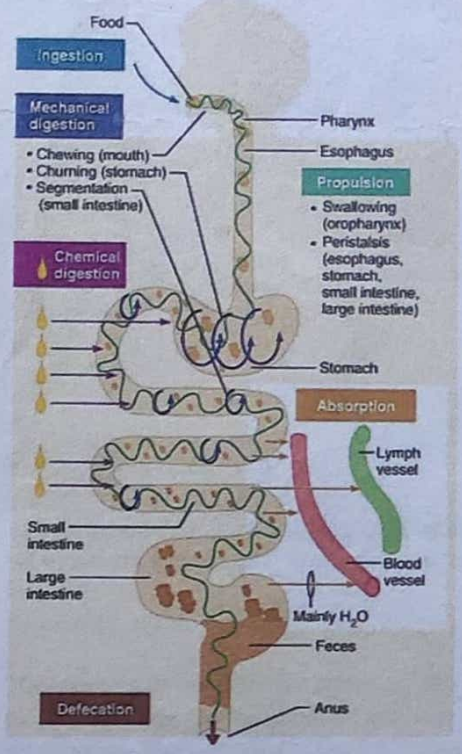
The Digestive system

The organs involved in the breakdown of food—collectively called the **digestive system.** 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 (16.5–23 ft) in a living person. The **accessory digestive organs** include the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.

Functions

1. Ingestion: taking food into the mouth.
2. Secretion: release of water, acid, buffers, and enzymes into the lumen of the GI tract.
3. Mixing and propulsion: churning and propulsion of food through the GI tract.
4. Digestion: mechanical and chemical breakdown of food.
5. Absorption: passage of digested products from the GI tract into the blood and lymph.
6. Defecation: the elimination of feces from the GI tract.



Layers of GIT:

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).

the epithelium of the mucosa is a simple columnar epithelium rich in mucus-secreting goblet cells. The slippery mucus it produces protects certain digestive organs from being digested themselves by enzymes working within their cavities and eases food passage along the tract.

The lamina propria, which underlies the epithelium, is loose 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.

A thin layer of smooth muscle fibers called the **muscularis mucosae,** 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 and nerve fibres. Its rich supply of elastic fibers enables the stomach to regain its normal shape after temporarily storing a large meal.

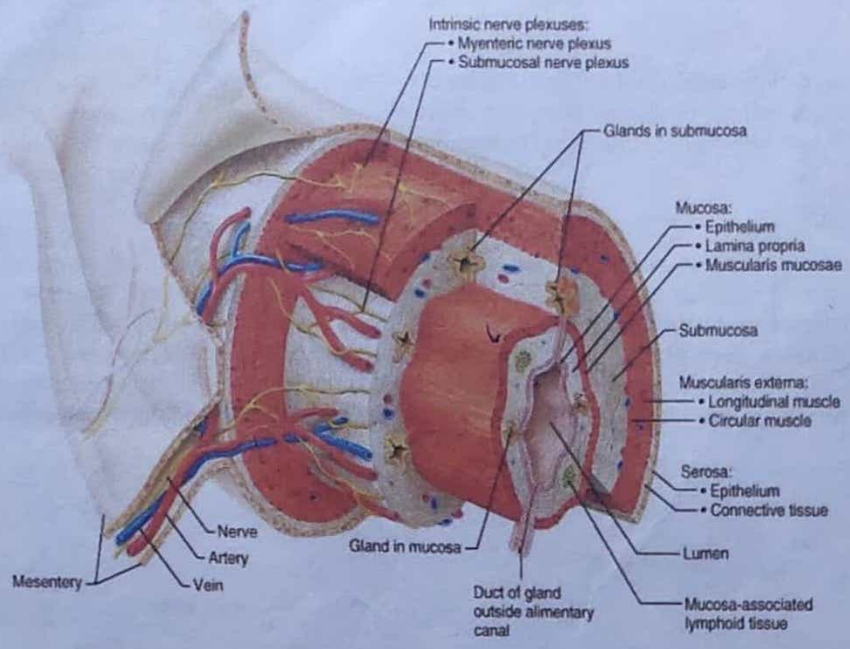
Muscularis

The **muscularis** contains *skeletal muscle* that produces voluntary swallowing. Skeletal muscle also forms the external

sphincter, which permits voluntary control of defecation. This layer is responsible for segmentation(break down) and peristalsis. It typically has an inner circular layer and an outer longitudinal layer of smooth muscle cells.

