PHYSIOLOGY OF DIGESTION

SEMESTER 4 HONS

ORGANS OF DIGESTIVE SYSTEM

The easiest way to understand the digestive system is to divide its organs into two main categories. The first group is the organs that make up the **alimentary canal**. **Accessory digestive organs** comprise the second group and are critical for orchestrating the breakdown of food and the assimilation of its nutrients into the body. Accessory digestive organs, despite their name, are critical to the function of the digestive system.

ALIMENTARY CANAL ORGANS

Also called the gastrointestinal (GI) tract or gut, the **alimentary canal** (aliment- = "to nourish") is a one-way tube about 7.62 meters (25 feet) in length during life and closer to 10.67 meters (35 feet) in length when measured after death, once smooth muscle tone is lost. The main function of the organs of the alimentary canal is to nourish the body. This tube begins at the mouth and terminates at the anus. Between those two points, the canal is modified as the pharynx, esophagus, stomach, and small and large intestines to fit the functional needs of the body. Both the mouth and anus are open to the external environment; thus, food and wastes within the alimentary canal are technically considered to be outside the body. Only through the process of absorption do the nutrients in food enter into and nourish the body's "inner space."

ACCESSORY STRUCTURES

Each **accessory digestive organ** aids in the breakdown of food. Within the mouth, the teeth and tongue begin mechanical digestion, whereas the salivary glands begin chemical digestion. Once food products enter the small intestine, the gallbladder, liver, and pancreas release secretions—such as bile and enzymes—essential for digestion to continue. Together, these are called accessory organs because they sprout from the lining cells of the developing gut (mucosa) and augment its function; indeed, you could not live without their vital contributions, and many significant diseases result from their malfunction. Even after development is complete, they maintain a connection to the gut by way of ducts.

HISTOLOGY OF THE ALIMENTARY CANAL

Throughout its length, the alimentary tract is composed of the same four tissue layers; the details of their structural arrangements vary to fit their specific functions. Starting from the lumen and moving outwards, these layers are the mucosa, submucosa, muscularis, and serosa, which is continuous with the mesentery.

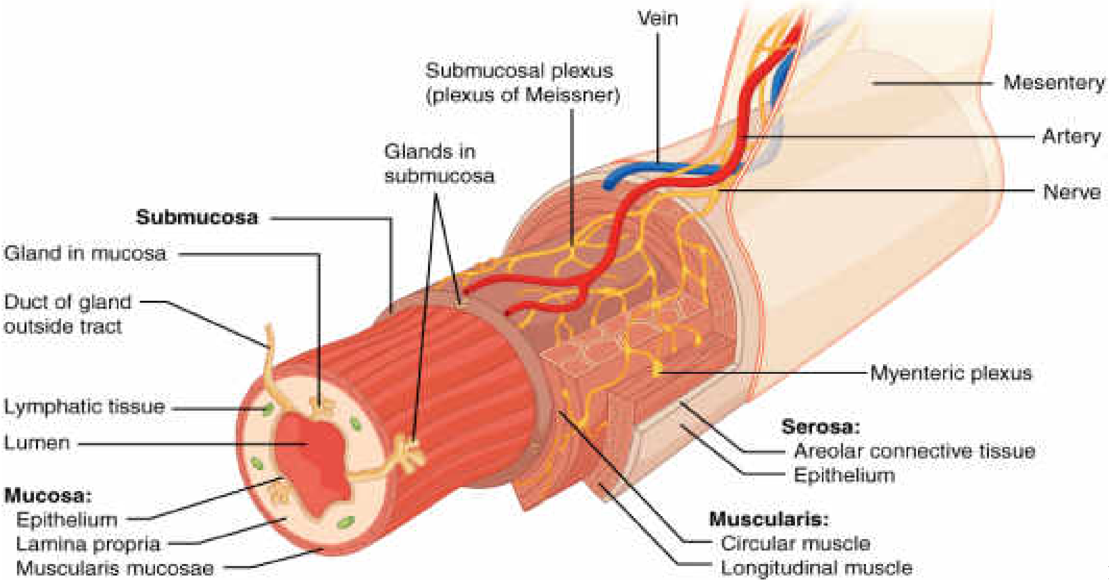

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Fig : **Layers of the Alimentary Canal**. The wall of the alimentary canal has four basic tissue layers: the mucosa, submucosa, muscularis, and serosa.

The **mucosa** is referred to as a mucous membrane, because mucus production is a characteristic feature of gut epithelium. The membrane consists of epithelium, which is in direct contact with ingested food, and the lamina propria, a layer of connective tissue analogous to the dermis. In addition, the mucosa has a thin, smooth muscle layer, called the muscularis mucosa (not to be confused with the muscularis layer, described below).

