University of Anbar
College of science
Department of biotechnology

Lectures of human physiology

Lec. 8

The Digestive System

(part 1)

By
Dr. Ali Mohammed Sameen

INTRODUCTION TO THE DIGESTIVE SYSTEM

Within the lumen of the gastrointestinal tract, large food molecules are hydrolyzed into their monomers (subunits). These monomers pass through the inner layer, or mucosa, of the small intestine to enter the blood or lymph in a process called absorption. Digestion and absorption are aided by specializations of the gastrointestinal tract.

The functions of the digestive system include:

1. Motility. This refers to the movement of food through the digestive tract through the processes of

a. *Ingestion:* Taking food into the mouth.

b. *Mastication:* Chewing the food and mixing it with saliva.

c. *Deglutition:* Swallowing food.

d. *Peristalsis* and *segmentation:* Rhythmic, wavelike contractions (peristalsis), and mixing contractions in different segments (segmentation), move food through the gastrointestinal tract.

2. Secretion. This includes both exocrine and endocrine secretions.

a. *Exocrine secretions:* Water, hydrochloric acid, bicarbonate, and many digestive enzymes are secreted into the lumen of the gastrointestinal tract. The stomach alone, for example, secretes 2 to 3 liters of gastric juice a day.

b. *Endocrine secretions:* The stomach and small intestine secrete a number of hormones that help to regulate the digestive system.

3. Digestion. This refers to the breakdown of food molecules into their smaller subunits, which can be absorbed.

4. Absorption. This refers to the passage of digested end products into the blood or lymph.

5. Storage and elimination. This refers to the temporary storage and subsequent elimination of indigestible food molecules.

6. Immune barrier. The simple columnar epithelium that lines the intestine, with its tight junctions between cells, provides a physical barrier to the penetration of pathological organisms and their toxins. Also, cells of the immune system reside in the connective tissue located just under the epithelium to promote immune responses.

Anatomically and functionally, the digestive system can be divided into the tubular **gastrointestinal (GI) tract,** or *alimentary canal,* and **accessory digestive organs.** The GI tract is approximately 9 m (30 ft) long and extends from the mouth to the anus. It traverses the thoracic cavity and enters the abdominal cavity at the level of the diaphragm. The anus is located at the inferior portion of the pelvic cavity. The organs of the GI tract include the *oral cavity, pharynx, esophagus, stomach, small intestine,* and *large intestine* (fig.1). The accessory digestive organs include the *teeth, tongue, salivary glands, liver, gallbladder,* and *pancreas.* The term *viscera* is frequently used to refer to the abdominal organs of digestion, but it can also refer to any organs in the thoracic and abdominal cavities.