Serosa

It is the protective outermost layer of the intraperitoneal organs, also called the visceral peritoneum. It is formed of areolar connective tissue covered with mesothelium, a single layer of squamous epithelial cells.



Nerve supply of GIT:

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

The neurons of the ENS are arranged into two plexuses: the myenteric plexus and submucosal plexus. The **myenteric plexus** is located between the longitudinal and circular smooth muscle layers of the muscularis. The **submucosal plexus** is found within the submucosa. The plexuses of the ENS consist of motor neurons, interneurons, and sensory neurons. Myenteric 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.

Autonomic Nervous System

The function of ENS is regulated by ANS. The vagus (X) nerves supply parasympathetic fibers to most parts of the GI tract. The parasympathetic nerves form neural connections with the ENS. stimulation of the parasympathetic nerves 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. 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.

Anatomy of the Gastro Intestinal Tract

The Mouth

The mouth, a mucosa-lined cavity, is also called the oral cavity, or buccal cavity (buk'al). Its boundaries are the lips anteriorly, cheeks laterally, palate superiorly, and tongue inferiorly.

Salivary Glands

A **salivary gland** is a gland that releases a secretion called saliva into the oral cavity. Saliva (1) cleanses the mouth, (2) dissolves food chemicals so that they can be tasted, (3) moistens food and aids in compacting it into a bolus, and (4) contains enzymes that begin the chemical breakdown of starchy foods.

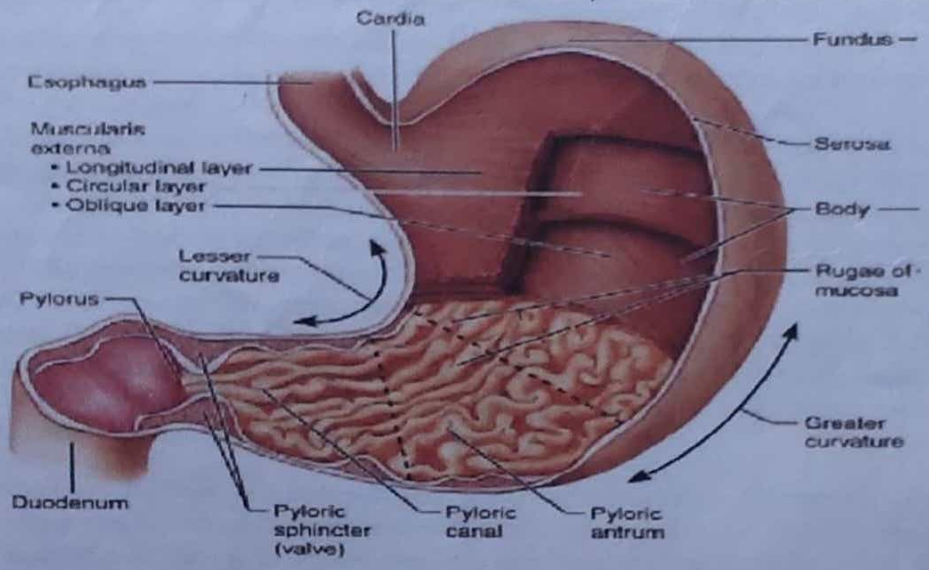
are three pairs of major salivary glands: the parotid, submandibular, and sublingual glands. The **parotid glands** are located inferior and anterior to the ears, between the skin and the masseter muscle. Each secretes saliva into the oral cavity via a **parotid duct** that pierces the buccinator muscle to open into the vestibule next to the second upper molar tooth.
The **submandibular glands** are found in the floor of the mouth; they open to the medial and partly inferior to the body of the mandible.
The **sublingual glands** are beneath the tongue and superior to the submandibular glands. Their ducts open into the floor of the mouth in the oral cavity proper.

