

The overall function of the **digestive system** is to take in food, break it down to **nutrient** molecules, **absorb** these molecules into the bloodstream, and then rid the body of any indigestible remains.

The digestive system is broken down into 2 main groups of organs: the **alimentary canal organs** and the **accessory digestive organs**.

The alimentary canal consists of organs thru which food and food waste will pass. It runs from the mouth to the anus and includes the **mouth, pharynx, esophagus, stomach, small intestine, and large intestine**. Accessory digestive organs contribute to the processes of digestion and absorption; but no food or food waste actually passes thru them. They include: **teeth, tongue, salivary glands, liver, gallbladder, and pancreas**.

There are several basic processes performed by the digestive system: (1) **Ingestion** → food is enclosed within the alimentary canal. (2) **Propulsion** → process of moving food thru the alimentary canal. This includes **deglutition**, i.e., swallowing (voluntary), and **peristalsis** (involuntary). Peristalsis is the primary means by which food is propelled thru the GI tract. It involves waves of alternating contraction and relaxation of smooth muscle in organ walls. (3) **Mechanical digestion** → initial breakdown that physically prepares food for further chemical digestion. Includes chewing, mixing of food and saliva by the tongue as well as churning of food in the stomach. (4) **Chemical digestion** → **hydrolytic breakdown** of food molecules into their chemical building blocks by **enzymes** secreted into the alimentary canal. Small amounts occur in the mouth and stomach. Majority occurs in the small intestine. (5) **Absorption** → passage of nutrients (along w/ vitamins, minerals, and water) from the lumen of the GI tract across the mucosa and into either blood or lymph. Primarily occurs in the small intestine. (6) **Defecation** → elimination of indigestible substances from the body via the **anus** in the form of **feces**.

Note that the lumen of the alimentary canal is technically outside of the body – (think about the raisin/donut analogy from lecture). The body controls this region in order to maximize nutrient digestion and absorption.

The activity of a digestive organ can be stimulated by the presence of undigested food, by stretch, by a change in luminal pH, by the presence of digestion end products, as well other things. Most digestive activity consists of the contraction of smooth muscle in the walls of digestive organs, the secretion of juices in to the alimentary canal lumen, or the secretion of hormones into the plasma.

Much of the control of digestive activity is intrinsic to the digestive organs and mediated by **enteric nerve plexuses** (which are a subsidiary of the ANS). A digestive reflex that is mediated by an enteric nerve plexus is a **short digestive reflex**. A reflex mediated by the brain is a **long digestive reflex**.

Most digestive organs are covered by a serous membrane, the **visceral peritoneum**. The abdominal wall is lined by another serous membrane, the **parietal peritoneum**. The

peritoneal cavity is the potential space btwn the visceral and parietal peritoneal membranes and contains a small amount of **peritoneal fluid**. This arrangement allows the digestive organs to slide somewhat without experiencing undue friction. Most digestive organs are suspended by a **mesentery**, a double layer of serous membranes that anchors organs in place. Mesenteries also provide a connective tissue road thru which nerves, blood vessels, and lymph vessels can travel. Organs lying against the abdominal wall have no mesenteries, lie posterior to the peritoneum, and thus are **retroperitoneal**. They include the duodenum, pancreas, ascending colon, descending colon, and rectum. These organs will have a serosa anteriorly and an **adventitia** posteriorly.

The **mouth** is a mucosa-lined cavity, a.k.a. the **oral** or **buccal cavity**. It's bounded by the **lips** anteriorly, **palate** superiorly, and **tongue** inferiorly. The anterior opening is the **oral orifice**. It's continuous posteriorly with the **oropharynx** via the **fauces**. The space btwn the lips and the teeth and gums is the **oral vestibule**, while the space btwn the teeth/gums and oropharynx is the **oral cavity proper**. It's lined by stratified squamous epithelium, which provides protection against heat, chemicals, abrasion, and pathogens.