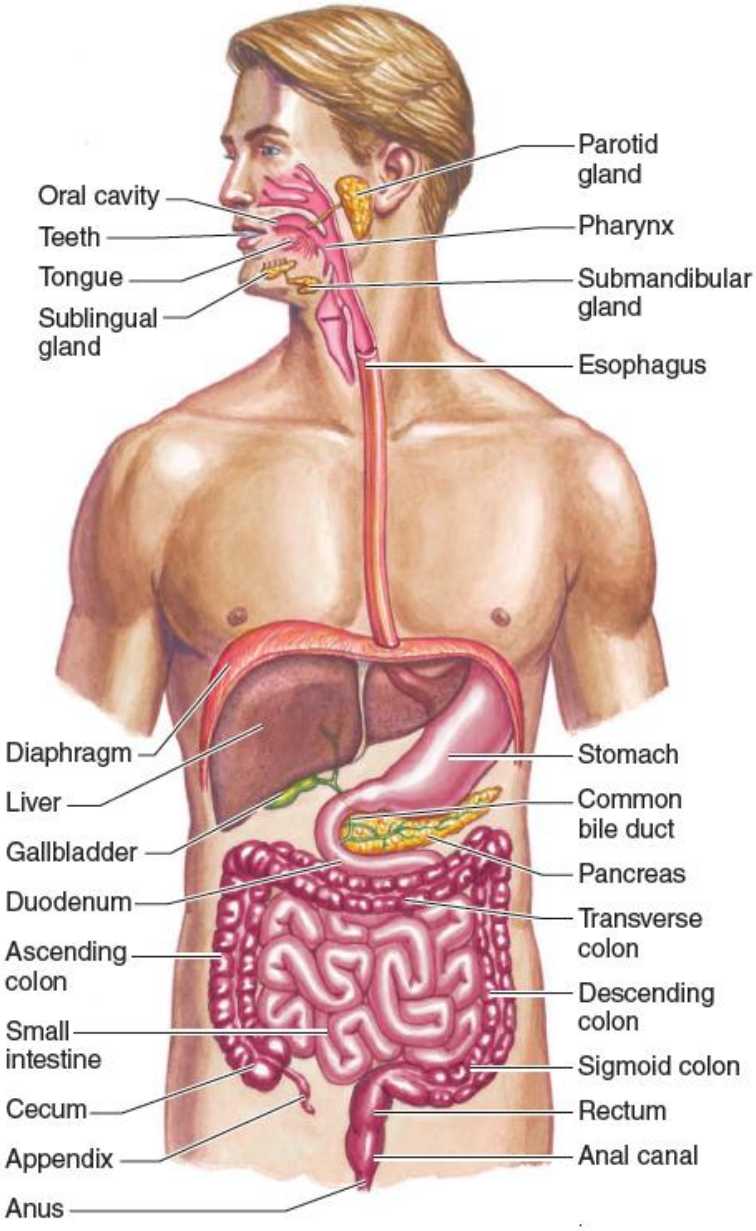

Figure 1 **The organs of the digestive system. The digestive system includes the gastrointestinal tract and the accessory digestive organs.**

Layers of the Gastrointestinal Tract

The GI tract from the esophagus to the anal canal is composed of four layers, or *tunics.* Each tunic contains a dominant tissue type that performs specific functions in the digestive process. The four tunics of the GI tract, from the inside out, are the *mucosa*, *submucosa*, *muscularis*, and *serosa* (fig. 2 *a).*

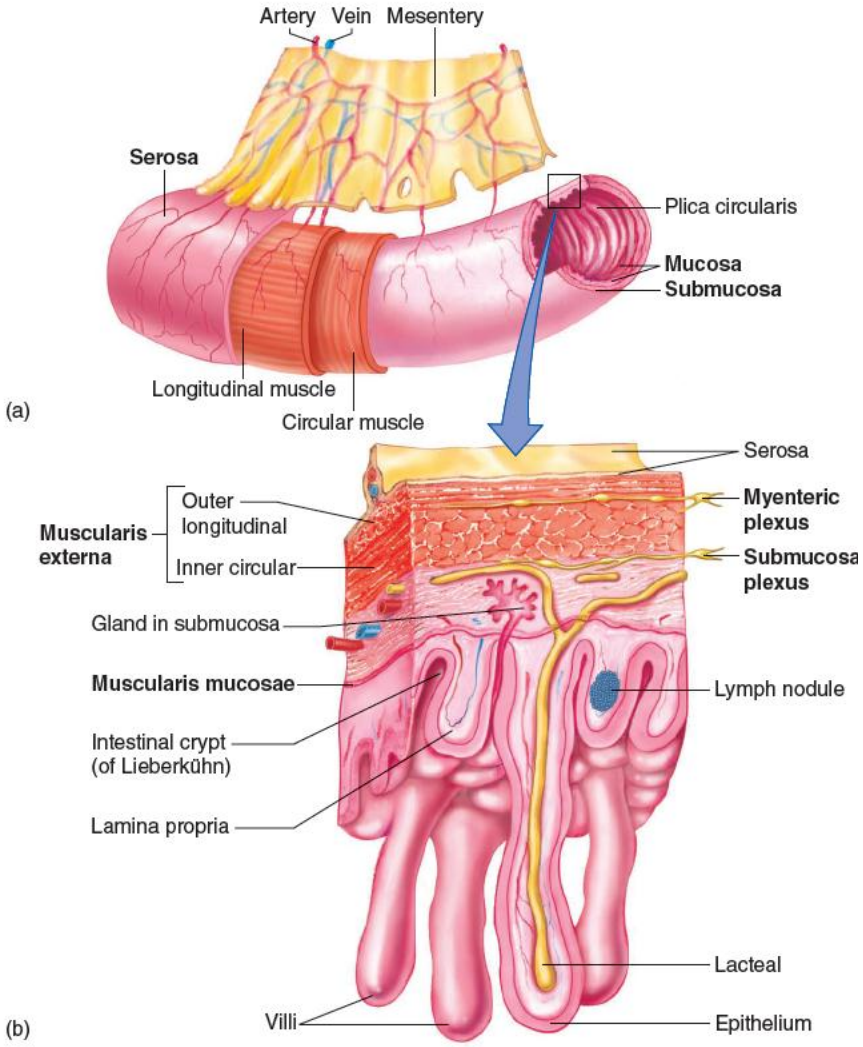

Figure 2 **The layers of the digestive tract. (*a*) An illustration of the major tunics, or layers, of the small intestine. The inset shows how folds of mucosa form projections called villi in the small intestine. (*b*) An illustration of a cross section of the small intestine showing layers and glands**

Mucosa

The **mucosa,** which lines the lumen of the GI tract, is the absorptive and major secretory layer. It consists of a simple columnar epithelium supported by the *lamina propria*, a thin layer of areolar connective tissue containing numerous lymph nodules, which are important in protecting against disease (fig. 2 *b)*. External to the lamina propria is a thin layer of smooth muscle called the *muscularis mucosae*. This is the muscle layer

responsible for the numerous small folds in certain portions of the GI tract. These folds greatly increase the absorptive surface area. Specialized goblet cells in the mucosa secrete mucus throughout most of the GI tract.

