Propulsion and Mixing of Food in the Alimentary Tract

For food to be processed optimally (mixing and propulsion) in the alimentary tract, the time that it remains in each part of the tract is critical (not too rapidly, not too slowly) and under the control of multiple automatic nervous and hormonal feedback mechanisms.

Ingestion of Food

The amount of food that a person ingests is determined principally by intrinsic desire for food called ***hunger*****,** while the type of food that a person preferentially seeks is determined by ***appetite***. The mechanics of ingestion can be achieved by two processes; ***mastication*** and ***swallowing***.

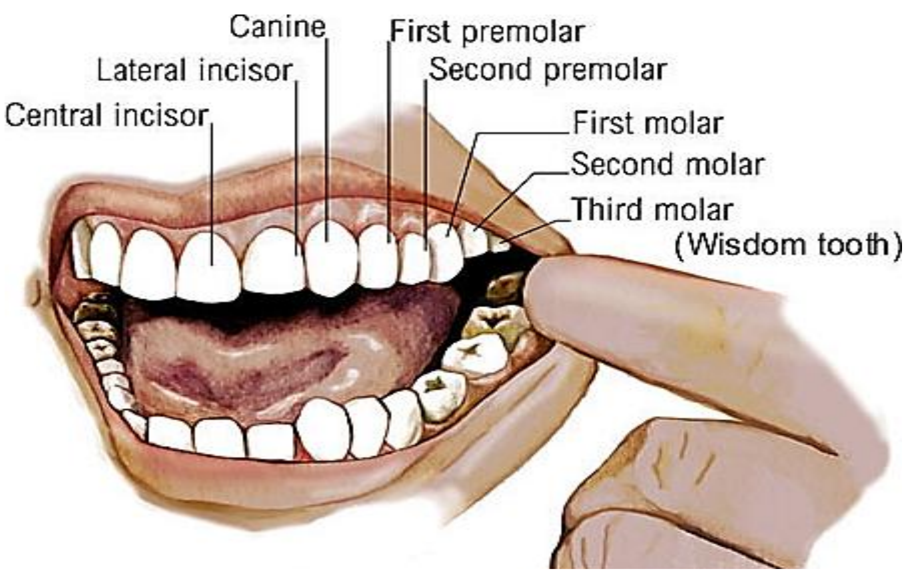
A. Mastication (Chewing)

Mastication is a process whereby ingested food is cut or crushed into small pieces mixed with saliva and formed into bolus in preparation for swallowing. This process is important for digestion of all foods because:

- The rate of digestion is absolutely dependent on the total surface area exposed to the digestive secretions because digestive enzymes act only on the surfaces of food particles.
- Most fruits and raw vegetables have indigestible cellulose membranes around their nutrient portions that must be broken before the food can be digested.
- Grinding the food to a very fine particles prevents excoriation of GIT and makes emptying of food ease from one segment to another.

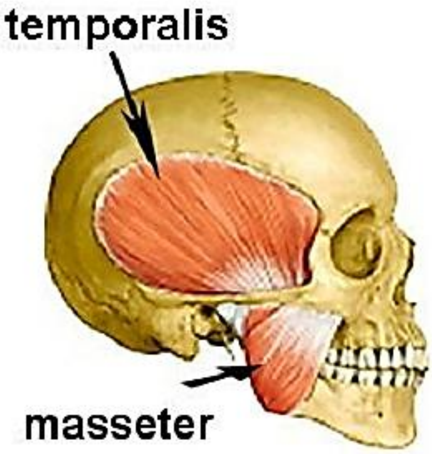
The mastication process required two important structures, teeth and jaw muscles:

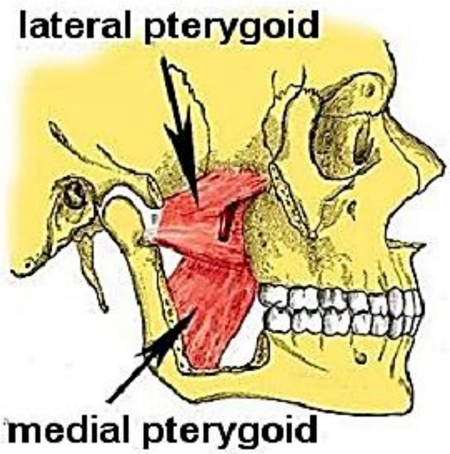
1. **The teeth:**
   In adult humans, there are normally 32 ***permanent teeth*** that disposed in two bilaterally symmetric arches in the maxillary and mandibular bones, with eight teeth in each quadrant: two incisors, one canine, two premolars, and three permanent molars. Twenty of the permanent teeth are preceded by ***deciduous (baby) teeth*****;** the remainder (the permanent molars) have no deciduous precursors. The teeth are designed for chewing by which the anterior teeth (incisors) providing a strong ***cutting action***, while the posterior teeth (molars) providing a ***grinding action***. All the jaw muscles working together can close the teeth with a force as great as 55 pounds on the incisors and 200 pounds on the molars.



