tract is specialized to assist in moving its contents from the oral end to the anal end. Deglutition, or swallowing, moves food and liquids, called a bolus, from the oral cavity into the esophagus. Peristalsis is responsible for moving material through most of the digestive tract. Muscular contractions occur in peristaltic waves, consisting of a wave of relaxation of the circular muscles, which forms a leading wave of distention in front of the bolus, followed by a wave of strong contraction of the circular muscles behind the bolus, which forces the bolus along the digestive tube. Each peristaltic wave travels the length of the esophagus in about 10 seconds. Peristaltic waves in the small intestine usually only travel for short distances. In some parts of the large intestine, material is moved by mass movements, which are contractions that extend over much larger parts of the digestive tract than peristaltic movements.

4. Mixing. Some contractions don't propel food (chyme) from one end of the digestive tract to the other but rather move the food back and forth within the digestive tract to mix it with digestive secretions and to help break it into smaller pieces. Segmental contractions are mixing contractions that occur in the small intestine.

5. Secretion. As food moves through the digestive tract, secretions are added to lubricate, liquefy, and digest the food. Mucus, secreted along the entire digestive tract, lubricates the food and the lining of the tract. The mucus coats and protects the epithelial cells of the digestive tract from mechanical abrasion, from the damaging effect of acid in the stomach, and from the digestive enzymes of the digestive tract. The secretions also contain large amounts of water, which liquefies the food, thereby making it easier to digest and absorb. Water also moves into the intestine by osmosis. Liver secretions break large fat droplets into much smaller droplets, which makes possible the digestion and absorption of fats. Enzymes secreted by the oral cavity, stomach, intestine, and pancreas break large food molecules down into smaller molecules that can be absorbed by the intestinal wall.



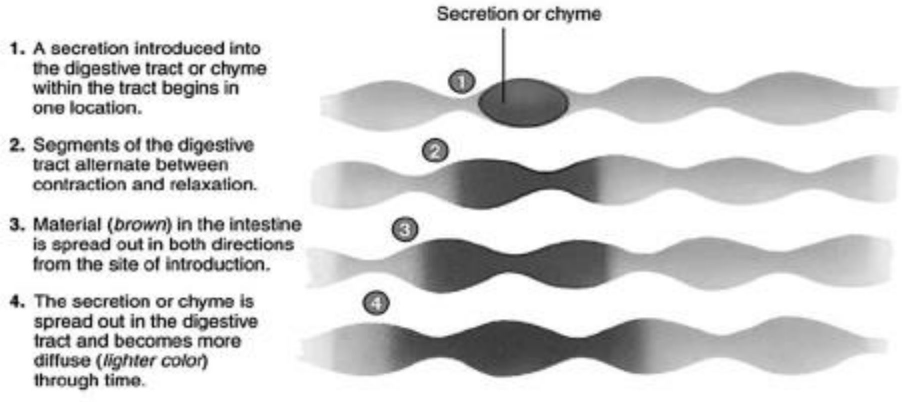
Peristalsis

6. Digestion is the breakdown of large organic molecules into their component parts: carbohydrates into monosaccharides, proteins into amino acids, and triglycerides into fatty acids and glycerol. Digestion consists of

mechanical digestion, which involves mastication and mixing of food, and chemical digestion, which is accomplished by digestive enzymes that are secreted along the digestive tract. Digestion of large molecules into their component parts must be accomplished before they can be absorbed by the digestive tract. Minerals and water are not broken down before being absorbed. Vitamins are also absorbed without digestion and lose their function if their structure is altered by digestion.

7. Absorption is the movement of molecules out of the digestive tract and into the circulation or into the lymphatic system. The mechanism by which absorption occurs depends on the type of molecule involved. Molecules pass out of the digestive tract by simple diffusion, facilitated diffusion, active transport, or cotransport.

8. Elimination is the process by which the waste products of digestion are removed from the body. During this process, occurring primarily in the large intestine, water and salts are absorbed and change the material in the digestive tract from a liquefied state to a semisolid state. These semisolid waste products, called feces, are then eliminated from the digestive tract by the process of defecation.



Segmental Contractions

Mastication

Food taken into the mouth is chewed, or masticated, by the teeth. The anterior teeth, the incisors, and the canines primarily cut and tear food, whereas the premolars and molars primarily crush and grind it. Mastication breaks large food particles into smaller ones, which have a much larger total surface area. Because digestive enzymes digest food molecules only at the surface of the particles, mastication increases the efficiency of digestion.

Four pairs of muscles move the mandible during mastication: The temporalis, masseter, medial pterygoid and lateral pterygoid.