The lips and cheeks help contain food during chewing and play a small role in speech. The **orbicularis oris** forms the core of the lips while the **buccinator** forms the core of the cheeks. The **labial frenula** are the small folds of tissue that join each lip to the gums.

The anterior portion of the roof of the oral cavity is the **hard palate**. The **palatine processes** of the **maxillary bones** and the **horizontal plates** of the **palatine bones** form its core. Posterior to the hard palate is the **soft palate**. It lacks bone and its core is primarily composed of skeletal muscle. During swallowing, it rises and closes off the entry to the nasopharynx. The soft palate is anchored to the tongue by the **palatoglossal arches** and to the wall of the oropharynx by the **palatopharyngeal arches**.

The tongue is composed of interlacing bundles of skeletal muscle. **Intrinsic muscles** of the tongue are confined to the tongue and adjust its shape. **Extrinsic muscles** of the tongue are anchored to skull structures and adjust the tongue's position. The tongue grips food and mixes it with saliva to form a soft moist mass called a **bolus**. It initiates swallowing by forcing the bolus into the oropharynx. The **lingual frenulum** is the fold of tissue that anchors the tongue to the floor of the oral cavity. The superior tongue surface bears **papillae**, projections of the mucosa. Papillae increase surface area, which creates friction that can assist in eating/manipulating foods. Papillae also contain **taste buds**. The root of the tongue contains the **lingual tonsil**.

Salivary glands produce 1-1.5 L of **saliva** per day which: (1) Moistens and cleanses the mouth. (2) Dissolves food particles and allows them to stimulate taste buds. (3) Moistens food facilitating its compaction into a bolus. (4) Contains mucus that lubricates the bolus facilitating swallowing. (5) Contains enzymes that begin chemical digestion of starch.

3 pairs of **extrinsic salivary glands**, which lie outside the oral cavity, produce most of the saliva involved in eating. Scattered throughout the oral mucosa are also small

intrinsic salivary glands, which help give the oral mucosa its moistness btwn meals. The extrinsic salivary glands are the **parotid glands**, **submandibular glands**, and the **sublingual glands**. The parotid is found anterior to the ear btwn the masseter and skin. The submandibular gland lies along the medial aspect of the body of the mandible. The sublingual gland lies anterior to the submandibular gland and under the tongue.

Saliva is 97-99% water. It also contains: (1) Electrolytes. (2) **Salivary amylase** – an enzyme that chemically digests starch. (3) **Secretory IgA** and **lysozyme** – which provide immune defense. (4) **Mucin** – protein that, when dissolved in water, forms mucus. Different cells within the salivary glands produce different kinds of saliva. **Serous cells** produce thin watery saliva while **mucous cells** produce thick sticky mucous-rich saliva.

Here's a summary of the digestive processes that occur within the mouth:

1. Presence of food activates the **salivatory nuclei of the pons and medulla** and salivation results.
2. Teeth and tongue mechanically digest food increasing the surface area available for digestive enzymes.
3. Food is mixed with saliva and compacted into a bolus.
4. Tongue pushes the bolus into the oropharynx as swallowing is voluntarily initiated.

Food passes from the oral cavity into the **oropharynx** and then the **laryngopharynx** and onward to the esophagus. The epiglottis closes off the larynx during swallowing, preventing food from entering the respiratory tract. The laryngopharynx and oropharynx are common pathways for food, liquid and air. (No food passes thru the nasopharynx, the superior-most portion of the pharynx.) No digestive processes are initiated within the pharynx. The oropharynx and the laryngopharynx are lined by friction-resistant stratified squamous epithelium. 3 sets of **pharyngeal constrictor muscles** propel the bolus down the pharynx and into the esophagus.

From esophagus to anal canal, the walls of the digestive tract have the same basic 4 layer arrangement: **mucosa**, **submucosa**, **muscularis externa**, and **serosa/adventitia**.