Epithelium—In the mouth, pharynx, esophagus, and anal canal, the epithelium is primarily a non-keratinized, stratified squamous epithelium. In the stomach and intestines, it is a simple columnar epithelium. Notice that the epithelium is in direct contact with the lumen, the space inside the alimentary canal. Interspersed among its epithelial cells are goblet cells, which secrete mucus and fluid into the lumen, and enteroendocrine cells, which secrete hormones into the interstitial spaces between cells. Epithelial cells have a very brief lifespan, averaging from only a couple of days (in the mouth) to about a week (in the gut). This process of rapid renewal helps preserve the health of the alimentary canal, despite the wear and tear resulting from continued contact with foodstuffs.

Lamina propria—In addition to loose connective tissue, the lamina propria contains numerous blood and lymphatic vessels that transport nutrients absorbed through the alimentary canal to other parts of the body. The lamina propria also serves an immune function by housing clusters of lymphocytes, making up the mucosa-associated lymphoid tissue (MALT). These lymphocyte clusters are particularly substantial in the distal ileum where they are known as Peyer’s patches. When you consider that the alimentary canal is exposed to foodborne bacteria and other foreign matter, it is not hard to appreciate why the immune system has evolved a means of defending against the pathogens encountered within it.

Muscularis mucosa—This thin layer of smooth muscle is in a constant state of tension, pulling the mucosa of the stomach and small intestine into undulating folds. These folds dramatically increase the surface area available for digestion and absorption.

As its name implies, the **submucosa** lies immediately beneath the mucosa. A broad layer of dense connective tissue, it connects the overlying mucosa to the underlying muscularis. It includes blood and lymphatic vessels (which transport absorbed nutrients), and a scattering of submucosal glands that release digestive secretions. Additionally, it serves as a conduit for a dense branching network of nerves, the submucosal plexus, which functions as described below.

The third layer of the alimentary canal is the **muscalaris** (also called the muscularis externa). The muscularis in the small intestine is made up of a double layer of smooth muscle: an inner circular layer and an outer longitudinal layer. The contractions of these layers promote mechanical digestion, expose more of the food to digestive chemicals, and move the food along the canal. In the most proximal and distal regions of the alimentary canal, including the mouth, pharynx, anterior part of the esophagus, and external anal sphincter, the muscularis is made up of skeletal muscle, which gives you voluntary control over swallowing and defecation. The basic two-layer structure found in the small intestine is modified in the organs proximal and distal to it. The stomach is equipped for its churning function by the addition of a third layer, the oblique muscle. While the colon has two layers like the small intestine, its longitudinal layer is segregated into three narrow parallel bands, the tenia coli, which make it look like a series of pouches rather than a simple tube.

The **serosa** is the portion of the alimentary canal superficial to the muscularis. Present only in the region of the alimentary canal within the abdominal cavity, it consists of a layer of visceral peritoneum overlying a layer of loose connective tissue. Instead of serosa, the mouth, pharynx, and esophagus have a dense sheath of collagen fibers called the adventitia. These tissues serve to hold the alimentary canal in place near the ventral surface of the vertebral column.

BLOOD SUPPLY

The blood vessels serving the digestive system have two functions. They transport the protein and carbohydrate nutrients absorbed by mucosal cells after food is digested in the lumen. Lipids are absorbed via lacteals, tiny structures of the lymphatic system. The blood vessels' second function is to supply the organs of the alimentary canal with the nutrients and oxygen needed to drive their cellular processes.

Specifically, the more anterior parts of the alimentary canal are supplied with blood by arteries branching off the aortic arch and thoracic aorta. Below this point, the alimentary canal is supplied with blood by arteries branching from the abdominal aorta. The celiac trunk services the liver, stomach, and duodenum, whereas the superior and inferior mesenteric arteries supply blood to the remaining small and large intestines.

The veins that collect nutrient-rich blood from the small intestine (where most absorption occurs) empty into the hepatic portal system. This venous network takes the blood into the liver where the nutrients are either processed or stored for later use. Only then does the blood drained from the alimentary canal viscera circulate back to the heart. To appreciate just how demanding the digestive process is on the cardiovascular system, consider that while you are "resting and digesting," about one-fourth of the blood pumped with each heartbeat enters arteries serving the intestines.

THE PERITONEUM

The digestive organs within the abdominal cavity are held in place by the peritoneum, a broad serous membranous sac made up of squamous epithelial tissue surrounded by connective tissue. It is composed of two different regions: the parietal peritoneum, which lines the abdominal wall, and the visceral peritoneum, which envelopes the abdominal organs. The peritoneal cavity is the space bounded by the visceral and parietal peritoneal surfaces. A few milliliters of watery fluid act as a lubricant to minimize friction between the serosal surfaces of the peritoneum.