The temporalis, masseter, and medial pterygoid muscles close the jaw; and the lateral pterygoid muscle opens it. The medial and lateral pterygoids and the masseter muscles accomplish protraction and lateral and medial excursion of the jaw. The temporalis retracts the jaw. All these movements are involved in tearing, crushing, and grinding food.

The chewing, or mastication, reflex, which is integrated in the medulla oblongata, controls the basic movements involved in chewing. The presence of food in the mouth stimulates sensory receptors, which activate a reflex that causes the muscles of mastication to relax. The muscles are stretched as the mandible is lowered, and stretch of the muscles activates a reflex that causes contraction of the muscles of mastication. Once the mouth is closed, the food again stimulates the muscles of mastication to relax, and the cycle is repeated. Descending pathways from the cerebrum strongly influence the activity of the mastication reflex so that chewing can be initiated or stopped consciously. The rate and intensity of chewing movements can also be influenced by the cerebrum.

Swallowing

Swallowing, or deglutition, is divided into three separate phases: voluntary, pharyngeal, and esophageal. During the voluntary phase, a bolus of food is formed in the mouth and pushed by the tongue against the hard palate, forcing the bolus toward the posterior part of the mouth and into the oropharynx.

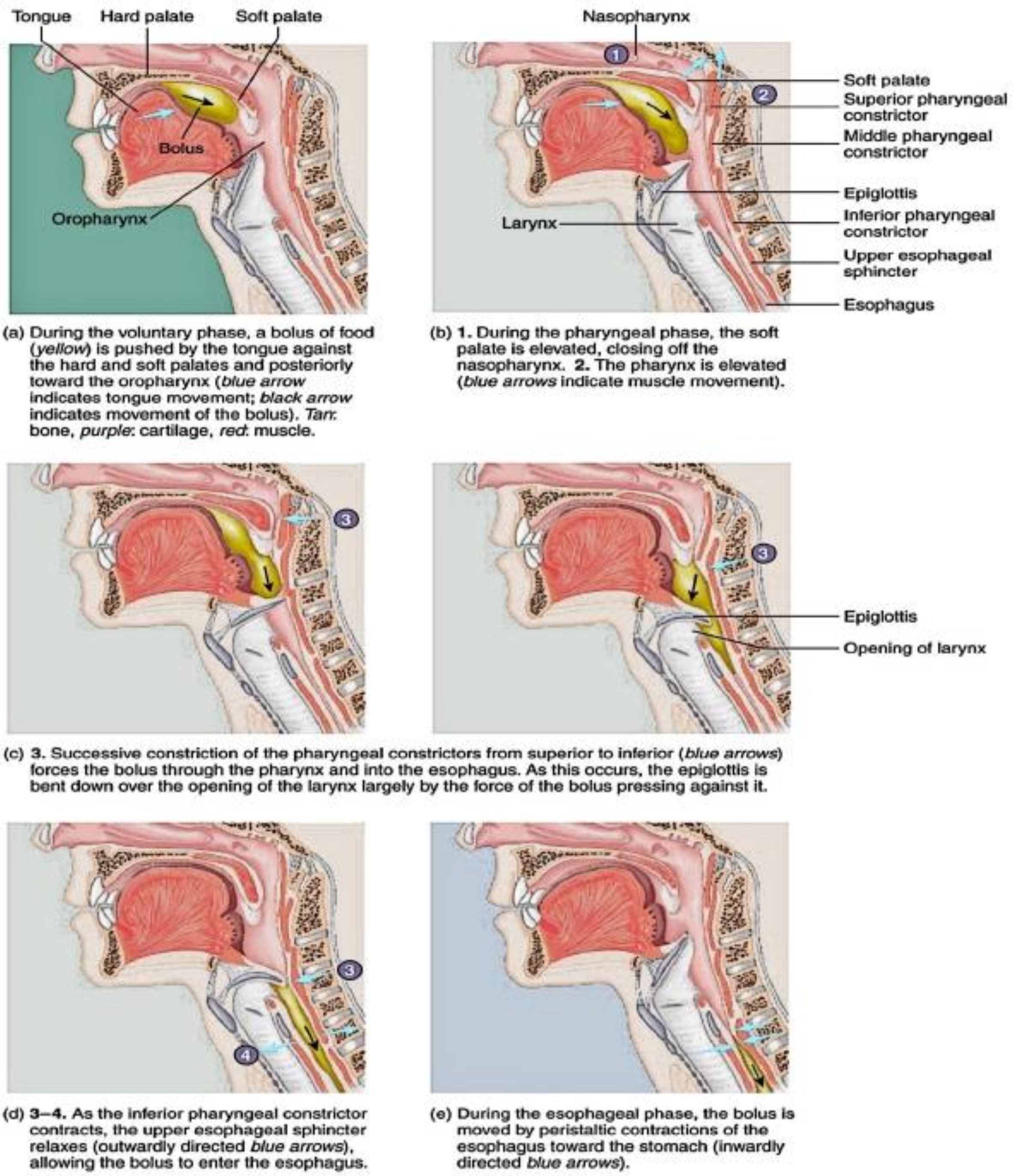
The pharyngeal phase of swallowing is a reflex that is initiated by stimulation of tactile receptors in the area of the oropharynx. Afferent action potentials travel through the trigeminal (V) and glossopharyngeal (IX) nerves to the swallowing center in the medulla oblongata. There, they initiate action potentials in motor neurons, which pass through the trigeminal (V), glossopharyngeal (IX), vagus (X), and accessory (XI) nerves to the soft palate and pharynx. This phase of swallowing begins with the elevation of the soft palate, which closes the passage between the nasopharynx and oropharynx. The pharynx elevates to receive the bolus of food from the mouth and moves the bolus down the pharynx into the esophagus. The superior, middle, and inferior pharyngeal constrictor muscles contract in succession, forcing the food through the pharynx. At the same time, the upper esophageal sphincter relaxes, the elevated pharynx opens the esophagus, and food is pushed into the esophagus. This phase of swallowing is unconscious and is controlled automatically, even though the muscles involved are skeletal. The pharyngeal phase of swallowing lasts about 1-2 seconds.