The mucosa is the innermost layer and lines the lumen. Its functions include: (1) Secretion of mucus and enzymes into the tract's lumen. (2) Secretion of hormones into the plasma. (3) Protection against infectious disease. (4) Absorption of digestive end products into plasma & lymph. The mucosa consists of 3 sublayers: **epithelium**, **lamina propria**, and the **muscularis mucosa**. The epithelium lines the lumen and is simple columnar in the intestines and stomach; and stratified squamous in the esophagus and anal canal. The **lamina propria** is a layer of loose connective tissue underneath the epithelium. It contains capillaries for nutrient absorption and lymph nodules for pathogen defense. The **muscularis mucosa** underlies the lamina propria. It's a thin layer of smooth muscle that can adjust the degree of folding of the mucosa.

The submucosa is external to the mucosa. It's made of dense connective tissue and contains blood and lymphatic vessels, lymphoid nodules, and nerve fibers. It's a strong

layer that provides vascular supply to most structures of the GI tract wall. It's the site of much of the nervous coordination of the secretory and motor activities of the mucosa.

The muscularis externa is external to the submucosa. It's primarily smooth muscle and is responsible for peristalsis and other movements. It's typically divided into 2 sublayers, an **inner circular layer** and an **outer longitudinal layer**. In several sites, the circular layer thickens to become a **sphincter**, which regulates passage of materials and prevents backflow. Blood vessels, lymphatic vessels, and a large number of nerve fibers are btwn the 2 layers. The nervous elements help coordinate the tone of both the layers of the externa and the secretory activities of the mucosa.

The serosa is the outermost layer of the intraperitoneal organs. It's a.k.a. the **visceral peritoneum**. It consists of a simple squamous epithelium overlying some thin areolar connective tissue. It's often associated with blood vessels, lymphatic vessels, and adipose tissue. The serosa not only supplies the vascular, nervous, and lymphatic elements to the gut wall, its moistness also reduces the amount of friction btwn organs. The esophagus has an adventitia rather than a serosa. It's a layer of fibrous connective tissue that firmly holds the organ in place. Retroperitoneal digestive organs have a serosa (on the side next to the peritoneal cavity) and an adventitia (on the dorsal side).

The **esophagus** is a muscular 10" tube that propels food from the laryngopharynx to the stomach. No digestive processes are initiated w/i the esophagus. It's collapsed when not propelling food. It runs thru the mediastinum and pierces the diaphragm at the **esophageal hiatus** and joins the stomach at the **cardiac orifice**. The so called **cardiac** or **gastroesophageal sphincter** surrounds this opening. Anatomically, it is not a true sphincter; it's more of a stricture that helps prevent reflux of stomach contents. The esophageal mucosa is a stratified squamous epithelium, which is thrown into folds when empty. The submucosa contains mucus-secreting glands for lubrication. The muscularis externa is unique in that it contains both skeletal and smooth muscle. Upper 1/3 is skeletal muscle. Middle 1/3 is a mix of skeletal and smooth muscle. Lower 1/3 is smooth muscle. The adventitia is the layer of dense connective tissue that binds the esophagus to surrounding structures (most prominently to the trachea). The presence of food in the esophagus triggers reflexes result in waves of peristalsis that force food down to the stomach.

The **stomach** is an enlarged segment of the tract that functions mainly in storing food and mixing it with **gastric juice** (creating a paste called **chyme**). Other functions of stomach include: (1) Chemical digestion of proteins. (2) Secretion of **intrinsic factor** – a chemical that is necessary for **vitamin B₁₂** absorption (necessary for RBC synthesis among other things). (3) Destruction of ingested bacteria via secreted **hydrochloric acid**.

The stomach's diameter and volume vary with its contents. The empty stomach's mucosa is thrown into visible folds called **rugae**. They allow the stomach to expand as it fills with food. The major regions of the stomach include:

1. **Cardiac region** – small area that surrounds the gastroesophageal junction.
2. **Fundus** – dome-shaped portion that bulges upward superolaterally to the cardia.