Submucosa

The relatively thick **submucosa** is a highly vascular layer of connective tissue that serves the mucosa. Absorbed molecules that pass through the columnar epithelial cells of the mucosa enter into blood and lymphatic vessels of the submucosa. In addition to blood vessels, the submucosa contains glands and nerve plexuses. The **submucosal plexus** (*Meissner's plexus*) (fig. 2 *b*) provides a nerve supply to the muscularis mucosae of the small and large intestine.

Muscularis

The **muscularis** (also called the *muscularis externa)* is responsible for segmental contractions and peristaltic movement through the GI tract. The muscularis has an inner circular and an outer longitudinal layer of smooth muscle. Contractions of these layers move the food through the tract and physically pulverize and mix the food with digestive enzymes. The **myenteric plexus** (*Auerbach's plexus*), located between the two muscle layers, provides the major nerve supply to the entire GI tract. It includes fibers and ganglia from both the sympathetic and parasympathetic divisions of the autonomic nervous system.

Serosa

The outer **serosa** completes the wall of the GI tract. It consists of areolar connective tissue covered with a layer of simple squamous epithelium, and is continuous with the mesentery and visceral peritoneum.

Regulation of the Gastrointestinal Tract

The GI tract is innervated by the sympathetic and parasympathetic divisions of the autonomic nervous system. parasympathetic nerves in general stimulate motility and secretions of the gastrointestinal tract. The vagus nerve is the source of parasympathetic activity in the esophagus, stomach, pancreas, gallbladder, small intestine, and upper portion of the large intestine. The lower portion of the large intestine receives parasympathetic innervation from spinal nerves in the sacral region. The submucosal plexus and myenteric plexus are the sites where parasympathetic preganglionic fibers synapse with postganglionic neurons that innervate the smooth muscle of the GI tract.

FROM MOUTH TO STOMACH

Peristaltic contractions of the esophagus deliver food to the stomach, which secretes very acidic gastric juice that is mixed with the food by gastric contractions. Proteins in the resulting mixture, called chyme, are partially digested by the enzyme pepsin. Mastication (chewing) of food mixes it with saliva, secreted by the salivary glands. In addition to mucus and various antimicrobial agents, saliva contains salivary amylase, an enzyme that can catalyze the partial digestion of starch. Deglutition, or swallowing, is divided into three phases: oral, pharyngeal, and esophageal. Swallowing is a complex activity that requires the coordinated contractions of 25 pairs of muscles in the mouth, pharynx, larynx, and esophagus. The muscles of the mouth, pharynx, and upper esophagus are striated and innervated by somatic motor neurons, whereas the muscles of the middle and lower esophagus are smooth and innervated by autonomic neurons. The oral phase is under voluntary control, while the pharyngeal and esophageal phases are automatic and controlled by the **swallowing center** in the brain stem In the oral phase, the

muscles of the mouth and tongue mix the food with saliva and create a bolus (a mass of a size to be swallowed) of food that the tongue muscles move toward the oropharynx. Receptors in the posterior portion of the oral cavity and oropharynx stimulate the pharyngeal phase of the swallowing reflex. The soft palate lifts to close off the nasopharynx from the oropharynx (so food does not go out the nose); the vocal cords close off the opening to the larynx, and the epiglottis covers the vocal cords; the larynx is moved away from the pathway of the bolus toward the esophagus (these activities help prevent choking); and the upper esophageal sphincter relaxes. These complex activities of the pharyngeal phase take less than 1 second. In the esophageal phase of swallowing, which lasts from 5 to 6 seconds, the bolus of food is moved by peristaltic contractions toward the stomach.

Once in the stomach, the ingested material is churned and mixed with hydrochloric acid and the protein-digesting enzyme pepsin. The mixture thus produced is pushed by muscular contractions of the stomach past the pyloric sphincter (pylorus ═ gatekeeper), which guards the junction of the stomach and the duodenum of the small intestine.

Esophagus

The esophagus is the portion of the GI tract that connects the pharynx to the stomach. It is a muscular tube approximately 25 cm (10 in.) long, located posterior to the trachea within the mediastinum of the thorax. Before terminating in the stomach, the esophagus passes through the diaphragm by means of an opening called the esophageal hiatus. The esophagus is lined with a nonkeratinized stratified squamous epithelium; its walls contain either skeletal or smooth muscle, depending on the location. The upper third of the esophagus contains skeletal muscle, the middle third contains a mixture of skeletal and smooth muscle, and the terminal portion contains only smooth muscle .