Composition 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, salivary amylase, a digestive enzyme that acts on starch and the proteins mucin.

Stomach:

Anatomy:- The stomach has four main regions: the cardia, fundus, body,and pylorus. The **cardia** surrounds the superior opening of the stomach. The rounded portion superior to and to the left of the cardia is the **fundus.** Inferior to the fundus is the large central portion of the stomach, called the **body.** The region of the stomach that connects to the duodenum is the **pylorus,**it has two parts, the **pyloric antrum,**which connects to the body of the stomach, and the **pyloric canal,** which leads into the duodenum. The pylorus communicates with the duodenum of the small intestine via a smooth muscle sphincter called the **pyloric sphincter.** The concave medial border of the stomach is called the **lesser curvature,** and the convex lateral border is called the **greater curvature.**



Histology:-

The lining epithelium of the stomach mucosa is a simple columnar epithelium composed entirely of goblet cells,this lead into the gastric glands that produce the stomach secretion called gastric juice. The glands in these regions contain a variety of secretory cells, including the four types described here:

1. Mucous neck cells, found in the upper, or "neck," regions of the glands, produce a thin, quite different type of mucus from that secreted by the goblet cells of the surface epithelium. It is not yet understood what special function this acidic mucus performs.

2. Parietal cells, found mainly in the middle region of the glands scattered among the chief cells, simultaneously secrete hydrochloric acid (HCl) and intrinsic factor. HCl makes the stomach contents extremely acidic (pH 1.5–3.5), a condition necessary for activation and optimal activity of pepsin. The acidity also helps in food digestion by denaturing proteins and breaking down cell walls of plant foods, and is harsh enough to kill many of the bacteria ingested with foods. Intrinsic factor is a glycoprotein required for vitamin B_{12} absorption in the small intestine.

3. Chief cells produce pepsinogen , the inactive form of the protein-digesting enzyme pepsin. The chief cells occur mainly in the basal regions of the gastric glands. When chief cells are stimulated, the first pepsinogen molecules they release are activated by HCl. But once pepsin is present, it also catalyzes the conversion of pepsinogen to pepsin. This positive feedback process is limited only by the amount of pepsinogen present. Chief cells also secrete insignificant amounts of lipases.

Enteroendocrine cells release a variety of chemical messengers directly into the interstitial fluid of the lamina propria. Some of these, for example histamine and serotonin, act locally as paracrines. Others, such as somatostatin, act both locally and as hormones, diffusing into the blood capillaries to influence several digestive system target organs. Gastrin, a hormone, plays essential roles in regulating stomach secretion and motility.

MECHANISM OF HCL SECRETION:- Parietal cells secrete hydrogen ions (H^+) and chloride ions (Cl^-) separately into the stomach lumen, the net effect is secretion of hydrochloric acid (HCl). **Proton pumps** powered by H^+/K^+ ATPases actively transport H^+ into the lumen while bringing potassium ions (K^+) into the cell. At the same time, Cl^- and K^+ diffuse out into the lumen through Cl^- and K^+ channels in the apical membrane. The enzyme *carbonic anhydrase,* which is especially plentiful in parietal cells, catalyzes the formation of carbonic acid (H_2CO_3) from water (H_2O) and carbon dioxide (CO_2). As carbonic acid dissociates, it provides a ready source of H^+ for the proton pumps but also generates bicarbonate ions (HCO_3^-). As HCO_3^- builds up in the cytosol, it exits the parietal cell in exchange for Cl^- via Cl^-/HCO_3^- antiporters in the basolateral membrane (next to the lamina propria). HCO_3^- diffuses into nearby blood capillaries. This "alkaline tide" of bicarbonate ions entering the bloodstream after a meal may be large enough to elevate blood pH slightly.

Small intestine:

Gross Anatomy

The small intestine is a convoluted tube extending from the pyloric sphincter in the epigastric region to the ileocecal valve in the right iliac region where it joins the large intestine. It is the longest part of the alimentary tube, but is only about half the diameter of the large intestine, ranging from 2.5 to 4 cm (1–1.6 inches). Although it is 6–7 m long in a cadaver, the small intestine is only about 2–4 m (7–13 ft) long during life because of muscle tone.