2. Chewing Muscles

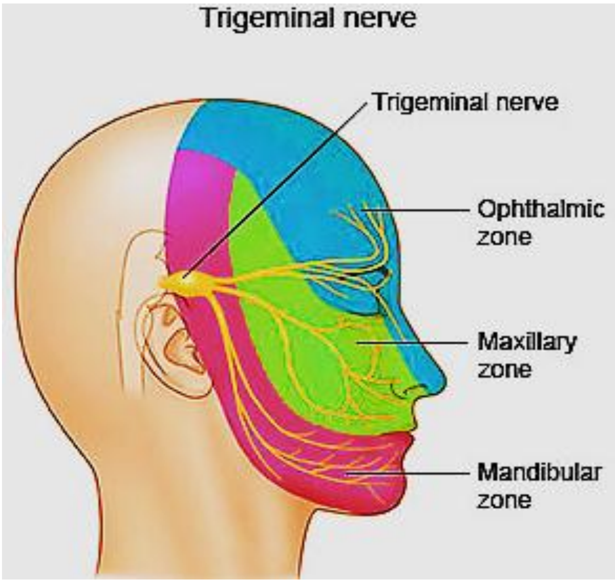
In humans, the mandible (lower jaw) is connected to the temporal bone of the skull via the ***temporomandibular joint***, an extremely complex joint which permits movement in all planes. The mandible is the only bone that moves during mastication and other activities, such as talking. The Muscles of mastication (also known as muscles of jaw) consist of four muscles the temporalis, masseter, later pterygoid and medial pterygoid muscles which originate on the skull and insert into the mandible, thereby allowing for jaw movements during contraction. These muscles work together to move the mandible at the temporomandibular joint and responsible for the chewing action, grinding the teeth, moving our mandible from side to side and also assisting us to speak. While these four muscles are the primary participants in mastication, other muscles are usually if not always helping the process, such as those of the tongue and the cheeks.





Chewing reflex:

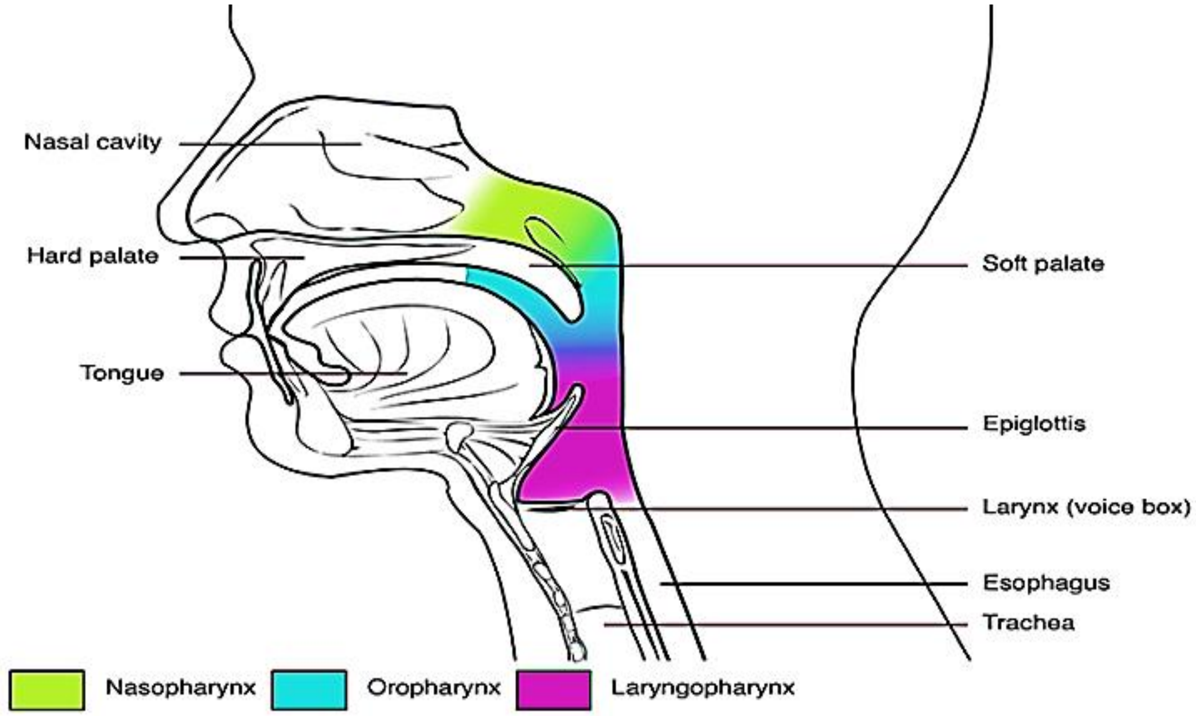
Most of the chewing muscles are innervated by the motor branch of the fifth cranial nerve known as **trigeminal nerve** because it consists of three branches: (1) the upper branch ***(Ophthalmic)*** innervates forehead, upper eyelid, cornea, conjunctiva, and dorsum of the nose, (2) the middle branch ***(Maxillary)*** supplies upper lip, lateral & posterior portions of nose, upper cheek, and upper jaw, upper teeth, and roof of mouth, (3) the lower branch ***(Mandibular)*** supplies lower lip, chin, posterior cheek, external ear, lower part of mouth, and anterior two-thirds of the tongue. The trigeminal nerve has sensory and motor nerve fibers, the sensory portion of the trigeminal supplies touch, pain, and temperature sensation to the face, while the motor division of the nerve supplies the muscles of mastication. The mandibular division carries the motor portion that conveys proprioceptive impulses from the temporomandibular joint to the nuclei of trigeminal nerve located in the brain stem that control the chewing process via stimulation chewing muscles to produce rhythmical chewing movements (elevation, depression, protrusion, retraction, and the side-to-side movements of the mandible) which is called ***chewing reflex*** in which the presence of a