Swallowed food is pushed from the oral to the anal end of the esophagus (and, afterward, of the intestine) by a wavelike muscular contraction called peristalsis (fig. 3). Movement of the bolus along the digestive tract occurs because the circular smooth muscle contracts behind, and relaxes in front of, the bolus. This is followed by shortening of the tube by longitudinal muscle contraction.

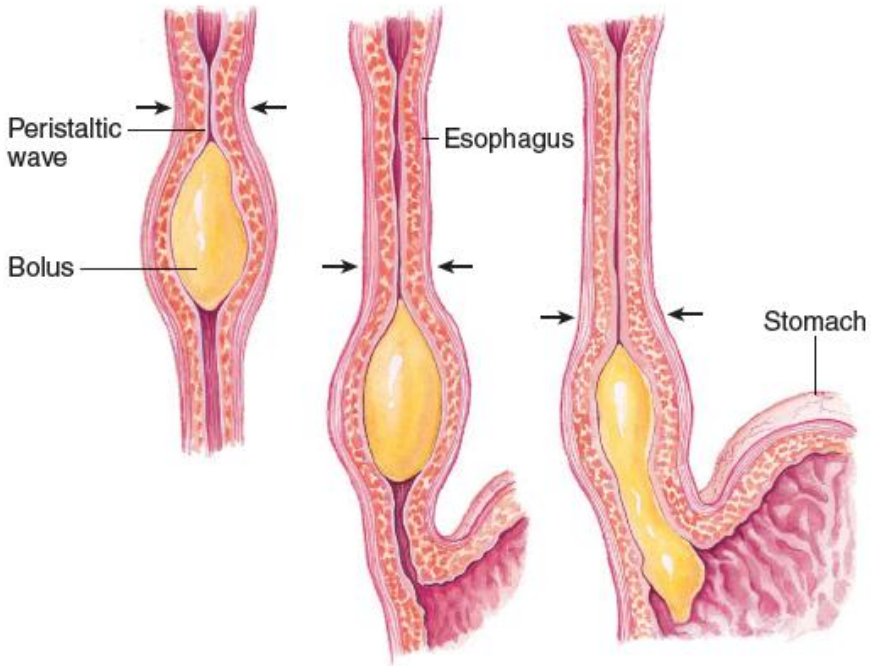

Figure 3 **Peristalsis in the esophagus**

Stomach

The J-shaped stomach is the most distensible part of the GI tract. It is continuous with the esophagus superiorly and empties into the duodenum of the small intestine inferiorly. The functions of the stomach are to store food, to initiate the digestion of proteins, to kill bacteria with the strong acidity of gastric juice, and to move the food into the small intestine as a pasty material called chyme. Swallowed food is delivered from the esophagus to the cardiac region of the stomach (fig. 4).

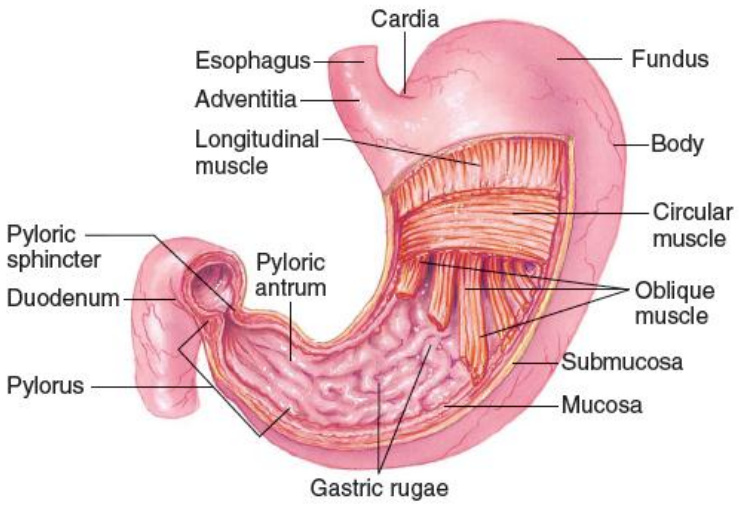

Figure 4 **Primary regions and structures of the stomach**

An imaginary horizontal line drawn through the cardiac region divides the stomach into an upper fundus and a lower body, which together compose about two-thirds of the stomach. The distal portion of the stomach is called the pyloric region. The pyloric region begins in a somewhat widened area, the antrum, and ends at the pyloric sphincter. Contractions of the stomach churn the chyme, mixing it more thoroughly with the gastric secretions. These contractions also push partially digested food from the antrum through the pyloric sphincter and into the first part of the small intestine.