During the pharyngeal phase, the vestibular folds are moved medially, the epiglottis is tipped posteriorly so that the epiglottic cartilage covers the opening into the larynx, and the larynx is elevated. These movements of the larynx prevent food from passing through the opening into the larynx.

The esophageal phase of swallowing takes about 5-8 seconds and is responsible for moving food from the pharynx to the stomach. Muscular contractions in the wall of the esophagus occur in peristaltic waves.

The peristaltic waves associated with swallowing cause relaxation of the lower esophageal sphincter in the esophagus as the peristaltic waves, and bolus of food, approach the stomach. This sphincter is not anatomically distinct from the rest of the esophagus, but it can be identified physiologically because it remains tonically constricted to prevent the reflux of stomach contents into the lower part of the esophagus.

The presence of food in the esophagus stimulates the enteric plexus, which controls the peristaltic waves. The presence of food in the esophagus also stimulates tactile receptors, which send afferent impulses to the medulla oblongata through the vagus nerves. Motor impulses, in turn, pass along the vagal efferent fibers to the striated and smooth muscles within the esophagus, thereby stimulating their contractions and reinforcing the peristaltic contractions.



(a) During the voluntary phase, a bolus of food (*yellow*) is pushed by the tongue against the hard and soft palates and posteriorly toward the oropharynx (*blue arrow* indicates tongue movement; *black arrow* indicates movement of the bolus). *Tan*: bone, *purple*: cartilage, *red*: muscle.

(b) **1.** During the pharyngeal phase, the soft palate is elevated, closing off the nasopharynx. **2.** The pharynx is elevated (*blue arrows* indicate muscle movement).

(c) **3.** Successive constriction of the pharyngeal constrictors from superior to inferior (*blue arrows*) forces the bolus through the pharynx and into the esophagus. As this occurs, the epiglottis is bent down over the opening of the larynx largely by the force of the bolus pressing against it.

(d) **3–4.** As the inferior pharyngeal constrictor contracts, the upper esophageal sphincter relaxes (outwardly directed *blue arrows*), allowing the bolus to enter the esophagus.

(e) During the esophageal phase, the bolus is moved by peristaltic contractions of the esophagus toward the stomach (inwardly directed *blue arrows*).

Three Phases of Swallowing (Deglutition)

Stomach

The stomach is an enlarged segment of the digestive tract in the left superior part of the abdomen. Its shape and size vary from person to person; even within the same individual its size and shape change from time to time, depending on its food content and the posture of the body.

Secretions of the Stomach

Ingested food and stomach secretions mixed together, form a semifluid material called chyme. The stomach functions primarily as storage and mixing chamber for the chyme. Although some digestion and absorption occur in the stomach, they are not its major functions.

Stomach secretions include mucus, hydrochloric acid, gastrin, histamine, intrinsic factor, and pepsinogen. Pepsinogen is the inactive form of the protein-digesting enzyme pepsin.