bolus of food in the mouth at first initiate reflex inhibition of the muscles of mastication, which allows the lower jaw to drop. The drop in turn initiates a stretch reflex of the jaw muscles that leads to rebound contraction. This automatically raises the jaw to cause closure of the teeth, but it also compresses the bolus again against the linings of the mouth, which inhibits the jaw muscles once again, allowing the jaw to drop and rebound another time; this is repeated again and again.

B. Swallowing

Swallowing is a complicated mechanism because the pharynx serves respiration as well as swallowing. The pharynx is the part of the throat situated immediately behind the mouth & nasal cavity, and above the esophagus and larynx, so it serves as a part of the digestive system and also of the conducting zone of the respiratory system. The human pharynx is conventionally divided into three sections: the upper section (nasopharynx) conduct with nasal cavity, the middle section (oropharynx) conduct oral cavity and esophagus, and the lower section (laryngopharynx) conduct the nasal cavity with larynx, trachea, and conduct it into the lungs. A flap of cartilage at the root of the tongue, which is depressed during swallowing to cover the opening of the larynx.



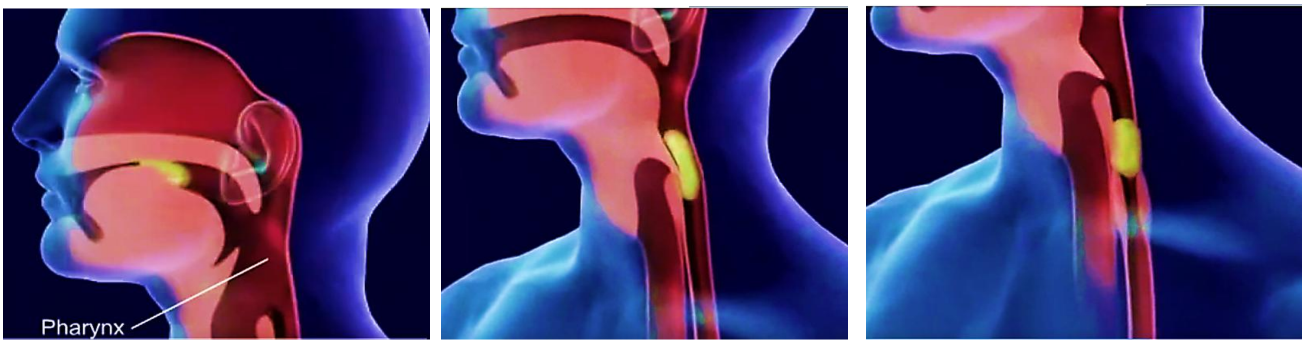
In general, swallowing can be divided into three stages:

