Digestive and Absorption

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Animals are not able to synthesise their own food, therefore they depend on ready-made food for their nutritional requirements. The term **nutrition** refers to the sum total of all the processes related with the conversion of the raw foodstuff into the stuff of the body to supply energy for different metabolic activities and also for the repair and growth. In other word we can define nutrition as the process by which an organism derives energy to work and other materials, required for growth and maintenance of the various activities of life.

DIGESTION

The process by which complex food is converted into simplest food with the help of digestive enzymes (Hydrolytic enzymes) is called digestion. Hence process of digestion is a hydrolytic process.

Types of Digestion

(1) **Intracellular :** When the process of digestion occurs within the cell in the food vacuole. Examples: Protozoa, Porifera, Coelenterata and free living platyhelminthes.

(2) **Extracellular :** When the process of digestion occurs outside the cell. Examples Coelenterates and phylum platyhelminthes to phylum chordata.

Digestive System of Human Body

Digestion in vertebrates occurs in the digestive tract or alimentary canal. The various parts involved in digestion can be broadly grouped in two groups -

(1) Digestive tract or alimentary canal

(2) Digestive glands

Digestive tract or alimentary canal

On the basis of the embryonic origin, the alimentary canal of vertebrates can be divided into three parts -

(1) **Fore gut / Stomodaeum :** Ectodermal. It includes buccal cavity / oral cavity, pharynx, oesophagus, stomach and small part of duodenum.

(2) **Mid gut / Mesodaeum :** Endodermal. It includes small intestine, and large intestine.

(3) **Hind gut / Proctodaeum:** Ectodermal. It includes anal canal and anus.

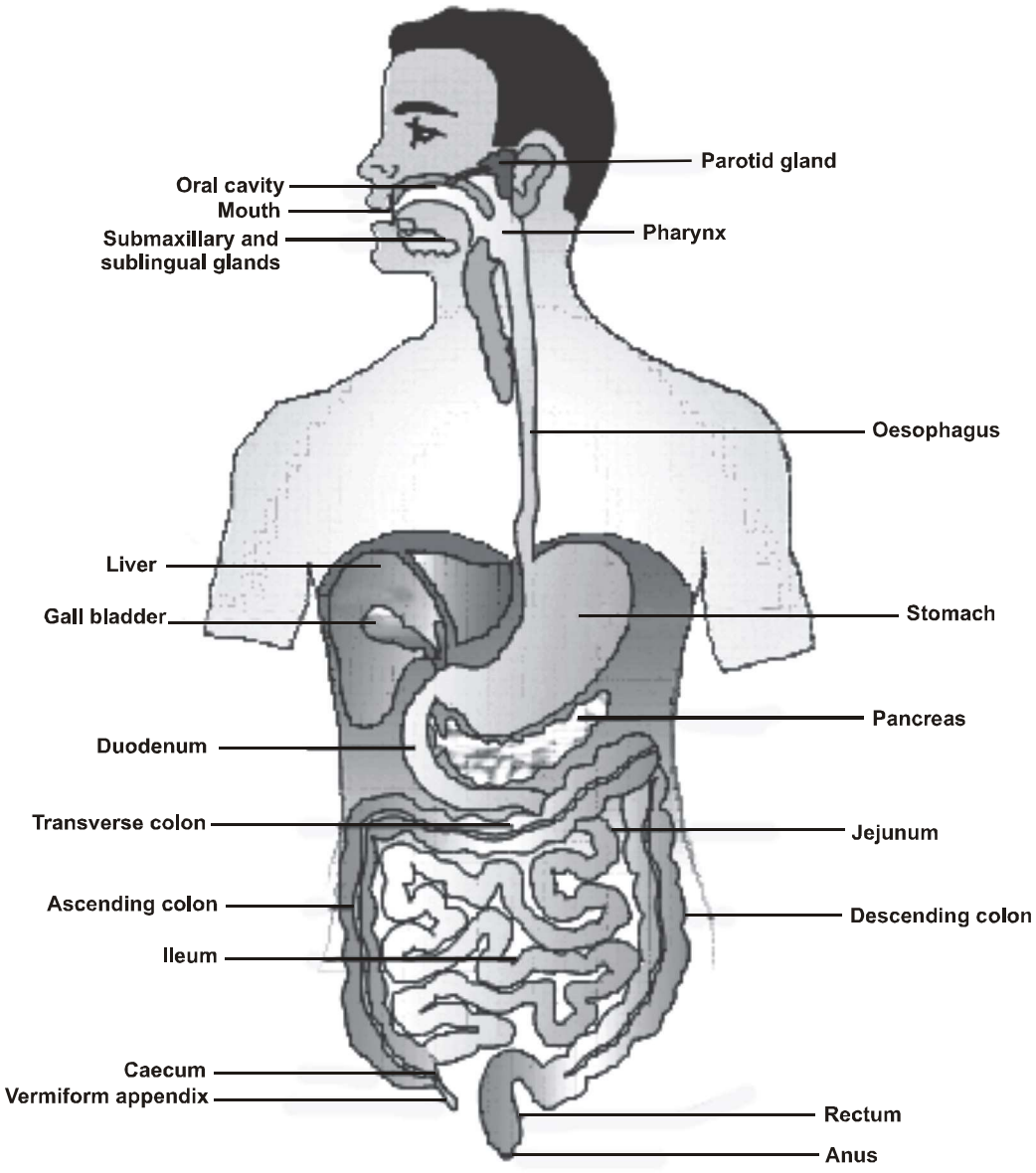
PARTS OF ALIMENTARY CANAL AND ITS HISTOLOGY :

Mouth :

The mouth is a transverse slit bounded by two movable lips or labia, upper lip and lower lip. Upper lip has small ridges on the sides. a tubercle in the middle and a vertical groove (philtrum) above.

Vestibule :

It is a narrow space between lips and gums in front and gums and cheeks on the sides. Its lining contains mucous glands. In the vestibule, a small median fold of mucous membrane, the superior labial frenulum, connects the middle of the upper lip to the gum and usually a similar but smaller inferior labial frenulum connects the middle of the lower lip to the gum.



The Human digestive system

BUCCOPHARYNGEAL CAVITY

It includes anterior buccal cavity lined by stratified squamous epithelial cells and posterior pharyngeal cavity lined by columnar epithelial cells. Pharynx is a vertical canal beyond the soft palate. The food and air passages cross here. Pharynx may be divided into three parts; Nasopharynx, Oropharynx and Laryngopharynx. Main structure of Buccopharyngeal cavity are –

(1) **Palate :** The roof of buccal cavity is called Palate. Palate is distinguished into three regions -

(i) Hard palate : Anterior, bony portion formed of maxilla and palatine bones in human. Hard palate have transverse ridges called palatine rugae. Such rugae or ridges are more developed in carnivorous mammals because their function is to firmly grip the food and prevent it from slipping out the cavity.

