The Digestive System

Digestion is the breaking down of food molecules for use by body cells.

The digestive system can be separated into two groups:

1. alimentary canal or gastrointestinal tract (GI) - a muscular tube which extends from the mouth to the anus and includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. The function of the GI tract is to break down food and absorb it through its lining into the blood.

2. accessory digestive organs - includes the teeth, gall bladder, salivary glands, liver, and pancreas. Secretions from these organs and glands contribute to the breakdown of food.

Digestive Processes

1. ingestion - eating or taking in food through the mouth.

2. propulsion - movement of food through the alimentary canal. It involves deglutition (swallowing) and peristalsis. Peristalsis is alternating waves of contraction and relaxation of the smooth muscles in the walls of the alimentary canal.

3. digestion - breakdown of food.

There are two processes involved in digestion:

a. mechanical digestion - physical processes which prepare food for chemical digestion by enzymes. Mechanical processes are mastication (chewing), mixing of food with saliva by the tongue, churning of food in the stomach and rhythmic local contractions, or segmentation in the intestines which mixes food with digestive juices and increases the rate of absorption.

b. chemical digestion - a series of enzyme-controlled catabolic reactions that break down large organic substances, such as carbohydrates, lipids, and proteins into molecules that are usable by body cells. Chemical digestion begins in the mouth and ends in the small intestine.

4. absorption - the transport of digested food from the GI tract into the blood and lymph where it is distributed to body cells.

5. defecation - elimination of indigestible substances from the body through the anus as feces.
Structure of the GI Tract Wall

From the esophagus to the anus, the walls have the same basic arrangement of tissues consisting of four layers or tunics.

1. mucosa or mucous membrane - inner layer which lines the cavity or lumen of the alimentary canal from the mouth to the anus. It consists of epithelial tissue below which is loose connective tissue and smooth muscle tissue. The layer may form small folds or villi which project into the lumen and increase the surface area for absorption.

   The functions are secretion of mucus, digestive enzymes and hormones, absorption of the products of digestion into the blood, and protection against pathogens.

2. submucosa - consists of dense connective tissue, elastic fibers, blood vessels, lymphatic vessels, lymph nodules, and nerve fibers. The nerve supply is part of the ANS and regulates the secretion of the glands and smooth muscle of the mucosa.

3. muscularis externa - consists of two layers of smooth muscle. The inner circular layer decreases the diameter of the tube and the outer longitudinal layer shortens the tube when they contract. Contraction of the smooth muscle layers mix the food with secretions and propel it through the tract (peristalsis).

   Between the circular and longitudinal layers is the nerve fibers from both the sympathetic and parasympathetic divisions of the ANS.

4. serosa or visceral peritoneum - the outermost layer composed of simple squamous epithelium and connective tissue. The visceral peritoneum is continuous with the parietal peritoneum that lines the wall of the abdomino-pelvic cavity. A peritoneal cavity between the visceral and parietal peritoneum contains serous fluid secreted by the serous membranes. The serous fluid lubricates the organs and allows them to slide over one another. The visceral and parietal peritoneum are connected by a fused double layer of parietal peritoneum called the mesentery. The mesentery contains blood vessels, lymphatic vessels, nerves, binds organs to each other, anchors organs to the abdominal wall, and stores fat.

Organs and Functions

Mouth - oral cavity - begins the process of chemical digestion.

Accessory organs include the lips, cheeks, teeth, tongue, palate, and salivary glands.

During mastication (chewing) the cheeks (buccal cavity) and lips help keep the food between the teeth, and the tongue constantly repositions the food between the teeth.

The teeth break pieces of food into smaller pieces which increases the surface area and promotes the activity of digestive enzymes.
The tongue is composed of skeletal muscle and its movements mix the food with saliva and a compact mass, or bolus, is formed. During swallowing, the tongue moves the bolus toward the pharynx. The uvula of the soft palate rises and closes off the nasopharynx.

