

## CHAPTER 10: DIGESTIVE SYSTEM

At the end of this chapter, student will be able to:

- a) Describe the general functions of the digestive system, and name its major divisions.
- b) Explain the difference between mechanical and chemical digestion, and name the end products of digestion.
- c) Describe the structure and functions of the teeth and tongue.
- d) Explain the functions of saliva.
- e) Describe the location and function of the pharynx and esophagus.
- f) Describe the structure and function of each of the four layers of the alimentary tube.
- g) Describe the location, structure, and function of the stomach, small intestine, liver, gallbladder, and pancreas.
- h) Describe absorption in the small intestine.
- i) Describe the location, structure and functions of the large intestine.
- j) Explain the functions of the normal flora of the colon.

### 10.1 INTRODUCTION TO THE DIGESTIVE.

The digestive system contributes to homeostasis by breaking down food into forms that can be absorbed and used by body cells. It also absorbs water, vitamins, and minerals, and eliminates wastes from the body. The food we eat contains a variety of nutrients, which are used for building new body tissues and repairing damaged tissues. Food is also vital to life because it is our only source of chemical energy. However, most of the food we eat consists of molecules that are too large to be used by body cells. Therefore, foods must be broken down into molecules that are small enough to enter body cells, a process known as **digestion**. The organs involved in the breakdown of food collectively called the **digestive system** are the focus of this chapter.

### 10.2 FUNCTIONS OF THE DIGESTIVE SYSTEM

Food provides the raw materials or nutrients that cells use to reproduce and to build new tissue. The energy needed for cell reproduction and tissue building is released from food in the process of cell respiration. The function of the **digestive system** is to change the complex

organic nutrient molecules into simple organic and inorganic molecules that can then be absorbed into the blood or lymph to be transported to cells.

Overall, the digestive system performs six basic processes:

- 1. Ingestion.** This process involves taking foods and liquids into the mouth (eating).
- 2. 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.
- 3. Mixing and propulsion.** Alternating contractions and relaxations of smooth muscle in the walls of the GI tract mix food and secretions and propel them toward the anus. This capability of the GI tract to mix and move material along its length is called **motility**.
- 4. 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.

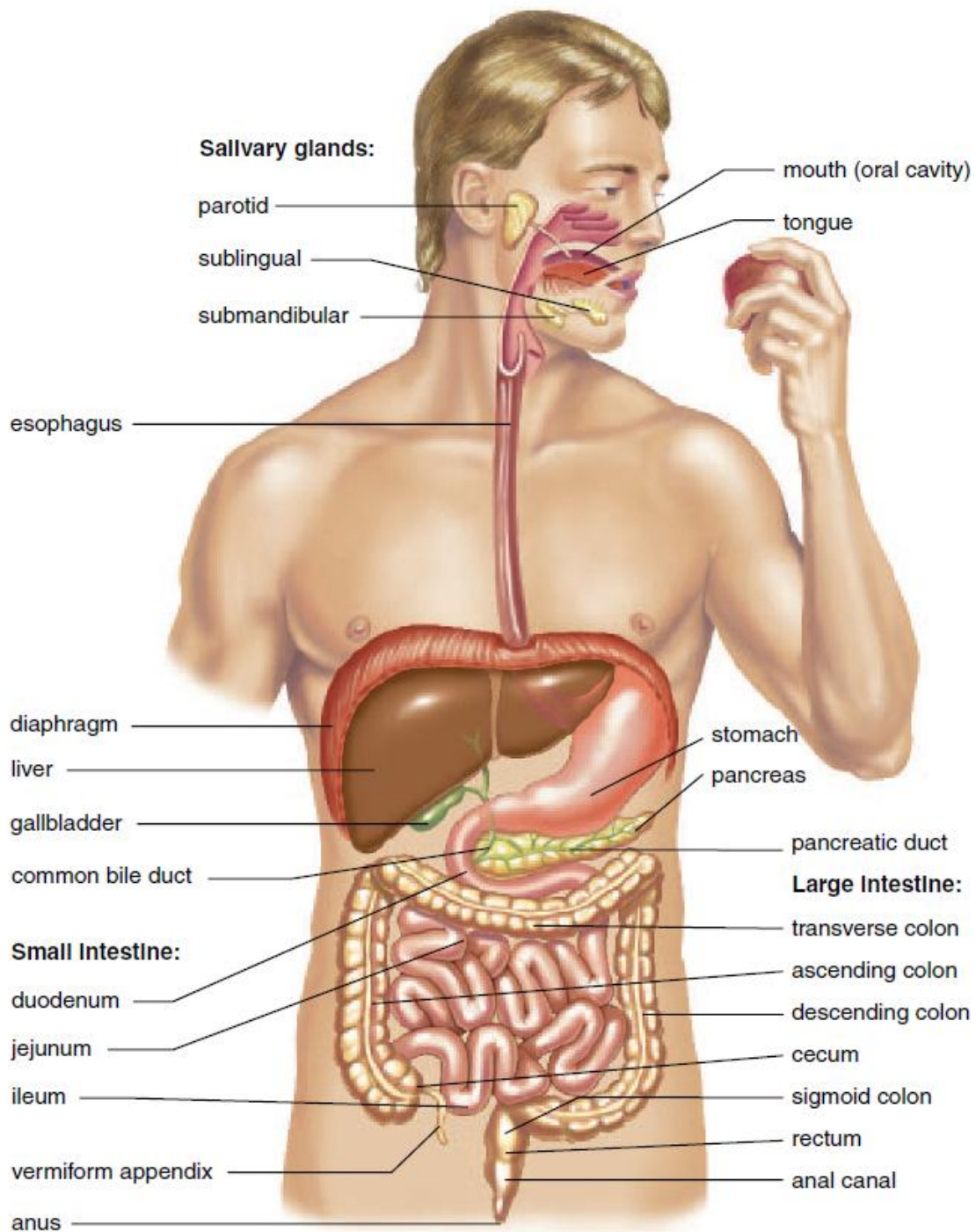
In **chemical digestion** the large carbohydrate, lipid, protein, and nucleic acid molecules in food are split into smaller molecules by hydrolysis. Digestive enzymes produced by the salivary glands, tongue, stomach, pancreas, and small intestine catalyze these catabolic reactions.

A few substances in food can be absorbed without chemical digestion. These include vitamins, ions, cholesterol, and water.

**5. Absorption.** Is the entrance of ingested and secreted fluids, ions, and the products of digestion into the epithelial cells lining the lumen of the GI tract is called **absorption**. The absorbed substances pass into blood or lymph and circulate to cells throughout the body.

**6. Defecation /Elimination.** Here the 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. The eliminated material is termed **feces**.

### 10.3 DIVISIONS OF THE DIGESTIVE SYSTEM



**Figure:** Digestive system. Trace the path of food from the mouth to the anus. The large intestine consists of the cecum, the colon (composed of the ascending, transverse, descending, and sigmoid colon), the rectum, and the anal canal. Note also the location of the accessory organs of digestion: the pancreas, the liver, and the gallbladder.

Two groups of organs compose the digestive system, the **gastrointestinal (GI) tract** and the **accessory digestive organs**.

**The gastrointestinal (GI) tract, or alimentary canal** is a continuous tube that extends from the mouth to the anus through the thoracic and abdominopelvic cavities.

**Organs** of the gastrointestinal tract include the **mouth, most of the pharynx, esophagus, stomach, small intestine, and large intestine**. The length of the GI tract is about 5–7 meters in a living person. It is longer in a cadaver (about 7–9 meters).

The **accessory digestive organs** include the **teeth, tongue, salivary glands, liver, gallbladder, and pancreas**.

Teeth aid in the physical breakdown of food, and the tongue assists in chewing and swallowing.

The other accessory digestive organs, however, never come into direct contact with food. They produce or store secretions that flow into the GI tract through ducts; these secretions aid in the chemical breakdown of food.

The GI tract contains food from the time it is eaten until it is digested and absorbed or eliminated. Muscular contractions in the wall of the GI tract physically break down the food by churning it and propel the food along the tract, from the esophagus to the anus. The contractions also help to dissolve foods by mixing them with fluids secreted into the tract. **Enzymes** secreted by accessory digestive organs and cells that line the tract break down the food chemically.

## 10.4 TYPES OF DIGESTION

The food we eat is broken down in two complementary processes:

**Mechanical digestion** is the physical breaking up of food into smaller pieces. Chewing is an example of this. As food is broken up, more of its surface area is exposed for the action of digestive enzymes.

The work of the digestive enzymes is the **chemical digestion** of broken-up food particles, in which complex chemical molecules are changed into much simpler chemicals that the body can utilize. Such enzymes are specific with respect to the fat, protein, or carbohydrate food molecules each can digest. For example, protein-digesting enzymes work only on proteins, not on carbohydrates or fats. Each enzyme is produced by a particular digestive organ and functions at a specific site. However, the enzyme's site of action may or may not be its site of production.

## 10.5 END PRODUCTS OF DIGESTION

The three types of complex organic molecules found in food are carbohydrates, proteins, and fats. Each of these complex molecules is digested to a much more simple substance that the body can then use.

Carbohydrates, such as starches and disaccharides, are digested to monosaccharides such as glucose, fructose, and galactose.

Proteins are digested to amino acids, and

Fats are digested to fatty acids and glycerol.

Also part of food, and released during digestion, are vitamins, minerals, and water.

## 10.6 GENERAL STRUCTURAL LAYERS OF THE ALIMENTARY TUBE

The wall of the GI tract from the lower esophagus to the anal canal has **the same basic, four-layered** arrangement of tissues. The four layers of the tract, from deep to superficial, are the **mucosa, submucosa, muscularis, and serosa.**

### MUCOSA

The mucosa, or inner lining of the GI tract, is a mucous membrane.

It is composed of:

- (1) a layer of epithelium in direct contact with the contents of the GI tract,
- (2) a layer of connective tissue called the lamina propria, and
- (3) a thin layer of smooth muscle (muscularis mucosae).

1. **The epithelium** in the mouth, pharynx, esophagus, and anal canal is mainly nonkeratinized stratified squamous epithelium that serves a **protective function.**

**Simple columnar epithelium**, which functions in secretion and absorption, lines the stomach and intestines.

Located among the epithelial cells are **exocrine cells** that secrete **mucus and fluid** into the lumen of the tract, and several types of **endocrine cells**, collectively called **enteroendocrine cells**, that secrete **hormones.**

2. **The lamina propria** is areolar connective tissue containing many blood and lymphatic vessels, which are the routes by which nutrients absorbed into the GI tract reach the other tissues of the body.

The lamina propria also contains the majority of the cells of the **mucosa-associated lymphatic tissue (MALT)**. These prominent lymphatic nodules contain immune system cells that protect against disease. MALT is present all along the GI tract, especially in the tonsils, small intestine, appendix, and large intestine.

3. A **thin layer of smooth muscle fibers** called 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. Movements of the muscularis mucosae ensure that all absorptive cells are fully exposed to the contents of the GI tract.

### **SUBMUCOSA**

The **submucosa** consists of areolar connective tissue that binds the mucosa to the muscularis. It contains many blood and lymphatic vessels that receive absorbed food molecules. There is also an extensive network of neurons known as the **submucosal plexus or Meissner's plexus**. The submucosa may also contain glands and lymphatic tissue.

### **MUSCULARIS**

The **muscularis** of the mouth, pharynx, and superior and 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 tract, the muscularis consists of **smooth muscle** that is generally found in two sheets: an inner sheet of **circular fibers** and an outer sheet of **longitudinal fibers**.

Involuntary contractions of the smooth muscle help break down food, mix it with digestive secretions, and propel it along the tract.