The small intestine has three subdivisions: the duodenum, which is mostly retroperitoneal, and the jejunum and ileum, both intraperitoneal organs. The relatively immovable duodenum , which curves around the head of the pancreas, is about 25 cm (10 inches) long. Although it is the shortest intestinal subdivision, the duodenum has the most features of interest. The bile duct, delivering bile from the liver, and the main pancreatic duct, carrying pancreatic juice from the pancreas, unite in the wall of the duodenum in a bulblike point called the hepatopancreatic ampulla . The ampulla opens into the duodenum via the volcano-shaped major duodenal papilla. The entry of bile and pancreatic juice is controlled by a muscular valve called the hepatopancreatic sphincter, or sphincter of Oddi. The jejunum , about 2.5 m (8 ft) long, extends from the duodenum to the ileum. The ileum, approximately 3.6 m (12 ft) in length, joins the large intestine at the ileocecal valve. The jejunum and ileum hang in sausage like coils in the central and lower part of the abdominal cavity, suspended from the posterior abdominal wall by the fan-shaped mesentery. These more distal parts of the small intestine are encircled and framed by the large intestine.

Histology:- The small intestine is highly adapted for nutrient absorption. Its length alone provides a huge surface area, and its wall has three structural modifications—plicae circulares, villi, and microvilli—that amplify its absorptive surface enormously. Villi are fingerlike projections of the mucosa, over 1 mm high, that give it a velvety texture, much like the soft nap of a towel. The epithelial cells of the villi are chiefly absorptive columnar cells. Microvilli, tiny projections of the plasma membrane of the absorptive cells of the mucosa, give the mucosal surface a fuzzy appearance called the brush border. The plasma membranes of the microvilli bear enzymes referred to as brush border enzymes, which complete the digestion of carbohydrates and proteins in the small intestine. Between the villi, the mucosa is studded with pits that lead into tubular intestinal glands called intestinal crypts, or crypts of Lieberkühn. The epithelial cells that line these crypts secrete intestinal juice, a watery mixture containing mucus that serves as a carrier fluid for absorbing nutrients from chyme. Deep in the crypts are specialized secretory cells called Paneth cells, which fortify the small intestine's defenses by releasing antimicrobial agents such as defensins and lysozyme. The submucosa is typical areolar connective tissue, and it contains both individual and aggregated lymphoid follicles, the latter called Peyer's patches. Peyer's patches increase in abundance toward the end of the small intestine, reflecting the fact that this region of the small intestine contains huge numbers of bacteria that must be prevented from entering the bloodstream. Elaborate mucus-secreting duodenal (Brunner's) glands are found in the submucosa of the duodenum only. These glands produce an alkaline mucus that helps neutralize the acidic chyme moving in from the stomach. When this protective mucus barrier is inadequate, the intestinal wall erodes and duodenal ulcers result.

LARGE INTESTINE:

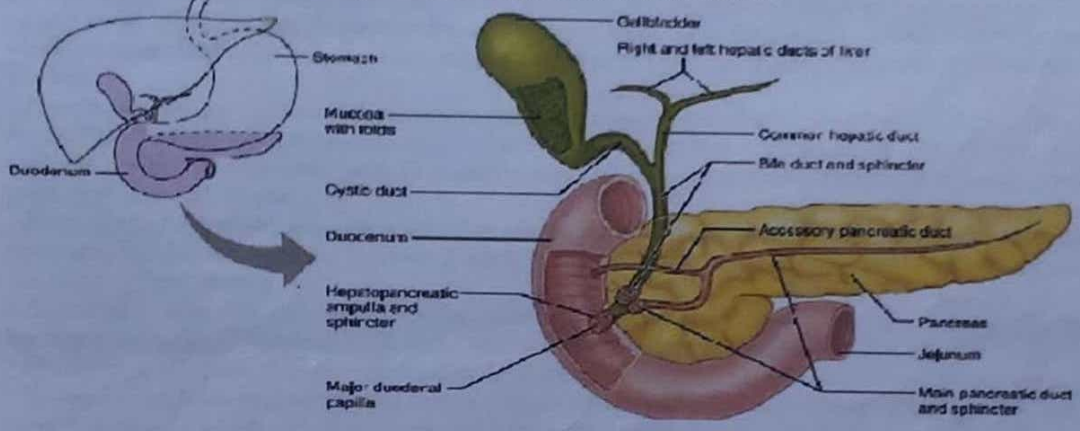
The **large intestine,** which is about 1.5 m long and 6.5 cm in diameter, extends from the ileum to the anus. Structurally, the four major regions of the large intestine are the cecum, colon, rectum, and anal canal. The opening from the ileum into the large intestine is guarded by a fold of mucous membrane called the **ileocecal sphincter(valve),** which allows materials from the small intestine to pass into the large intestine. Hanging inferior to the ileocecal valve is the **cecum,** a small pouch about 6 cm long. Attached to the cecum is a twisted, coiled tube, measuring about 8 cm in length, called the **appendix.** The open end of the cecum merges with a long tube