The salivary glands secrete saliva which moistens the food particles, begins chemical digestion of carbohydrates by enzymes, dissolves food chemicals so they can be tasted, and cleanses the mouth and teeth. Saliva is mainly water and also contains sodium, potassium, chlorine, phosphate, bicarbonate ions, the enzyme salivary amylase, the protein mucin, lysozyme, IgA, and metabolic wastes.

There are three major pairs of extrinsic salivary glands which lie outside of the oral cavity.

1. parotid glands - they are the largest and are located in front of and just below the ear between the skin and masseter muscle. Their ducts open next to the upper second molar. The serous cells secrete a clear, watery fluid containing salivary amylase.

2. submandibular glands - they are located beneath the base of the tongue in the posterior part of the floor of the mouth. Their ducts open just behind the lower central incisors. The saliva is more viscous than the parotid and is secreted by serous and mucous cells.

3. sublingual glands - they are the smallest and are located anterior to the submandibular glands. Their ducts open on the floor of the mouth under the tongue. Saliva is very viscous and stringy and is secreted mainly by mucous cells.

The mucous membrane lining the mouth contains many small buccal glands which secrete small amounts of saliva.

Secretion of saliva is controlled by the parasympathetic division of the ANS. Chemoreceptors and pressoreceptors in the mouth send impulses to the salivary nuclei in the pons and medulla. Parasympathetic activity increases the production of saliva by way of the facial nerve (VII) and glossopharyngeal nerve (IX).

Pharynx

The muscles in the walls of the pharynx contain a longitudinal layer and a circular layer or pharyngeal constrictor muscles composed of skeletal muscle. Alternating contraction of the muscles propels the food into the esophagus.
Esophagus

The esophagus is 10 inches long and extends from the pharynx to the stomach. The esophagus joins the stomach after passing through the diaphragm at the esophageal hiatus. Where the esophagus joins the stomach is circular muscle called the gastroesophageal sphincter which is relaxed when swallowing.

Stomach

The stomach is a temporary "storage tank". It is J-shaped and extends from the esophagus to the duodenum of the small intestine. The stomach is divided into four regions:

1. cardia or cardiac region - a small area near the esophageal opening.
2. fundus - rounded portion that extends laterally and anteriorly to the cardia
3. body - large central portion of the stomach
4. pylorus - inferior end. A pyloric sphincter separates the stomach from the duodenum of the small intestine.

The convex lateral surface of the stomach is the greater curvature and the concave medial surface is the lesser curvature. Extending from the curvatures are the two mesenteries: the lesser omentum ("tether") and the greater omentum which attach the stomach to other digestive organs and to the body wall. The lesser omentum extends from the liver to the lesser curvature and joins the visceral peritoneum covering the stomach. The greater omentum extends from the greater curvature and covers the coils of the intestine, encloses the spleen, wraps around the transverse colon and attaches to the parietal peritoneum of the posterior wall of the abdominal cavity.

The wall of the stomach has a third layer of smooth muscle in the muscularis externa that is oblique. The arrangement of longitudinal, circular, and oblique muscles moves, churns, mixes, and breaks down food.

When the stomach is empty, the mucosa layer has large folds called rugae. The rugae are lined with simple columnar epithelium which contain narrow openings, called gastric pits which lead to gastric glands. The gastric glands produce gastric juice.
The gastric glands contain four types of secretory cells.

1. **mucous cells** - they secrete mucus and are found in the necks of the glands near the openings of the gastric pits. They are the primary cells of the cardia and pylorus.

2. **parietal or oxyntic cells** - they are scattered among the mucous cells. They secrete **hydrochloric acid** (HCL) and the pH is about 1.5 - 3.5. which activates the enzyme **pepsin** and **intrinsic factor**, which is a glycoprotein necessary for the absorption of vitamin B₁₂ from the small intestine.

3. **chief or zymogenic cells** - they are found in the basal region of the gastric glands. They secrete **pepsinogen** which is an inactive form of pepsin. Pepsinogen molecules are activated by HCL to form pepsin. The formation of pepsin acts as a positive feedback mechanism stimulating more pepsinogen to convert to pepsin.