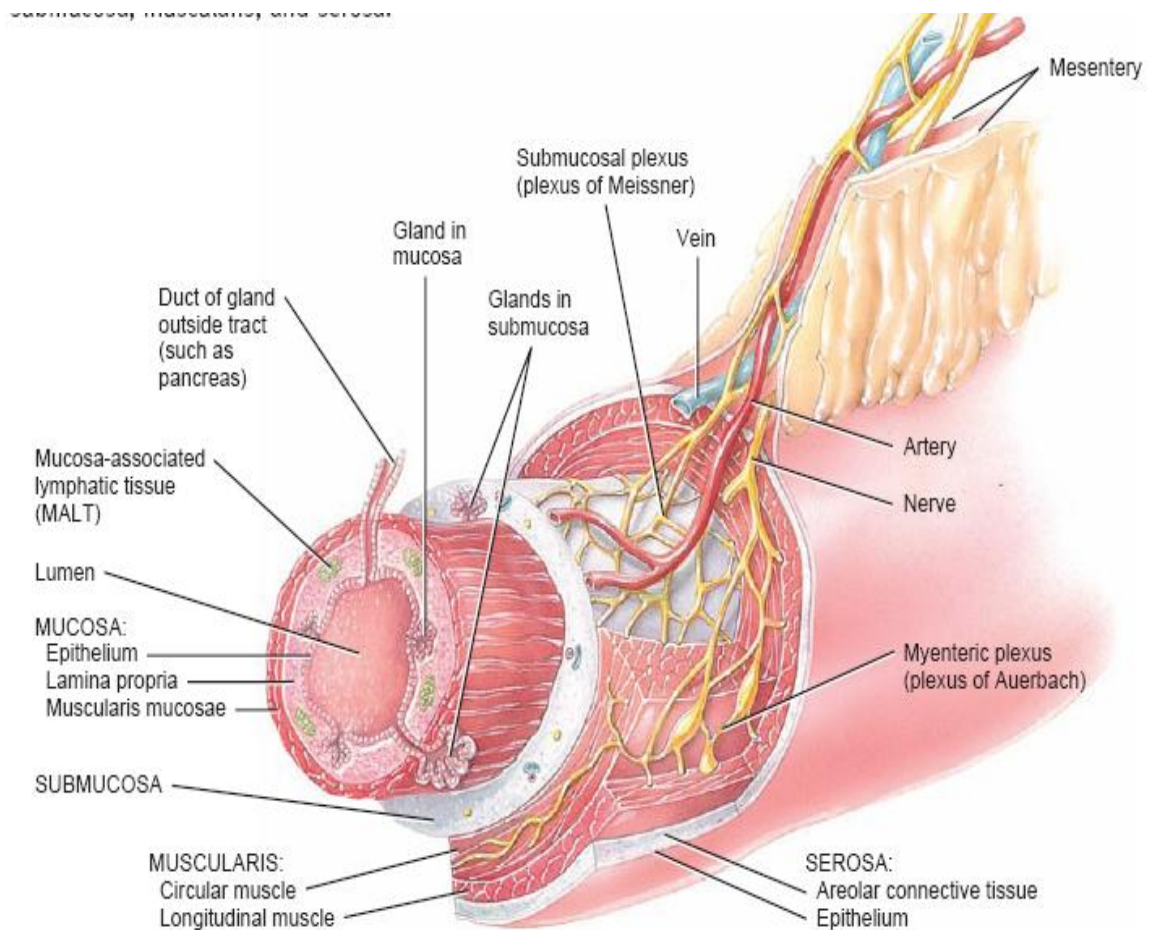
Between the layers of the muscularis is a second plexus of neurons **the myenteric plexus or Auerbach's plexus**.

### **SEROSA**

Those portions of the GI tract that are suspended in the abdominopelvic cavity have a superficial layer called the **serosa**.

As its name implies, the serosa is a serous membrane composed of areolar connective tissue and simple squamous epithelium (mesothelium). The serosa is also called the **visceral peritoneum** because it forms a portion of the peritoneum.

The esophagus lacks a serosa; instead only a single layer of areolar connective tissue called the **adventitia** forms the superficial layer of this organ.



## 10.7 DETAILS ABOUT PERTONEUM

The **peritoneum** is the largest serous membrane of the body; it consists of a layer of simple squamous epithelium (mesothelium) with an underlying supporting layer of areolar connective tissue.

The peritoneum is divided into the **parietal peritoneum**, which lines the wall of the abdominopelvic cavity, and the **visceral peritoneum**, which covers some of the organs in the cavity and is their **serosa**

The thin space containing lubricating serous fluid that is between the parietal and visceral portions of the peritoneum is called the **peritoneal cavity**. In certain diseases, the peritoneal cavity may become distended by the accumulation of several liters of fluid, a condition called **ascites**.

Some organs lie on the posterior abdominal wall and are covered by peritoneum only on their

anterior surfaces; they are not in the peritoneal cavity. Such organs, including the kidneys, ascending and descending colons of the large intestine, duodenum of the small intestine, and pancreas, are said to be **retroperitoneal**.

Unlike the pericardium and pleurae, which smoothly cover the heart and lungs, the peritoneum contains large folds that weave between the viscera. The folds bind the organs to one another and to the walls of the abdominal cavity. They also contain blood vessels, lymphatic vessels, and nerves that supply the abdominal organs.

There are five major peritoneal folds: **the greater omentum, falciform ligament, lesser omentum, mesentery, and mesocolon**.

The **greater omentum** (omentum: fat skin), the largest peritoneal fold, drapes over the transverse colon and coils of the small intestine like a fatty apron. The greater omentum is a double sheet that folds back on itself, giving it a total of four layers. From attachments along the stomach and duodenum, the greater omentum extends downward anterior to the small intestine, then turns and extends upward and attaches to the transverse colon. The greater omentum normally contains a considerable amount of adipose tissue. Its adipose tissue content can greatly expand with weight gain. The many lymph nodes of the greater omentum contribute macrophages and antibody producing plasma cells that help combat and contain infections of the GI tract.

**2. The falciform ligament** attaches the liver to the anterior abdominal wall and diaphragm. The liver is the only digestive organ that is attached to the anterior abdominal wall.

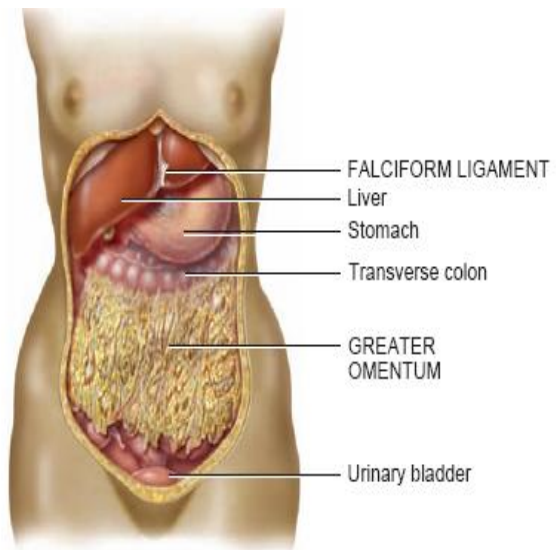
**3. The lesser omentum** arises as an anterior fold in the serosa of the stomach and duodenum, and it suspends the stomach and duodenum from the liver. It is the pathway for blood vessels entering the liver and contains the hepatic portal vein, common hepatic artery, and common bile duct, along with some lymph nodes.

**4. The mesentery** ( middle), binds the jejunum and ileum of the small intestine to the posterior abdominal wall. It extends from the posterior abdominal wall to wrap around the small intestine and then returns to its origin, forming a double-layered structure. Between the two layers are blood and lymphatic vessels and lymph nodes.

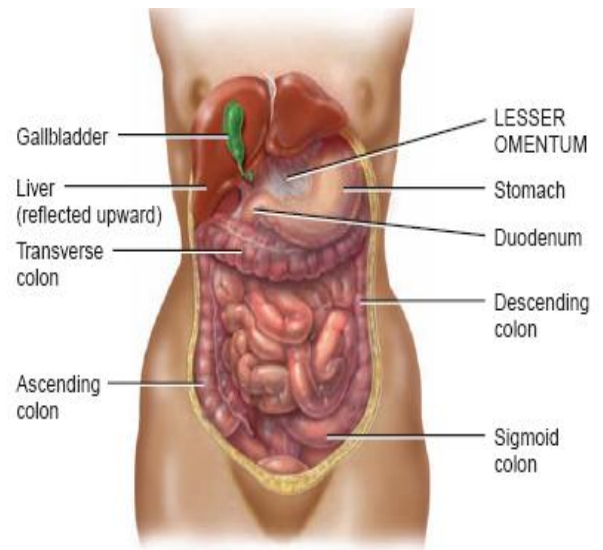
**5. Two separate folds of peritoneum, called the mesocolon** bind the transverse colon (transverse mesocolon) and sigmoid colon (sigmoid mesocolon) of the large intestine to the



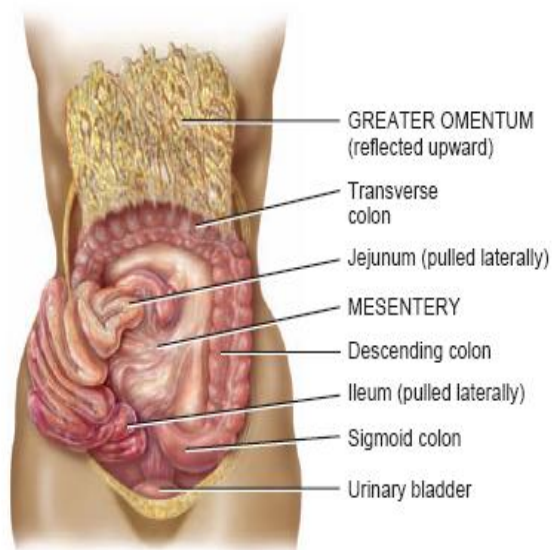
posterior abdominal wall . It also carries blood and lymphatic vessels to the intestines. Together, the mesentery and mesocolon hold the intestines loosely in place, allowing movement as muscular contractions mix and move the luminal contents along the GI tract.



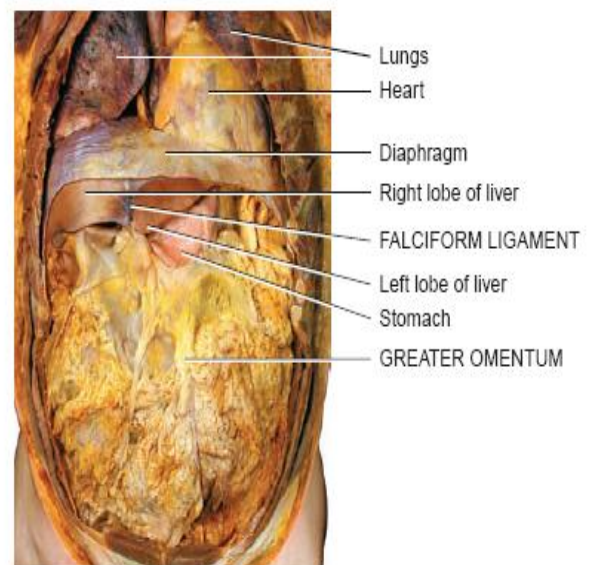
(b) Anterior view



(c) Lesser omentum, anterior view (liver and gallbladder lifted)



(d) Anterior view (greater omentum lifted and small intestine reflected to right side)



(e) Anterior view

## Neural innervations of GI tract

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

It consists of about 100 million neurons that extend from the esophagus to the anus. The neurons of the ENS are arranged into **two plexuses: the myenteric plexus and submucosal plexus**.

The **myenteric plexus** (myo- muscle), or **plexus of Auerbach**, is located between the longitudinal and circular smooth muscle layers of the muscularis.

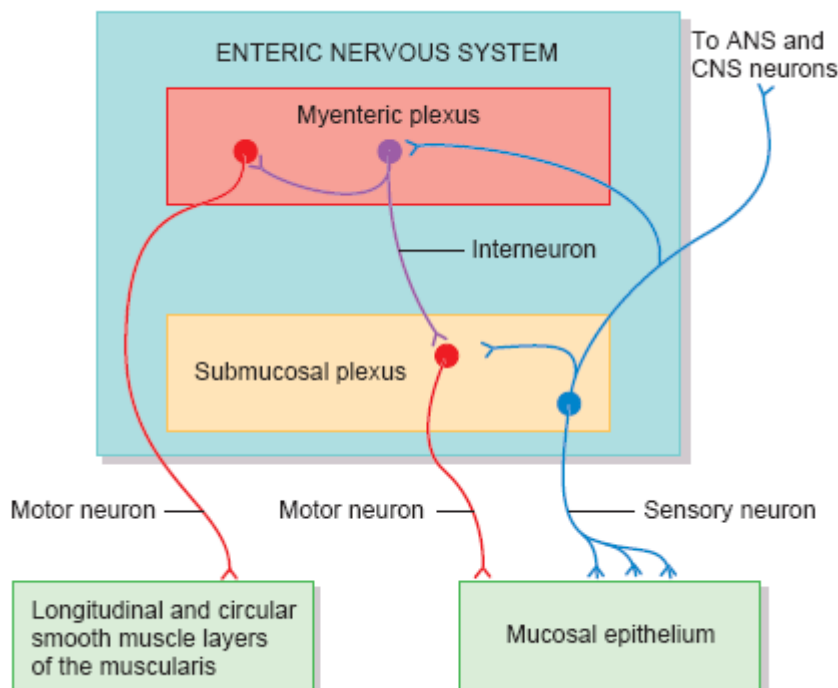
The **submucosal plexus**, or **plexus of Meissner**, is found within the submucosa.

The plexuses of the ENS consist of motor neurons, interneurons, and sensory neurons.

Because the motor neurons of the myenteric plexus supply the longitudinal and circular smooth muscle layers of the muscularis, this plexus mostly controls GI tract motility (movement), particularly the frequency and strength of contraction of the muscularis.

**The motor neurons** of the submucosal plexus supply the secretory cells of the mucosal epithelium, controlling the secretions of the organs of the GI tract.

**The interneurons** of the ENS interconnect the neurons of the myenteric and submucosal plexuses.



**The sensory neurons** of the ENS supply the mucosal epithelium. Some of these sensory neurons function **as chemoreceptors**, receptors that are activated by the presence of certain chemicals in food located in the lumen of a GI organ.