(ii) Soft palate : Posterior soft part, made up of connective tissue and muscles.

(iii) Vellum palati/uvula : Posterior most part of soft palate, which hangs in the region of pharynx. It closes the internal nostrils during degglutition.

(2) **Palatine glands :** Numerous mucous glands. Chiefly present in soft palate, secretes mucous for lubrication.

(3) **Naso-palatine duct :** One pair, present in rabbit, extends from nasal passage to the buccal passage, contains Jacobson's organ concerned with olfaction.

(4) **Vibrissae:** A tuft of hairs on upper lip of rabbit.

(5) **Hare-cleft :** A cleft on the upper lip of rabbit, which makes it bilobed.

(6) **Tongue (linguae) :**

- Ectodermal,
- Highly muscular (mesodermal) and protrusible present on the floor of buccopharyngeal cavity the cells present are stratified squamous epithelial cells.
- The upper surface of the tongue has small projects called papillae. Some of which bears taste buds.
- Taste papillae are of following types-

(i) Circumvallate : Circular, largest, 8 to12 in number, present in the posterior part of the tongue extending from one side to another. They possess taste buds. These are the largest of all the papillae.

(ii) Fungiform : Mushroom shaped (Fungi - shaped), numerous, present at the anterior margins and tip of the tongue. They have 200 taste buds.

(iii) Foliate : Leaf like flat, less 8-10 in number, present at the posterior margin of the tongue. They are absent in human and found in rabbit.

(iv) Filiform : Conical shaped, smallest and most numerous distributed throughout tongue. They are without taste buds.

- Hence, in human taste is recognized with the help of circumvallate and fungiform taste papillae. In man the anterior end of tongue feels sweet taste, posterior part feel bitter taste, sides feel sour taste and a small part behind the anterior end feel salty taste.

Functions of tongue :

Important function of tongue are as follows -

(i) Acts as universal toothbrush, as it helps in tooth cleaning.

(ii) Helps in speaking.

(iii) Helps in degglutition.

(iv) Helps in mixing saliva with food.

(v) Helps in taste detection.

(vi) In dog helps in regulation of body temperature. The phenomenon is called as "Panting".

(vii) In frog and other animals, it helps in prey capturing

(7) Teeth :

Teeth are differentiated into various types:

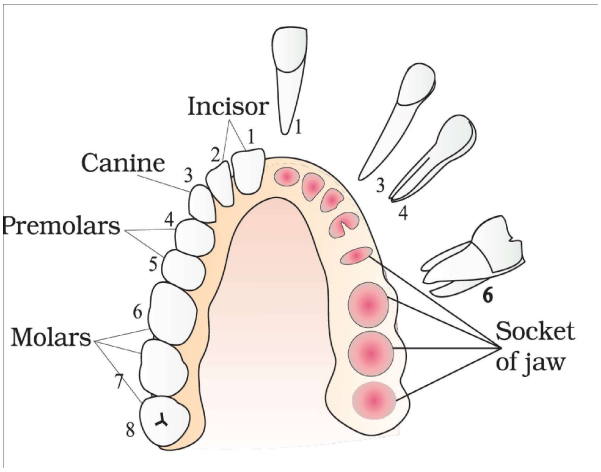


Fig. : Arrangement of different types of teeth in the jaws on one side and the sockets on the other side

Differentiation of teeth :

Morphologically, teeth can be distinguished as homodont or heterodont.

(i) **Homodont :** When all the teeth are structurally and functionally similar.

(ii) **Heterodont :** When the teeth are different in structure and functions. They are distinguished into four types incisors, canines, premolars and molars.

(a) **Incisors :** They are single-rooted monocuspid and long, curved and sharp-edged. They are adapted for cutting or cropping and biting.

(b) **Canines :** There is one pointed canine in each half of upper jaw and each half of lower jaw next to the incisors. They are meant for piercing, tearing and offence and defence. They are single rooted and monocuspid.

(c) **Premolars :** They have one root and two cusps (bicuspid). They are meant for crushing, grinding and chewing.

(d) **Molars:** They have more than two roots (upper molars have three roots and lower molars have two roots) and 4 cuspid.

Attachment of teeth :

On the basis of attachment of teeth at their bases with the jaw bones, teeth can be differentiated into -

(i) **Acrodont :** Teeth are attached to the free surface or summit of the jaw bone, as in a shark or frog. Such teeth are apt to break off easily but are replaced.

(ii) **Pleurodont :** In this condition, common in urodeles and lizards, teeth are attached to the inner side of jaw bone by their base as well as one side.

(iii) **Thecodont :** Such teeth are characteristic of mammals. Teeth have well developed roots implanted in deep individual pits or sockets called **alveoli or theca,** in the jaw bone.

Succession of teeth :

According to their replacement (succession), teeth can be divided into 3 categories: polyphyodont, diphyodont and monophyodont.

(i) **Polyphyodont :** In lower vertebrates, teeth can be replaced an indefinite number of times during life. e.g.,

- Fishes, amphibia, reptilia.

(ii) **Diphyodont:** In most mammals teeth develop during life in two successive sets, a condition known as diphyodont. Teeth of the first set are known as **deciduous teeth or milk teeth or lacteal teeth** whereas the second set is called **permanent teeth.**

(iii) **Monophyodont :** In some mammals such as platypus, marsupials, moles, sirenians, toothed whale etc. only one set of teeth develops known as monophyodont condition.

Structure of teeth :

Teeth divided into three parts -

(i) **Root :** Inner most, attached to the bone with the help of cement (hyaluronic acid).

(ii) **Neck :** Middle, small, covered with gum. Gum provides strength to the teeth.

(iii) **Apex or crown :** External exposed part of teeth. Longest part, white in colour.

- A small cavity present inside teeth called as pulp cavity or dentine pulp cavity. It contains blood vessels, lymphatic vessels, nerve fibres, connective tissue etc. and provides nutrition to odontoblast cells or osteoblast cells.
- The odontoblast cells are mesodermal in embryonic origin forming immediate covering of the pulp cavity. The cells secrete dentine/ivory.
- Bulk of tooth in a mammal is formed of dentine. Dentine is a layer of inorganic substances (62-69%), which surrounds the odontoblast cells. It is mesodermal in origin.
- Enamel, secreted by Ameloblast/Enameloblast cells, forms the outermost covering. It is ectodermal and made up of 92% of inorganic substances, hence considered as **hardest part of the body.**
- The inorganic substances present are [$Ca_3(PO_4)_2$,$Ca(OH)_2$.H_2o] Calcium phosphate (85%), Calcium hydroxide and Calcium Carbonate. Cement/Cementum attaches the tooth root to the bone.