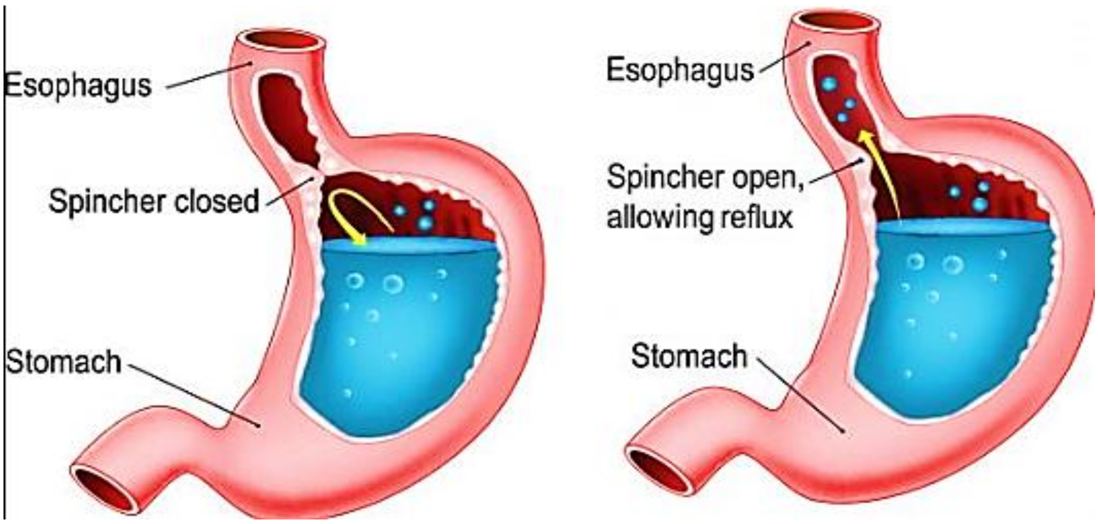
1. **Oral Stage (Voluntary):**
   This phase begins when food is placed in the mouth and moistened with saliva to be prepared into a smaller size that is well lubricated known as ***bolus*** that can be easily passed from the front to the back of the mouth. The food bolus is then voluntarily moved further into the oropharynx by pressure of the tongue upward and backward and also requires the voluntary elevation of the soft palate in order to prevent food from entering the nose. The muscles that control the oral phase of swallowing are stimulated by nerves located in the brainstem, called cranial nerves which include the 5^{th} trigeminal nerve, the 7^{th} facial nerve, and the 12^{th} hypoglossal nerve.
2. **Pharyngeal Stage (Involuntary):**
   As the bolus of food enters the posterior mouth and pharynx, it stimulates epithelial swallowing receptor areas around the opening of the pharynx, which send impulses to the ***swallowing center*** in the brain stem (medulla & lower pons). This center send motor impulses to the muscles of

pharynx and upper esophagus by the 5th trigeminal nerve, the 9th glossopharyngeal nerve, and the 10th vagus nerve to initiate a series of automatic muscle contractions of several muscles in the back of the mouth, pharynx, and esophagus leading to close larynx and open the esophagus. A critical part of the pharyngeal phase is the involuntary closure of the larynx by the epiglottis and vocal cords, and the temporary inhibition of breathing for less than 6 seconds. These actions prevent food from going down into the trachea to protect the lungs from injury, because entrance of food and other particles into the lungs can lead to severe infections and irritation of the lung tissue known as ***aspiration pneumonia*** caused by problems with the pharyngeal phase of the swallowing reflex.

3. **Esophageal Stage:**
As food leaves the pharynx, it enters the esophagus which leads food into the stomach due to its powerful coordinated muscular contractions. The passage of food through the esophagus during this phase requires the coordinated action of the vagus nerve, the glossopharyngeal nerve, and from nerve fibers from the sympathetic nervous system. The esophagus has two important sphincters that allow the food bolus to flow in a forward direction while preventing it from going in the wrong direction (regurgitation). The upper esophageal sphincter prevents food or saliva from being regurgitated back into the mouth, while the lower esophageal sphincter ensures that food remains in the stomach, preventing regurgitation back into the esophagus. The reflux of stomach contents into the esophagus cause a painful sensation ***(heart burn)*** because it is highly acidic and contain many proteolytic enzymes leading to damage esophageal mucosa.

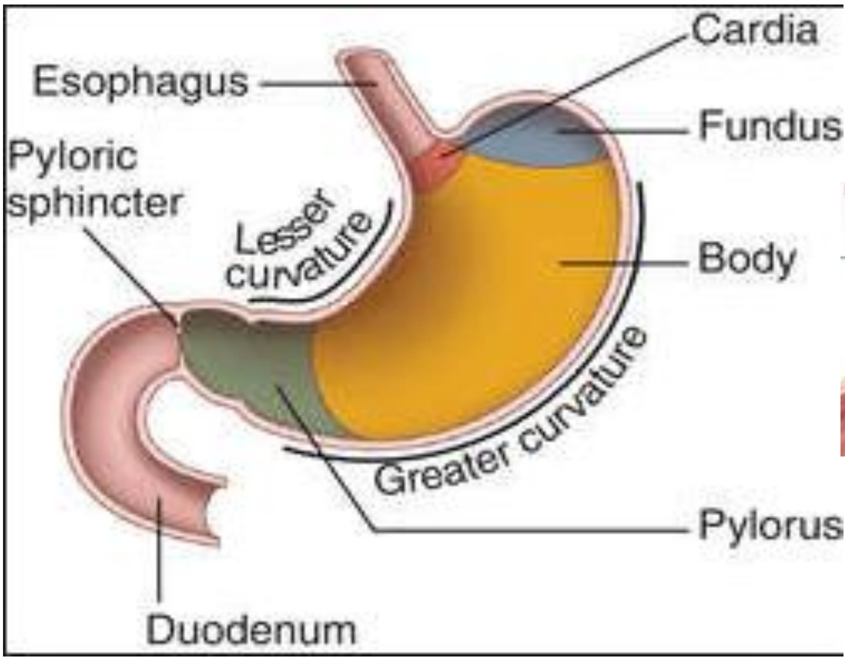
In general, healthy people can swallow with very little deliberate thought and effort. If the nervous system is disrupted due to a stroke or another disease, then problems with swallowing can occur such as ***dysphagia*** that can lead to choking, lack of appetite &weight loss, as well as aspiration pneumonia.