Other sensory neurons function **as stretch receptors**, receptors that are activated when food distends (stretches) the wall of a GI organ.

## **AUTONOMIC NERVOUS SYSTEM**

Although the neurons of the ENS can function independently, they are subject to regulation by the neurons 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 from the sacral spinal cord.

**The parasympathetic** nerves that supply the GI tract form neural connections with the ENS. Parasympathetic preganglionic neurons of the vagus or pelvic splanchnic 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 *GI* (gastrointestinal) 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 stretch receptors) 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.

## **MOUTH:**

The **mouth**, also referred to as the **oral** or **buccal cavity**, is formed by the cheeks, hard and soft palates, and tongue.

The **cheeks** form the lateral walls of the oral cavity. They are covered externally by skin and internally by a mucous membrane. Buccinator muscles and connective tissue lie between the skin and mucous membranes of the cheeks.

The **lips** or **labia** (fleshy borders) are fleshy folds surrounding the opening of the mouth. They contain the orbicularis oris muscle and are covered externally by skin and internally by a mucous membrane. During chewing, contraction of the buccinator muscles in the cheeks and orbicularis oris muscle in the lips helps keep food between the upper and lower teeth. These muscles also assist in speech.

The **oral vestibule** of the oral cavity is a space bounded externally by the cheeks and lips and internally by the gums and teeth. The **oral cavity proper** is a space that extends from the gums and teeth to the **fauces**, the opening between the oral cavity and the oropharynx(throat). The **palate** is a wall or septum that separates the oral cavity from the nasal cavity, forming the roof of the mouth. This important structure makes it possible to chew and breathe at the same time.

The **hard palate** the anterior portion of the roof of the mouth is formed by the maxillae and palatine bones and is covered by a mucous membrane; it forms a bony partition between the oral and nasal cavities.

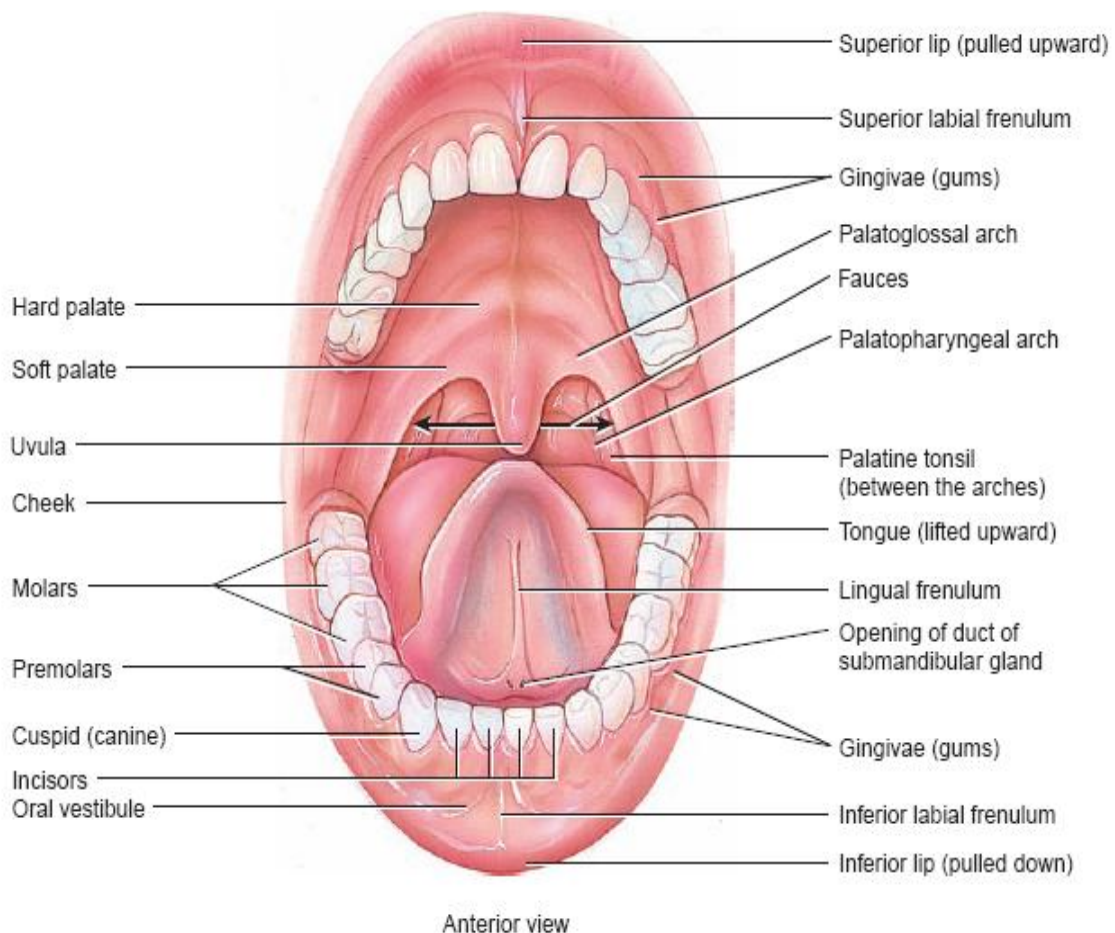
The **soft palate**, which forms the posterior portion of the roof of the mouth, is an arch-shaped muscular partition between the oropharynx and nasopharynx that is lined with mucous membrane.

Hanging from the free border of the soft palate is a conical muscular process called the **uvula**.

During swallowing, the soft palate and uvula are drawn superiorly, closing off the nasopharynx and preventing swallowed foods and liquids from entering the nasal cavity.

Lateral to the base of the uvula are two muscular folds that run down the lateral sides of the soft palate: Anteriorly, the **palatoglossal arch** extends to the side of the base of the tongue; posteriorly, the **palatopharyngeal arch** extends to the side of the pharynx.

The **palatine tonsils** are situated between the arches, and the **lingual tonsils** are situated at the base of the tongue. At the posterior border of the soft palate, the mouth opens into the oropharynx through the fauces



## SALIVARY GLANDS

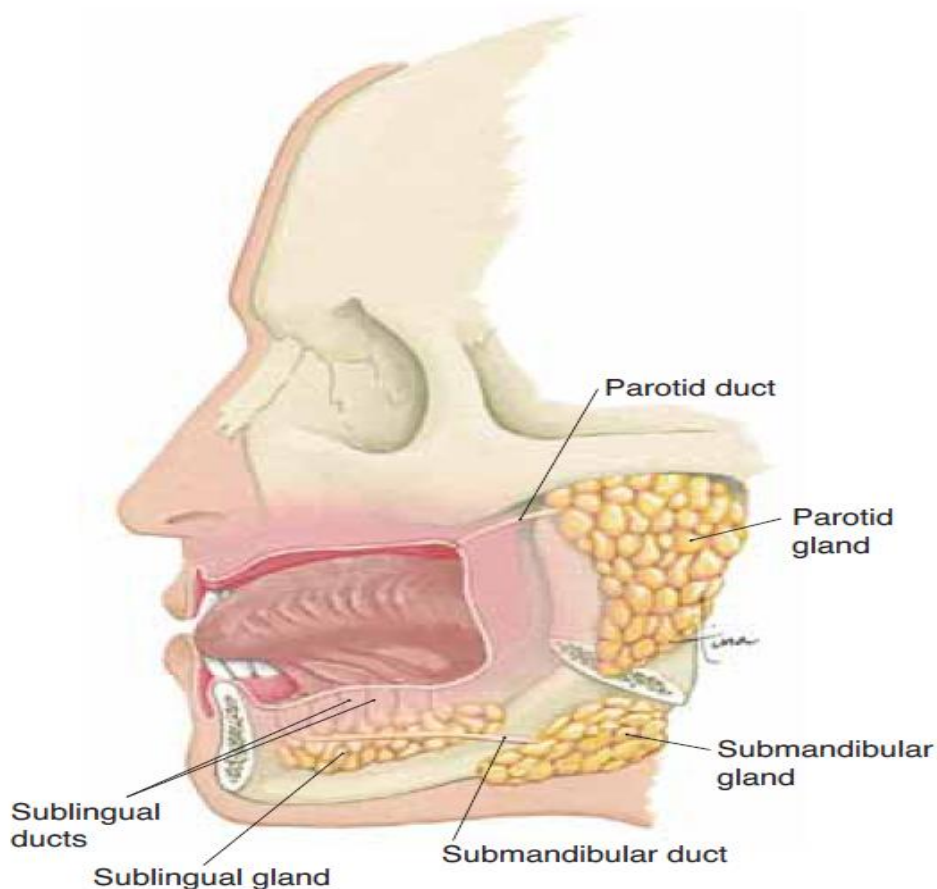
A **salivary gland** is a gland that releases a secretion called saliva into the oral cavity. Ordinarily, just enough saliva is secreted to keep the mucous membranes of the mouth and pharynx moist and to cleanse the mouth and teeth. When food enters the mouth, however, secretion of saliva increases, and it lubricates, dissolves, and begins the chemical breakdown of the food. The mucous membrane of the mouth and tongue contains **many small salivary glands** that open directly, or indirectly via short ducts, to the oral cavity. These glands include **labial, buccal, and palatal glands** in the lips, cheeks, and palate, respectively, and **lingual glands** in the tongue, all of which make a small contribution to saliva.

However, most saliva is secreted by the **major salivary glands**, which lie beyond the oral mucosa, into ducts that lead to the oral cavity. **There are three pairs of major salivary glands: the parotid, submandibular, and sublingual glands**

The **parotid glands** are located inferior and anterior to the ears, between the skin and the masseter muscle. Each secretes saliva into the oral cavity via a **parotid duct**.

The **submandibular glands** are found in the floor of the mouth; they are medial and partly inferior to the body of the mandible. Their ducts are the **submandibular ducts**.

The **sublingual glands** are beneath the tongue and superior to the submandibular glands. Their ducts are the **lesser sublingual ducts**.



**Figure:** The salivary glands shown in left lateral view.

### **Composition and Functions of Saliva**

Chemically, **saliva** is 99.5% water and 0.5% solutes. Among the solutes are ions, including sodium, potassium, chloride, bicarbonate, and phosphate. Also present are some dissolved gases and various organic substances, including urea and uric acid, mucus, immunoglobulin A, the bacteriolytic enzyme lysozyme and salivary amylase, a digestive enzyme that acts on starch.

**The water** in saliva provides a medium for **dissolving foods** so that they can be tasted by gustatory receptors and so that digestive reactions can begin.

**Chloride ions** in the saliva activate salivary amylase, an enzyme that starts the breakdown of starch.

**Bicarbonate and phosphate ions** buffer acidic foods that enter the mouth, so saliva is only slightly acidic (pH 6.35–6.85).

Salivary glands help **remove waste** molecules from the body, which accounts for the presence of urea and uric acid in saliva.

**Mucus** lubricates food so it can be moved around easily in the mouth, formed into a ball, and swallowed.

**Immunoglobulin A (IgA)** prevents attachment of microbes so they cannot penetrate the epithelium, and the enzyme **lysozyme** kills bacteria.

### **Salivation**

The secretion of saliva, called **salivation** is controlled by the **autonomic nervous system**.

Amounts of saliva secreted daily vary considerably but average 1000–1500 mL

Normally, **parasympathetic stimulation** promotes continuous secretion of a moderate amount of saliva, which keeps the mucous membranes moist and lubricates the movements of the tongue and lips during speech.

The saliva is then swallowed and helps moisten the esophagus. Eventually, most components of saliva are reabsorbed, which prevents fluid loss.

**Sympathetic stimulation** dominates during stress, resulting in dryness of the mouth.

If the body becomes dehydrated, the salivary glands stop secreting saliva to conserve water; the resulting dryness in the mouth contributes to the sensation of thirst.

**The feel and taste of food** also are stimulators of salivary gland secretions.

The smell, sight, sound, or thought of food may also stimulate secretion of saliva.

The **tongue** is an accessory digestive organ composed of **skeletal muscle** covered with mucous membrane. Together with its associated muscles, it forms the **floor** of the oral cavity. The tongue is divided into symmetrical lateral halves by a median septum that extends its entire length, and it is attached inferiorly to the hyoid bone, styloid process of the temporal bone, and mandible.

Each half of the tongue consists of an identical complement of **extrinsic and intrinsic muscles**.

The **extrinsic muscles** of the tongue, which include the **hyoglossus, genioglossus, and styloglossus** move the tongue from side to side and in and out to maneuver food for chewing, shape the food into a rounded mass, and force the food to the back of the mouth for swallowing. They also form the floor of the mouth and hold the tongue in position.

The **intrinsic muscles** alter the shape and size of the tongue for speech and swallowing. The intrinsic muscles include the **longitudinalis superior, longitudinalis inferior, transversus linguae, and verticalis linguae muscles**.