3. **Body** – large midportion of the stomach.
4. **Pyloric region** – funnel-shaped region connecting the body of the stomach to the small intestine. Wider part of the “funnel” is the **pyloric antrum**. Narrow part is the **pyloric canal**. Terminus of the stomach is the **pylorus**. Junction btwn the pylorus and the duodenum is controlled by the **pyloric sphincter**.

The convex lateral surface of the stomach is the **greater curvature**. The concave medial surface of the stomach is the **lesser curvature**. Hanging from the curvatures are the **omenta**. The **lesser omentum** is a mesentery that connects the lesser curvature of the stomach to the liver. The **greater omentum** is a fold of mesentery that drapes from the inferior surface of the greater curvature, covers the small intestine, and attaches to the transverse colon.

The stomach contains the 4 typical layers. The epithelium and the muscularis externa are adapted for the special functions of the stomach. The gastric mucosa is a simple columnar epithelium with millions of tube-like invaginations known as **gastric pits**. The surface epithelial cells are also known as **surface mucous cells** b/c they secrete a basic mucus \approx 1mm thick. The gastric pits lead into **gastric glands**, which secrete gastric juice (2-3 L/ day). Cells comprising the gastric glands vary depending on the particular region of the stomach. The basic cell types are:

1. **Mucous neck cells** – found in the upper portion of the gland. Secrete acidic mucus and function as stem cells for surface mucous cells.
2. **Chief cells** – primary function is the secretion of **pepsinogen**, an inactive form the protease, **pepsin**. Pepsinogen is activated by HCl and by pepsin itself.
3. **Parietal cells** – found in the midportion of the glands. Secrete **hydrochloric acid** (which gives the stomach its low pH – usually 1-3) as well as **intrinsic factor**.
4. **Enteroendocrine cells** – secrete multiple hormones into the plasma. An example is **gastrin** released by **G cells**. Gastrin is a hormone that regulates the stomach’s motility and secretory activity.

The presence of acid and proteases w/i the stomach lumen begs the question of “*why is the stomach not digested by itself?*” The answer is manifold:

1. A thick coating of **bicarbonate-containing mucus** lines the wall.
2. Damaged cells are quickly shed and replaced.
3. Epithelium is linked by **tight junctions**, which prevent leaking of gastric juice.

The gastric muscularis externa contains 3 layers rather than the normal 2. Deep to the circular layer of muscle is the **oblique layer**. The oblique layer allows the stomach to churn, mix, and pummel food.

There are 2 basic types of muscular movements in the stomach: **Mixing waves** which mix ingested materials with the gastric secretions; and **Peristaltic waves** that are more powerful and force chyme towards the pyloric sphincter. Each peristaltic wave forces a small amount of chyme thru the pylorus.

Note that food products are not absorbed in the stomach. (Alcohol and some drugs are.)

Gastric activity (i.e., muscle contractions and the secretion of gastric juice) is stimulated:

1. By the sight/smell/taste/thought of food. This is known as the **cephalic phase**. The sight or thought of food stimulates the cerebral cortex which stimulates the hypothalamus (which is also directly stimulated by taste and olfaction). The hypothalamus then initiates parasympathetic signals to the stomach via the vagus nerve. ACh released by the vagus nerve stimulates gastric activity. ACh also stimulates the stomach to release the hormone gastrin. Gastrin then stimulates gastric activity.
2. Indirectly in response to stretch or the presence of amino acids w/i the stomach. Both activate short and long reflexes (vagovagal reflexes) that stimulate gastric activity as well as gastrin release. This is known as the **gastric phase** and is responsible for the greatest volume of gastric juice secretion.
3. Indirectly by the initial filling of the duodenum with chyme. The initial presence of chyme causes duodenal endocrine cells to release **intestinal gastrin**, which also stimulates gastric activity. This is known as the **intestinal phase**.