4. **enteroendocrine cells** - "gut endocrine". They release hormones or hormone-like products such as **gastrin**, **histamine**, **endorphins** (natural opiate), **serotonin**, **cholecystokinin** (CCK), and **somatostatin** which diffuse into the blood and influence organs of the digestive system.

The chemical breakdown of **proteins** begins in the stomach and food is converted into a creamy mass containing gastric juice and partially digested food called **chyme**. When chyme reaches the pyloric sphincter, a small amount is allowed through into the duodenum with each wave of contraction or peristalsis.

**Regulation of Gastric Secretion**

The secretion of gastric juice is regulated by both nervous and hormonal mechanisms.
Parasympathetic impulses from the nuclei in the medulla are transmitted by the **vagus nerve** (X) and stimulate the gastric glands.

There are three phases of gastric secretion which may occur at the same time.

1. **cephalic (reflex) phase** - occurs before food enters the stomach and prepares the stomach for digestion. The sight, smell, taste, or thought of food causes nerve impulses from the cerebral cortex or feeding center in the hypothalamus to send impulses to the medulla. From the medulla, the impulses travel over parasympathetic fibers to the vagus nerve which stimulates the gastric glands.
2. **gastric phase** - occurs when food reaches the stomach. Food causes distension of the stomach walls and causes stimulation of stretch receptors. The receptors send impulses to the medulla and back to the gastric glands or directly to the gastric glands. Low acidity, proteins, and caffeine directly stimulate the release of gastrin which stimulates other gastric glands to secrete juices.

3. **intestinal phase** - When partially digested proteins leave the stomach and enter the duodenum, they stimulate the mucosa of the duodenum to secrete intestinal or enteric gastrin which is a hormone that stimulates gastric glands to continue secretion. As the intestine becomes distended, the enterogastric reflex is triggered which inhibits gastric secretion. The sympathetic fibers are activated causing the pyloric sphincter to close, preventing more food from entering the duodenum. Intestinal hormones called enterogastrones inhibit gastric secretion. Enterogastrones include: secretin, cholecystokinin (CCK), and gastric inhibitory peptide (GIP).

Liquids pass through the stomach more rapidly than solids. Carbohydrates pass through faster than proteins, and fats move through the slowest.

**Small Intestine**

The small intestine extends from the pyloric sphincter of the stomach and loops and coils until it reaches the ileocecal valve of the large intestine.

The small intestine is divided into three regions.

1. **duodenum** - it is about 10 inches long and begins at the pyloric sphincter and extends to the jejunum.

2. **jejunum** it is about 8 feet long and extends from the duodenum to the ileum.

3. **ileum** - it is about 12 feet long and extends from the jejunum to the ileocecal valve of the large intestine.

Digestion is completed and the major amount of absorption occurs in the small intestine.

The wall of the small intestine contains circular folds or plicae circulares, of the mucosa and submucosa, villi, or finger-like projections of the mucosa and microvilli, or projections of the mucosal membrane. Each villus contains an arteriole, venule, capillary network, and lymphatic vessel. The microvilli contain intestinal digestive enzymes that complete the digestion of carbohydrates and proteins and form a fuzzy looking brush border. All three structures (plicae circulares, villi, microvilli) increase the absorptive area and are more abundant in the upper part of the small intestine.
The mucosa contains many pits which lead to intestinal glands called intestinal crypts or crypts of Lieberkühn. These glands secrete intestinal juice which is a watery fluid containing mucus and nutrients.

The submucosa of the duodenum contains Brunner's glands or duodenal glands which produce an alkaline mucus that neutralizes the chyme from the stomach.

Peyer's patches, which are lymph nodules, are most abundant in the ileum. They destroy bacteria before it can enter the bloodstream.