The dorsum (upper surface) and lateral surfaces of the tongue are covered with **papillae** which contain **taste buds**, the receptors for gustation (taste). Some papillae lack taste buds, but they contain receptors for **touch** and increase friction between the tongue and food, making it easier for the tongue to move food in the oral cavity.

**Lingual glands** of the tongue secrete both mucus and a watery serous fluid that contains the enzyme **lingual lipase**, which acts on triglycerides.

## TEETH

The **teeth**, or **dentes**, are accessory digestive organs located in sockets of the alveolar processes of the mandible and maxillae.

The alveolar processes are covered by the **gingivae**, or gums, which extend slightly into each socket. The sockets are lined by the **periodontal ligament** or **membrane** (odont- tooth), that anchors the teeth to the socket walls.

A typical tooth has **three major external regions: the crown, root, and neck**.

The **crown** is the visible portion above the level of the gums.

The **root**, they are one to three roots embedded in the socket

The **neck** is the constricted junction of the crown and root near the gum line.

**Internally, dentin** forms the majority of the tooth. Dentin gives the tooth its basic shape and rigidity. The dentin of the crown is covered by **enamel**, which consists primarily of calcium phosphate and calcium carbonate. Enamel serves to protect the tooth from the wear and tear of chewing. It also protects against acids that concerned with the treatment of abnormal conditions of the tissues immediately surrounding the teeth, such as gingivitis.

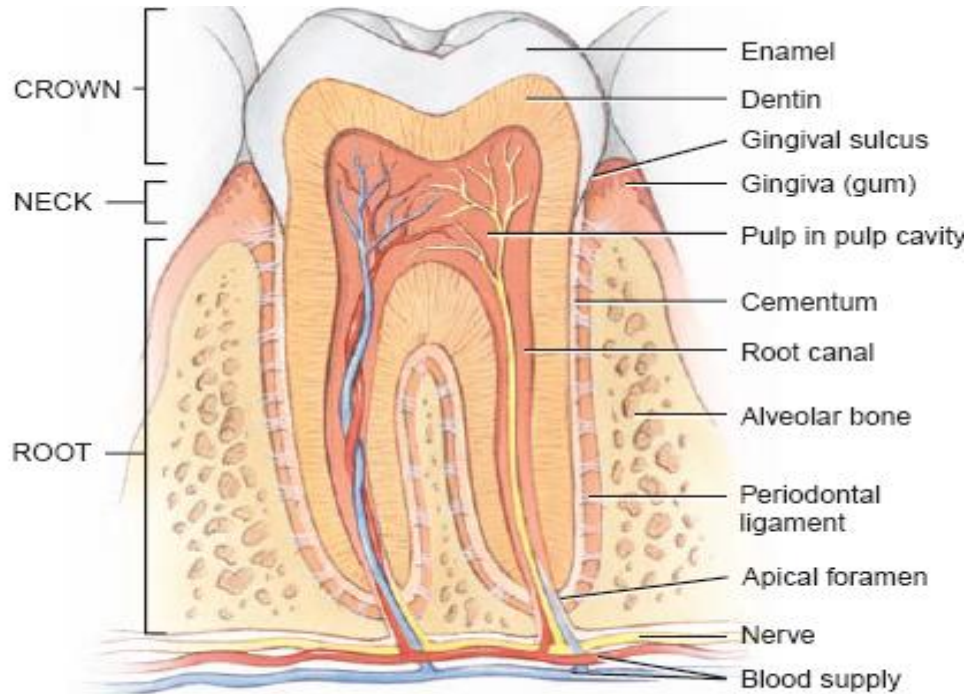
The dentin of the root is covered by **cementum**, another bonelike substance, which attaches the root to the periodontal ligament.

The dentin of a tooth encloses a space. The enlarged part of the space, the **pulp cavity**, lies within the crown and is filled with **pulp**, a connective tissue containing blood vessels, nerves,



and lymphatic vessels.

Narrow extensions of the pulp cavity, called **root canals**, run through the root of the tooth. Each root canal has an opening at its base, the **apical foramen**, through which blood vessels, lymphatic vessels, and nerves extend.



Sagittal section of a mandibular (lower) molar

Humans have two **dentitions**, or sets of teeth: **deciduous and permanent**.

The **deciduous teeth** (decidu- falling out), also called **primary teeth, milk teeth, or baby teeth** begin to erupt at about **6 months** of age, and approximately two teeth appear each month thereafter, until all 20 are present usually complete by the age of **2 years**.

**The incisors** are adapted for cutting into food, based to their position they are **central** or **lateral incisors**.

Next to the incisors, moving posteriorly, are the **cuspid (canines)**, which have a pointed surface called a **cusp**. Cuspids are used to tear and shred food.

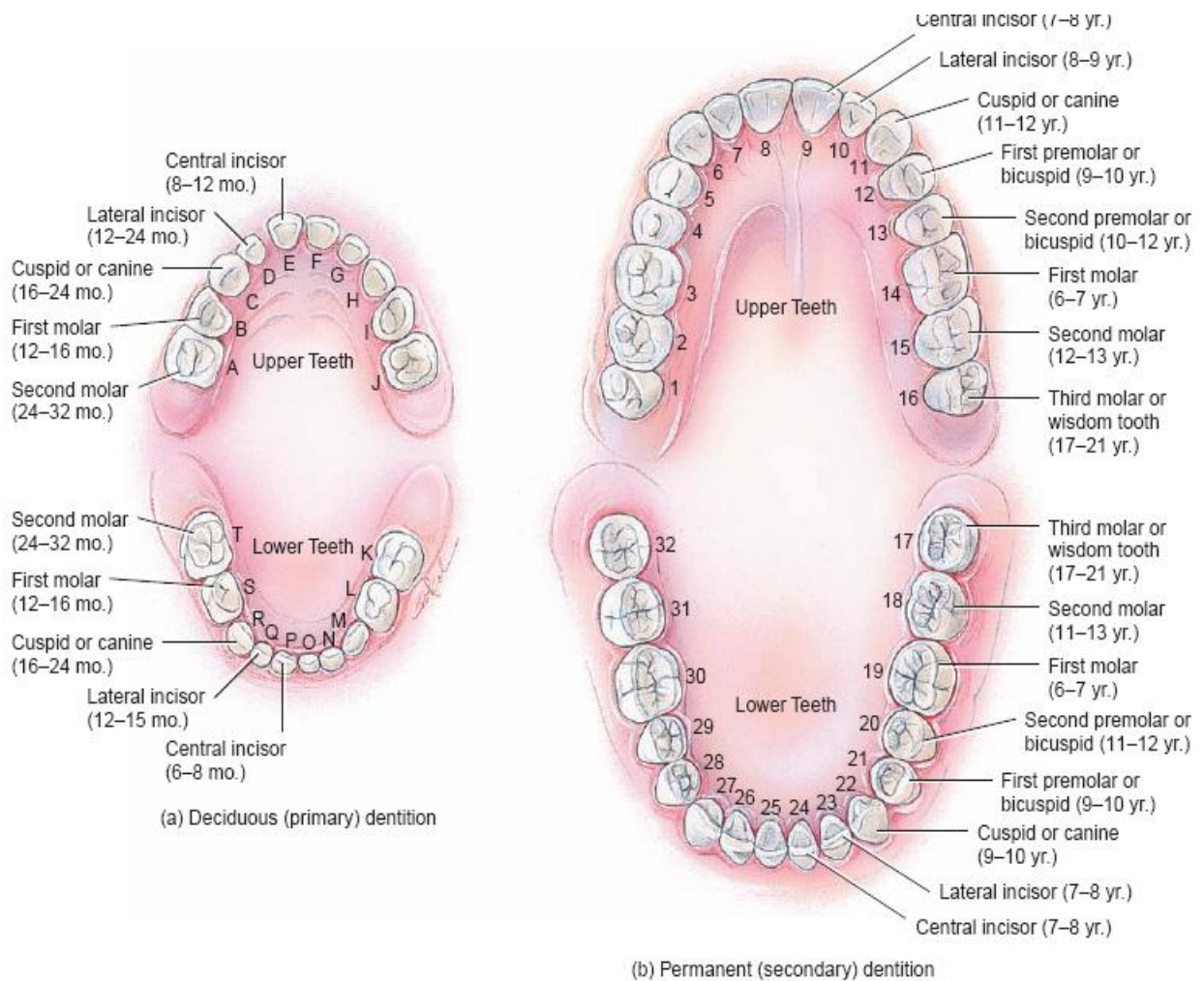
Posterior to the cuspids lie the **first and second molars**, which have four cusps. The molars crush and grind food to prepare it for swallowing.

All the deciduous teeth are lost generally between ages **6 and 12 years** and are replaced by the **permanent (secondary) teeth**. The permanent dentition contains 32 teeth that erupt between age 6 and adulthood. The pattern resembles the deciduous dentition, with the following exceptions.

The deciduous molars are replaced by the **first and second premolars (bicuspid)**,

The **permanent molars**, which erupt into the mouth posterior to the premolars, do not replace any deciduous teeth and erupt as the jaw grows to accommodate them. The **first molars** at age 6 (six-year molars), the **second molars** at age 12 (twelve-year molars), and the **third molars (wisdom teeth)** after age 17 or not at all.

Often the human jaw does not have enough room posterior to the second molars to accommodate the eruption of the third molars. In this case, the third molars remain embedded in the alveolar bone and are said to be **impacted**. They often cause pressure and pain and must be removed surgically.



## Summary of Digestive Activities in the Mouth

STRUCTURE	ACTIVITY	RESULT
Cheeks and lips	Keep food between teeth.	Foods uniformly chewed during mastication.
Salivary glands	Secrete saliva.	Lining of mouth and pharynx moistened and lubricated. Saliva softens, moistens, and dissolves food and cleanses mouth and teeth. Salivary amylase splits starch into smaller fragments.
Tongue		
Extrinsic tongue muscles	Move tongue from side-to-side and in and out.	Food maneuvered for mastication, shaped into bolus, and maneuvered for swallowing.
Intrinsic tongue muscles	Alter shape of tongue.	Swallowing and speech.
Taste buds	Serve as receptors for gustation (taste) and presence of food in mouth.	Secretion of saliva stimulated by nerve impulses from taste buds to salivary nuclei in brain stem to salivary glands.
Lingual glands	Secrete lingual lipase.	Triglycerides broken down into fatty acids and diglycerides.
Teeth	Cut, tear, and pulverize food.	Solid foods reduced to smaller particles for swallowing.

## PHARYNX

When food is first swallowed, it passes from the mouth into the **pharynx**, a funnel-shaped tube that extends from the internal nares to the esophagus posteriorly and to the larynx anteriorly. The pharynx is composed of skeletal muscle and lined by mucous membrane, and as described in the preceding chapter is divided into three parts: the nasopharynx, the oropharynx, and the laryngopharynx. The nasopharynx functions only in respiration, but both the oropharynx and laryngopharynx have digestive as well as respiratory functions. Swallowed food passes from the mouth into the oropharynx and laryngopharynx; the muscular contractions of these areas help propel food into the esophagus and then into the stomach. No digestion takes place in the pharynx. Its only related function is swallowing, the mechanical movement of food. When the bolus of food is pushed backward by the tongue, the constrictor muscles of the pharynx contract as part of the swallowing reflex. The reflex center for swallowing is in the medulla, which coordinates the many actions that take place: constriction of the pharynx, cessation of breathing, elevation of the soft palate to block the nasopharynx, elevation of the larynx and closure of the epiglottis, and peristalsis of the esophagus.

## ESOPHAGUS

The **esophagus** is a collapsible muscular tube, about 25 cm (10 in.) long, that lies posterior to the trachea. The esophagus begins at the inferior end of the laryngopharynx and passes through the mediastinum anterior to the vertebral column. Then it pierces the diaphragm through an opening called the **esophageal hiatus**, and ends in the superior portion of the stomach. Sometimes, part of the stomach protrudes above the diaphragm through the esophageal hiatus. This condition, termed a **hiatus hernia**.

At **each end of the esophagus**, the muscularis becomes slightly more prominent and forms two sphincters, the **upper esophageal sphincter (UES)**, which consists of skeletal muscle, and the **lower esophageal sphincter (LES)**, which consists of smooth muscle.