Gastric activity is inhibited:

1. By the accumulation of chyme within the duodenum. In response to stretch, the duodenal endocrine cells begin to release hormones known as **enterogastrones**. These include **cholecystokinin**, **secretin**, and **vasoactive intestinal peptide** and they act to inhibit gastric activity.
2. By various drugs, stress, anxiety, and fear, i.e. by increased sympathetic activity.

The stomach typically empties about four hours after a meal, although the size and contents of the meal can greatly influence the rate of emptying.

The **small intestine** is the site of most digestion and almost all nutrient absorption. It's a highly convoluted tube extending from the pyloric sphincter to the ileocecal valve where it joins the large intestine. It's the longest part of the alimentary tube. The name reflects that its diameter is less than that of the large intestine. It's divided into 3 unequal sections: the **duodenum**, **jejunum**, and the **ileum**.

The duodenum is the shortest of the 3 divisions – about 12". It's mostly retroperitoneal and curves almost 180° around the head of the pancreas. It receives the **common bile duct** (delivering bile from the liver and gallbladder) and the **main pancreatic duct** (delivering pancreatic juice from the pancreas). These 2 ducts unite in the duodenal wall to form the **hepatopancreatic ampulla**. The ampulla opens into the duodenum via the **major duodenal papilla**. The **hepatopancreatic sphincter** controls entry of bile and pancreatic juice into the intestinal lumen. The duodenum ends in a sharp bend where it joins the jejunum. The jejunum is intraperitoneal and 8' long. It extends from duodenum to ileum and is suspended by mesentery. It's the primary site of digestion and absorption. The ileum is intraperitoneal and 12' long. It's also suspended by mesentery and joins the colon at the ileocecal valve. It's primarily involved in absorption of electrolytes and vitamins.

The microscopic anatomy is highly modified for absorption. Structures that maximize surface area include: **circular folds (plicae circulares)**, **villi**, and **microvilli**. Plicae circulares are deep, circular, permanent folds of the mucosa and submucosa. They increase surface area and slow the movement of chyme. This provides more time for absorption and digestion to occur. Villi are fingerlike extensions of the mucosa. Absorptive epithelial cells line their surface. Within the core of each villus is the lamina propria, which contains blood capillaries (for absorption of amino acids and monosaccharides) and a **lacteal** (for absorption of fatty acids). Microvilli are tiny projections of the plasma membrane of each absorptive epithelial cell. They give the cell's luminal surface a fuzzy appearance known as the **brush border**. Membrane bound enzymes are embedded in the brush border and function in nutrient breakdown.

The small intestine contains the 4 basic layers. The epithelium is an unremarkable simple columnar with goblet cells. Epithelial invaginations known as **intestinal glands (crypts of Lieberkuhn)** secrete over 2 L/day of **intestinal juice**, which consists primarily of mucus, electrolytes, and water. The intestinal glands also contain enteroendocrine cells (which secrete hormones like intestinal gastrin, secretin, and cholecystokinin into the plasma), **Paneth cells** (which secrete antimicrobial chemicals like lysozyme), and intraepithelial lymphocytes (which kill antigens w/o any need to ask permission). The submucosa is unremarkable except in the proximal duodenum and terminal ileum. The proximal duodenal submucosa contains **alkaline mucus glands** that help counteract the acidic chyme. The terminal ileal submucosa contains **Peyer's patches**. The muscularis externa has the typical 2 layers – inner circular and outer longitudinal. The small intestine is the primary site of a mixing activity known as **segmentation**. Segmentation consists of alternating contractions and relaxations that mix the intestinal contents rather than propel it forward. The small intestine has a serosa except in those areas where it is retroperitoneal. There, it's covered by an adventitia.