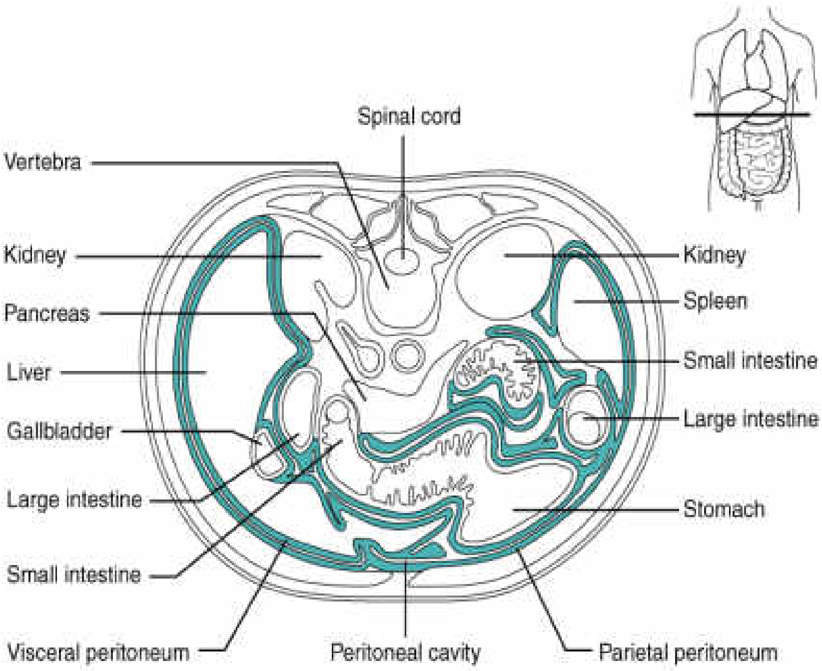


Figure: The Peritoneum. A cross-section of the abdomen shows the relationship between abdominal organs and the peritoneum (darker lines).
Disorders of the…

Digestive System: Peritonitis

Inflammation of the peritoneum is called peritonitis. Chemical peritonitis can develop any time the wall of the alimentary canal is breached, allowing the contents of the lumen entry into the peritoneal cavity. For example, when an ulcer perforates the stomach wall, gastric juices spill into the peritoneal cavity. Hemorrhagic peritonitis occurs after a ruptured tubal pregnancy or traumatic injury to the liver or spleen fills the peritoneal cavity with blood. Even more severe peritonitis is associated with bacterial infections seen with appendicitis, colonic diverticulitis, and pelvic inflammatory disease (infection of uterine tubes, usually by sexually transmitted bacteria). Peritonitis is life threatening and often results in emergency surgery to correct the underlying problem and intensive antibiotic therapy. When your great grandparents and even your parents were young, the mortality from peritonitis was high. Aggressive surgery, improvements in anesthesia safety, the advance of critical care expertise, and antibiotics have greatly improved the mortality rate from this condition. Even so, the mortality rate still ranges from 30 to 40 percent.

The visceral peritoneum includes multiple large folds that envelope various abdominal organs, holding them to the dorsal surface of the body wall. Within these folds are blood vessels, lymphatic vessels, and nerves that innervate the organs with which they are in contact, supplying their adjacent organs. The five major peritoneal folds are described in table. Note that during fetal development, certain digestive structures, including the first portion of the small intestine (called the duodenum), the pancreas, and portions of the large intestine (the ascending and descending colon, and the rectum) remain completely or partially posterior to the peritoneum. Thus, the location of these organs is described as **retroperitoneal**.

The Five Major Peritoneal Folds (Table)

Fold	**Description**
Greater omentum	Apron-like structure that lies superficial to the small intestine and transverse colon; a site of fat deposition in people who are overweight
Falciform ligament	Anchors the liver to the anterior abdominal wall and inferior border of the diaphragm
Lesser omentum	Suspends the stomach from the inferior border of the liver; provides a pathway for structures connecting to the liver
Mesentery	Vertical band of tissue anterior to the lumbar vertebrae and anchoring all of the small intestine except the initial portion (the duodenum)
Mesocolon	Attaches two portions of the large intestine (the transverse and sigmoid colon) to the posterior abdominal wall

Composition of saliva:

Produced in salivary glands, human saliva comprises 99.5% water, but also contains many important substances, including electrolytes, mucus, antibacterial compounds and various enzymes.