The upper esophageal sphincter regulates the movement of food from the pharynx into the esophagus;

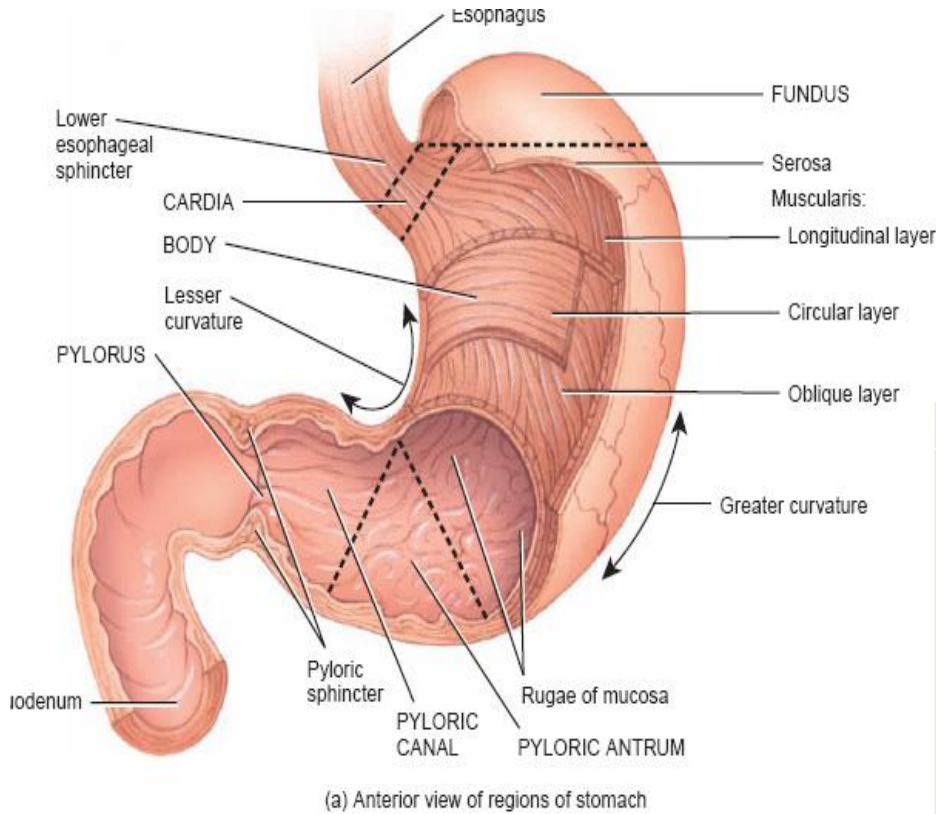
The lower esophageal sphincter regulates the movement of food from the esophagus into the stomach, that means the LES relaxes to permit food to enter the stomach, and then contracts to prevent the backup of stomach contents.

The movement of food from the mouth into the stomach is achieved by the act of swallowing, or **deglutition**. Deglutition is facilitated by the secretion of saliva and mucus and involves the mouth, pharynx, and esophagus. Swallowing occurs in **three stages**:

- (1) **the voluntary stage**, in which the bolus is passed into the oropharynx;
- (2) **the pharyngeal stage**, the involuntary passage of the bolus through the pharynx into the esophagus; and
- (3) **the esophageal stage**, the involuntary passage of the bolus through the esophagus into the stomach.

Summary of Digestive Activities in the Pharynx and Esophagus		
STRUCTURE	ACTIVITY	RESULT
Pharynx	Pharyngeal stage of deglutition.	Moves bolus from oropharynx to laryngopharynx and into esophagus; closes air passageways.
Esophagus	Relaxation of upper esophageal sphincter.	Permits entry of bolus from laryngopharynx into esophagus.
	Esophageal stage of deglutition (peristalsis).	Pushes bolus down esophagus.
	Relaxation of lower esophageal sphincter.	Permits entry of bolus into stomach.
	Secretion of mucus.	Lubricates esophagus for smooth passage of bolus.

# STOMACH

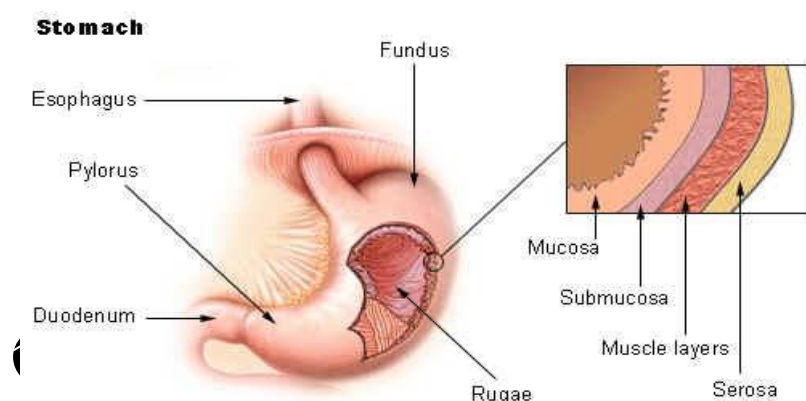


### Functions of the Stomach

1. Mixes saliva, food, and gastric juice to form chyme.
2. Serves as a reservoir for food before release into small intestine.
3. Secretes gastric juice, which contains HCl (kills bacteria and denatures protein), pepsin (begins the digestion of proteins), intrinsic factor (aids absorption of vitamin B<sub>12</sub>), and gastric lipase (aids digestion of triglycerides).
4. Secretes gastrin into blood.

The **stomach** is located in the upper left quadrant of the abdominal cavity, to the left of the liver and in front of the spleen. Although part of the alimentary tube, the stomach is not a tube, but rather a sac that extends from the esophagus to the small intestine. Because it is a sac, the stomach is a reservoir for food, so that digestion proceeds gradually and we do not have to eat constantly. Both mechanical and chemical digestion takes place in the stomach.

The **cardiac orifice** is the opening of the esophagus, and the **fundus** is the portion above the



level of this opening. The **body** of the stomach is the large central portion, bounded laterally by the greater curvature and

medially by the lesser curvature. **The pylorus** is adjacent to the duodenum of the small intestine, and the **pyloric sphincter** surrounds the junction of the two organs. **The fundus and body are mainly storage areas, whereas most digestion takes place in the pylorus.** When the stomach is empty, the mucosa appears wrinkled or folded. These folds are called **rugae**; they flatten out as the stomach is filled and permit expansion of the lining without tearing it. The **gastric pits** are the glands of the stomach and consist of several types of cells; their collective secretions are called **gastric juice**. These cells are:

**Mucous cells** secrete mucus, which coats the stomach lining and helps prevent erosion by the gastric juice.

**Chief cells** secrete **pepsinogen**, an inactive form of the enzyme **pepsin**.

**Parietal cells** produce hydrochloric acid (HCl); these cells have enzymes called **proton pumps**, which secrete H<sup>+</sup> ions into the stomach cavity. The H<sup>+</sup> ions unite with Cl<sup>-</sup> ions that have diffused from the parietal cells to form HCl in the lumen of the stomach. HCl converts pepsinogen to pepsin, which then begins the digestion of proteins to polypeptides, and also gives **gastric juice its pH of 1 to 2**. This very acidic pH is necessary for pepsin to function and also kills most microorganisms that enter the stomach. The parietal cells also secrete intrinsic factor, which is necessary for the absorption of vitamin B12.

**Enteroendocrine cells** called G cells secrete the hormone gastrin. Gastric juice is secreted in small amounts at the sight or smell of food. This is a parasympathetic response that ensures that some gastric juice will be present in the stomach when food arrives. The presence of food in the stomach causes the G cells to secrete **gastrin**, a hormone that stimulates the secretion of greater amounts of gastric juice.

The external muscle layer of the stomach consists of three layers of smooth muscle: **circular, longitudinal, and oblique layers**. These three layers are innervated by the mesenteric plexuses of the enteric nervous system. Stimulatory impulses are carried from the CNS by the vagus nerves (10th cranial) and provide for very efficient mechanical digestion to change food into a thick liquid called chyme. The pyloric sphincter is usually contracted when the stomach is churning food; it relaxes at intervals to permit small amounts of chyme to pass into the duodenum. This sphincter then contracts again to prevent the backup of intestinal contents into the stomach

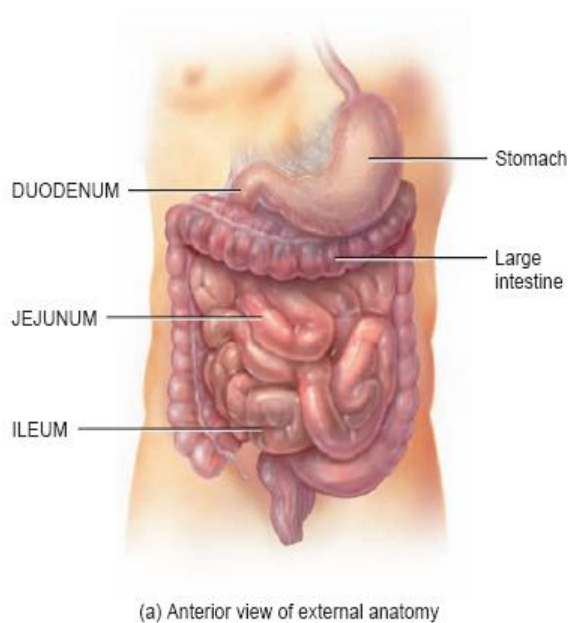
## Summary of Digestive Activities in the Stomach

STRUCTURE	ACTIVITY	RESULT
<b>MUCOSA</b>		
Chief cells	Secrete pepsinogen.	Pepsin, the activated form, breaks down proteins into peptides.
	Secrete gastric lipase.	Splits triglycerides into fatty acids and monoglycerides.
Parietal cells	Secrete hydrochloric acid.	Kills microbes in food; denatures proteins; converts pepsinogen into pepsin.
	Secrete intrinsic factor.	Needed for absorption of vitamin B <sub>12</sub> , which is used in red blood cell formation (erythropoiesis).
Surface mucous cells and mucous neck cells	Secrete mucus.	Forms a protective barrier that prevents digestion of stomach wall.
	Absorption.	Small quantity of water, ions, short-chain fatty acids, and some drugs enter the bloodstream.
G cells	Secrete gastrin.	Stimulates parietal cells to secrete HCl and chief cells to secrete pepsinogen; contracts lower esophageal sphincter, increases motility of the stomach, and relaxes pyloric sphincter.
Muscularis	Mixing waves.	Macerate food and mix it with gastric juice, forming chyme.
	Peristalsis.	Forces chyme through pyloric sphincter.
Pyloric sphincter	Opens to permit passage of chyme into duodenum.	Regulates passage of chyme from stomach to duodenum; prevents backflow of chyme from duodenum to stomach.

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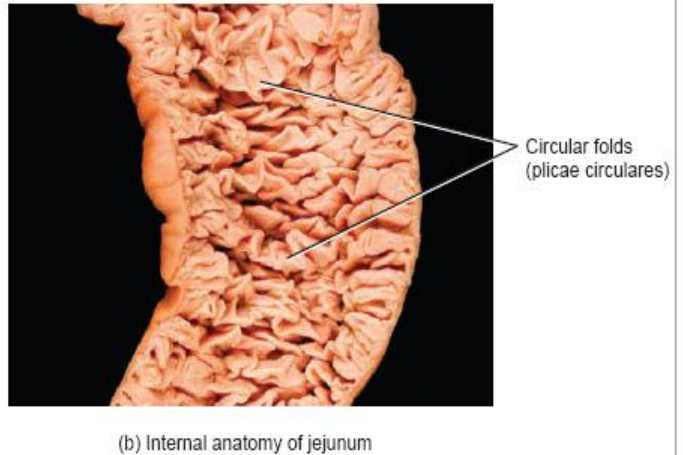


## SMALL INTESTINE



### Functions of the Small Intestine

1. Segmentations mix chyme with digestive juices and bring food into contact with the mucosa for absorption; peristalsis propels chyme through the small intestine.
2. Completes the digestion of carbohydrates, proteins, and lipids; begins and completes the digestion of nucleic acids.
3. Absorbs about 90% of nutrients and water that pass through the digestive system.



The **small intestine** is about 1 inch (2.5 cm) in diameter and approximately 20 feet (6 m) long and extends from the stomach to the cecum of the large intestine. Within the abdominal cavity, the large intestine encircles the coils of the small intestine.