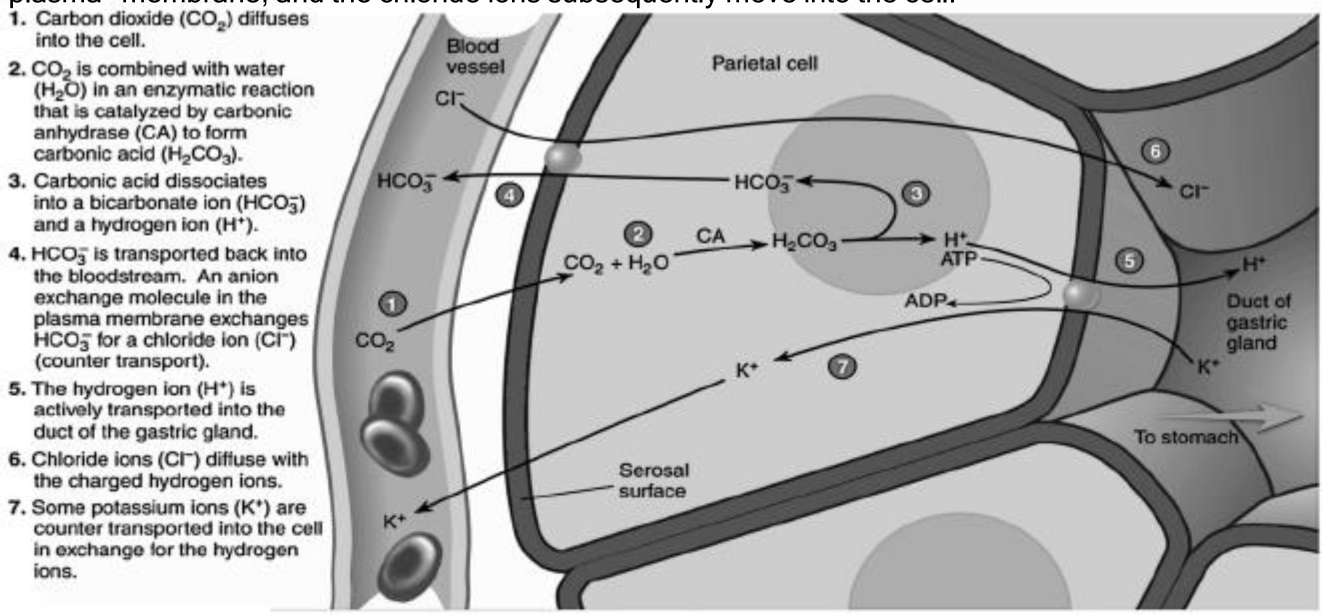
The surface mucous cells and mucous neck cells secrete viscous and alkaline mucus that covers the surface of the epithelial cells and forms a layer 1-1.5 mm thick. The thick layer of mucus lubricates and protects the epithelial cells of the stomach wall from the damaging effect of the acidic chyme and pepsin. Irritation of the stomach mucosa results in stimulation of the secretion of a greater volume of mucus.

Parietal cells in the gastric glands of the pyloric region secrete intrinsic factor and a concentrated solution of hydrochloric acid. Intrinsic factor is a glycoprotein that binds with vitamin B_{12} and makes the vitamin more readily absorbed in the ileum. Vitamin B_{12} is important in deoxyribonucleic acid (DNA) synthesis.

Hydrochloric acid produces the low pH of the stomach, which is normally between 1 and 3. Although the hydrochloric acid secreted into the stomach has a minor digestive effect on ingested food, one of its main functions is to kill bacteria that are ingested with essentially everything humans put into their mouths. Some pathogenic bacteria may avoid digestion in the stomach, however, because they have an outer coat that resists stomach acids.

The low pH of the stomach also stops carbohydrate digestion by inactivating salivary amylase. Stomach acid also denatures many proteins so that proteolytic enzymes can reach internal peptide bonds, and it provides the proper pH environment for the function of pepsin.

Hydrogen ions are derived from carbon dioxide and water, which enter the parietal cell from its serosal surface, which is the side opposite the lumen of the gastric pit. Once inside the cell, carbonic anhydrase catalyzes the reaction between carbon dioxide and water to form carbonic acid. Some of the carbonic acid molecules then dissociate to form hydrogen ions and bicarbonate ions. The hydrogen ions are actively transported across the mucosal surface of the parietal cell into the lumen of the stomach; some potassium ions are moved into the cell in exchange for the hydrogen ions. Although hydrogen ions are actively transported against a steep concentration gradient, chloride ions diffuse with the hydrogen ions from the cell through the plasma membrane. Diffusion of chloride ions with the positively charged hydrogen ions reduces the amount of energy needed to transport the hydrogen ions against both a concentration gradient and an electrical gradient. Bicarbonate ions move down their concentration gradient from the parietal cell into the extracellular fluid. During this process, bicarbonate ions are exchanged for chloride ions through an anion exchange molecule, which is located in the plasma membrane, and the chloride ions subsequently move into the cell.