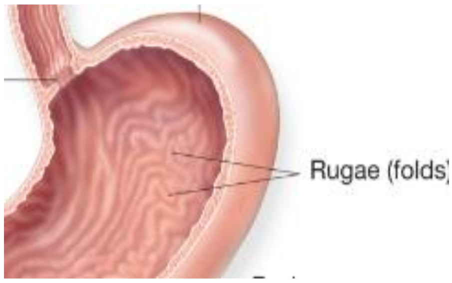




Motor Functions of the Stomach

There are four main regions in the stomach: the cardia, fundus, body, and pylorus. The **cardia** is the point where the esophagus connects to the stomach and through which food passes into the stomach. The **fundus** is the dome-shaped located inferior to the diaphragm, above and to the left of the cardia. The **body** is the main part of the stomach and located below the fundus. The **pylorus** is funnel-shaped that connects the stomach to the duodenum, its wider end called ***pyloric antrum*** that connects to the body of the stomach, while the narrower end is called the ***pyloric canal***, which connects to the duodenum via ***pyloric sphincter*** and controls stomach emptying. The convex lateral surface of the stomach is called the ***greater curvature*** which bind stomach with the posterior abdominal wall via the greater omentum, while the concave medial border of stomach is called the ***lesser curvature*** that bind the stomach with the liver by the ***lesser omentum***. In the absence of food, the stomach deflates inward, and its mucosa and submucosa fall into a large fold called a **ruga**. The muscularis layer of stomach consists of three sublayers of smooth muscles; inner oblique, middle circular, and outer longitudinal to give the muscularis the ability to vigorously churn and mix food.





The motor functions of the stomach are threefold:

1. **Storage Function:**
   When food stretches the stomach, the muscular wall of the body bulges progressively outward, accommodating greater and greater quantities of food up to a limit in the completely relaxed stomach of 0.8 to 1.5 liters.
2. **Mixing Function:**
   As long as food is in the stomach, weak peristaltic constrictor waves called ***mixing waves,*** begin in the mid- to upper portions of the stomach wall and move toward the antrum about once every 15 to 20 seconds. As the constrictor waves progress from the body of the stomach into the antrum, they become more intense and force the antral contents under higher pressure toward the pylorus. When these constrictor rings approaches the pylorus, the pyloric muscle itself often contracts, which further impedes emptying through the pylorus. Therefore, most of the antral contents are squeezed upstream through the peristaltic ring toward the body of the stomach, not through the pylorus. Thus, the moving peristaltic constrictive ring, combined with this upstream squeezing

action (retropulsion) is an exceedingly important mixing mechanism in the stomach. Besides the peristaltic contractions that occur when food is present in the stomach, another type of intense contractions, called ***hunger contractions*** which are rhythmical peristaltic contractions in the body of the stomach occurs when the stomach has been empty for several hours or more and lasts for 2 to 3 minutes. Hunger contractions are most intense in young, and also greatly increased by the person's having lower than normal levels of blood sugar. After food in the stomach has become thoroughly mixed with the stomach secretions, the resulting mixture that passes down the gut is called ***chyme***. The degree of fluidity of the chyme leaving the stomach depends on the relative amounts of food, water, and stomach secretions and on the degree of digestion that has occurred.

3. Emptying Function:

The peristaltic waves, in addition to causing mixing in the stomach, also provide a pumping action called the ***pyloric pump*** that forces chyme into the duodenum throughout the pyloric sphincter, which is usually open enough for water and other fluids to empty from the stomach into the duodenum with ease. Conversely, the constriction of pyloric sphincter usually prevents passage of food particles until they have become mixed in the chyme to almost fluid consistency. The degree of constriction of the pylorus is increased or decreased under the influence of nervous and humoral reflex signals from both the stomach and the duodenum. Emptying of the stomach is controlled only to a moderate degree by stomach factors such as the degree of filling in the stomach and the excitatory effect of gastrin on stomach peristalsis. Probably the more important control of stomach emptying resides in inhibitory feedback signals from the duodenum, including both enterogastric inhibitory nervous feedback reflexes and hormonal feedback by CCK. These feedback inhibitory mechanisms work together to slow the rate of emptying when (1) too much chyme is already in the small intestine or (2) the chyme is excessively acidic, contains too much unprocessed protein or fat, is hypotonic or hypertonic, or is irritating. In this way, the rate of stomach emptying is limited to that amount of chyme that the small intestine can process.