The inner surface of the stomach is thrown into long folds called *rugae,* which can be seen with the unaided eye. Microscopic examination of the gastric mucosa shows that it is likewise folded. The openings of these folds into the stomach lumen are called **gastric pits.** The cells that line the folds secrete various products into the stomach; these cells form the exocrine **gastric glands** (fig. 4).

Gastric glands contain several types of cells that secrete different products:

1. mucous neck cells, which secrete mucus (these supplement the surface mucous cells, which line the luminal surface of the stomach and the gastric pits).

2. parietal cells, which secrete *hydrochloric acid (HCl);*
3. chief (or **zymogenic) cells,** which secrete *pepsinogen*, an inactive form of the protein-digesting enzyme *pepsin.*
4. enterochromaffin-like (ECL) cells, found in the stomach and intestine, which secrete *histamine* and *5-hydroxytryptamine* (also called *serotonin)* as paracrine regulators of the GI tract;
5. G cells, which secrete the hormone *gastrin* into the blood; and
6. D cells, which secrete the hormone *somatostatin.*

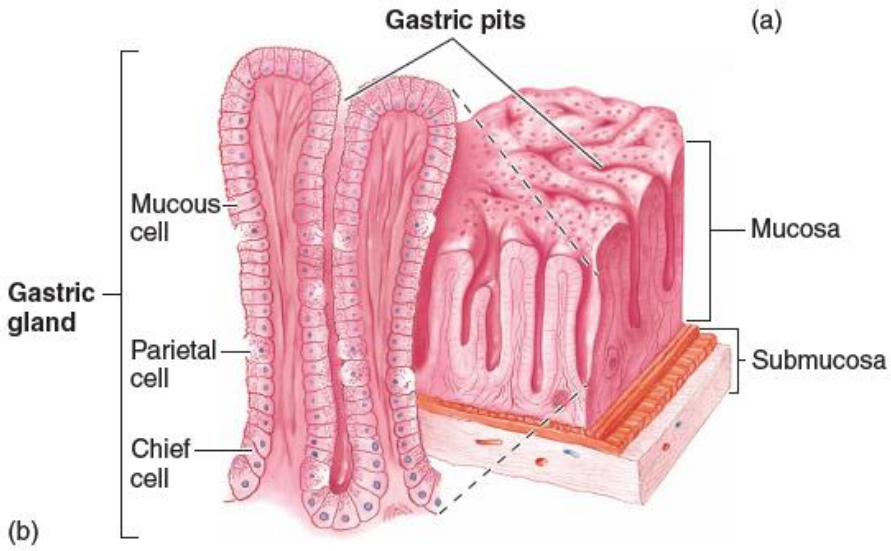

Figure 5 **Gastric pits and gastric glands of the mucosa. (*a*) Gastric pits are the openings of the gastric glands. (*b*) Gastric glands consist of several types of cells (including mucous cells, chief cells, and parietal cells), each of which produces a specific secretion**

Pepsin and Hydrochloric Acid Secretion

The parietal cells secrete H^+ (protons), at a pH as low as 0.8, into the gastric lumen by primary active transport (involving carriers that function as an ATPase). These carriers, known as H^+ / K^+ ATPase pumps, transport H^+ uphill against a million-to-one concentration gradient into the lumen of the stomach while they transport K^+ in the opposite direction. In a process termed potassium recycling, the K^+ inside the parietal cell then leaks out through K^+ channels to prevent depletion of K^+ in the gastric lumen (fig. 6). The apical surface of each parietal cell has

numerous microvilli with a high surface area to allow the insertion of a large number of H^+ / K^+ pumps.

The parietal cells' basolateral membranes (facing the blood in capillaries of the lamina propria) take in Cl^- against its electrochemical gradient by coupling its transport to the downhill movement of bicarbonate (HCO_3^-). The bicarbonate ion is produced within the parietal cells by the dissociation of carbonic acid, formed from CO_2 and H_2O by the enzyme carbonic anhydrase. Therefore, the parietal cells can secrete Cl^- (by facilitative diffusion) as well as H^+ into the gastric juice while they secrete bicarbonate into the blood (fig. 6). The secretion of Cl^-, as well as K^+ recycling, is required for continued activity of the H^+ / K^+ pumps.