The enzymes of the microvilli are peptidases which break down peptides into amino acids, sucrase, maltase, and lactase, which split disaccharides into simple sugars and intestinal lipase which splits fats into fatty acids and glycerol.

Accessory organs to the small intestine include the liver, gall bladder, and pancreas.

Liver

The liver is located under the diaphragm and consists of four lobes separated by connective tissue. The liver is covered by a fibrous capsule. The functional units of the liver are called liver lobules. A lobule consists of cords of hepatocytes or liver cells arranged in a radial pattern around a central vein. Between the cords are blood-filled capillaries called sinusoids. Inside the sinusoids are hepatic macrophages called Kupffer cells which remove bacteria and debris. At each of the six corners of the lobule is a portal triad which consists of a branch of the hepatic artery, a branch of the hepatic portal vein, and a bile duct.

Hepatocytes secrete a yellow-green liquid called bile. Bile contains water, bile salts, bile pigments called biliverdin and bilirubin, cholesterol, electrolytes, neutral fats, and phospholipids.

Bile salts are cholesterol derivatives which emulsify fats. Emulsification distributes them as a suspension of tiny fat droplets which increases the surface area for fat-digesting enzymes. Bile salts also make cholesterol more soluble, and aid in fat and cholesterol absorption. Fat soluble vitamins, such as A, D, E, and K are absorbed along with fatty acids and cholesterol.

Bilirubin is a waste product formed from the heme portion of the hemoglobin molecule when worn out red blood cells are broken down. Bilirubin is metabolized in the small intestine and one of the products, urobilinogen give feces its color.

Bile flows through canals called bile canaliculi that run between hepatocytes toward bile ducts in the portal triads. The bile ducts fuse to form the hepatic duct which joins the cystic duct draining the gall bladder and becomes the common bile duct which enters the duodenum.
Gall Bladder

The gall bladder is a green muscular sac located on the ventral side of the right lobe of the liver and is attached by the cystic duct. The inner wall of the gall bladder has rugae similar to the stomach.

The function of the gall bladder is to store bile until it is needed by the small intestine for digestion. At the end of the common bile duct is the sphincter of Oddi or hepatopancreatic sphincter which is normally contracted. As bile collects in the duct, it backs up into the cystic duct and flows into the gall bladder where it is stored.

The liver continuously produces bile but it is not released into the small intestine until the gall bladder contracts and releases the stored bile. Cholecystokinin or CCK is released from the intestinal mucosa when fats and partially digested proteins are present in the duodenum. The sphincter of Oddi relaxes and bile is released.

Pancreas

The pancreas extends across the posterior abdominal wall in the C-shaped curve of the duodenum. A centrally located pancreatic duct fuses with the common bile duct just before it enters the duodenum.

The pancreas is made up of small clusters of glandular epithelial cells, 99% of which are exocrine cells called acini. The remaining cells are islets of Langerhan’s, alpha, beta, and delta cells, which are endocrine cells. The acini contain zymogen granules which contain digestive enzymes collectively called pancreatic juice. Pancreatic juice is a clear, colorless liquid consisting mostly of water, some salts, sodium bicarbonate, and enzymes. About 1,200 to 1,500 ml is produced each day.

The digestive enzymes include:

1. **pancreatic amylase** - carbohydrate digestion in which starch and glycogen are split into disaccharides

2. **pancreatic lipase** - neutral fat digestion in which triglycerides are split into glycerol and fatty acids.

3. **proteases (trypsin, chymotrypsin, carboxypeptidase)** - protein digestion in which bonds between particular amino acids in proteins are split. The proteases are produced and released in inactive forms like pepsin in the stomach and are activated in the duodenum where they perform their work. In the duodenum, trypsinogen is activated to trypsin by the enzyme enterokinase, a brush border enzyme. Trypsin then activates procarboxypeptidase and chymotrypsinogen to carboxypeptidase and chymotrypsin.