Milk teeth or deciduous or temporary teeth:

Are 20 in number, 10 each in upper jaw and in the lower jaw. The milk teeth begin to erupt when the child is about 6 months old and should all be present by the end of 24 months. The permanent teeth begin to replace the milk teeth in the 6 years of age, these teeth are 32 and usually complete by 24 years. Milk teeth of man includes 8 incisors, 4 canines, 8 molars (premolars are absent) temporary teeth $\rightarrow$ (2,1,0,2) Permanent teeth are 8 incisors, 4 canines, 8 premolars, 12 molars (2,1,2,3)

Dental formula :

Each mammalian species is characterized by its own specific dentition with a definite number and arrangement of teeth. Hence, dentition is of taxonomic importance. It is expressed by a dental formula as below -

Dental formulae of some common ammals:

Horse and pig	$\frac{3.1.4.3}{3.1.4.3} \times 2 = 44$	Cat	$\frac{3.1.3.1}{3.1.2.1} \times 2 = 30$
Dog	$\frac{3.1.4.2}{3.1.4.3} \times 2 = 42$	Squirrel	$\frac{1.0.2.3}{1.0.1.3} \times 2 = 22$
Lemur	$\frac{2.1.3.3}{2.1.3.3} \times 2 = 36$	Rat	$\frac{1.0.0.3}{1.0.0.3} \times 2 = 16$
Man (adult set)	$\frac{2.1.2.3}{2.1.2.3} \times 2 = 32$	Elephant	$\frac{1.0.0.3}{0.0.0.3} \times 2 = 14$
Cow	$\frac{0.0.3.3}{3.1.3.3} \times 2 = 32$	Human (milk set)	$\frac{2.1.0.2}{2.1.0.2} \times 2 = 20$

Oral cavity leads into a short pharynx which serves as a comman passage for food and air, A cartilaginous flap called **epiglotis** prevents the entry of food into glottis (opening of wind pipe) during swallowing.

Oesophagus (food tube)

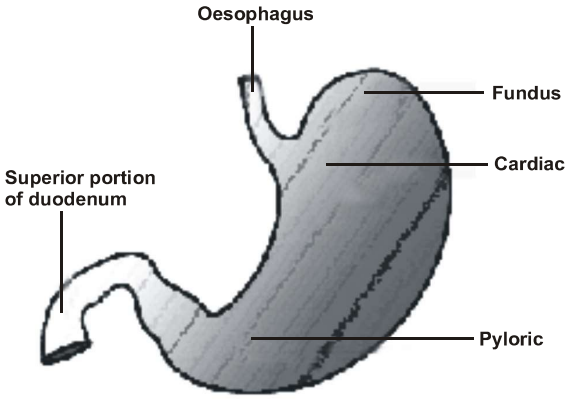
Morphology : Single, ectodermal, dorsal to trachea, approximately 25 cm long. passes through thoracic cavity and opens into stomach present in abdominal cavity. Oesophagus anteriorly opens into pharynx and posteriorly into stomach.

Function : Conduction of food.

STOMACH

Structure :

- Single oval, elongated, unilobed and **J** shaped and present within abdominal cavity below diaphragm.
- It consists of three parts as cardiac into which oesophagus opens, fundic, pyloric which opens into the first part of small intestine.
- Two types of valves are present in the stomach viz. **Cardiac sphincter** valve between oesophagus and stomach and **pyloric sphincter** valve between stomach and duodenum.
- In new born baby cardiac sphincter is much less developed that is why regurgitation of gastric contents is very common.
- Inner surface of stomach is raised into numeros longitudinal folds called gastric rugae.



Anatomical regions of human stomach

- In new born baby cardiac sphincter is much less developed that is why regurgitation of gastric contents is very common.
- Inner surface of stomach is raised into numeros longitudinal folds called gastric rugae.

(i) **Anterior part :** (Cardiac) cells present are mucous neck cells secreting mucous.

(ii) **Middle part :** (Fundic gastric)/Main gastric glands in human has four distinct types of cells -

(a) **Peptic or zymogenic or chief or central cells:** Secretes two digestive proenzymes pepsinogen and prorennin.

(b) **Oxyntic or parietal cells :** Secretes HCl and castle's intrinsic factor required for the absorption of vitamin B12. Hyperacidity is abnormally high degree of acidity due to the secretion of large quantity of HCl i.e. gastric juice.

(c) **Mucous neck cells:** Secretes alkaline mucous.

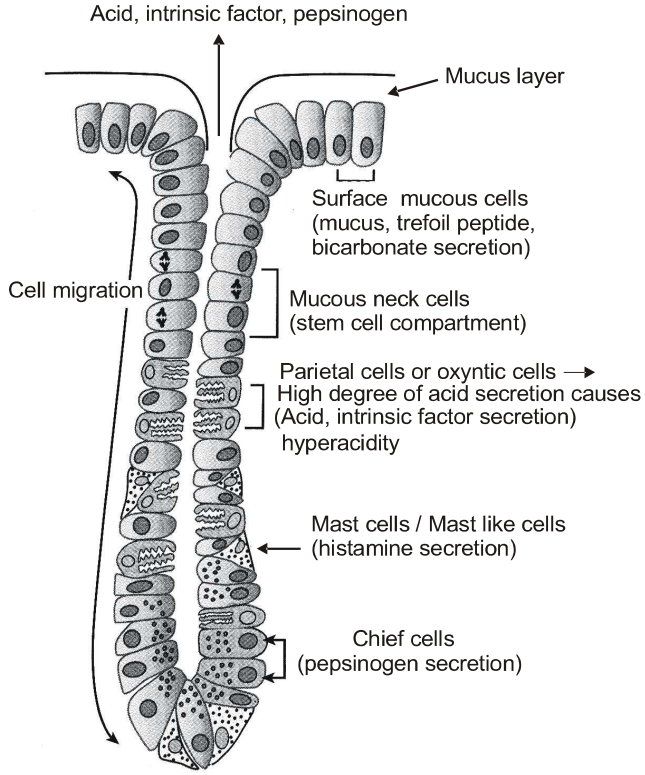
(d) **Argentaffin cells or Kultchitsky or enterochromaffin cells :** Responsible for the secretion of vasoconstrictor serotonin. It plays a role regulation of muscular movements.

(iii) **Posterior part :** (Pyloric) gastric glands in human-cells are mucous neck cells secreting mucous and some cells, called "gastrin" or "G" cells, secrete a hormone, named gastrin, which increases the motility of gastric wall and stimulates gastric glands for active secretion.

Functions :

(l) Storage of food.

(2) Churning of food to mix with gastric juice.