Motility and secretory activity of the small intestine is enhanced by parasympathetic stimulation and inhibited by sympathetic activity. Segmentation is the primary motility activity. Once nutrient digestion is completed waves of peristaltic activity (**migrating motor complexes**) sweep any residue to the large intestine. Gastrin released by the stomach relaxes the ileocecal sphincter allowing the leftovers of the small intestine to be propelled into the colon. This is known as the **gastroileal reflex**.

The **liver** is an accessory digestive organ that has multiple functions including:

1. Carbohydrate metabolism – storage and release of glucose
2. Removal of drugs, toxins, and foreign chemicals from the plasma
3. Storage of vitamins (A, D, E, and K) and minerals (iron and copper)
4. Protein metabolism
5. Lipid metabolism
6. Synthesis of plasma proteins (e.g., albumin, fibrin, etc.)
7. Phagocytosis of old RBCs and of pathogens.
8. Production of **bile** (0.5-1 L/day).

The liver is the largest internal organ in the body and is located underneath the diaphragm and partially shielded by the ribcage on the right side of the body. It's attached to the diaphragm via the **coronary ligament** and to the anterior abdominal wall by the **falciform ligament**. The liver is traditionally divided into 4 lobes: **right, left, caudate, and quadrate**. The large left and right lobes are easily viewed anteriorly and are separated by the falciform ligament. The caudate and quadrate lobes are smaller and best viewed from the posteroinferior aspect. The gallbladder rests in a recess on the interior of the right lobe. The liver is attached to the lesser curvature of the stomach via the lesser omentum. The **hepatic artery** and **hepatic portal vein** run to the liver in the lesser omentum and enter the liver at its hilum (the **porta hepatis**). The **hepatic ducts** along with lymphatic vessels exit the liver at its hilum. The main digestive output of the liver is bile. It exits the liver as follows:

1. Bile from the left and right sides of the liver leaves via the **left and right hepatic ducts** respectively.
2. The left and right hepatic ducts fuse to form the **common hepatic duct**.
3. The common hepatic duct fuses with the **cystic duct** of the gallbladder to form the **common bile duct**.
4. Common bile duct fuses with the **pancreatic duct** and enters the duodenum as the **hepatopancreatic ampulla**.

A connective tissue capsule and visceral peritoneum almost completely surround the liver (except for a **bare area** at the liver's superiormost point). The capsule sends septa w/i the liver to provide structural support. The septa divide the liver interior into hexagonal shaped **liver lobules**. The center of each lobule contains a **central vein**. Extending out from the central vein like spokes are the **hepatic cords**, which are composed of **hepatocytes**. At each of the 6 corners of a lobule is a **portal triad** – a **branch** of the **hepatic artery** (a **portal arteriole**), a **branch** of the **hepatic portal vein** (a **portal venule**), and a **bile duct**. The portal venules and the portal arterioles are linked to the central vein by capillaries known as **liver sinusoids**, which run btwn the hepatic cords.

Blood flows into a liver lobule at any of its 6 corners. Blood from the portal venule and portal arteriole mingles in the sinusoids and flows towards the central vein. As blood flows thru the sinusoids:

1. Gases are exchanged btwn the blood and the hepatocytes
2. Nutrients are taken up from the plasma by hepatocytes.
3. Toxins and poisons are removed from the plasma by hepatocytes.
4. Pathogens and old RBCs are engulfed by **hepatic macrophages**.

Blood will reach the central vein and central veins will combine into larger veins that eventually coalesce to form the **hepatic veins**. Meanwhile running alongside the liver sinusoids are the **bile canaliculi**. Hepatocytes secrete bile into bile canaliculi and canaliculi empty into bile ducts at the portal triads. The portal triad bile ducts eventually combine to yield the left and right hepatic ducts that exit the liver. Note that blood flows inward from the portal triads to the central vein, while bile flows outward towards the portal triads.