Movements of the Small Intestine

The movements of the small intestine, like those elsewhere in the gastrointestinal tract, can be divided into mixing contractions, propulsive, and folding contractions:

1. Mixing Contractions (Segmentation)

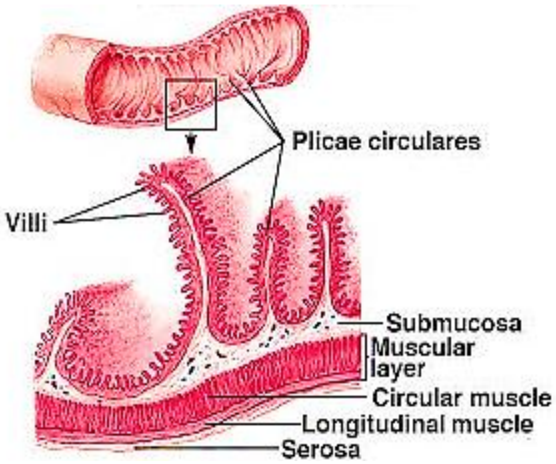
When a portion of the small intestine becomes distended with chyme, stretching of the intestinal wall elicits localized concentric contractions (segmentation) divide the intestine into spaced segments that have the appearance of a chain of sausages spaced at intervals along the intestine and lasting a fraction of a minute. These segmentation contractions chop the chyme 2-3 times per minute and promoting progressive mixing of the food with secretions of the small intestine. The maximum frequency of the segmentation contractions in the small intestine is not over 12 per minute in the duodenum and proximal jejunum, while in the terminal ileum, the maximum frequency is usually 8 to 9 contractions per minute.

2. Propulsive Movements

Chyme is propelled through the small intestine by ***peristaltic waves*** toward the anus at a velocity of (0.5 - 2 cm / sec), faster in the proximal intestine and slower in the terminal intestine. So this forward movement of the chyme is very slow with a net movement along the small intestine normally averages only (1 cm / min). This means that 3-5 hours are required for passage of chyme from the pylorus to the ileocecal valve. Peristaltic activity of the small intestine is greatly increased after a meal due to ***gastroenteric reflex*** via the myenteric plexus that is initiated by distention of the stomach and partly by the beginning entry of chyme into the duodenum. In addition to the nervous signals, several hormonal factors also affect peristalsis, some of them enhance intestinal motility such as *gastrin, CCK, insulin, motilin,* and *serotonin*, while *secretin* and *glucagon* inhibit small intestinal motility. The function of the peristaltic waves in the small intestine is not only to cause progression of chyme toward the ileocecal valve but also to spread out the chyme along the intestinal mucosa. On reaching the ileocecal valve, the chyme is sometimes blocked for several hours until the person eats another meal; at that time, a ***gastroileal reflex*** intensifies peristalsis in the ileum and forces the remaining chyme through the ileocecal valve into the cecum of the large intestine. Although peristalsis in the small intestine is normally weak, intense irritation of the intestinal mucosa (as occurs in some severe cases of infectious diarrhea) can cause both powerful and rapid peristalsis, called the ***peristaltic rush*** which is powerful peristaltic contractions travel long distances in the small intestine within minutes, sweeping the contents of the intestine into the colon and thereby relieving the small intestine of irritative chyme and excessive distention.

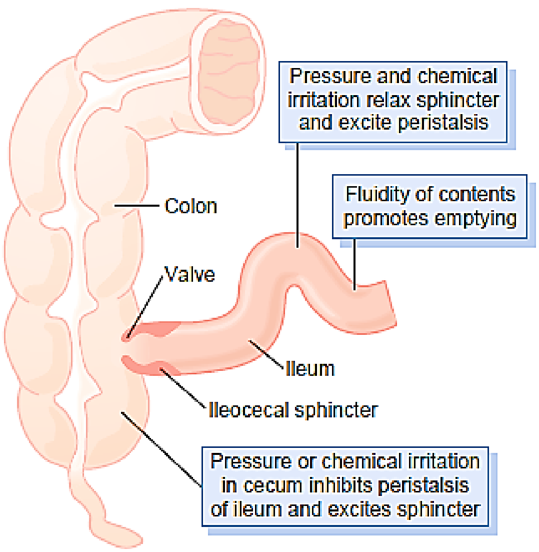
3. **Folding Movements**

The muscularis mucosae can cause short folds in the intestinal mucosa known as ***plica circulares*** to increase the surface area exposed to the chyme, thereby increasing absorption. In addition, individual fibers from this muscle extend into the intestinal villi and cause them to contract intermittently causing shortening, elongating, and shortening again of the villi, so that lymph flows freely from the central lacteals of the villi into the lymphatic system. These mucosal and villous contractions are initiated mainly by local nervous reflexes in the submucosal nerve plexus that occur in response to chyme in the small intestine.