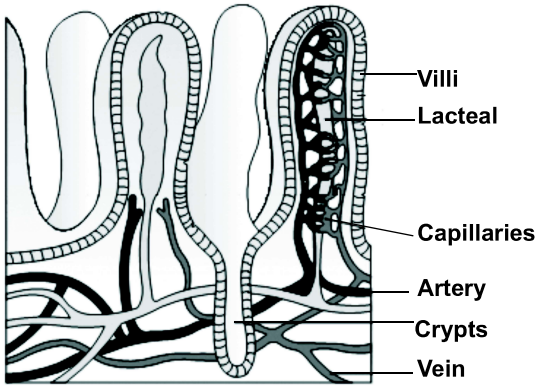


Structure of a gastric gland from the fundus

SMALL INTESTINE

Structure:

- Endodermal, longest part of alimentary canal present in the abdominal cavity, supported by a peritoneal membrane called mesentery.
- Wall of jejunum and ileum has circular or spiral internal fold called **fold of kerckring or valvulae conniventes.**
- Also numerous finger like projection called villi project from the wall of lumen, increasing internal surface area about ten time.
- The distal end of ileum leads into the large intestine by ileo-caecal valve in man.



A section of small intestinal mucosa showing villi

Parts : It is approximately 6.25 metres in human. It is divisible into three parts duodenum, jejunum and ileum.

Parts of Small Intestine		
Duodenum (Proximal part)	**Jejunum (Middle part)**	**Ileum (Distal part)**
25 cm. Long Forming U-shaped/C-shaped loop before leading to jejunum, pancreas lies in the loop.	About 2-2.5 m long and about 4 cm wide. Wall is thicker and more vascular. Villi thicker and tongue-like.	About 3.5 m long and about 3.5 cm wide. Wall is thinner and less vascular. Villi thinner and finger like.

(3) Glands of small intestine: Various glands found in small intestine.

Glands of small intestine		
Brunner's Gland	**Payer's Patches**	**Crypts of Leiberkuhn**
Found in duodenum only. Alkaline mucus secreting gland so known as mucus gland.	These are lymph nodules. They produce **lymphocytes**. Lymphocytes are phagocytic in nature which destroy harmful bacteria.	Known as intestinal gland. Secrete **succus entericus i.e. intestinal juice.**

Function :

Digestion and absorption of food.

Large intestine :

Large intestine, the name large intestine is due to large diameter (4-6 cm).

Structure :

Endodermal, approximately 1.5-1.75 metre long.

Parts : They are following -

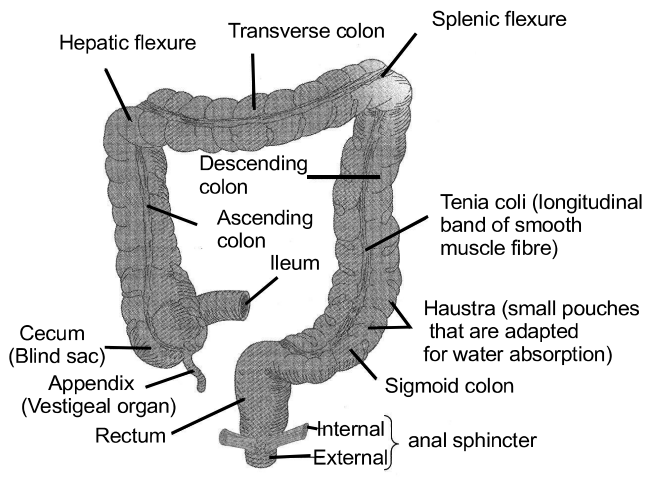
(i) Caecum : It is small blind sac which hosts some symbiotic microorganism. It is Spirally coiled 6 cm long in human. Its posterior end is present as a blind sac in abdominal cavity called vermiform appendix. Vermiform appendix is vestigeal and narrow finger like in structure.

(ii) Colon : Single endodermal approximately 1.3 m long in human distinguished into four limbs as ascending, transverse, descending and pelvic or sigmoid limb. Colon is concerned with absorption of water of undigested food, 5% salts, vitamins etc. hence concerned with faeces formation. Colon bacteria also synthesized vit. B_{12}

(iii) Rectum : Single small dilated sac like in human. It is concerned with storage of faeces. Rectum has strong sphincter muscle in its wall. The **sphincter** keeps the canal as well as anus, closed when not used for defecation.

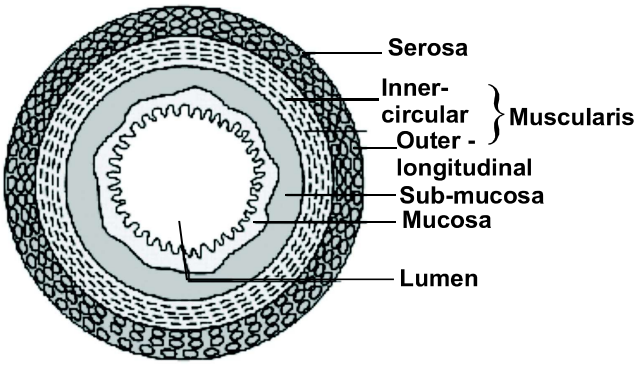
Function : Absorption of water from undigested food.

(iv) Anal canal and anus : Anal canal connects rectum with anus and it is about 3 cm. long. Anus is the terminal inferior opening of alimentary canal.



The human colon

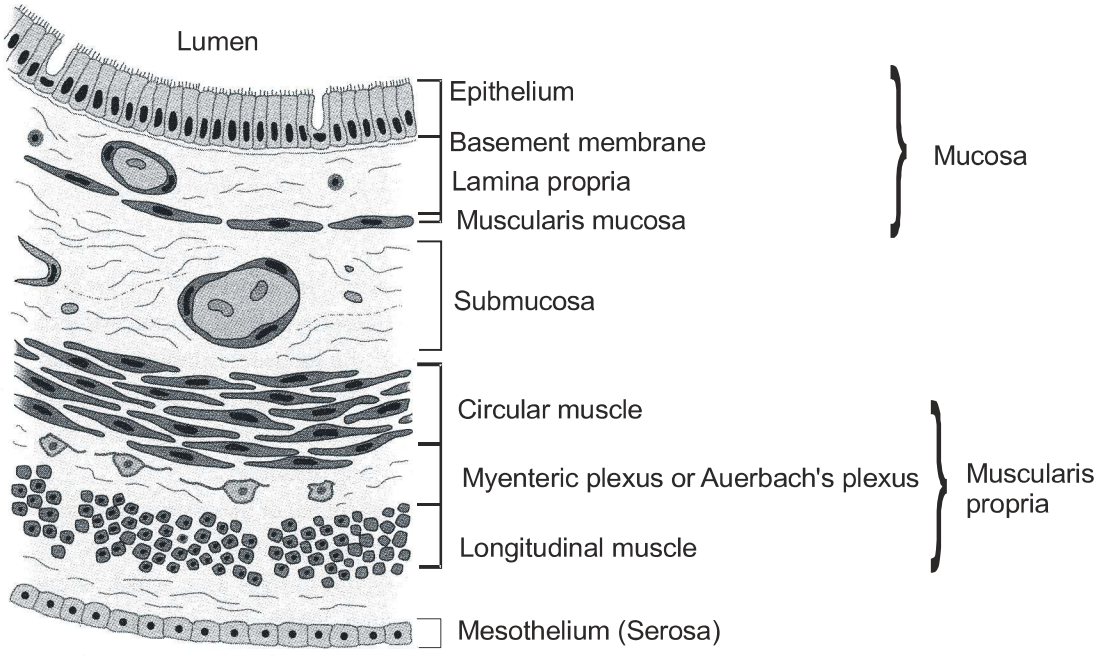
Histology:



Diagrammatic representation of transverse section of gut

The wall of alimentary canal from oesophagus to rectum possesses four layers namely serosa, muscularis, sub-mucosa and mucosa.