4. **nucleases (deoxyribonuclease, ribonuclease)** - nucleic acid digestion in which nucleic acids are split into nucleotides.
Pancreatic secretion is regulated by both the parasympathetic nervous system and hormonal mechanisms. When parasympathetic impulses stimulate the secretion of gastric juice, impulses are simultaneously transmitted along the vagus (X) nerve to the pancreas stimulating the secretion of pancreatic enzymes.

As chyme enters the duodenum, the hormone secretin is released in response to HCL in the intestine and the hormone cholecystokinin (CCK) is released in response to the presence of proteins and fats in the chyme. Secretion stimulates the pancreas to secrete pancreatic juice that is rich in sodium bicarbonate ions which neutralize the acid in the chyme. CCK stimulates the acini to secrete digestive pancreatic enzymes.

Large Intestines

The large intestine is 5 feet long and the major functions are to absorb water from indigestible food, and to form and eliminate feces.

The large intestine consists of the cecum, appendix, colon, rectum, and anal canal.

The cecum is a pouchlike structure that hangs slightly below the ileocecal valve. Attached to the cecum is a closed end coiled tube called the vermiform appendix. The appendix has no digestive function, but it does contain lymphatic tissue.

The colon has four regions. The ascending colon begins at the cecum, ascends on the right side of the abdominal cavity, makes a right angle turn to the left and continues across the abdominal cavity as the transverse colon. As the transverse colon approaches the spleen, it curves abruptly downward and becomes the descending colon. Where it enters the pelvis, it becomes the S-shaped sigmoid colon and terminates as the rectum at about the third sacral vertebra.

The rectum becomes the anal canal at the tip of the coccyx. The mucous membrane at the anal canal has a series of longitudinal folds called anal columns which contain a network of arteries and veins. The anal canal opens to the outside as the anus which is guarded by two sphincter muscles: the internal anal sphincter which is composed of smooth muscle and the external anal sphincter which is composed of skeletal muscle. The sphincters are normally closed except during defecation.

The wall of the large intestine differs from that of the small intestine. No villi or circular folds are found in the mucosa. The mucosa contains goblet cells which produce mucus. The only significant secretion of the large intestine is mucus. The muscularis is reduced to three flat bands of muscle. Their tension on the wall, or tone, causes the wall to pucker into pocketlike sacs called haustra.

Chyme is prepared for elimination by the action of enteric bacteria (intestinal). The bacteria ferment any remaining carbohydrates and release hydrogen, carbon dioxide, and methane gas. These gases contribute to flatus (gas) in the colon.
Bacteria also convert remaining proteins to amino acids and break down the amino acids into simpler substances, decompose bilirubin, and synthesize B complex vitamins and Vitamin K.

The passage of chyme from the ileum into the cecum is regulated by the action of the ileocecal valve. The valve normally remains mildly contracted so that the passage of chyme into the cecum is usually a slow process. Immediately following a meal, the gastrocolic reflex occurs in which peristalsis of the ileum forces any chyme in the ileum into the cecum. Stomach gastrin also relaxes the valve. When the cecum is distended, the ileocecal valve contracts. The chyme fills the cecum and accumulates in the ascending colon. The most frequent movements are haustral contractions. The haustra are relaxed and distended as they fill and when the distension reaches a certain point, the walls contract and squeeze the contents to the next haustrum. Mass peristalsis occurs which are long, slow-moving powerful contractions that begin at about the middle of the transverse colon three or four times a day (usually during a meal) and propels the contents toward the rectum.

The chyme becomes a semisolid product known as feces, or stool which consists of water, undigested food, mucus, sloughed off epithelial cells from the mucosa of the GI tract, bacteria, and products of bacterial decomposition.

As mass peristaltic action pushes the fecal material into the rectum, the distension of the rectal wall stimulates stretch receptors causing the defecation reflex. The walls of the sigmoid colon and rectum contract, and the anal sphincters relax. Voluntary contractions of the diaphragm and abdominal muscles aid defecation by increasing the pressure inside the abdomen, which pushes the walls of the sigmoid colon and rectum inward.