Movements of the Colon

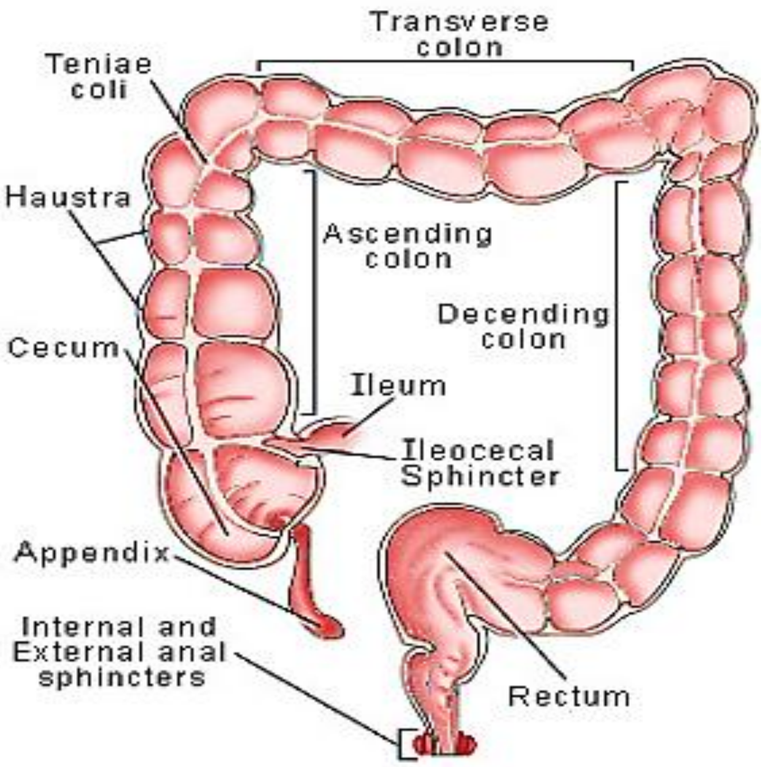
A principal function of the ileocecal valve is to prevent backflow of fecal contents from the colon into the small intestine because this valve itself protrudes into the lumen of the cecum and therefore is forcefully closed when excess pressure in the cecum tries to push cecal contents backward against the valve lips. The reflexes from the cecum to the ileocecal sphincter and ileum are mediated both by way of the myenteric plexus in the gut wall itself and of the extrinsic autonomic nerves, especially by way of the prevertebral sympathetic ganglia. Resistance to emptying at the ileocecal valve prolongs the stay of chyme in the ileum and thereby facilitates absorption. Normally, only 1500 to 2000 milliliters of chyme empty into the cecum each day. The principal functions of the colon are: **(1) Absorption** of water and electrolytes from the chyme to form solid feces particularly in the proximal half of the colon, and **(2) Storage** of fecal matter particularly in the distal half of colon until it can be expelled.



The movements of the colon are normally ***very sluggish*** but still have characteristics similar to those of the small intestine and can be divided once again into mixing and propulsive movements:

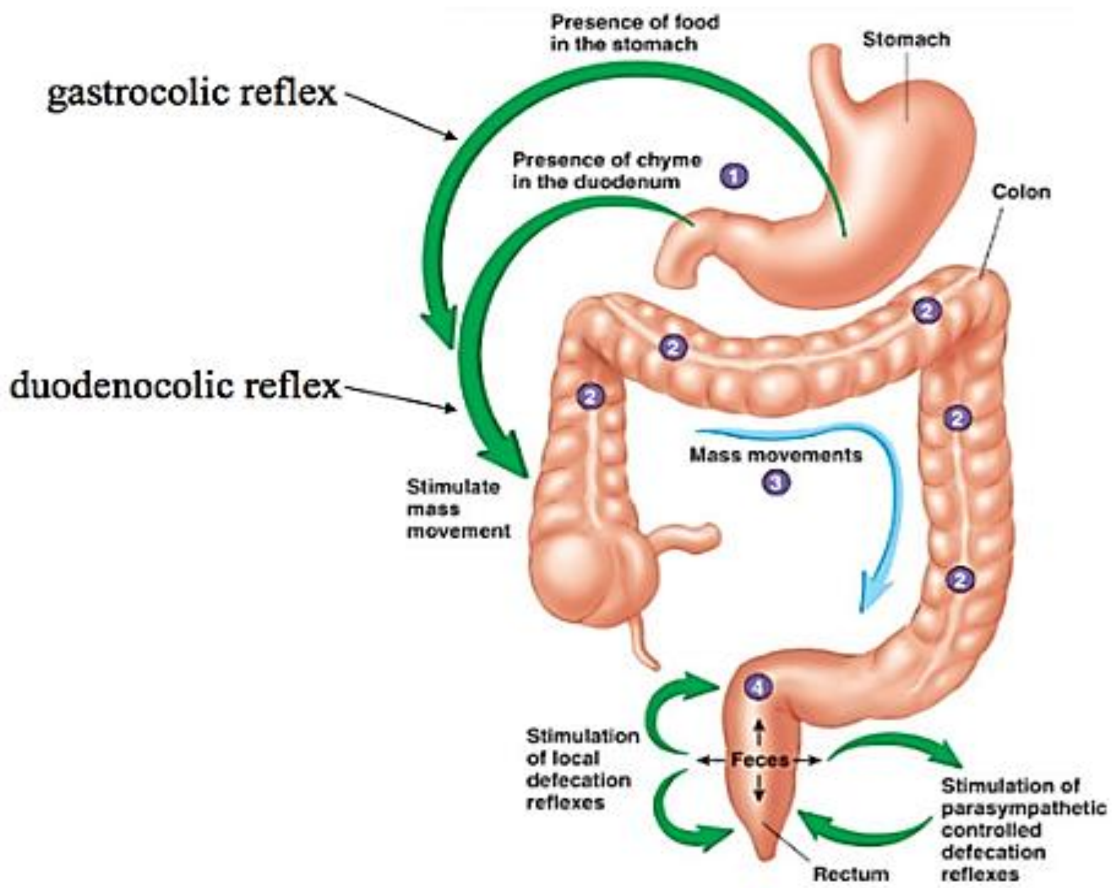
1. Mixing Movements (Haustrations)