- **Serosa** is the outermost layer and is made up of a thin mesothelium (epithelium of visceral organs) with some connective tissues.
- **Muscularis** is formed by smooth muscles usually arranged into an inner circular and an outer longitudinal layer. An oblique muscle layer may be present in some regions.
- The **sub-mucosal layer** is formed of loose connectivetissues containing nerves, blood and lymph vessels. In duodenum, glands are also present in sub-mucosa.
- The innermost layer lining the lumen of the alimentary canal is the mucosa. This layer forms irregular folds (rugae) in the stomach and small finger-like foldings called villi in the small intestine.
- The cells lining the villi produce numerous microscopic projections called **microvilli** giving a brush border appearance. These modifications increase the surface area enormously. Villi are supplied with a network of capillaries and a large lymph vessel called the **lacteal**. Mucosal epithelium has goblet cells which secrete mucus that help in lubrication.
- Mucosa also forms glands in the stomach (gastric glands) and crypts in between the bases of villi in the intestine (crypts of Lieberkuhn). All the four layers show modifications in different parts of the alimentary canal.



Organization of the wall of the intestine into functional layers

DIGESTIVE GLANDS

The various types of digestive glands present in mammals are salivary glands, gastric glands, intestinal glands, pancreas and liver. The digestive glands secrete digestive juices. Parasympathetic nervous system increases the secretion of digestive juice whereas sympathetic nervous system decreases it.

SALIVARY GLANDS

The three pairs of salivary glands present in humans are as follows -

(1) **Parotid :** One-pair, largest salivary gland present below pinna. A **stenson's duct** arises from each gland, opening in vestibule between the 2nd molar teeth of upper jaw and cheeks. Parotid glands secrete enzymes. Viral infection of parotid glands causes **"Mumps"** (by paramyxo virus).

(2) **Sub-mandibular / sub-maxillary :** One-pair, present at the junction of upper and lower jaw in cheek region. A **wharton's duct** arises from each gland and opens on lower jaw.

(3) **Sub-lingual :** One-pair, present in the floor of buccopharyngeal cavity. 6-8 ducts, called **ducts of rivinus or Bartholin's duct** arises from these glands and opens below tongue on the floor of buccopharyngeal cavity.

Saliva / salivary juice :

The secretion of salivary glands is called saliva or salivary juice. Some of the characteristics are as follows -

(1) Amount: 1.0-1.5 litre/day

(2) Chemical nature: Slightly acidic.

(3) pH : 6.3 - 6.8

(4) Control of secretion: Autonomic reflex (parasympathetic nervous system increases salivation while sympathetic nervous system inhibit secretion.)

(5) Chemical composition: Water (99.5%), mucous (acts as lubricant), salts (NaCI, $NaHCO_3$ etc.), enzymes (ptyalin, lysozyme) etc.

Functions :

Salivary juice and its enzymes -

(1) Makes the medium slightly acidic for the action of its enzyme.

(2) Help in taste detection, deglutition, speaking etc.

(3) Starch $\xrightarrow[\text{(Salivary amylase)}]{\text{Ptyalin/Diastase}}$ Maltose + Isomaltose + Limit Dextrin

(4) Bacteria (living) $\xrightarrow{\text{Lysozyme}}$ Bacteria killed.

GASTRIC GLANDS

There are approximately 35 million of gastric glands present in human stomach and grouped into three categories as already described along with stomach. The gastric gland secretes gastric juice.

Gastric juice

(1) Amount : 1-1.5 liters/day.

(2) Chemical nature: Highly acidic

(3) pH : 1.0 - 3.5 (due to presence of HCl)

(4) Control of secretion: By gastrin hormone.

(5) Chemical composition: Water (99%), mucous, inorganic salts, castle's intrinsic factor, HCI (0.5%, conc) and enzymes prorennin and pepsinogen and gastric lipase.

Functions of gastric juice and its enzymes

(1) Inactivates the action of ptyalin.

(2) Makes the medium acidic for the action of gastric enzymes.

(3) HCl kills micro organisms.

(4) HCl kills the living organism (prey etc.) if ingested.

(5) Pepsinogen (inactive) $\xrightarrow{HCl}$ Pepsin (active).

(6) Prorennin (inactive) $\xrightarrow{HCl}$ Rennin (active).

(7) Proteins + Peptones $\xrightarrow[pH-1-3]{Pepsin}$ Polypeptides + Oligopeptides

(8) Casein (milk protein) $\xrightarrow[ca^{2+}]{Rennin}$ Paracasienate

above phenomenon is called **"curding of milk".**

(9) Lipids $\xrightarrow{\text{Lipase}}$ Triglycerides + Monoglycerides.

(10) HCl is antiseptic.

(11) It act as preservative.

Lactose intolerance :

Among mammals, man alone takes milk even after becoming adult. In some humans, secretion of **lactase** decreases or ceases with age. This condition is called lactose intolerance. Lactose intolerant persons fail to digest lactose of milk. In their large intestine, lactose is fermented by bacteria, producing gases and acids.

INTESTINAL GLANDS

Intestinal glands in mammals is a collective name for crypts of Lieberkuhn (secretes alkaline enzymatic juice) and Brunner's glands (secretes mucous). Intestinal glands secrete intestinal juice

Succus entericus (intestinal juice)

(1) Amount: 1.5 - 2.0 L /day.

(2) Chemical nature: Alkaline.

(3) pH : 7.6 - 8.3

(4) Control of secretion: Nervous and hormonal (Enterocrinin, Duocrinin etc.)

(5) Chemical composition: Water (99%), mucous, inorganic salts, enzymes etc.

Function of Intestinal juice and its enzymes :

(1) Inhibits the action of gastric enzymes.

(2) Makes the medium alkaline for the action of it's enzymes.

(3) Starch $\xrightarrow{\text{Amylase}}$ Maltose + Isomaltose + Limit dextrin.

(4) Maltose $\xrightarrow[\alpha\text{-glucosidase}]{\text{(Maltase)}}$ Glucose + Glucose.

(5) Isomaltose $\xrightarrow{\text{Isomaltose}}$ Glucose + Glucose.

(6) Lactose (milk sugar) $\xrightarrow[\beta\text{-galactosidase}]{\text{(Lactase)}}$ Glucose + Galactose.

(7) Sucrose (cane sugar) $\xrightarrow[\beta\text{-fructosidase}]{\text{Sucrase / Invertase}}$ Glucose + Fructose.