d the **colon**, which is divided into ascending, transverse, descending, and sigmoid portions. The colon continues across the domen to the left side as the **transverse colon and** passes inferiorly to the level of the iliac crest as the **descending colon.** The **sigmoid colon** begins near the left iliac crest, projects medially to the midline, and terminates as the rectum. The **rectum,** the last 20 cm of the GI tract, lies anterior to the sacrum and coccyx. The terminal 2–3 cm of the rectum is called the **anal canal.** The opening of the anal canal to the exterior, called the **anus.**

the bacterial flora of the large intestine colonize the colon, metabolize some host-derived proteins (mucin, heparin, and hyaluronic acid) and ferment some of the indigestible carbohydrates (cellulose, xylan, and others), releasing irritating acids and a mixture of gases (including dimethyl sulfide, H_2, N_2, CH_4, and CO_2). Some of these gases (such as dimethyl sulfide) are quite odorous. The bacterial flora also synthesize B complex vitamins and most of the vitamin K the liver requires to synthesize some of the clotting proteins.

LIVER AND GALLBLADDER

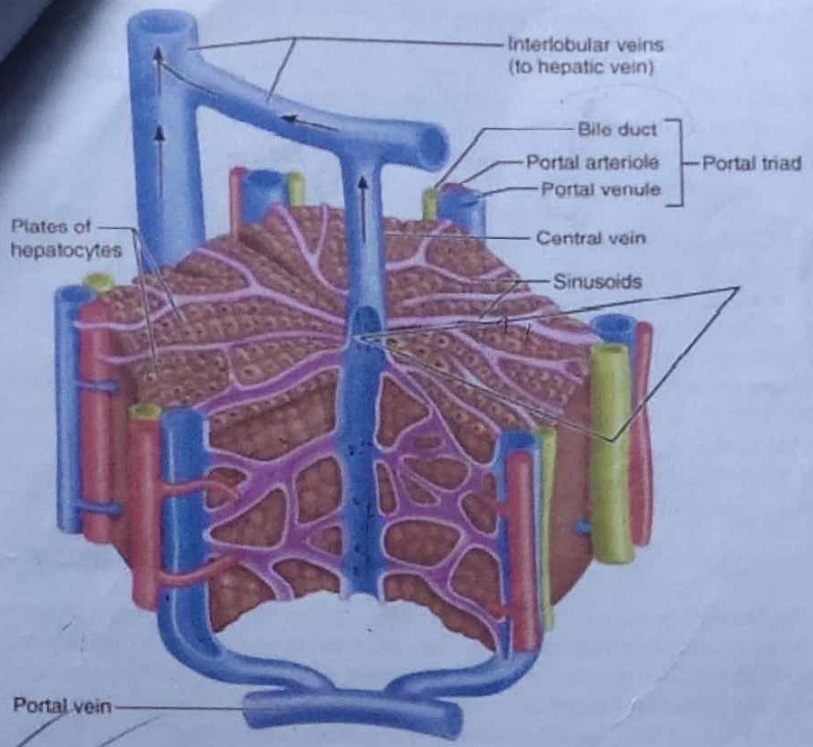
The **liver** is the heaviest gland of the body, weighing about 1.4 kg in an average adult. The liver is divided into two principal lobes—a large **right lobe** and a smaller **left lobe**—by the **falciform ligament.**
the liver is composed of several components . the structural and functional units of liver called liver lobules. Each lobule is a roughly hexagonal (six-sided) structure consisting of plates of liver cells, or hepatocytes, organized like bricks in a garden wall. The hepatocyte plates radiate outward from a central vein running in the longitudinal axis of the lobule. At each of the six corners of a lobule is a portal triad (portal tract region), so named because three basic structures are always present there: a branch of the hepatic artery (supplying oxygen-rich arterial blood to the liver), a branch of the hepatic portal vein (carrying venous blood laden with nutrients from the digestive viscera), and a bile duct. Between the hepatocyte plates, there are enlarged capillaries, the liver sinusoids. Blood from both the hepatic portal vein and the hepatic artery percolates from the triad regions through these sinusoids and empties into the central vein. From the central veins blood eventually enters the hepatic veins, which drain the liver, and empty into the inferior vena cava. Forming part of the sinusoid walls are star-shaped