The small intestine has the following parts: **duodenum, jejunum, ileum.**

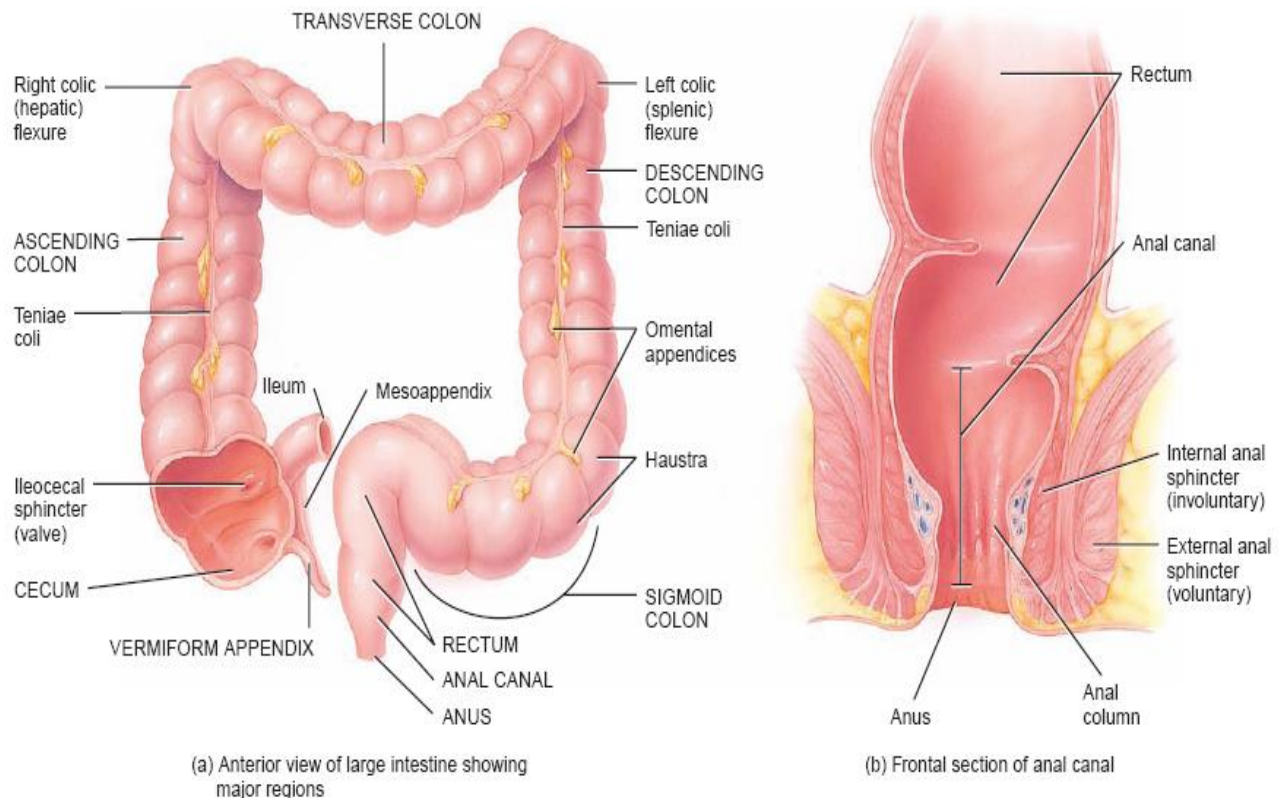
The **duodenum** is the first 10 inches (25 cm) of the small intestine. The common bile duct enters the duodenum at the ampulla of Vater (or hepatopancreatic ampulla).

The **jejunum** is about 8 feet long, and the **ileum** is about 11 feet in length.

Digestion is completed in the small intestine, and the end products of digestion are absorbed into the blood and lymph. The mucosa has simple columnar epithelium that includes cells with **microvilli and goblet cells that secrete mucus.** **Enteroendocrine** cells secrete the hormones of the small intestine. Lymph nodules called **Peyer's patches** are especially abundant in the ileum to destroy absorbed pathogens. The external muscle layer has the typical **circular and longitudinal** smooth muscle layers that mix the chyme with digestive secretions and propel the chyme toward the colon. Stimulatory impulses to the enteric nerves of these muscle layers are carried by the vagus nerves. The waves of peristalsis, however, can take place without stimulation by the central nervous system; the enteric nervous system can

function independently and promote normal peristalsis. **There are three sources of digestive secretions that function within the small intestine: the liver, the pancreas, and the small intestine itself. We will return to the small intestine after considering these other organs.**

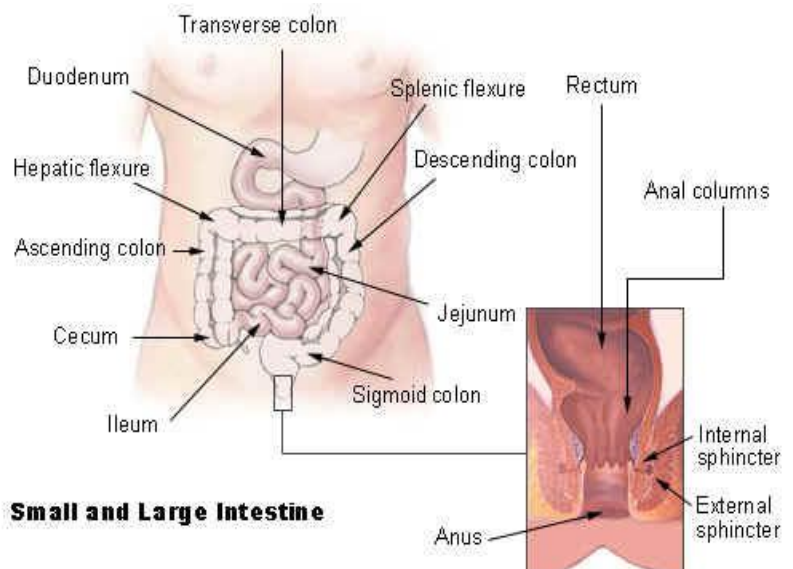
## LARGE INTESTINE



### Functions of the Large Intestine

1. Haustral churning, peristalsis, and mass peristalsis drive the contents of the colon into the rectum.
2. Bacteria in the large intestine convert proteins to amino acids, break down amino acids, and produce some B vitamins and vitamin K.
3. Absorbing some water, ions, and vitamins.
4. Forming feces.
5. Defecating (emptying the rectum).

The **large intestine**, also called the **colon**, is approximately 2.5 inches (6.3 cm) in diameter and 5 feet (1.5 m) in length. It extends from the ileum of the small intestine to the anus, the terminal opening. The **cecum** is the first portion, and at its junction with



the ileum is the **ileocecal valve**, which is not a sphincter but serves the same purpose. After undigested food (which is now mostly cellulose) and water pass from the ileum into the cecum, closure of the ileocecal valve prevents the backflow of fecal material. Attached to the cecum is the **appendix**, a small, dead-end tube with abundant lymphatic tissue. The remainder of the colon consists of the **ascending, transverse, and descending colon**, which encircle the small intestine; the **sigmoid colon**, which turns medially and downward; **the rectum; and the anal canal**. The rectum is about 6 inches long, and the anal canal is the last inch of the colon that surrounds the anus.

No digestion takes place in the colon. The only secretion of the colonic mucosa is mucus, which lubricates the passage of fecal material. The **longitudinal smooth** muscle layer of the colon is in three bands called **taeniae coli**. The rest of the colon is “gathered” to fit these bands. This gives the colon a puckered appearance; the puckers or pockets are called **haustra**, which provide for more surface area within the colon. **The functions of the colon are the absorption of water, minerals, and vitamins and the elimination of undigestible material**. About 80% of the water that enters the colon is absorbed (400 to 800 mL per day). **Positive and negative ions are also absorbed. The vitamins absorbed are those produced by the normal flora**, the trillions of bacteria that live in the colon. **Vitamin K is produced and absorbed** in amounts usually sufficient to meet a person’s daily need. **Other vitamins produced in smaller amounts include riboflavin, thiamin, biotin, and folic acid.**

## ELIMINATION OF FECES

Feces consist of cellulose and other undigestible material, dead and living bacteria, and water. Elimination of feces is accomplished by the **defecation reflex**, a spinal cord reflex that may be controlled voluntarily. The rectum is usually empty until peristalsis of the colon pushes feces into it. These waves of peristalsis tend to occur after eating, especially when food enters the duodenum. The wall of the rectum is stretched by the entry of feces, and this is the stimulus for the defecation reflex. Stretch receptors in the smooth muscle layer of the rectum generate sensory impulses that travel to the sacral spinal cord. The returning motor impulses cause the smooth muscle of the rectum to contract.

Surrounding the anus is the **internal anal sphincter**, which is made of smooth muscle. As part of the reflex, this sphincter relaxes, permitting defecation to take place. The **external anal sphincter** is made of skeletal muscle and surrounds the internal anal sphincter.

If defecation must be delayed, the external sphincter may be voluntarily contracted to close the anus. The awareness of the need to defecate passes as the stretch receptors of the rectum adapt. These receptors will be stimulated again when the next wave of peristalsis reaches the rectum.

## LIVER

The **liver** consists of two **large lobes**, right and left, and fills the upper right and center of the abdominal cavity, just below the diaphragm. **The structural unit** of the liver is the **liver lobule**, a roughly hexagonal column of liver cells (hepatocytes). Between adjacent lobules are **branches of the hepatic artery and portal vein**. **The capillaries of a lobule are sinusoids**, large and very permeable vessels between the rows of liver cells. The sinusoids receive blood from both the hepatic artery and portal vein, and it is with this mixture of blood that the liver cells carry out their functions. The hepatic artery brings oxygenated blood, and the portal vein brings blood from the digestive organs and spleen. **Each lobule has a central vein**. The central veins of all the lobules unite to form **the hepatic veins**, which take blood out of the liver to the **inferior vena cava**. The cells of the liver have many functions, but their only digestive function is the production of **bile**. Bile enters the **small bile ducts, called bile canaliculi**, on the liver cells, which unite to form **larger ducts** and finally merge to form the **hepatic duct**, which takes bile out of the liver. The hepatic duct unites with **the cystic duct** of the gallbladder to form the **common bile duct**, which takes bile to the duodenum. Bile is mostly water and has an excretory function in that it carries bilirubin and excess cholesterol to the intestines for elimination in feces. The digestive function of bile is accomplished by **bile salts**, which **emulsify** fats in the small intestine. Emulsification means that large fat globules are broken into smaller globules. This is mechanical, not chemical, digestion; the fat is still fat but now has more surface area to facilitate chemical digestion. **Production of bile is stimulated by the hormone secretin**, which is produced by the duodenum when food enters the small intestine.

## OTHER FUNCTIONS OF LIVER

The **liver** is a remarkable organ, and only the brain is capable of a greater variety of functions. The liver cells (hepatocytes) produce many enzymes that catalyze many different chemical reactions. These reactions are the functions of the liver. As blood flows through the

sinusoids (capillaries) of the liver materials are removed by the liver cells, and the products of the liver cells are secreted into the blood.

**1. Carbohydrate metabolism:** the liver regulates the blood glucose level. Excess glucose is converted to glycogen (glycogenesis) when blood glucose is high; the hormones insulin and cortisol facilitate this process. During hypoglycemia or stress situations, glycogen is converted back to glucose (glycogenolysis) to raise the blood glucose level. Epinephrine and glucagon are the hormones that facilitate this process. The liver also changes other monosaccharides to glucose. Fructose and galactose, for example, are end products of the digestion of sucrose and lactose. Because most cells, however, cannot readily use fructose and galactose as energy sources, they are converted by the liver to glucose, which is easily used by cells.

**2 Amino acid metabolism:** The liver regulates blood levels of amino acids based on tissue needs for protein synthesis. **Of the 20** different amino acids needed for the production of human proteins, the liver is able to **synthesize 12**, called the **nonessential amino acids**. The chemical process by which this is done is called **transamination**, the transfer of an amino group (NH<sub>2</sub>) from an amino acid present in excess to a free carbon chain that forms a complete, new amino acid molecule. The other **eight amino acids**, which the liver cannot synthesize, are called the **essential amino acids**. In this case, “**essential**” means that the amino acids must be supplied by our food, because the liver cannot manufacture them. Similarly, “**non-essential**” means that the amino acids do not have to be supplied in our food because the liver *can* make them. All 20 amino acids are required in order to make our body proteins. Excess amino acids, those not needed right away for protein synthesis, cannot be stored. However, they do serve another useful purpose. By the process of **deamination**, which also occurs in the liver, the NH<sub>2</sub> group is removed from an amino acid, and the remaining carbon chain may be converted to a simple carbohydrate molecule or to fat. Thus, excess amino acids are utilized for energy production: either for immediate energy or for the potential energy stored as fat in adipose tissue. The NH<sub>2</sub> groups that were detached from the original amino acids are combined to **form urea**, a waste product that will be removed from the blood by the kidneys and excreted in urine.

**3. Lipid metabolism:** The liver forms **lipoproteins**, which are molecules of lipids and proteins, for the transport of fats in the blood to other tissues. The liver also **synthesizes**

**cholesterol and excretes excess cholesterol into bile** to be eliminated in feces. Fatty acids are a potential source of energy, but in order to be used in cell respiration they must be broken down to smaller molecules. In the process of **beta-oxidation**, the long carbon chains of fatty acids are split into two-carbon molecules called **acetyl groups**, which are simple carbohydrates. These acetyl groups may be used by the liver cells to produce **ATP** or may be combined to form **ketones** to be transported in the blood to other cells. These other cells then use the ketones to produce ATP in **cell respiration**.

**4. Synthesis of plasma proteins:** The liver synthesizes many of the proteins that circulate in the blood. **Albumin**, the most abundant plasma protein, helps maintain blood volume by pulling tissue fluid into capillaries. The **clotting factors** are also produced by the liver. These, as you recall, include **prothrombin, fibrinogen, and Factor 8**, which circulate in the blood until needed in the chemical clotting mechanism. The liver also synthesizes alpha and beta **globulins**, which are proteins that serve as carriers for other molecules, such as fats, in the blood.

**5. Formation of bilirubin:** This is another familiar function: The liver contains fixed macrophages that phagocytize old red blood cells (RBCs). Bilirubin is then formed from the heme portion of the hemoglobin. The liver also removes from the blood the bilirubin formed in the spleen and red bone marrow and excretes it into bile to be eliminated in feces.