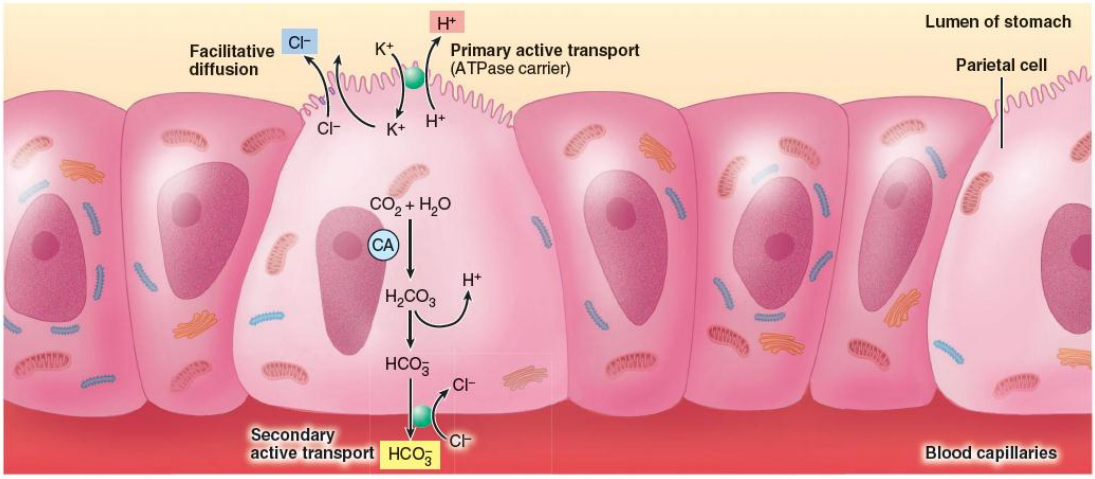

Figure 6 **Secretion of gastric acid by parietal cells.**

Digestion and Absorption in the Stomach

Proteins are only partially digested in the stomach by the action of pepsin, while carbohydrates and fats are not digested at all by pepsin. (Digestion of starch begins in the mouth with the action of salivary amylase and continues for a time when the food enters the stomach, but amylase soon becomes inactivated by the strong acidity of gastric juice.) The complete digestion of food molecules occurs later, when chyme enters the small intestine. Therefore, people who have had partial gastric resections— and

even those who have had complete gastrectomies—can still adequately digest and absorb their food.

SMALL INTESTINE

The small intestine (fig. 7) is the portion of the GI tract between the pyloric sphincter of the stomach and the ileocecal valve opening into the large intestine. It is called “small” because of its relatively small diameter compared to the large intestine. The small intestine is the longest part of the GI tract, however. It is approximately 3 m (12 ft) long in a living person, but it will measure nearly twice this length in a cadaver when the muscle wall is relaxed. The first 20 to 30 cm extending from the pyloric sphincter is the duodenum. The next two-fifths of the small intestine is the jejunum, and the last three-fifths is the ileum. The ileum empties into the large intestine through the ileocecal valve. The products of digestion are absorbed across the epithelial lining of the intestinal mucosa. Absorption of carbohydrates, lipids, amino acids, calcium, and iron occurs primarily in the duodenum and jejunum. Bile salts, vitamin B 12 , water, and electrolytes are absorbed primarily in the ileum. Absorption occurs at a rapid rate as a result of extensive foldings of the intestinal mucosa, which greatly increase its absorptive surface area. The mucosa and submucosa form large folds called plicae circulares, which can be observed with the unaided eye. The surface area is further increased by microscopic folds of mucosa called villi, and by foldings of the apical plasma membrane of epithelial cells (which can be seen only with an electron microscope) called microvilli.

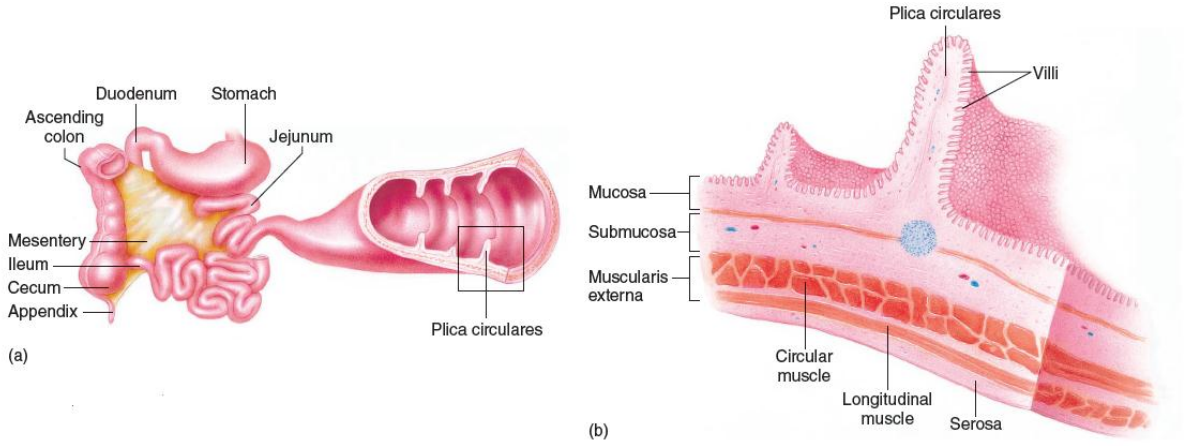

Figure 7 **The small intestine. (a) The regions of the small intestine. (b) A section of the intestinal wall showing the tissue layers, plicae circulares, and villi**