- Water: 99.49%
- Electrolytes:
  - 2–21 mmol/L sodium (lower than blood plasma)
  - 10–36 mmol/L potassium (higher than plasma)
  - 1.2–2.8 mmol/L calcium (similar to plasma)
  - 0.08–0.5 mmol/L magnesium
  - 5–40 mmol/L chloride (lower than plasma)
  - 25 mmol/L bicarbonate (higher than plasma)
  - 1.4–39 mmol/L phosphate
  - Iodine (mmol/L concentration is usually higher than plasma, but dependent variable according to dietary iodine intake)
- Mucus (mucus in saliva mainly consists of mucopolysaccharides and glycoproteins)
- Antibacterial compounds (thiocyanate, hydrogen-peroxide, and secretory immunoglobulin A)
- Epidermal growth factor (EGF)
- Various enzymes; most notably:
  - α-amylase (EC3.2.1.1), or ptyalin, secreted by the acinar cells of the parotid and submandibular glands, starts the digestion of starch before the food is even swallowed; it has a pH optimum of 7.4
  - Lingual lipase, which is secreted by the acinar cells of the sublingual gland; has a pH optimum around 4.0 so it is not activated until entering the acidic environment of the stomach
  - Kallikrein, an enzyme that proteolytically cleaves high-molecular-weight kininogen to produce bradykinin, which is a vasodilator; it is secreted by the acinar cells of all three major salivary glands
  - Antimicrobial enzymes that kill bacteria:
    - Lysozyme
    - Salivary lactoperoxidase
    - Lactoferrin
    - Immunoglobulin A
  - Proline-rich proteins (function in enamel formation, Ca^{2+}-binding, microbe killing and lubrication)
  - Minor enzymes including: salivary acid phosphatases A+B, N-acetylmuramoyl-L-alanine amidase, NAD(P)H dehydrogenase (quinone), superoxide dismutase, glutathione transferase, class 3 aldehyde dehydrogenase, glucose-6-phosphate isomerase, and tissue kallikrein (function unknown)
- Cells: possibly as many as 8 million human and 500 million bacterial cells per mL. The presence of bacterial products (small organic acids, amines, and thiols) causes saliva to sometimes exhibit a foul odor.

- Opiorphin, a pain-killing substance found in human saliva
- Haptocorrin, a protein which binds to Vitamin B12 to protect it against degradation in the stomach, before it binds to intrinsic factor.

The important components of pancreatic juice are:

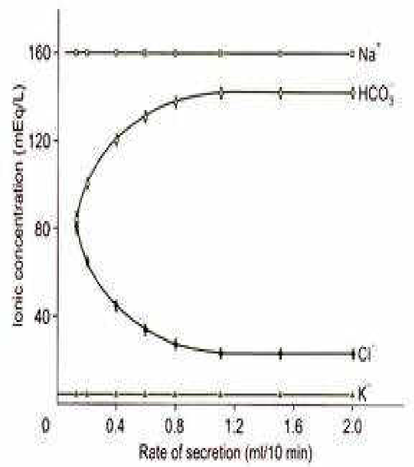


Fig. 5.17: Level of various ions in pancreatic juice depending on the rate of secretion. When the rate of secretion is high, level of bicarbonate is more compared to chloride ions

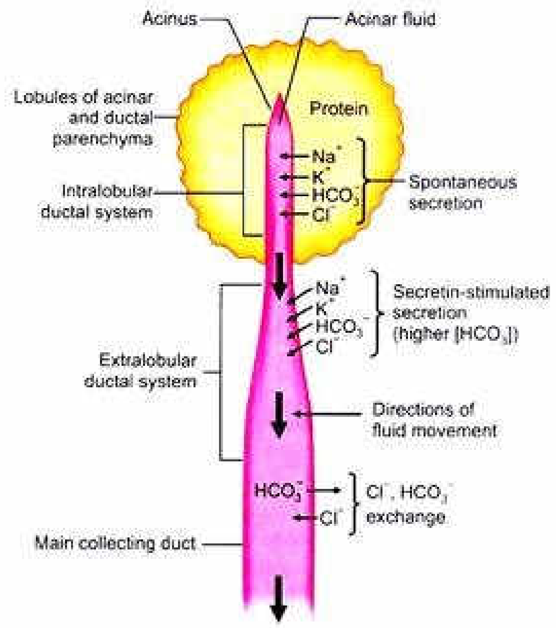


Fig. 5.18: Modification of the composition that is brought about during the process of secretion of pancreatic juice from the acini into the collecting duct of the gland

i. H_2O

ii. Cations: Na^+, K^+, Mg^{++}, Ca^{++}

iii. Anions: HCO_3^-, Cl^-, SO_4^-, HOP_4^-

Enzymes

1. Trypsinogen
2. Chymotrypsinogen
3. Procarboxypeptidase A
4. Procarboxypeptidase B
5. Proelastase
6. Lipase
7. Cholesterol esterase
8. Prophospholipase