**6. Phagocytosis by Kupffer cells:** The fixed macrophages of the liver are called **Kupffer cells** (or stellate reticuloendothelial cells). Besides destroying old RBCs, Kupffer cells phagocytize pathogens or other foreign material that circulate through the liver. Many of the bacteria that get to the liver come from the colon. These bacteria are part of the normal flora of the colon but would be very harmful elsewhere in the body. The bacteria that enter the blood with the water absorbed by the colon are carried to the liver by way of portal circulation. The Kupffer cells in the liver phagocytize and destroy these bacteria, removing them from the blood before the blood returns to the heart.

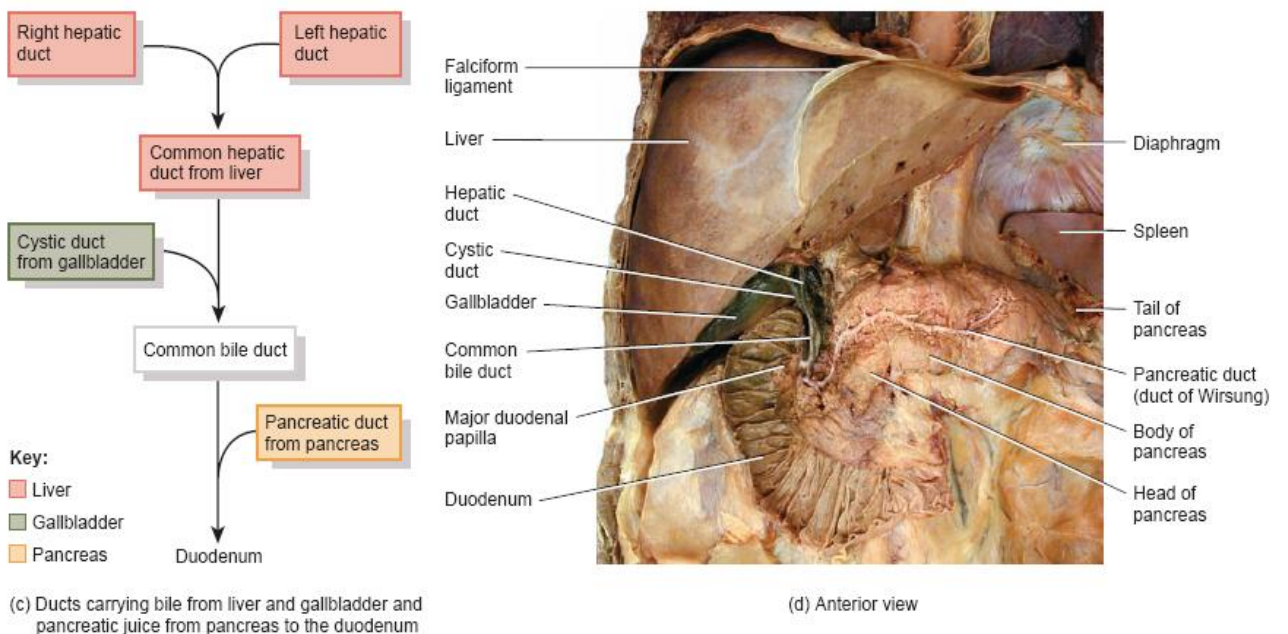
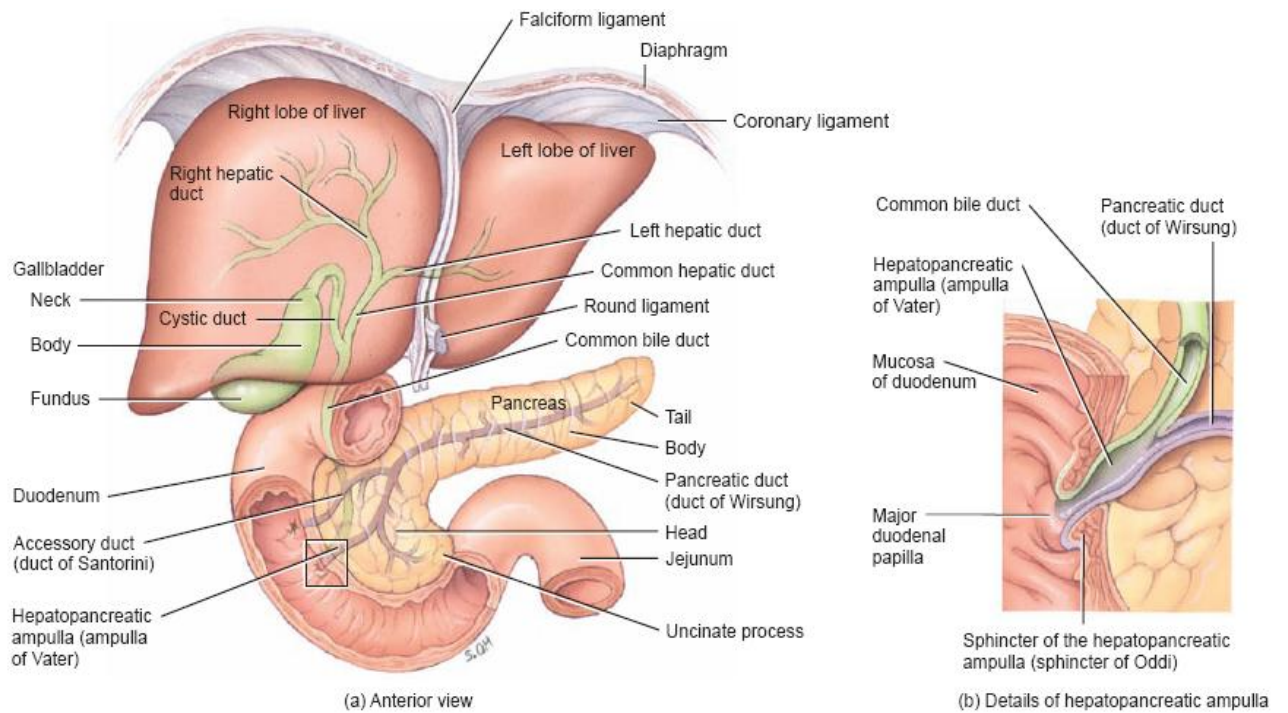
**7. Storage:** The liver stores the fat-soluble vitamins A, D, E, and K, and the water-soluble vitamin B12. Up to a 6- to 12-month supply of vitamins A and D may be stored, and beef or chicken liver is an excellent dietary source of these vitamins. Also stored by the liver are the minerals iron and copper. You already know that iron is needed for hemoglobin and

myoglobin and enables these proteins to bond to oxygen. Copper (as well as iron) is part of some of the proteins needed for cell respiration, and is part of some of the enzymes necessary for hemoglobin synthesis.

**8. Detoxification:** The liver is capable of synthesizing enzymes that will detoxify harmful substances, that is, change them to less harmful ones. **Alcohol, for example**, is changed to acetate, which is a two carbon molecule (an acetyl group) that can be used in cell respiration. **Medications** are all potentially toxic, but the liver produces enzymes that break them down or change them. When given in a proper dosage, a medication exerts its therapeutic effect but is then changed to less active substances that are usually excreted by the kidneys. An overdose of a drug means that there is too much of it for the liver to detoxify in a given time, and the drug will remain in the body with possibly harmful effects. This is why alcohol should never be consumed when taking medication. Such a combination may cause the liver's detoxification ability to be overworked and ineffective, with the result that both the alcohol and the medication will remain toxic for a longer time. Barbiturates taken as sleeping pills after consumption of alcohol have too often proved fatal for just this reason. Ammonia is a toxic substance produced by the bacteria in the colon. Because it is soluble in water, some ammonia is absorbed into the blood, but it is carried first to the liver by portal circulation. The liver converts ammonia to urea, a less toxic substance, before the ammonia can circulate and damage other organs, especially the brain. The urea formed is excreted by the kidneys.

## GALLBLADDER

The **gallbladder** is a sac about 3 to 4 inches (7.5 to 10 cm) long located on the undersurface of the right lobe of the liver. Bile in the hepatic duct of the liver flows through the **cystic duct** into the gallbladder ; which stores bile until it is needed in the small intestine. The gallbladder also concentrates bile by absorbing water .When fatty foods enter the duodenum, the enteroendocrine cells of the duodenal mucosa secrete the hormone **cholecystokinin**. This hormone stimulates contraction of the smooth muscle in the wall of the gallbladder, which forces bile into the cystic duct, then into the common bile duct, and on into the duodenum.



## PANCREAS

The **pancreas** is located in the upper left abdominal quadrant between the curve of the duodenum and the spleen and is about 6 inches (15 cm) in length.

**The endocrine functions** of the pancreas were discussed in the Chapter (endocrine system), so only **the exocrine functions** will be considered here.



The **exocrine glands** of the pancreas are called **acini** (singular: acinus). They produce enzymes that are involved in the digestion of all three types of complex food molecules. The pancreatic enzyme **amylase** digests starch to maltose. **Lipase** converts emulsified fats to fatty acids and glycerol. The emulsifying or fat-separating action of bile salts increases the surface area of fats so that lipase works effectively. **Trypsinogen** is an inactive enzyme that is changed to active **trypsin** in the duodenum. Trypsin digests **polypeptides** to shorter chains of amino acids. The **pancreatic enzyme juice** is carried by **small ducts** that unite to form **larger ducts**, then finally the main **pancreatic duct**. An accessory duct may also be present. The main pancreatic duct emerges from the medial side of the pancreas and joins the common bile duct to the duodenum. The pancreas also produces a **bicarbonate juice** (containing sodium bicarbonate), which is alkaline. Because the gastric juice that enters the duodenum is very acidic, it must be neutralized to prevent damage to the duodenal mucosa. This neutralizing is accomplished by **the sodium bicarbonate in pancreatic juice**, and the pH of the duodenal chyme is raised to about 7.5. Secretion of pancreatic juice is stimulated by the hormones **secretin and cholecystokinin**, which are produced by the duodenal mucosa when chyme enters the small intestine. **Secretin** stimulates the production of bicarbonate juice by the pancreas, and **cholecystokinin** stimulates the secretion of the pancreatic enzymes.

## ABSORPTION

Most absorption of the end products of digestion takes place in the small intestine (although the stomach does absorb water and alcohol). The process of absorption requires a large surface area, which is provided by several structural modifications of the small intestine. **Plica circulares**, or circular folds, are macroscopic folds of the mucosa and submucosa, somewhat like accordion pleats. The mucosa is further folded into projections called **villi**, which give the inner surface of the intestine a velvet like appearance. Each columnar cell of the villi also has **microvilli** on its free surface. Microvilli are microscopic folds of the cell membrane, and are collectively called the brush border. The absorption of nutrients takes place from the lumen of the intestine into the vessels within the villi. Notice that within each villus is a **capillary network** and a **lacteal**, which is a dead-end lymph capillary. **Water-soluble nutrients** are absorbed into the blood in the capillary networks. **Monosaccharides, amino acids, positive ions, and the water-soluble vitamins (vitamin C and the B vitamins)** are absorbed by active transport.

**Negative ions** may be absorbed by either passive or active transport mechanisms. **Water** is absorbed by osmosis following the absorption of minerals, especially **sodium**. **Certain nutrients** have additional special requirements for their absorption: For example, **vitamin B12** requires the intrinsic factor produced by the parietal cells of the gastric mucosa, and the efficient absorption of **calcium ions** requires parathyroid hormone and vitamin D. **Fat-soluble nutrients** are absorbed into the lymph in the lacteals of the villi. Bile salts are necessary for the efficient absorption of **fatty acids** and the **fat-soluble vitamins** (A, D, E, and K). Once absorbed, fatty acids are recombined with glycerol to form triglycerides. These triglycerides then form globules that include cholesterol and protein; these lipid–protein complexes are called **chylomicrons**.

In the form of chylomicrons, most absorbed fat is transported by the lymph and eventually enters the blood in the left subclavian vein. Blood from the capillary networks in the villi does not return directly to the heart but first travels through the portal vein to the liver. This pathway enables the liver to regulate the blood levels of glucose and amino acids, store certain vitamins, and remove potential poisons from the blood.