Villi and Microvilli

Each villus is a fingerlike fold of mucosa that projects into the intestinal lumen (fig. 8). The villi are covered with columnar epithelial cells, among which are interspersed mucus-secreting goblet cells. The lamina propria, which forms the connective tissue core of each villus, contains numerous lymphocytes, blood capillaries, and a lymphatic vessel called the central lacteal (fig. 8). Absorbed monosaccharides and amino acids enter the blood capillaries; absorbed fat enters the central lacteals. Epithelial cells at the tips of the villi are continuously exfoliated (shed) and are replaced by cells that are pushed up from the bases of the villi. The epithelium at the base of the villi invaginates downward to form narrow pouches that open through pores to the intestinal lumen. These structures are called intestinal crypts, or crypts of Lieberkühn.

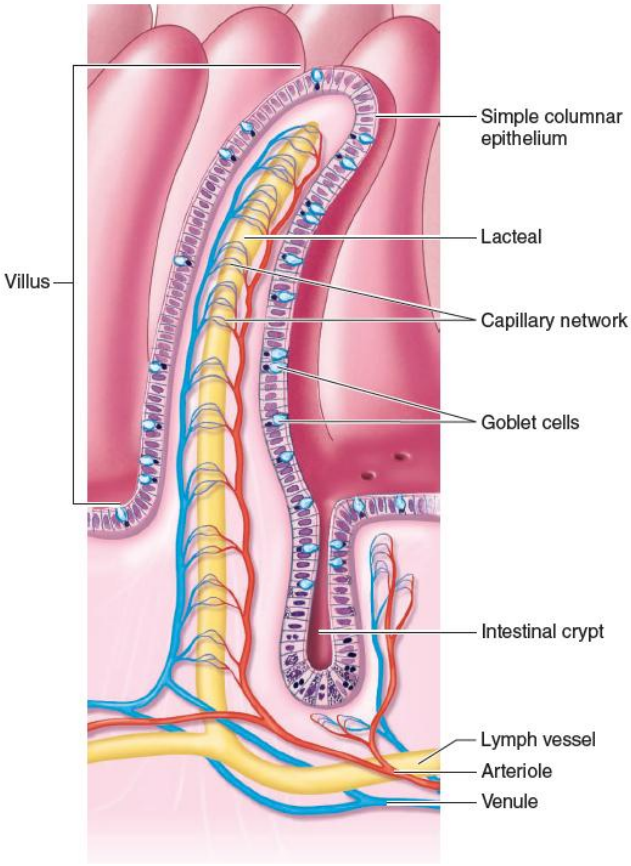

Figure 8 **The structure of an intestinal villus. The figure also depicts an intestinal crypt (crypt of Lieberkühn**

Microvilli are formed by foldings at the apical surface of each epithelial cell membrane. These minute projections can be seen clearly only in an electron microscope. In a light microscope, the microvilli produce a somewhat vague brush border on the edges of the columnar epithelial cells. The terms brush border and microvilli are thus often used interchangeably in describing the small intestine (fig. 9).

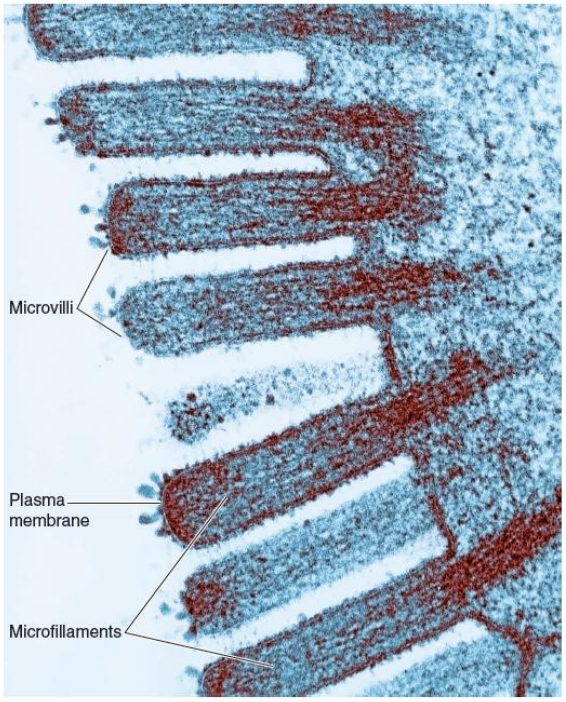

Figure 9 **Electron micrograph of microvilli in the small intestine**

Intestinal Enzymes

In addition to providing a large surface area for absorption, the plasma membranes of the microvilli contain digestive enzymes that hydrolyze disaccharides, polypeptides, and other substrates (table 1). These **brush border enzymes** are not secreted into the lumen, but instead remain attached to the plasma membrane with their active sites exposed to the chyme (fig. 10). One brush border enzyme, **enterokinase** (also called **enteropeptidase)**, is required for activation of the protein-digesting enzyme *trypsin*, which enters the small intestine in pancreatic juice. Activated trypsin then activates other pancreatic juice enzymes.