(1–5: Proteolytic enzymes; 6–8: Lipolytic enzymes)

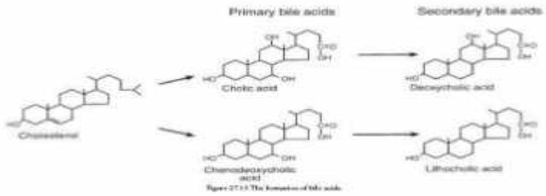
Others:

Amylase, Deoxyribonuclease, Ribonuclease

Miscellaneous: Immunoglobulins, Albumins, Kallikrein, Trypsin inhibitor, Co-lipase.

Bile Juice

- **Bile Composition;**
- Water (85%),
- bile salts (10%),(Cholic, chenodeoxycholic, deoxycholic, and lithocholic acid)
- mucus
- pigments (3%), bile pigments e.g bilirubin glucuronide
- fats (1%), such as Phospholipids (lecithin) , cholesterol.
- 0.7% inorganic salts.



PROCESS OF DIGESTION

We all associate the process of digestion with the stomach, right? But what if I told you, the digestive process starts from the mouth itself. There are various other organs involved in the digestion process occurring in the human body. Let us educate ourselves about this procedure. The digestion process is a series of reactions of food with the digestive hormones and juices. This starts right from the oral cavity.

Why is digestion important?

It is an important process that breaks down the proteins, fats, carbohydrates, vitamins, minerals into simpler forms so that it can be absorbed easily into the body cells. During this process, proteins are converted into amino acids, carbohydrates are converted into simple sugars and fats are broken down into fatty acids and glycerol. Many digestive enzymes and hormones act on food, at various stages during the process of digestion. The whole process occurs in a sequential manner.

The following table shows the digestive process in a simple format.

Organ	**Movement**	**Digestive juices/enzymes added**	**Food that is broken down**
Mouth	Chewing	Saliva	Starch(Carbohydrate)
Oesophagus	Peristalsis	—-	—-
Stomach	Churning	Stomach acid and Digestive Enzymes	Proteins
Small Intestine	Peristalsis	Digestive Juices	Carbohydrates, proteins, starch
Pancreas	——	Pancreatic juice	Carbohydrates, Fats, proteins
Liver	——	Bile	Fats
Large Intestine	Peristalsis	—-	Bacteria act on the remaining food particles.

Mechanism of Digestion

The digestion process can be divided into different stages, such as digestion in the:

- Oral cavity
- Stomach
- Small intestine
- Large intestine

Digestion includes a complex combination of mechanical and chemical processes. Some of the activities in the process include ingestion and propulsion of food, mechanical or physical digestion, chemical digestion, absorption, and defecation.

Digestion in the Oral Cavity

When food is taken in through the mouth, chewing and mixing of the food occurs. There is also a chemical breakdown of carbohydrates, due to the action of saliva from the salivary glands. 30% of the starch is hydrolyzed by the action of amylase, which is a salivary enzyme. The other enzyme, lysozyme is an antibacterial agent that prevents infections.

Starch + Salivary amylase → Maltose

Mastication of food and swallowing of food are the important activities that take place here in the oral cavity. Food is broken down into smaller particles by the chewing action of teeth. As saliva is added, it mixes with the food particles, slowly moistening and lubricating the food. This small ball is called a bolus, which is then swallowed. The pharynx helps in the movement of the bolus into the oesophagus, from where it moves to the stomach through the peristaltic movements of the oesophagus.

Digestion in the Stomach

When food reaches the stomach, it stays for approximately 4 to 5 hours. There are various gastric glands in the mucosa lining of the stomach. The mucus neck cells secrete mucus. The Peptic Cells secrete the proenzyme pepsinogen. The Parietal or Oxyntic Cells secrete HCl (Hydrochloric acid) and intrinsic factor that is essential for vitamin B12 absorption.

Food in the stomach gets mixed thoroughly with the gastric juices through the churning movements of the stomach muscle. This mass of food that is semi-digested, acidic and pulpy is called the chyme. It is mostly the proteins that get digested in the stomach. The mucus and the bicarbonates of the gastric juice help in protecting the mucosal epithelium from the highly acidic HCl. Mucus also helps in lubricating the food.

The different chemical reactions that take place in the stomach are summarised as follows.

- ***Gastric juices and enzymes:***
  - HCl provides the acidic pH.
  - Pepsinogen(proenzyme) is converted into Pepsin by HCl
  - Pepsin, in turn, converts protein into peptones & proteoses.

- Prorenin (proenzyme) is converted into Renin by HCl.
- Casein (milk protein) is converted into peptides by Renin.