They are combined contractions of the circular and longitudinal strips of muscle that cause the unstimulated portion of the large intestine to bulge outward into baglike sacs called ***haustrations***, in which circular muscles constricted and the longitudinal muscle of the colon contracted and aggregated into three longitudinal strips called the ***teniae coli***. Each haustration usually reaches peak intensity in about 30 seconds and then disappears during the next 60 seconds. They also at times move slowly toward the anus during contraction, especially in the cecum and ascending colon, and thereby provide a minor amount of forward propulsion of the colonic contents. After another few minutes, new haustral contractions occur in other areas nearby. Therefore, all fecal material is gradually exposed to mucosal surface of large intestine, so fluid & dissolved substances are progressively absorbed until only 80 to 200 milliliters of feces are expelled each day.



2. Propulsive Movements (Mass Movements)

From the cecum to the sigmoid, ***mass movements*** can take over the propulsive role for many minutes at a time and usually occur only one to three times each day especially during the first hour after eating breakfast. A mass movement is a modified type of peristalsis develops progressively more force for about 30 seconds, and relaxation occurs during the next 2 to 3 minutes. A series of mass movements usually persists for 10 to 30 minutes, then they cease but return perhaps a half day later. When they have forced a mass of feces into the rectum, the desire for defecation is felt. Appearance of mass movements after meals is facilitated by *gastrocolic* and *duodenocolic reflexes*, which are transmitted by way of the autonomic nervous system. Irritation in the colon can also initiate intense mass movements. For instance, a person who has an ulcerated condition of the colon mucosa **(*ulcerative colitis*)** frequently has mass movements that persist almost all the time.



Defecation

When a mass movement forces feces into the rectum, the desire for defecation occurs immediately, including reflex contraction of the rectum and relaxation of the anal sphincters. Continual dribble of fecal matter through the anus is prevented by tonic constriction of:

(1) Internal anal sphincter: Thickening of circular smooth muscle lies immediately inside the anus.
(2) External anal sphincter: Composed of striated voluntary muscle that surrounds the internal sphincter and controlled by somatic nervous system and therefore is under *voluntary*, *conscious* that is usually kept continuously constricted unless conscious signals inhibit the constriction.

Ordinarily, defecation is initiated by two types of **defecation reflexes:**

1. **Intrinsic reflex**
   When feces enter the rectum, distention of the rectal wall initiates afferent signals that spread through the myenteric plexus to initiate peristaltic waves in the descending colon, sigmoid, and rectum, forcing feces toward the anus. As the peristaltic wave approaches the anus, the internal anal sphincter is relaxed by inhibitory signals from the myenteric plexus, and the external anal sphincter is also consciously, voluntarily relaxed at the same time, so defecation occurs.
2. **Parasympathetic defecation reflex**
   When the nerve endings in the rectum are stimulated, signals are transmitted first into the spinal cord and back to the descending colon, sigmoid, rectum, and anus by way of parasympathetic nerve fibers in the ***pelvic nerves.*** These parasympathetic signals greatly intensify the peristaltic waves as well as relax the internal anal sphincter, thus converting the intrinsic myenteric defecation reflex from a weak effort into a powerful process. Defecation signals entering the spinal cord initiate other effects, such as taking a deep breath to move the diaphragm downward and then contracting the abdominal muscles to increase the pressure in the abdomen, thus forcing fecal contents into the

rectum to cause new reflexes. People who too often inhibit their natural reflexes are likely to become severely constipated. Conversely, in newborn babies and in some people with transected spinal cords, the defecation reflexes cause automatic emptying of the lower bowel at inconvenient times during the day because of lack of conscious control on the external anal sphincter.