hepatic macrophages, also called Kupffer cells (koop'fer) which remove debris such as bacteria and worn-out blood cells from the blood as it flows past. During liver injury, hepatocytes secrete vascular endothelial growth factor (VEGF) which binds to specific receptors on endothelial cells lining the sinusoids. The endothelial cells proliferate and release other growth factors, such as hepatocyte growth factor (HGF) and interleukin 6, which in turn prompt the hepatocytes to multiply and replace dead and dying liver tissue. The regenerative capacity of the liver is exceptional; it can regenerate to its former size even after surgical removal or loss of 70% of its normal mass.
Secreted bile flows through tiny canals, called bile canaliculi, that run between adjacent hepatocytes toward the bile duct branches in the portal triads. Notice that blood and bile flow in opposite directions is in the liver lobule. Bile entering the bile ducts eventually leaves the liver via the common hepatic duct to travel toward the duodenum.

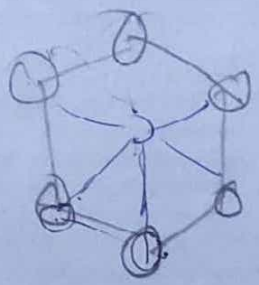


The Gallbladder
The gallbladder is a thin-walled green muscular sac about 10 cm long. Its rounded fundus protrudes from the inferior margin of the liver. The gallbladder stores bile that is not immediately needed for digestion and concentrates it by absorbing some of its water and ions. When its muscular wall contracts, bile is expelled into its duct, the cystic duct, and then flows into the bile duct.

Role and Composition of Bile

Each day, hepatocytes secrete 800–1000 mL of **bile,** a yellow, brownish, or olive-green liquid. It has a pH of 7.6–8.6 and consists mostly of water, bile salts, cholesterol, a phospholipid called lecithin, bile pigments, and several ions. The principal bile pigment is **bilirubin.** The phagocytosis of aged red blood cells liberates iron, globin, and bilirubin. The iron and globin are recycled; the bilirubin is secreted into the bile and is eventually broken down in the intestine. One of its breakdown products—**stercobilin**—gives feces their normal brown color. Bile is partially an excretory product and partially a digestive secretion. Bile salts, which are sodium salts and potassium salts of bile acids, play a role in **emulsification,** the breakdown of large lipid globules into a suspension of small lipid globules. The small lipid globules present a very large surface area that allows pancreatic lipase to more rapidly accomplish digestion of triglycerides. Bile salts also aid in the absorption of lipids following their digestion.