After the action of the gastric juices and enzymes, food then enters the small intestine.

Digestion in the Small Intestine

In the small intestine, further digestion takes place. Due to the various movements of this organ, the chyme is further mixed and churned. There are many enzymes that are secreted into the small intestine from organs such as pancreas, liver; apart from the intestinal juices. All these react with the food particles and digest them into smaller particles that can be absorbed into the bloodstream.

The different chemical reactions that occur are summarised below:

- ***Pancreatic juices:***
  - Amylase converts starch into Maltose.
  - Enterokinase converts Trypsinogen into Trypsin
  - Trypsin converts proteins into Dipeptides
  - Trypsin converts Chymotrypsinogen into Chymotrypsin.
  - Chymotrypsin converts peptones into Dipeptides.
  - Trypsin converts Procarboxypeptidase into Carboxypeptidase.
  - Carboxypeptidase converts proteoses into Dipeptides.
  - Trypsin converts Proelastase into Elastase.
  - Elastase converts elastin into Dipeptides.
  - Pancreatic amylase converts polysaccharides (Starch) into Disaccharides.
  - Nucleases in the pancreatic juice, act on nucleic acids and form nucleotides and nucleosides.
- ***Intestinal juices:***
  - Maltase converts maltose into glucose.
  - Sucrase converts sucrose into glucose & fructose.
  - Lactase converts lactose into glucose & galactose.

- Aminopeptidases convert peptides into amino acids.
- Dipeptidases convert dipeptides into amino acids

$$\text{Dipeptides} \xrightarrow{\text{Dipeptidases}} \text{Amino acids}$$

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose + Glucose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose + Galactose}$$

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose + Fructose}$$

$$\text{Nucleotides} \xrightarrow{\text{Nucleotidases}} \text{Nucleosides} \xrightarrow{\text{Nucleosidases}} \text{Sugars + Bases}$$

$$\text{Di and Monoglycerides} \xrightarrow{\text{Lipases}} \text{Fatty acids + Glycerol}$$

- ***Bile*** -Bile converts fat globules into fat droplets through a process called emulsification. Fats are broken down into diglycerides and monoglycerides.
- ***Pancreatic lipase*** – It converts triglycerides into fatty acids & glycerol.

The bio-macromolecules are broken down in the duodenum region. All the simpler forms of the digested food are absorbed in the jejunum and ileum regions. Any leftover undigested, unabsorbed food particles are then passed on to the large intestine.

Digestion in the Large Intestine

In the large intestine, the digestion activity is significantly less. Here, bacterial action on the leftover food particles occurs. Minerals, water, and certain drugs are absorbed in the large intestine. The mucus secreted by the large intestine helps in holding the waste particles, apart from lubricating it.

Any undigested and unabsorbed waste particles called as the faecal matter, are then passed to the rectum, from where it is eliminated through the anus.

Control of the Digestive Processes

The digestive processes are controlled by the hormones and the nerves. There is a constant flurry of signals between the brain and the alimentary canal. Hormones control the digestion process by signalling the body at appropriate times to make the digestive juices. They also send signals to the brain to indicate being hungry or full. The nervous system, through the brain and spinal cord, controls the digestive processes

ABSORPTION

Absorption is the process by which water, minerals, vitamins and end products of digestion are absorbed through the mucosa of alimentary canal (especially the small intestines) into blood stream either directly or via lymphatic vessels. In the stomach there is little absorption. Water, alcohol, glucose and simple salts are absorbed to a certain degree. The main absorption occurs in small intestines especially in the lower (ileum) part, the upper part of the small intestine is mainly associated with the process of digestion.

The mucous membrane of small intestine is covered with minute finger like projections known as **villi**. Each villus contains arteriole, a venule, a capillary network and a lacteal (lymphatic vessel).Nutrients that diffuses through the epithelial cells which covers the villus are able to pass through the capillary walls and the lacteal enters the blood. About 90% of all absorption takes place throughout the length of the small intestine. The other 10% occurs in the stomach and large intestine. Both monosaccharides and amino acids are absorbed by a positive pressure gradient between the intestinal content and the blood as well as by an active process involving enzymatic reactions and transported in the blood stream to the liver via the hepatic portal system. The excess amount of glucose is converted into glycogen and stored in the liver, when need arises glycogen is converted into glucose and is utilized by the body.

Movements of the gastro intestinal tract

Deglutition is the process by which the masticated food is transported across the pharynx and reaches the stomach. Due to contractile movements of the stomach, the food is well mixed up with gastric juice.

After being in the stomach for 3 or 4 hours the pyloric sphincter opens pushing the food into the duodenum.