Hydrochloric Acid Production by Parietal Cells in the Gastric Glands of the Stomach

Chief cells within the gastric glands secrete pepsinogen. Pepsinogen is packaged in zymogen granules, which are released by exocytosis when pepsinogen secretion is stimulated. Once pepsinogen enters the lumen of the stomach, hydrochloric acid and previously formed pepsin molecules convert it to pepsin. Pepsin exhibits optimum enzymatic activity at a pH of 3 or less. Pepsin catalyzes the cleavage of some covalent bonds in proteins, thus breaking them into smaller peptide chains.

Regulation of Stomach Secretion

Approximately 2-3L of gastric secretions (gastric juice) is produced each day. The amount and type of food entering the stomach dramatically affects the secretion amount, but up to 700 mL is secreted as a result of a typical meal. Both nervous and hormonal mechanisms regulate gastric secretions. The neural mechanisms involve reflexes integrated within the medulla oblongata and local reflexes integrated within the enteric plexus of the GI tract. In addition, higher brain centers influence the reflexes. Chemical signals that regulate stomach secretions include the hormones gastrin, secretin, gastric-inhibitory polypeptide, and cholecystokinin, as well as the paracrine chemical signal histamine.

Regulation of stomach secretion is divided into three phases: cephalic, gastric, and intestinal.

1. Cephalic phase. In the cephalic phase of gastric regulation, the sensations of the taste and smell of food, stimulation of tactile receptors during the process of chewing and swallowing, and pleasant thoughts of food stimulate centers within the medulla oblongata that influence gastric secretions. Action potentials are sent from the medulla along parasympathetic neurons within the vagus (X) nerves to the stomach. Within the stomach wall, the preganglionic neurons stimulate postganglionic neurons in the enteric plexus. The postganglionic neurons, which are primarily cholinergic, stimulate secretory activity in the cells of the stomach mucosa.

Parasympathetic stimulation of the stomach mucosa results in the release of the neurotransmitter acetylcholine, which increases the secretory activity of both the parietal and chief cells and stimulates the secretion of gastrin and histamine from endocrine cells. Gastrin is released into the circulation and travels to the parietal cells, where it stimulates additional hydrochloric acid and pepsinogen secretion. In addition, gastrin stimulates endocrine cells to release histamine, which stimulates parietal cells to secrete hydrochloric acid. The histamine receptors on the parietal cells are called H_2 receptors, and are different from the H_1 receptors involved in allergic reactions. Drugs that block allergic reactions do not affect histamine-mediated stomach acid secretion and vice versa. Acetylcholine, histamine, and gastrin working together cause a greater secretion of hydrochloric acid than any of them does separately. Of the three, histamine has the greatest stimulatory effect.

2. Gastric phase. The greatest volume of gastric secretions is produced during the gastric phase of gastric regulation. The presence of food in the stomach initiates the gastric phase. The primary stimuli are distention of the stomach and the presence of amino acids and peptides in the stomach.

Distention of the stomach wall, especially in the body or fundus, results in the stimulation of mechanoreceptors. Action potentials generated by these receptors initiate reflexes that involve both the CNS and enteric reflexes, resulting in secretion of mucus, hydrochloric acid, pepsinogen, intrinsic factor, and gastrin. The presence of partially digested proteins or moderate amounts of alcohol or caffeine in the stomach also stimulates gastrin secretion.