Functions of the Liver

In addition to secreting bile, which is needed for absorption of dietary fats, the liver performs many other vital functions:

- ***Carbohydrate metabolism.*** The liver is especially important in maintaining a normal blood glucose level. When blood glucose is low, the liver can break down glycogen to glucose and release the glucose into the bloodstream. The liver can also convert certain amino acids and lactic acid to glucose, and it can convert other sugars, such as fructose and galactose, into glucose. When blood glucose is high, as occurs just after eating a meal, the liver converts glucose to glycogen and triglycerides for storage.
- ***Lipid metabolism.*** Hepatocytes store some triglycerides; break down fatty acids to generate ATP; synthesize lipoproteins, which transport fatty acids, triglycerides, and cholesterol to and from body cells; synthesize cholesterol;and use cholesterol to make bile salts.
- ***Protein metabolism.*** Hepatocytes *deaminate* (remove the amino group, NH_2, from) amino acids so that the amino acids can be used for ATP production or converted to carbohydrates or fats. The resulting toxic ammonia (NH_3) is then converted into the much less toxic urea, which is excreted in urine. Hepatocytes also synthesize most plasma proteins, such as alpha and beta globulins, albumin, prothrombin,and fibrinogen.
- ***Processing of drugs and hormones.*** The liver can detoxify substances such as alcohol and excrete drugs such as penicillin, erythromycin, and sulfonamides into bile. It can also chemically alter or excrete thyroid hormones and steroid hormones such as estrogens and aldosterone.
- ***Excretion of bilirubin.*** As previously noted, bilirubin, derived from the heme of aged red blood cells, is absorbed by the liver from the blood and secreted into bile. Most of the bilirubin in bile is metabolized in the small intestine by bacteria and eliminated in feces.
- ***Synthesis of bile salts.*** Bile salts are used in the small intestine for the emulsification and absorption of lipids.
- ***Storage.*** In addition to glycogen, the liver is a prime storage site for certain vitamins (A, B12, D, E, and K) and minerals (iron and copper), which are released from the liver when needed elsewhere in the body.
- ***Phagocytosis.*** The stellate reticuloendothelial (Kupffer) cells of the liver phagocytize aged red blood cells, white blood cells, and some bacteria.
- ***Activation of vitamin D.*** The skin, liver, and kidneys participate in synthesizing the active form of vitamin D.

PANCREAS:

The pancreas consists of a head, a body, and a tail and is usually connected to the duodenum by two ducts. The **head** is the expanded portion of the organ near the curve of the duodenum; superior to and to the left of the head are the central **body** and the tapering **tail.** Pancreatic juices are secreted by exocrine cells into small ducts that ultimately unite to form two larger ducts, the pancreatic duct and the accessory duct. These in turn convey the secretions into the small intestine. The **pancreatic duct** is the larger of the two ducts. In most people, the pancreatic duct joins the common bile duct from the liver and gallbladder and enters the duodenum as a dilated common duct called the **hepatopancreatic ampulla (ampulla of Vater).** The ampulla opens on an elevation of the duodenal mucosa known as the **major duodenal papilla**. The passage of pancreatic juice and bile through the hepatopancreatic ampulla into the small intestine is regulated by a mass of smooth muscle known as the **sphincter of the hepatopancreatic ampulla (sphincter of Oddi).**

other major duct of the pancreas, the **accessory duct (duct of Santorini),** leads from the pancreas and empties into the duodenum

Histology of the Pancreas

The pancreas is made up of small clusters of glandular epithelial cells. About 99% of the clusters, called **acini**, constitute the *exocrine* portion of the organ. The cells within acini secrete a mixture of fluid and digestive enzymes called **pancreatic juice.** The remaining 1% of the clusters, called **pancreatic islets (islets of Langerhans),** form the *endocrine* portion of the pancreas. These cells secrete the hormones glucagon, insulin, somatostatin, and pancreatic polypeptide.