## REGULATION OF DIGESTIVE SECRETIONS

Secretion	Nervous Regulation	Chemical Regulation
Saliva	Presence of food in mouth or sight of food; parasympathetic impulses along 7th and 9th cranial nerves	None
Gastric juice	Sight or smell of food; parasympathetic impulses along 10th cranial nerves	Gastrin produced by the G cells of the gastric mucosa when food is present in the stomach
Bile: Secretion by the liver	None	Secretin produced by the enteroendocrine cells of the duodenum when chyme enters
Contraction of	None	Cholecystokinin—produced by the enteroendocrine cells of

the gallbladder		the duodenum when chyme enters
Enzyme pancreatic juice	None	Cholecystokinin from the duodenum
Bicarbonate pancreatic juice	None	Secretin from the duodenum
Intestinal juice	Presence of chyme in the duodenum; parasympathetic impulses along 10th cranial nerves	None

## Summary of Digestive Enzymes

ENZYME	SOURCE	SUBSTRATES	PRODUCTS
<b>SALIVA</b>			
Salivary amylase	Salivary glands.	Starches (polysaccharides).	Maltose (disaccharide), maltotriose (trisaccharide), and $\alpha$ -dextrins.
Lingual lipase	Lingual glands in the tongue.	Triglycerides (fats and oils) and other lipids.	Fatty acids and diglycerides.
<b>GASTRIC JUICE</b>			
Pepsin (activated from pepsinogen by pepsin and hydrochloric acid)	Stomach chief cells.	Proteins.	Peptides.
Gastric lipase	Stomach chief cells.	Triglycerides (fats and oils).	Fatty acids and monoglycerides.
<b>PANCREATIC JUICE</b>			
Pancreatic amylase	Pancreatic acinar cells.	Starches (polysaccharides).	Maltose (disaccharide), maltotriose (trisaccharide), and $\alpha$ -dextrins.
Trypsin (activated from trypsinogen by enterokinase)	Pancreatic acinar cells.	Proteins.	Peptides.
Chymotrypsin (activated from chymotrypsinogen by trypsin)	Pancreatic acinar cells.	Proteins.	Peptides.
Elastase (activated from proelastase by trypsin)	Pancreatic acinar cells.	Proteins.	Peptides.
Carboxypeptidase (activated from procarboxypeptidase by trypsin)	Pancreatic acinar cells.	Amino acid at carboxyl end of peptides.	Amino acids and peptides.
Pancreatic lipase	Pancreatic acinar cells.	Triglycerides (fats and oils) that have been emulsified by bile salts.	Fatty acids and monoglycerides.
<b>Nucleases</b>			
Ribonuclease	Pancreatic acinar cells.	Ribonucleic acid.	Nucleotides.
Deoxyribonuclease	Pancreatic acinar cells.	Deoxyribonucleic acid.	Nucleotides.
<b>BRUSH BORDER</b>			
$\alpha$ -Dextrinase	Small intestine.	$\alpha$ -Dextrins.	Glucose.
Maltase	Small intestine.	Maltose.	Glucose.
Sucrase	Small intestine.	Sucrose.	Glucose and fructose.
Lactase	Small intestine.	Lactose.	Glucose and galactose.
Enterokinase	Small intestine.	Trypsinogen.	Trypsin.
<b>Peptidases</b>			
Aminopeptidase	Small intestine.	Amino acid at amino end of peptides.	Amino acids and peptides.
Dipeptidase	Small intestine.	Dipeptides.	Amino acids.
Nucleosidases and phosphatases	Small intestine.	Nucleotides.	Nitrogenous bases, pentoses, and phosphates.

## AGING AND THE DIGESTIVE SYSTEM

Many changes can be expected in the aging digestive system. The sense of taste becomes less acute, less saliva is produced, and there is greater likelihood of periodontal disease and loss of teeth. Secretions are reduced throughout the digestive system, and the effectiveness of peristalsis diminishes. Indigestion may become more frequent, especially if the LES loses its tone, and there is a greater chance of esophageal damage. In the colon, diverticula may form; these are bubble-like outpouchings of the weakened wall of the colon that may be asymptomatic or become infected. Intestinal obstruction, of the large or small bowel, occurs with greater frequency among the elderly. Sluggish peristalsis contributes to constipation, which in turn may contribute to the formation of hemorrhoids. The risk of oral cancer or colon cancer also increases with age. The liver usually continues to function adequately even well into old age, unless damaged by pathogens such as the hepatitis viruses or by toxins such as alcohol. There is a greater tendency for gallstones to form, perhaps necessitating removal of the gallbladder. Inflammation of the gallbladder (cholecystitis) is also more frequent in older adults. In the absence of specific diseases, the pancreas usually functions well, although acute pancreatitis of unknown cause is somewhat more likely.

- **Applications to the nursing care**

## ***1• DISORDERS OF THE STOMACH***

**Vomiting** is the expulsion of stomach and intestinal contents through the esophagus and mouth.

Stimuli include irritation of the stomach, motion sickness, food poisoning, or diseases such as meningitis. The vomiting center is in the medulla, which coordinates the simultaneous contraction of the diaphragm and the abdominal muscles. This squeezes the stomach and upper intestine, expelling their contents. As part of the reflex, the lower esophageal sphincter relaxes, and the glottis closes. If the glottis fails to close, as may happen in alcohol or drug intoxication, aspiration of vomitus may occur and result in fatal obstruction of the respiratory passages.

**Pyloric stenosis** means that the opening of the pyloric sphincter is narrowed, and emptying of the stomach is impaired. This is most often a congenital disorder caused by hypertrophy of the pyloric sphincter. For reasons unknown, this condition is more common in male infants than in female infants. When the stomach does not empty efficiently, its internal pressure increases. Vomiting relieves the pressure; this is a classic symptom of pyloric stenosis. Correcting this condition requires surgery to widen the opening in the sphincter.

A **gastric ulcer** is an erosion of the mucosa of the stomach. Because the normal stomach lining is adapted to resist the corrosive action of gastric juice, ulcer formation is the result of oversecretion of HCl or undersecretion of mucus. As erosion reaches the submucosa, small blood vessels are ruptured and bleed. If vomiting occurs, the vomitus has a “coffee-ground” appearance due to the presence of blood acted on by gastric juice. A more serious complication is perforation of the stomach wall, with leakage of gastric contents into the abdominal cavity, and **peritonitis**.

The bacterium called *Helicobacter pylori* is the cause of most gastric ulcers. For many patients, a few weeks of antibiotic therapy to eradicate this bacterium has produced rapid healing of their ulcers. This bacterium also seems to be responsible for virtually all cases of stomach cancer. The medications that decrease the secretion of HCl are useful for ulcer patients not helped by antibiotics.

## **2• GALLSTONES**

One of the functions of the gallbladder is to concentrate bile by absorbing water. If the bile contains a high concentration of cholesterol, absorption of water may lead to precipitation and the formation of cholesterol crystals. These crystals are **gallstones**. If the gallstones are small, they will pass through the cystic duct and common bile duct to the duodenum without causing symptoms. If large, however, the gallstones cannot pass out of the gallbladder, and may cause mild to severe pain that often radiates to the right shoulder. Obstructive jaundice may occur if bile backs up into the liver and bilirubin is reabsorbed into the blood. Several treatments are available for gallstones. Medications that dissolve gallstones work slowly, over the course of several months, and are useful if biliary obstruction is not severe.

An instrument that generates shock waves (called a lithotripter) may be used to pulverize the stones into smaller pieces that may easily pass into the duodenum; this procedure is called **lithotripsy**. Surgery to remove the gallbladder (cholecystectomy) is required in some cases. The hepatic duct is then connected directly to the common bile duct, and dilute bile flows into the duodenum. Following such surgery, the patient should avoid meals high in fats.

## **3• DISORDERS OF THE INTESTINES**

**Duodenal ulcers** are erosions of the duodenal wall caused by the gastric juice that enters from the stomach. The most serious consequences are bleeding and perforation. **Paralytic ileus** is the cessation of contraction of the smooth muscle layer of the intestine. This is a possible complication of abdominal surgery, but it may also be the result of peritonitis or inflammation elsewhere in the abdominal cavity. In the absence of peristalsis, intestinal obstruction may occur. Bowel movements cease, and vomiting occurs to relieve the pressure within the alimentary tube. Treatment involves suctioning the intestinal contents to eliminate any obstruction and to allow the intestine to regain its normal motility.

**Lactose intolerance** is the inability to digest lactose because of deficiency of the enzyme lactase. Lactase deficiency may be congenital, a consequence of prematurity, or acquired later in life. The delayed form is quite common among people of African or Asian ancestry, and in part is genetic. When lactose, or milk sugar, is not digested, it undergoes fermentation in the intestine. Symptoms include diarrhea, abdominal pain, bloating, and flatulence (gas formation).

**Salmonella food poisoning** is caused by bacteria in the genus *Salmonella*. These are part of the intestinal flora of animals, and animal foods such as meat and eggs may be sources of infection. These bacteria are not normal for people, and they cause the intestines to secrete large amounts of fluid. Symptoms include diarrhea, abdominal cramps, and vomiting and usually last only a few days. For elderly or debilitated people, however, salmonella food poisoning may be very serious or even fatal.

**Diverticula** are small outpouchings through weakened areas of the intestinal wall. They are more likely to occur in the colon than in the small intestine and may exist for years without causing any symptoms. The presence of diverticula is called **diverticulosis**. Inflammation of diverticula is called **diverticulitis**, which is usually the result of entrapment of feces and bacteria. Symptoms include abdominal pain and tenderness and fever. If uncomplicated, diverticulitis may be treated with antibiotics and modifications in diet. The most serious complication is perforation of diverticula, allowing fecal material into the abdominal cavity, causing peritonitis. A diet high in fiber is believed to be an important aspect of prevention, to provide bulk in the colon and prevent weakening of its wall.

#### **4• INFANT BOTULISM**

Botulism is most often acquired from food. When the spores of the botulism bacteria are in an anaerobic (without oxygen) environment such as a can of food, they germinate into active bacteria that produce a neurotoxin. If people ingest food containing this toxin, they will develop the paralysis that is characteristic of botulism. For infants less than 1 year of age, however, ingestion of just the bacterial spores may be harmful. The infant's stomach does not produce much HCl, so ingested botulism spores may not be destroyed. Of equal importance, the infant's normal colon flora is not yet established. Without the normal population of colon bacteria to provide competition, spores of the botulism bacteria may germinate and produce their toxin. An affected infant becomes lethargic and weak; paralysis may progress slowly or rapidly.

Treatment (antitoxin) is available, but may be delayed if botulism is not suspected. Many cases of infant botulism have been traced to honey that was found to contain botulism spores. Such spores are not harmful to older children and adults, who have a normal colon flora that prevents the botulism bacteria from becoming established.

#### **5• FIBERS**



*Fiber* is a term we use to refer to the organic materials in the cell walls of plants. These are mainly cellulose and pectins. The role of dietary fiber and possible benefits that a high-fiber diet may provide are currently the focus of much research. It is important to differentiate what is known from what is, at present, merely speculation. Many studies have shown that populations (large groups of people, especially those of different cultures) who consume high-fiber diets tend to have a lower frequency of certain diseases.

These include diverticulitis, colon cancer, coronary artery disease, diabetes, and hypertension. Such diseases are much more common among populations whose diets are low in vegetables, fruits, and whole grains, and high in meat, dairy products, and processed foods. In contrast, a 2005 study showed no protective effect of fiber against colon cancer. What we can say for sure is that fiber may not be the only dietary or environmental factor involved.

Claims that high-fiber diets directly lower blood levels of cholesterol and fats are not supported by definitive clinical or experimental studies. One possible explanation may be that a person whose diet consists largely of high-fiber foods simply eats less of the foods high in cholesterol and fats, and this is the reason for that person's lower blood levels of fats and cholesterol. Should people try to make great changes in their diets? Probably not, not if they are careful to limit fat intake and to include significant quantities of vegetables and fruits.

Besides the possible benefits of fiber, unprocessed plant foods provide important amounts of vitamins and minerals.

## **6• HEPATITIS**

**Hepatitis** is inflammation of the liver caused by any of several viruses. The most common of these hepatitis viruses have been designated A, B, and C, although there are others. Symptoms of hepatitis include anorexia, nausea, fatigue, and possibly jaundice.

Severity of disease ranges from very mild (even asymptomatic) to fatal. The three hepatitis viruses have different modes of transmission and different consequences for affected people.

**Hepatitis A** is an intestinal virus that is spread by the fecal–oral route. Food contaminated by the hands of people with mild cases is the usual vehicle of transmission, although shellfish harvested from water contaminated with human sewage are another possible source of this virus. Hepatitis A is most often mild, recovery provides lifelong immunity, and the carrier

state is not known to occur. A vaccine is available, but people who have been exposed to hepatitis A may receive gamma globulin by injection to prevent the disease.

**Hepatitis B** is contracted by exposure to the body fluids of an infected person; these fluids include blood and semen. Hepatitis B may be severe or even fatal, and approximately 10% of those who recover become carriers of the virus. Possible consequences of the carrier state are chronic hepatitis progressing to cirrhosis or primary liver cancer. Of equal importance, carriers are sources of the virus for others, especially their sexual partners. A vaccine is available for hepatitis B, and healthcare workers who have contact with blood, even *just* occasional contact, should receive it. Other potential recipients of the vaccine are the sexual partners of carriers. Pediatricians now consider this vaccine one of the standard ones for infants.

**Hepatitis C** virus is also present in body fluids and is spread by blood or mucous membrane contact. Most people develop chronic disease, but many may remain asymptomatic for years after being infected. With active disease the virus may cause liver failure. The only therapy then is a liver transplant. It is important for healthcare personnel, and their patients, to know that these types of hepatitis are not spread by blood transfusions. Donated blood is tested for all three viruses.