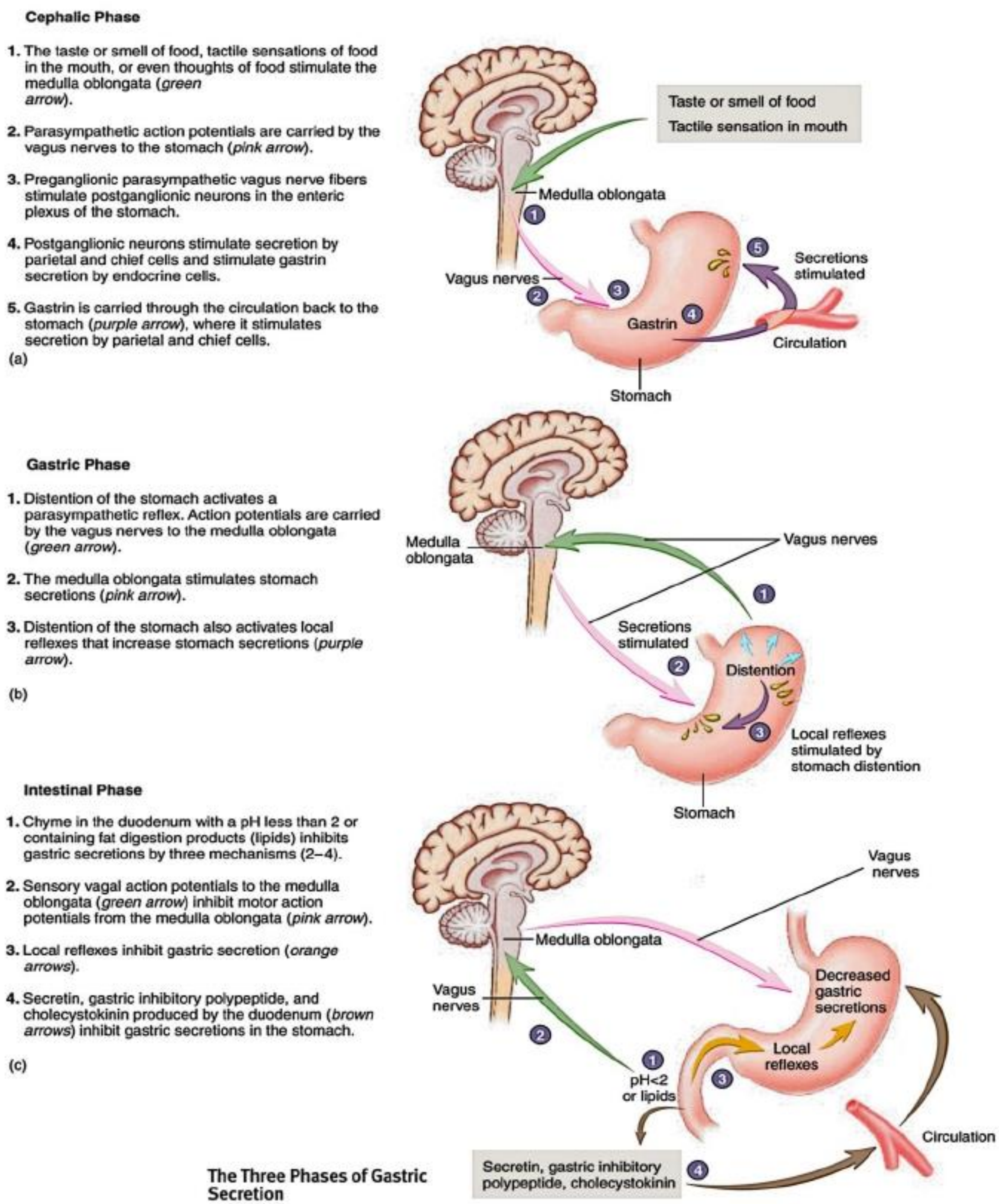
When the pH of the stomach contents falls below 2, increased gastric secretion produced by distention of the stomach is blocked. This negative-feedback mechanism limits the secretion of gastric juice.

Amino acids and peptides released by the digestive action of pepsin on proteins directly stimulate parietal cells of the stomach to secrete hydrochloric acid. The mechanism by which this response is mediated is not clearly understood. It doesn't involve known neurotransmitters, and, when the pH drops below 2, the response is inhibited. Histamine also stimulates the secretory activity of parietal cells.

3. Intestinal phase. The entrance of acidic stomach contents into the duodenum of the small intestine controls the intestinal phase of gastric regulation.The presence of chyme in the duodenum activates both neural and hormonal mechanisms. When the pH of the chyme entering the duodenum drops to 2 or below, or if the chyme contains fat digestion products, gastric secretions are inhibited.

Acidic solutions in the duodenum cause the release of the hormone secretin into the circulatory system. Secretin inhibits gastric secretion by inhibiting both parietal and chief cells. Acidic solutions also initiate a local enteric reflex, which inhibits gastric secretions.

Fatty acids and certain other lipids in the duodenum and the proximal jejunum initiate the release of two hormones: gastric inhibitory polypeptide and cholecystokinin ,Gastric inhibitory polypeptide strongly inhibits gastric secretion, and cholecystokinin inhibits gastric secretions to a lesser degree. Hypertonic solutions in the duodenum and jejunum also inhibit gastric secretions. The mechanism appears to involve the secretion of a hormone referred to as enterogastrone, but the actual existence of this hormone has never been established.