Bile secretion is the primary digestive function of the liver. Bile is a mixture of bile salts, bile pigments (e.g., **bilirubin**) and other chemicals. It's synthesized by the liver, stored and concentrated by the gallbladder, and secreted into the duodenum. The bile salts **emulsify** fats. Because of their hydrophobic nature, fats tend to clump together in the watery environs of the GI tract. Clumped fat reduces the surface area exposed to fat-digesting enzymes. Emulsification is the act of separating the large fat globules into tiny separate fatty droplets. This increases the available surface area for lipases to work upon. Note that bile salts are reabsorbed in the ileum and travel back to the liver (via the hepatic portal circulation) where they are reused. The recycling path that bile follows is known as the **enterohepatic circulation**.

The **gallbladder** is a thin-walled green muscular sac found on the ventral surface of the liver. It functions primarily in the storage and concentration of bile. Its wall has 3 layers: an inner mucosa lined by simple columnar epithelium and folded into rugae; a smooth muscle muscularis that contracts to expel bile into the duodenum when required; and an outer serosa.

The liver continuously produces bile. However the hepatopancreatic sphincter is normally closed. This results in bile backing up into the common bile duct, cystic duct, and ultimately into the gallbladder. When fatty chyme arrives in the small intestine, intestinal glands secrete the hormone cholecystinin. CCK causes the contraction of the gallbladder and the relaxation of the hepatopancreatic sphincter, thus causing bile to flow into the duodenum.

The **pancreas** is mostly retroperitoneal and deep to the greater curvature of the stomach. The **head** of the pancreas sits next to the duodenum as it emanates from and loops away from the pylorus. The **body** extends behind the stomach and its **tail** ends at the spleen. The pancreas primarily consists of **acini** – small clusters of enzyme secreting cells. These acinar cells empty their secretion into **small pancreatic ducts**. Small pancreatic ultimately empty into the **main pancreatic duct**, which runs centrally along the long axis of the pancreas. Recall that the main pancreatic duct combines with the common bile duct to form the hepatopancreatic ampulla, which empties into the duodenum at the major duodenal papilla. Sometime an **accessory pancreatic duct** will branch from the main pancreatic duct and empty directly into the duodenum,

The major function of the acinar and duct cells is the secretion of **pancreatic juice** (1.5 L/day). Acinar cells contribute digestive enzymes to the pancreatic juice including:

1. Protein-digesting enzymes (a.k.a. **proteases** such as **trypsinogen**, **chymotrypsinogen**, and **procarboxypeptidase**). These proteases are released in an inactive form known as **zymogens**. The active forms are **trypsin**, **chymotrypsin**, and **carboxypeptidase**.
2. Fat-digesting enzymes such as **pancreatic lipase**.
3. Carbohydrate-digesting enzymes such as **pancreatic amylase**.
4. Nucleic acid-digesting enzymes such as **nuclease**.

Duct cells contribute a **watery bicarbonate-rich solution**. The bicarbonate gives pancreatic juice a slightly alkaline pH which helps neutralize the acidity of the chyme.

When acidic, fatty chyme arrives the duodenal enteroendocrine cells secrete secretin and cholecystokinin (CCK). CCK travels in the blood to the pancreas where it primarily stimulates the secretion of enzymes by the acinar cells. Secretin also travels to the pancreas and stimulates the duct cells to release large amounts of the bicarbonate-rich fluid. CCK also causes contraction of the gallbladder as well as relaxation of the hepatopancreatic sphincter. During the cephalic and gastric phases of gastric secretion, parasympathetic input to the pancreas via the vagus nerve also prompts pancreatic juice release.

Scattered amidst the pancreatic acini are the hormone-producing **islets of Langerhans**. Their major function is the regulation of blood glucose levels. Islets of Langerhans consist of 2 primary cell types. **Alpha cells** secrete the hormone **glucagon**. **Beta cells** secrete the hormone **insulin**. Glucagon is released in response to low plasma [glucose]. Glucagon acts to increase plasma [glucose]. Insulin is released in response to high plasma [glucose] and acts to lower plasma [glucose].