Composition of Pancreatic Juice

Approximately 1200 to 1500 ml of clear pancreatic juice is produced daily. It consists mainly of water, and contains enzymes and electrolytes (primarily bicarbonate ions). The acinar cells produce the enzyme-rich component of pancreatic juice. The epithelial cells lining the smallest pancreatic ducts release the bicarbonate ions that make it alkaline (about pH 8). The high pH of pancreatic fluid helps neutralize acid chyme entering the duodenum and provides the optimal environment for activity of intestinal and pancreatic enzymes. Like pepsin of the stomach, pancreatic proteases (protein-digesting enzymes) are produced and released in inactive forms, which are activated in the duodenum, where they do their work. This prevents the pancreas from self-digestion. For example, within the duodenum, trypsinogen is activated to trypsin by enteropeptidase, an intestinal brush border protease. Trypsin, in turn, activates two other pancreatic proteases (procarboxypeptidase and chymotrypsinogen) to their active forms, carboxypeptidase and chymotrypsin, respectively. Other pancreatic enzymes—amylase, lipases, and nucleases—are secreted in active form, but require that ions or bile be present in the intestinal lumen for optimal activity.

DIGESTION OF SPECIFIC FOODS:

Proteins

Proteins digested in the GI tract include not only dietary proteins (typically about 125 g per day), but also 15–25 g of enzyme proteins secreted into the GI tract lumen by its various glands and (probably) an equal amount of protein derived from sloughed and disintegrating mucosal cells. In healthy individuals, much of this protein is digested all the way to its amino acid monomers.

Protein digestion begins in the stomach when pepsinogen secreted by the chief cells is activated to pepsin (actually a group of protein-digesting enzymes). Pepsin functions optimally in the acidic pH range found in the stomach: 1.5–2.5. It preferentially cleaves bonds involving the amino acids tyrosine and phenylalanine so that proteins are broken into polypeptides and small numbers of free amino acids (see Figure 23.33). Pepsin, which hydrolyzes 10–15% of ingested protein, is inactivated by the high pH in the duodenum, so its proteolytic activity is restricted to the stomach. Rennin (the enzyme that coagulates milk protein) is not produced in adults.

Protein fragments entering the small intestine from the stomach are greeted by a host of proteolytic enzymes. Trypsin and chymotrypsin secreted by the pancreas cleave the proteins into smaller peptides, which in turn become the grist for other enzymes. The pancreatic and brush border enzyme carboxypeptidase splits off one amino acid at a time from the end of the polypeptide chain that bears the carboxyl group. Other brush border enzymes such as aminopeptidase and dipeptidase liberate the final amino acid products (Figure 23.34). Aminopeptidase digests a protein, one amino acid at a time, by working from the amine end. Both carboxypeptidase and aminopeptidase can independently dismantle a protein, but the teamwork between these enzymes and between trypsin and chymotrypsin, which attack the more internal parts of the protein, speeds up the process tremendously.

Lipids

Although the American Heart Association recommends a low-fat diet, the amount of lipids (fats) ingested daily varies tremendously among American adults, ranging from 30 g to 150 g or more. The small intestine is essentially the sole site of lipid digestion because the pancreas is the only significant source of fat-digesting enzymes, or lipases (Figure 23.33). Triglycerides (neutral fats or triacylglycerols) are the most abundant fats in the diet.

Because triglycerides and their breakdown products are insoluble in water, fats need special "pretreatment" with bile salts to be digested and absorbed in the watery environment of the small intestine. In aqueous solutions, triglycerides aggregate to form large fat globules, and only the triglyceride molecules at the surfaces of such fatty masses are accessible to the water-soluble lipase enzymes. However, this problem is quickly resolved because as the fat globules enter the duodenum, they are coated with detergent-like bile salts (Figure 23.35). Bile salts have both nonpolar and polar regions. Their nonpolar (hydrophobic) parts cling to the fat molecules, and their polar (ionized hydrophilic) parts allow them to repel each other and to interact with water. As a result, fatty droplets are pulled off the large fat globules, and a stable emulsion—an aqueous suspension of fatty droplets, each about 1 mm in diameter—is formed. Emulsification does not break chemical bonds. It just reduces the attraction between fat molecules so that they can be more widely dispersed. This process vastly increases the number of triglyceride molecules exposed to the pancreatic lipases. Without bile, lipids would be incompletely digested in the time food is in the small intestine. The pancreatic lipases catalyze the breakdown of fats by cleaving off two of the fatty acid chains, thus yielding free fatty acids and monoglycerides (glycerol with one fatty acid chain attached). Fat-soluble vitamins that ride with fats require no digestion.