The Three Phases of Gastric Secretion

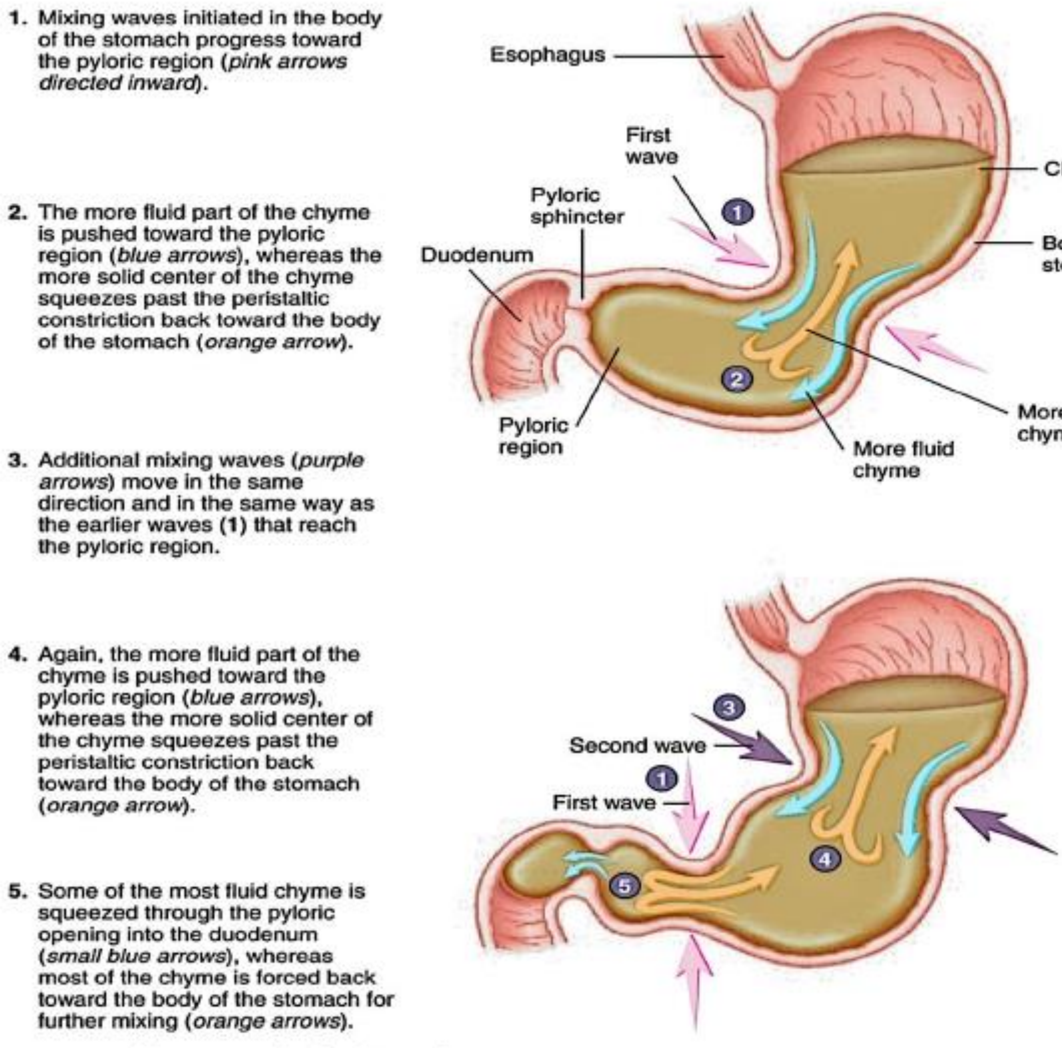
(*a*) Cephalic phase. (*b*) Gastric phase. (*c*) Intestinal phase.

Mixing of Stomach Contents

Ingested food is thoroughly mixed with the secretions of the stomach glands to form chyme. This mixing is accomplished by gentle mixing waves, which are peristaltic-like contractions that occur about every 20 seconds and proceed from the body toward the pyloric sphincter to mix the ingested material with the secretions of the stomach. Peristaltic waves occur less frequently, are significantly more powerful than mixing waves, and force the chyme near the periphery of the stomach toward the pyloric sphincter. The more solid material near the center of the stomach is pushed superiorly toward the cardiac region for further digestion. Roughly 80% of the contractions are mixing waves, and 20% are peristaltic waves.

Stomach Emptying

The amount of time food remains in the stomach depends on a number of factors, including the type and volume of food. Liquids exit the stomach within 1 1/2 - 2 1/2 hours after ingestion. After a typical meal, the stomach is usually empty within 3-4 hours. The pyloric sphincter usually remains partially closed because of mild tonic contraction. Each peristaltic contraction is sufficiently strong to force a small amount of chyme through the pyloric opening and into the duodenum. The peristaltic contractions responsible for movement of chyme through the partially closed pyloric opening are called the pyloric pump.