The intestine shows three important types of movements. They are:

Pendular movement These movements are induced by contraction of the circular and longitudinal muscles of the intestine. This movement contributes to the thorough mixing of chyme with the digestive juice.

Segmental movement: This movement occurs by the contraction of the circular muscles, which produces transverse folds, dividing the intestine into short segment.

Peristaltic Movement: It is the wave like contraction of the alimentary canal, which propels the food through the gastro intestinal tract.

I) CARBOHYDRATE ABSORPTION

All carbohydrates are absorbed in the form of monosaccharides. The small intestine is highly efficient at this, absorbing monosaccharides at an estimated rate of 120 grams per hour. All normally digested dietary carbohydrates are absorbed; indigestible fibers are eliminated in the feces. The monosaccharides **glucose and galactose** are transported into the epithelial cells by common protein carriers via **secondary active transport** (that is, co-transport with sodium ions). The monosaccharides leave these cells via facilitated diffusion and enter the capillaries through intercellular clefts. The monosaccharide **fructose** (which is in fruit) is absorbed and transported by facilitated diffusion alone and it is not ATP dependent. The monosaccharides combine with the transport proteins immediately after the disaccharides are broken down.

II) PROTEIN ABSORPTION

Active transport mechanisms, primarily in the duodenum and jejunum, absorb most proteins as their breakdown products, amino acids. Almost all (95 to 98 percent) protein is digested and absorbed in the small intestine. The type of carrier that transports an amino acid varies. Most carriers are linked to the active transport of sodium. Short chains of two amino acids (d-ipeptides) or three amino acids (tri-peptides) are also transported actively. However, after they enter the absorptive epithelial cells, they are broken down into their amino acids before leaving the cell and entering the capillary blood via diffusion. Although whole proteins are not absorbed usually, in rare cases intact proteins are taken up by endocytosis and released on the opposite side of epithelial cell by exocytosis. This process, most common in newborn infants, reflects the immaturity of their intestinal mucosa and accounts for many early food allergies. These food allergies usually disappear as the mucosa mature.

III) LIPID ABSORPTION

About 95 percent of lipids are absorbed in the small intestine. Bile salts not only speed up lipid digestion, they are also essential to the absorption of the end products of lipid digestion. Short-chain fatty acids are relatively water soluble and can enter the absorptive cells (enterocytes) directly. Despite being hydrophobic, the small size of short-chain fatty acids enables them to be absorbed by enterocytes via simple diffusion, and then take the same path as monosaccharides and amino acids into the blood capillary of a villus.

The large and hydrophobic long-chain fatty acids and monoacylglycerides are not so easily suspended in the watery intestinal chyme. However, bile salts and lecithin resolve this issue by enclosing them in a **micelle**, which is a tiny sphere with polar (hydrophilic) ends facing the watery environment and hydrophobic tails turned to the interior, creating a receptive environment for the long-chain fatty acids. The core also includes cholesterol and fat-soluble vitamins. Without micelles, lipids would sit on the surface of chyme and never come in contact with the absorptive surfaces of the epithelial cells. Micelles can easily squeeze between microvilli and get very near the luminal cell surface. At this point, lipid substances exit the micelle and are absorbed via simple diffusion.

The free fatty acids and monoacylglycerides that enter the epithelial cells are reincorporated into triglycerides. The triglycerides are mixed with phospholipids and cholesterol, and surrounded with a protein coat. This new complex, called a **chylomicron**, is a water-soluble lipoprotein. After being processed by the Golgi apparatus, chylomicrons are released from the cell. Too big to pass through the basement membranes of blood capillaries, chylomicrons instead enter the large pores of lacteals. The lacteals come together to form the lymphatic vessels. The chylomicrons are transported in the lymphatic vessels and empty through the thoracic duct into the subclavian vein of the circulatory system. Once in the bloodstream, the enzyme **lipoprotein lipase** breaks down the triglycerides of the chylomicrons into free fatty acids and glycerol. These breakdown products then pass through capillary walls to be used for energy by cells or stored in adipose tissue as fat. Liver cells combine the remaining chylomicron remnants with proteins, forming lipoproteins that transport cholesterol in the blood.