(8) Polypeptides + Oligopeptides $\xrightarrow[\text{Amino-peptidase}]{\text{Erepsin}}$ Amino acids.

(9) Trypsinogen (inactive) $\xrightarrow{\text{Enterokinase}}$ Trypsin (active).

(10) Lipids $\xrightarrow{\text{Lipase}}$ Fatty acids + Glycerol + Monoglycerides.

(11) Phospholipids $\xrightarrow{\text{Phospholipase}}$ phosphorous + Fatty acids + Glycerol + Monoglycerides.

(12) Organic phosphate $\xrightarrow{\text{Phosphetase}}$ Free phosphate.

(13) Nucleic acid $\xrightarrow{\text{Polynucleotidase}}$ Nucleotides.

(14) Nucleosides $\xrightarrow{\text{Nucleosidase}}$ Nitrogenous bases.

PANCREAS :

Single, endodermal, flat, leaf-like yellowish, heterocrine (mixed) gland, present between the ascending and descending limb of duodenum and opens into duodenum through pancreatic duct. It can be divided into following parts -

Exocrine :

It is the major part (about 85%) of pancreas. The exocrine tissue of the pancreas consists of rounded lobules (acini) that secrete an alkaline pancreatic juice. The juice is carried by the main pancreatic duct, also called **duct of Wirsung,** into the duodenum through the hepatopancreatic ampulla **(ampulla of vater).** An accessory pancreatic duct, also named **duct of Santorini,** may sometimes lead directly into the duodenum.

Endocrine :

Minor part (15% only) also called as islets of Langerhans scattered in the exocrine part. It consist of four various type of cells, as α cells, β cells, δ cells and PP cells. α-cells secretes glucagon hormone, β-cells secretes insulin hormone and δ cells secrets somatostatin. The PP cells secrete pancreatic polypeptide hormone to control somatostatin. The secretion passes directly into blood.

Pancreatic juice

(1) Amount: 1-1.5 L /day

(2) Chemical nature: alkaline

(3) pH: 7.1-8.2

(4) Control of secretion: Hormonal and normal mechanism.

Secretin hormones stimulate the production of more alkaline pancreatic juice but low in enzyme content. Pancreozymin or Cholecystokinin stimulates the production of enzyme rich pancreatic juice.

(5) Chemical composition: Water (99%), enzymes and salts.

Functions of pancreas and its enzymes :

(1) The islets' of Langerhans secrete insulin and glucagon hormones.

(2) The exocrine part of pancreas secretes pancreatic juice.

(3) Elastase: It act upon elastin protein.

(4) Trypsinogen $\xrightarrow[\text{Intestinal juice}]{\text{Enterokinase of}}$ Trypsin.

(5) Trypsinogen $\xrightarrow[\text{Autocatalysis}]{\text{Trypsin}}$ Trypsin.

(6) Chymotrypsinogen $\xrightarrow[\text{Autocatalysis}]{\text{Trypsin}}$ chymotrypsin.

(7) Polypeptides + Peptones $\xrightarrow[\text{Pancreatic protease}]{\text{Trypsin}}$ Tripeptides + Dipeptides + Oligopeptides.

(8) Starch $\xrightarrow[\text{(Pancreatic amylase)}]{\text{Amylopsin}}$ Maltose + Isomaltose + Limit dextrin

(9) Emulsified Lipids $\xrightarrow[\text{(Pancreatic lipase)}]{\text{Steapsin}}$ Fatty acids + Glycerol + Monoglycerides

(10) Nucleic acid $\xrightarrow{\text{Nuclease}}$ Nucleotides + Nucleosides

(11) Nucleosides $\xrightarrow{\text{Nucleosidase}}$ Purines + Pyrimidines.

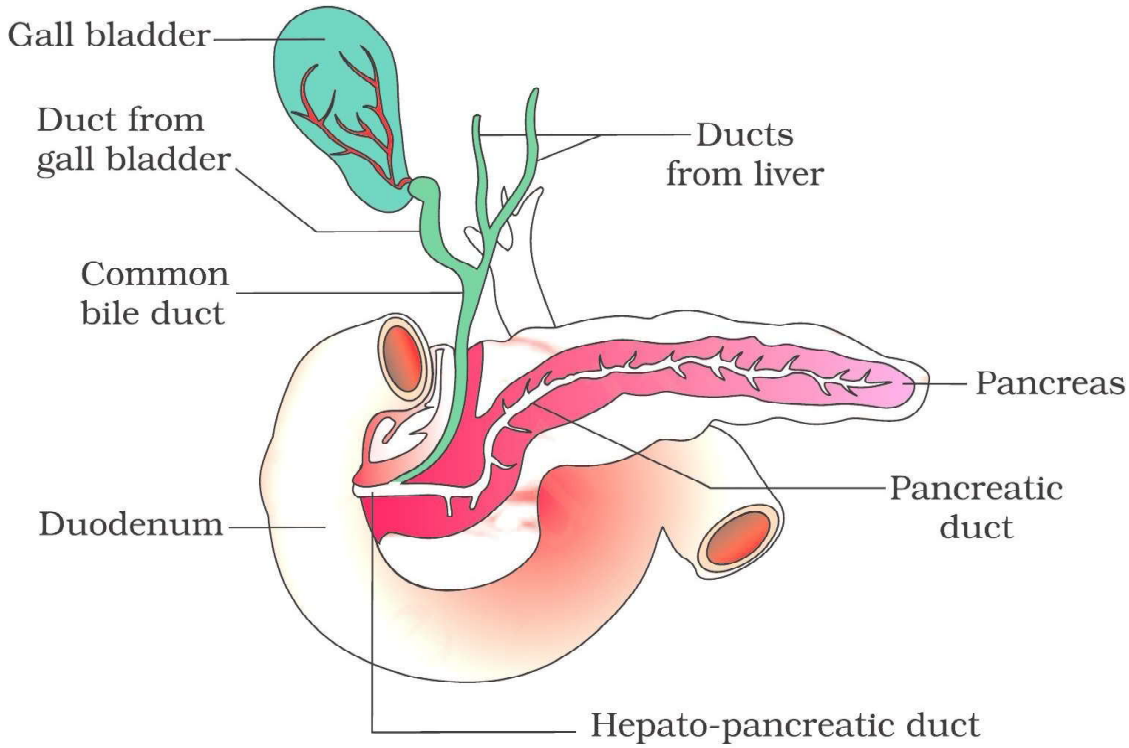
(12) Polypeptides $\xrightarrow{\text{Cymotrypsin}}$ Oligopeptides.