Movements in the Stomach

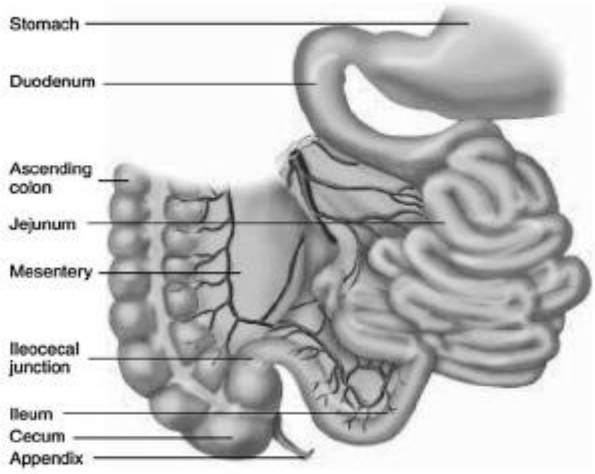
Small Intestine

The small intestine consists of three parts: the duodenum, the jejunum, and the ileum. The entire small intestine is about 6 m long (range: 4.6 - 9m). The duodenum is about 25 cm long (the term duodenum means 12, suggesting that it is 12 inches long). The jejunum, constituting about two-fifths of the total length of the small intestine, is about 2.5m long; and the ileum, constituting three-fifths of the small intestine, is about 3.5m long. Two major accessory glands, the liver and the pancreas, are associated with the duodenum.

The small intestine is the site at which the greatest amount of digestion and absorption occur. Each day, about 9L of water enters the digestive system. It comes from water that is ingested and from fluid secretions produced by glands along the length of the digestive tract. Most of the water, 8 - 8.5L, moves by osmosis, with the absorbed solutes, out of the small intestine. A small part, 0.5 - 1L, enters the colon.

Secretions of the Small Intestine

The mucosa of the small intestine produces secretions that primarily contain mucus, electrolytes, and water. Intestinal secretions lubricate and protect the intestinal wall from the acidic chyme and the action of digestive enzymes. They also keep the chyme in the small intestine in a liquid form to facilitate the digestive process. The intestinal mucosa produces most of the secretions that enter the small intestine, but the secretions of the liver and the pancreas also enter the small intestine and play essential roles in the process of digestion. Most of the digestive enzymes entering the small intestine are secreted by the pancreas. The intestinal mucosa also produces enzymes, but these remain associated with the intestinal epithelial surface.



The Small Intestine

The duodenal glands, intestinal glands, and goblet cells secrete large amounts of mucus. This mucus provides the wall of the intestine with protection against the irritating effects of acidic chyme and against the digestive enzymes that enter the duodenum from the pancreas. Secretin and cholecystokinin are released from the intestinal mucosa and stimulate hepatic and pancreatic secretions.
The vagus nerve, secretin, and chemical or tactile irritation of the duodenal mucosa stimulate secretion from the duodenal glands. Goblet cells produce mucus in response to the tactile and chemical stimulation of the mucosa.

Enzymes of the intestinal mucosa are bound to the membranes of the absorptive cell microvilli. These surface-bound enzymes include disaccharidases, which break disaccharides down to monosaccharides; peptidases, which hydrolyze the peptide bonds between small amino acid chains; and nudeases, which break down nucleic acids. Although these enzymes are not secreted into the intestine, they influence the digestive process significantly, and the large surface area of the intestinal epithelium brings these enzymes into contact with the intestinal contents. Small molecules, which are breakdown products of digestion, are absorbed through the microvilli and enter the circulatory or lymphatic systems.

Movement in the Small Intestine

Mixing and propulsion of chyme are the primary mechanical events that occur in the small intestine. These functions are the result of segmental or peristalic contractions, which are accomplished by the smooth muscle in the wall of the small intestine and which are only propagated for short distances. Segmental contractions mix the intestinal contents, and peristaltic contractions propel the intestinal contents along the digestive tract. A few peristaltic contractions may precede the entire length of the intestine. Frequently, intestinal peristaltic contractions are continuations of peristaltic contractions that begin in the stomach. These contractions both mix and propel substances through the small intestine as the wave of contraction proceeds. The contractions move at a rate of about 1 cm/min. The movements are slightly faster at the proximal end of the small intestine and slightly slower at the distal end. It usually takes 3-5 hours for chyme to move from the pyloric region to the ileocecal junction.

Local mechanical and chemical stimuli are especially important in regulating the motility of the small intestine. Smooth muscle contraction increases in response to distention of the intestinal wall. Solutions that are either hypertonic or hypotonic, solutions with a low pH, and certain products of digestion like amino acids and peptides also stimulate contractions of the small intestine. Local reflexes, which are integrated within the enteric plexus of the small intestine, mediate the response of the small intestine to these mechanical and chemical stimuli. Stimulation through parasympathetic nerve fibers may also increase the motility of the small intestine, but the parasympathetic influences in the small intestine are not as important as those in the stomach.

The ileocecal sphincter at the juncture between the ileum and the large intestine remains mildly contracted most of the time, but peristaltic waves reaching it from the small intestine cause it to relax and allow movement of chyme from the small intestine into the cecum. Cecal distention, however, initiates a local reflex that causes more intense constriction of the ileocecal sphincter. Closure of the sphincter facilitates digestion and absorption in the small intestine by slowing the rate of chyme movement from the small intestine into the large intestine and prevents material from returning to the ileum from the cecum.