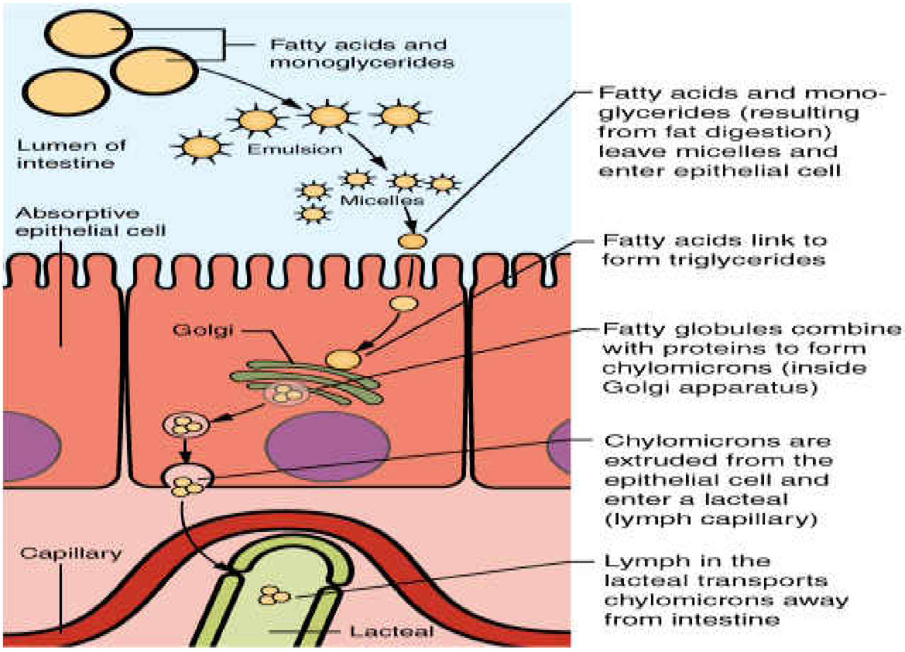


Figure. Lipid Absorption. Unlike amino acids and simple sugars, lipids are transformed as they are absorbed through epithelial cells.

IV)NUCLEIC ACID ABSORPTION

The products of nucleic acid digestion—pentose sugars, nitrogenous bases, and phosphate ions—are transported by carriers across the villus epithelium via **active transport**. These products then enter the bloodstream.

V) MINERAL ABSORPTION

The electrolytes absorbed by the small intestine are from both GI secretions and ingested foods. Since electrolytes dissociate into ions in water, most are absorbed via active transport throughout the entire small intestine. During absorption, co-transport mechanisms result in the accumulation of sodium ions inside the cells, whereas anti-port mechanisms reduce the potassium ion concentration inside the cells. To restore the sodium-potassium gradient across the cell membrane, a sodium-potassium pump requiring ATP pumps sodium out and potassium in.

In general, all minerals that enter the intestine are absorbed, whether you need them or not. Iron and calcium are exceptions; they are absorbed in the duodenum in amounts that meet the body's current requirements, as follows:

Iron—The ionic iron needed for the production of hemoglobin is absorbed into mucosal cells via active transport. Once inside mucosal cells, ionic iron binds to the protein ferritin, creating iron-ferritin complexes that store iron until needed. When the body has enough iron, most of the stored iron is lost when worn-out epithelial cells slough off. When the body needs iron because, for example, it is lost during acute or chronic bleeding, there is increased uptake of iron from the intestine and accelerated release of iron into the bloodstream. Since women experience significant iron loss during menstruation, they have around four times as many iron transport proteins in their intestinal epithelial cells as do men.

Calcium—Blood levels of ionic calcium determine the absorption of dietary calcium. When blood levels of ionic calcium drop, parathyroid hormone (PTH) secreted by the parathyroid glands stimulates the release of calcium ions from bone matrices and increases the re-absorption of calcium by the kidneys. PTH also up regulates the activation of vitamin D in the kidney, which then facilitates absorption of intestinal calcium ion.

VI)VITAMIN ABSORPTION

The small intestine absorbs the vitamins that occur naturally in food and supplements. Fat-soluble vitamins (A, D, E, and K) are absorbed along with dietary lipids in micelles via simple diffusion. This is why you are advised to eat some fatty foods when you take fat-soluble vitamin supplements. Most water-soluble vitamins (including most B vitamins and vitamin C) also are absorbed by simple diffusion. An exception is vitamin B_{12}, which is a very large molecule. Intrinsic factor secreted in the stomach binds to vitamin B_{12}, preventing its digestion and creating a complex that binds to mucosal receptors in the terminal ileum, where it is taken up by endocytosis. Large intestine absorbs some of the K and B vitamins made by its enteric bacteria.

VII) WATER ABSORPTION

Each day, about nine liters of fluid enter the small intestine. About 2.3 liters are ingested in foods and beverages, and the rest is from GI secretions. About 95 percent of this water is absorbed in the small intestine by osmosis. The normal rate of water absorption is 300 to 400 ml per hour.Water absorption is driven by the concentration gradient of the water: The concentration of water is higher in chyme than it is in epithelial cells. Thus, water moves down its concentration gradient from the chyme into cells. As noted earlier, much of the remaining water is then absorbed in the colon.