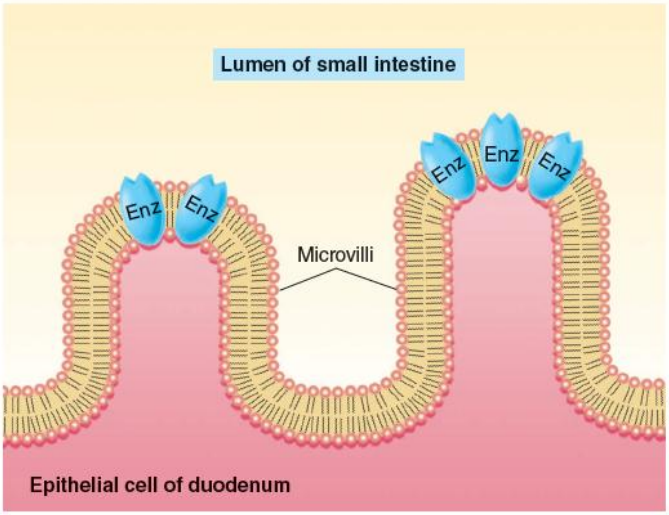

Figure 10 Location of brush border

Table 1 | Brush Border Enzymes Attached to the Cell Membrane of Microvilli in the Small Intestine

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

Intestinal Contractions and Motility

Two major types of contractions occur in the small intestine: peristalsis and segmentation. Peristalsis is much weaker in the small intestine than in the esophagus and stomach. Stretch and chemical changes in a bolus of chyme are relayed to interneurons of the enteric nervous system in the myenteric plexus, which direct excitation and smooth muscle contraction behind the bolus and inhibition and muscle relaxation ahead of the bolus.

Nevertheless, intestinal motility is slow, as required for proper absorption of nutrients.

The major contractile activity of the small intestine is segmentation. This term refers to muscular constrictions of the lumen, which occur simultaneously at different intestinal segments (fig.11). This action serves to mix the chyme more thoroughly. Segmentation contractions occur more frequently in the proximal than in the distal end of the intestine, producing the pressure difference and helping to move chyme through the small intestine.

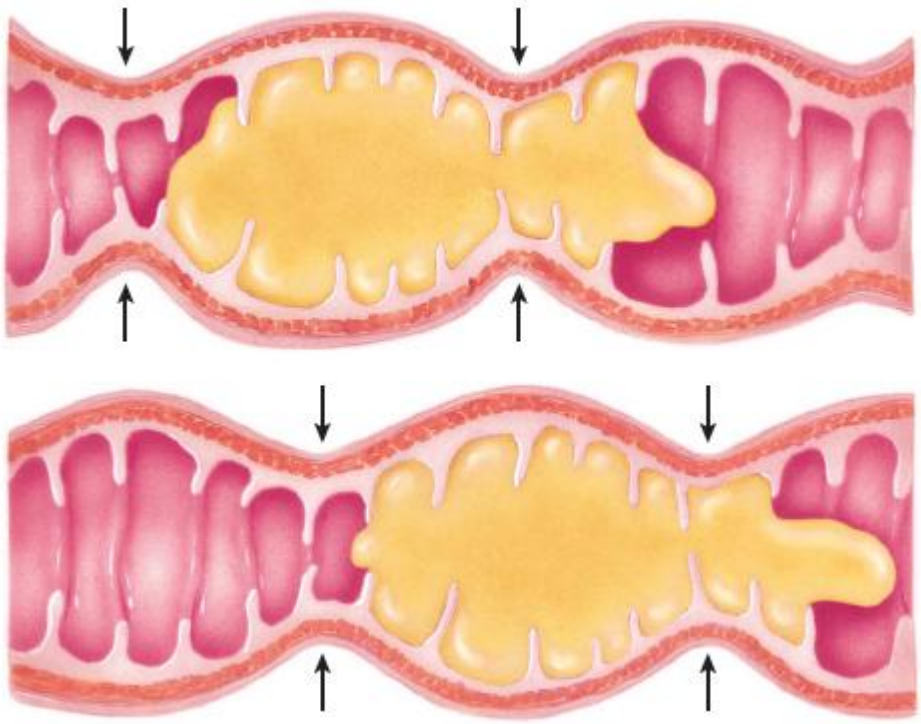

Figure 11 **Segmentation of the small intestine**

-Reference

Fox, S. I. (2014). Fox Human Physiology.