LIVER

Structure :

- The liver is largest and heaviest gland in the body. It is divided into two main lobes: right and left lobes separated by the falciform ligament.
- A pear-shaped sac, the gall bladder is attached to the posterior surface of the liver by connective tissue. The right and left hepatic ducts join to form the **common hepatic duct.** The latter joins the **cystic duct,** which arises from the gall bladder.
- The cystic duct and common hepatic duct join to form **common bile duct or ductus cholidochus** which passes downwards posteriorly to join the main pancreatic duct to form the hepatopancreatic ampulla (ampulla of Vater). The ampulla opens into the duodenum. The opening is guarded by the **sphincter of Oddi.**
- The **sphincter of Boyden** surrounds the opening of the bile duct before it is joined with the pancreatic duct.
- The basic structural and functional unit of the liver is the hepatic lobule. Each lobule is covered by a thin connective tissue sheath called **Glisson's capsule**.

  Each lobule is composed of plates of polyhedral, glycogen-rich cells, the hepatocytes, arranged radially around a central vein. Hepatocytes around central vein are arranged in **cord** like arrangement. Between the plates are radial blood sinusoids. The sinusoids are lined with scattered phagocytic **kupffer cells** that eat bacteria and foreign substance.



The duct systems of liver, gall bladder and pancreas

Functions of liver :

Liver, the largest gland of vertebrate body, is an essential organ, which performs many functions-

(1) It secretes bile which is a complex watery fluid containing bile salts (Na taurocholate and Na glycocholate), bile pigments (biliverdin and bilirubin), cholesterol, mucin, lecithin and fats etc. It breaks and emulsifies the fat.

(2) In the liver, haemoglobin of the worn out erythrocytes breaks down to bile pigments bilirubin and biliverdin.

(3) Excess quantities of carbohydrates (glucose) are converted to glycogen **(Glycogenesis)** in the presence of insulin in the liver cells, and stored therein.

(4) Glycogen is a reserve food material, which is changed into glucose **(Glycogenolysis)** and released into the blood at concentrations maintained constant by the liver. In this way, blood-sugar level is maintained under diverse dietary conditions.

(5) Under abnormal conditions, liver can convert proteins and fats into glucose by complex chemical reactions. Formation of this "new sugar" i.e. from non-carbohydrate sources, is called **gluconeogenesis.**

(6) In the embryo, red blood cells are manufactured by the liver. In the adult, liver stores inorganic salts of iron, copper and vitamin B12 (anti-anaemic factor) and thus helps in the formation of red blood cells and haemoglobin.

(7) Fibrinogen, prothrombin and certain other blood coagulation factors are formed in the liver.

(8) The plasma proteins serum albumin and serum globulin are synthesized by the liver.

(9) Liver synthesizes vitamin A from the provitamins A (carotenoid pigments). Liver cells also store fat-soluble vitamin A, D, E and K. Besides, it is the principal storage organ for vitamin B12.

(10) The liver is the site of detoxification of different toxic substances either produced in the body or taken along with food.

(11) Kupffer cells in the liver sinusoids phagocytose and remove bacteria, worn-out blood elements and foreign particles.

Gall bladder :

The gall bladder is a slate-blue, pear-shaped sac connected with an supported from liver by a small omentum or ligament. Its distal part is called fundus, while the narrow part, continued as cystic duct, is called the neck.

BILE :

(1) Amount: 800-1000 ml daily. On the average about 700 ml.

(2) Source: Secreted by hepatic cells

(3) Storage site: Gall bladder

(4) Colour: Greenish-blue

(5) Chemical nature: Alkaline

(6) pH : 7.6-8.6

Functions of bile :

(1) Emulsification of fats.

(2) Helps in absorption of fat-soluble vitamins.

(3) Increases alkalinity to make the medium suitable for enzymatic action.

(4) Elimination of excess of bile pigments.

(5) Stercobilin and urobilin (urobilin found in urine) is formed by bilirubin and biliverdin is responsible for colouration of faeces.

PHYSIOLOGY OF DIGESTION

The process of digestion involves following steps-

(1) Ingestion : It is the intake of food most of the animals capture the prey/food with the help of mouth or tongue.

(2) Mastication: The process occurs in the buccopharyngeal cavity of mammals with the help of teeth. During this process food is broken down into small pieces, which increases its surface area.

(3) Deglutition / swallowing : The passage of food from buccopharyngeal cavity to oesophagus/ stomach. In mammals bolus of the masticated food is formed in buccopharyngeal cavity which easily slides into oesophagus. It is a voluntary reflex mechanism.

- **Peristalsis** is alternate contraction and relaxation of circular and longitudinal muscles produces the wave of contraction due to which the food passes from front to backward direction in the lumen of alimentary canal. The phenomenon is called as peristalsis.

  Antiperistalsis is the peristaltic wave occuring in the reverse direction. It occurs in alimentary canal and results in vomiting. The phenomenon is called as "Regurgitation".

(4) Digestion : The process of digestion is accomplished by mechanical and chemical processes.

Oral cavity :

- The buccal cavity performs two major functions, mastication of food and facilitation of swallowing. The teeth and the tongue with the help of saliva masticate and mix up the food thoroughly. Mucus in saliva helps in lubricating and adhering the masticated food particles into a **bolus**. The bolus is then conveyed into the pharynx and then into the oesophagus by swallowing or deglutition.
- The bolus further passes down through the oesophagus by successive waves of muscular contractions called peristalsis. The gastro-oesophageal sphincter controls the passage of food into the stomach.
- The saliva secreted into the oral cavity contains electrolytes (Na^+, K^+ , Cl^- , HCO^-) and enzymes, salivary amylase and lysozyme. The chemical process of digestion is **initiated** in the oral cavity by the hydrolytic action of the carbohydrate splitting enzyme, the salivary amylase. About 30 per cent of starch is hydrolysed here by this enzyme (optimum pH 6.8) into a disaccharide – maltose. Lysozyme present in saliva acts as an antibacterial agent that prevents infections.

$$\text{Starch} \xrightarrow[\text{pH 6.8}]{\text{Salivary Amylase}} \text{Maltose}$$

Stomach :

The mucosa of stomach has gastric glands. Gastric glands have three major types of cells namely -

(i) mucus neck cells which secrete mucus;

(ii) peptic or chief cells which secrete the proenzyme pepsinogen; and

(iii) parietal or oxyntic cells which secrete HCl and intrinsic factor (factor essential for absorption of vitamin B_{12}).

- The stomach stores the food for 4-5 hours. The food mixes thoroughly with the acidic gastric juice of the stomach by the churning movements of its muscular wall and is called the **chyme**.
- The proenzyme pepsinogen, on exposure to hydrochloric acid gets converted into the active enzyme pepsin, the proteolytic enzyme of the stomach. Pepsin converts proteins into proteoses and peptones (peptides).
- The mucus and bicarbonates present in the gastric juice play an important role in lubrication and protection of the mucosal epithelium from excoriation by the highly concentrated hydrochloric acid.
- HCl provides the acidic pH (pH 1.8) optimal for pepsins.
- **Rennin** is a proteolytic enzyme found in gastric juice of infants which helps in the digestion of milk proteins. Small amounts of lipases are also secreted by gastric glands.