The **large intestine** functions primarily to propel indigestible food remains and then expel them as feces. As it does it also absorbs any excess water remaining. It's about 5' in length. Its name arises from the size of its diameter. It begins at the **ileocecal valve** and terminates at the **anus**.

The large intestine is divided into:

1. **Cecum** – a blind pouch just beneath the ileocecal valve.
2. **Appendix** – a blind extension of the posteromedial cecum. It contains many lymphoid nodules and serves as bacterial reservoir of sorts.
3. **Colon** – **ascending colon** travels up from the cecum along the right side of the abdominal cavity. Just beneath the liver it turns medially. This curve is known as the **hepatic** or **right colic flexure**. It then continues across the abdominal cavity as the **transverse colon**. At the spleen, it turns inferiorly. This curve is known as the **splenic** or **left colic flexure**. It then continues as the **descending colon**. Where it enters the pelvis it becomes the S-shaped **sigmoid colon**. When the sigmoid colon passes the level of the 3rd lumbar vertebra, it becomes the **rectum**. The **anal canal** is the terminal portion of the rectum where it leaves the abdominopelvic cavity.

2 sphincters surround the anal canal. The **internal anal sphincter** is composed of smooth muscle and is involuntary. The **external anal sphincter** is composed of skeletal muscle and voluntary (to a point).

The colon exhibits 3 features not seen elsewhere along the GI tract.

1. The longitudinal layer of the muscularis externa is reduced into 3 bands of smooth muscle known as **teniae coli**.
2. The muscle tone of the teniae coli causes the wall of the large intestine to “pucker” into sacs called **haustra**.
3. Hanging from the large intestine are fat-filled bags of visceral peritoneum.

The colonic mucosa is simple columnar epithelium with multitudes of goblet cells. Goblet cell mucus provides fecal lubrication. The terminal anal canal is lined by stratified squamous epithelium. The colon has no plicae, villi, or microvilli. The colon does have **colonic intestinal glands**. Their primary output is mucus. The submucosa is unremarkable. The muscularis externa is unique in that the outer longitudinal layer is transformed into teniae coli. W/i the lower sigmoid and rectum the teniae coli broaden and fuse to form a uniform longitudinal layer. The colon is retroperitoneal except for the transverse and sigmoid portions (anchored by the transverse mesocolon and sigmoid mesocolon).

Millions of bacteria colonize the large intestine. They breakdown indigestible carbohydrate residues and produce many B vitamins as well as most of the body's vitamin K supply.

Typically 100 g of feces are produced per day consisting of 75% water and 25% solids. Solids include dead bacteria, fat, inorganic matter, protein, undigested plant fibers, bile pigments, and shed epithelial cells.

Muscular movements w/i the colon include:

1. **Segmentation** – the mixing increases the contact btwn feces and mucosa, which facilitates water reabsorption.
2. **Haustral contractions** – push food residue and fecal matter of haustrum to haustrum. Instigated by the stretching of a haustrum.
3. **Migrating motor complexes** – sweeping waves of peristalsis that move over large areas of the colon and force its contents towards the rectum. They typically occur 1-3 times/day. Mass movements are also initiated by the presence of food within the stomach. This is known as the **gastrocolic reflex**.
4. **Defecation** – when fecal matter enters and stretches the rectum, stretch receptors measure the degree of stretch. If stretch is above a certain level, signals are sent to the spinal cord and the defecation reflex is initiated. Parasympathetic output to the rectum and anal canal results in relaxation of the internal anal sphincter and waves of contraction of the rectal muscularis. Conscious input from the cerebral cortex maintains closure of the external anal sphincter – unless rectal stretch reaches threshold level. Defecation occurs with relaxation of the external sphincter coupled with powerful contractions of the descending colon, sigmoid colon, and rectum. It's assisted by the rise in intra-abdominal pressure created by the contraction of the diaphragm and abdominal muscles. The muscles of the pelvic floor must also relax during defecation.