Small Intestine :

- The bile, pancreatic juice and the intestinal juice are the secretions released into the small intestine. Pancreatic juice and bile are released through the hepato-pancreatic duct. The pancreatic juice contains inactive enzymes – trypsinogen, chymotrypsinogen, procarboxypeptidases, amylases, lipases and nucleases.
- Trypsinogen is activated by an enzyme, **enterokinase,** secreted by the intestinal mucosa into active trypsin, which in turn activates the other enzymes in the pancreatic juice.
- The bile released into the duodenum contains bile pigments (bilirubin and bili-verdin), bile salts, cholesterol and phospholipids but no enzymes. Bile helps in emulsification of fats, i.e., breaking down of the fats into very small micelles. Bile also activates lipases.
- The intestinal mucosal epithelium has goblet cells which secrete mucus. The secretions of the brush border cells of the mucosa alongwith the secretions of the goblet cells constitute the intestinal juice or succus entericus.
- This juice contains a variety of enzymes like disaccharidases (e.g. maltase), dipeptidases, lipases, nucleosidases, etc.
- The mucus alongwith the bicarbonates from the pancreas protects the intestinal mucosa from acid as well as provide an alkaline medium (pH 7.8) for enzymatic activities. Sub-mucosal glands (Brunner's glands) also help in this.
- Proteins, proteoses and peptones (partially hydrolysed proteins) in the chyme reaching the intestine are acted upon by the proteolytic enzymes of pancreatic juice as given below:

$$\left.\begin{matrix}\text{Proteins}\\ \text{Peptones}\\ \text{Proteoses}\end{matrix}\right\} \xrightarrow[\text{Carboxypeptidase}]{\text{Trypsin/ Chymotrypsin}} \text{Dipeptides}$$

Carbohydrates in the chyme are hydrolysed by pancreatic amylase into disaccharides.

$$\text{Polysaccharides (starch)} \xrightarrow{\text{Amylase}} \text{Disaccharides}$$

Fats are broken down by lipases with the help of bile into di-and monoglycerides.

$$\text{Fats} \xrightarrow{\text{Lipases}} \text{Diglycerides} \longrightarrow \text{Monoglycerides}$$

Nucleases in the pancreatic juice acts on nucleic acids to form nucleotides and nucleosides

$$\text{Nucleicacids} \xrightarrow{\text{Neucleases}} \text{Nucleotides} \longrightarrow \text{Nucleosides}$$

The enzymes in the succus entericus act on the end products of the above reactions to form the respective simple absorbable forms. These final steps in digestion occur very close to the mucosal epithelial cells of the intestine.

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

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

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

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

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

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

The breakdown of biomacromolecules mentioned above occurs in the duodenum region of the small intestine. The simple substances thus formed are absorbed in the jejunum and ileum regions of the small intestine. The undigested and unabsorbed substances are passed on to the large intestine.

Large intestine :

- No significant digestive activity occurs in the large intestine. The functions of large intestine are:

(i) Absorption of some water, minerals and certain drugs;

(ii) Secretion of mucus which helps in adhering the waste (undigested) particles together and lubricating it for an easy passage.

- The undigested, unabsorbed substances called faeces enters into the caecum of the large intestine through ileo-caecal valve, which prevents the back flow of the faecal matter. It is temporarily stored in the rectum till defaecation.

Note : The activities of the gastro-intestinal tract are under **neural and hormonal control** for proper coordination of different parts. The sight, smell and/or the presence of food in the oral cavity can stimulate the secretion of saliva. Gastric and intestinal secretions are also, similarly, stimulated by neural signals. The muscular activities of different parts of the alimentary canal can also be moderated by neural mechanisms, both local and through CNS. Hormonal control of the secretion of digestive juices is carried out by the local hormones produced by the gastric and intestinal mucosa.

Summary of physiology of digestion (Major gastrointestinal enzyme in mammals)

Name of gland	Name of digestive juice & optimum pH	Name of enzyme	Site of action	Substrates	Products
Salivary glands	Saliva (6.3 - 6.8)	Ptyalin / Salivary amylase	Mouth	Starch, dextrins, glycogen	Dextrins, maltose, isomaltose and limit dextrin.
Gastric glands	Gastric Juice (1-3)	Pepsin Rennin Gastric lipase	Stomach Stomach Stomach	Proteins, casein (Milk) Casein Fats	Peptones, paracasein (curd). Proteoses Paracasein Fatty acid and Glycerol
Liver	Bile juice (7.6-8.6)	No enzymes	Duodenum	Fat	Makes the food alkaline, emulsifies fat and kills the harmful bacteria.

ABSORPTION OF DIGESTED PRODUCTS

- Absorption is the process by which the end products of digestion pass through the intestinal mucosa into the blood or lymph. It is carried out by passive, active or facilitated transport mechanisms.
- Small amounts of monosacharides like glucose, amino acids and some of electrolytes like chloride ions are generally absorbed by simple diffusion. The passage of these substances into the blood depends upon the concentration gradients.
- However, some of the substances like fructose and some amino acids are absorbed with the help of the carrier ions like Na+. This mechanism is called the facilitated transport.
- Transport of water depends upon the osmotic gradient.
- Active transport occurs against the concentration gradient and hence requires energy. Various nutrients like amino acids, monosacharides like glucose, electrolytes like Na+ are absorbed into the blood by this mechanism.
- Fatty acids and glycerol being insoluble, cannot be absorbed into the blood. They are first incorporated into small droplets called **micelles** which move into the intestinal mucosa. They are re-formed into very small protein coated fat globules called the **chylomicrons** which are transported into the lymph vessels (lacteals) in the villi. These lymph vessels ultimately release the absorbed substances into the blood stream.
- Absorption of substances takes place in different parts of the alimentary canal, like mouth, stomach, small intestine and large intestine. **However, maximum absorption occurs in the small intestine.**
- A summary of absorption (sites of absorption and substances absorbed) is given in Table

The Summary of Absorption in Different Parts of Digestive System

Mouth	Stomach	Small Intestine	Large Intestine
Certain drugs coming in contact with the mucosa of mouth and lower side of the tongue are absorbed into the blood capillaries lining them.	Absorption of water, simple sugars, and alcohol etc. takes place.	Principal organ for absorption of nutrients. The digestion is completed here and the final products of digestion such as glucose, fructose, fatty acids, glycerol and amino acids are absorbed through the mucosa into the blood stream and lymph.	Absorption of water, some minerals and drugs takes place.

- The absorbed substances finally reach the tissues which utilise them for their activities. This process is called **assimilation.** The digestive wastes, solidified into coherent faeces in the rectum initiate a neural reflex causing an urge or desire for its removal. The egestion of faeces to the outside through the anal opening **(defaecation)** is a voluntary process and is carried out by a mass peristaltic movement.