HUMAN PHYSIOLOGY
(DIGESTION AND ABSORPTION)

NUTRITION

The nutrition is the procurement of substances necessary for growth, maintenance and activities of a living organism.

❖ Types of nutrition

(1) Autotrophic / Holophytic: The mode of nutrition in which individuals are capable to synthesize their own food. Such organisms are considered as autotrophs. They can be grouped into following two categories -

(i) Photoautotrophs: Individuals which synthesize their own food from CO_2 and H_2O in presence of sunlight. **e.g.** green plants, *Euglena*.

(ii) Chemoautotrophs: The individuals which synthesize their food with the help of chemical energy **e.g.** sulphur bacteria, nitrite bacteria, nitrate bacteria etc.

(2) Heterotrophic: The mode of nutrition in which animals derive organic food materials by consuming bodies or products of other living or dead plants or animals. On the basis of their mode of feeding, heterotrophic nutrition is categorized into following three types:

(i) Holotrophic or Holozoic: In this mode of nutrition individuals ingest mostly solid food. **e.g.** most of the animals

(ii) Saprotrophic or Saprobiotic: The way to feed on dead organic matter. Saprotrophs absorb food through their body surface, organic fluids formed due to putrefaction of dead organism. **e.g.** bacteria, fungi, some protozoans etc.

(iii) Parasitic: The mode of nutrition in which individuals derive their food from the body of their host. Such organisms are called parasites. These may live inside or upon the bodies of their hosts, or may only periodically visit them for feeding. **e.g.** ectoparasites such as lice and endoparasites like *Ascaris* and *Taenia*

(3) Myxotrophic nutrition: The mode of nutrition in which autotrophic as well as heterotrophic nutrition is present. **e.g.** *Euglena*

❖ Animal Nutrition

Animals are unable to synthesise their own food. Therefore, they have to depend, directly or indirectly, on plants for their nutritional requirements.The food is required to derive energy to perfom work, to synthesize materials, to grow and to maintain various activities of life. Proteins, carbohydrates, lipids, vitamins and minerals are the components of food.

Modes of Animal Nutrition

On the basis of food, holozoic or holotrophic animals are classified into the following types:

(1) Herbivorous: Animals those exclusively feed on plants. Their length of alimentary canal is more as compared to others. **e.g.** Tadpole larva of frog, rabbit, cow, horse, sheep etc.

(2) Carnivorous: Animals which kill and feed upon other animals. **e.g.** tiger, lion etc.

(3) Omnivorous: Animals which can take both plant and animal product as food. They have maximum type of digestive enzymes. **e.g.** Human, Dog, Prawn.

(4) Insectivorous: The animal which feeds on insects. **e.g.** frog, common bat, wall lizard

(5) Detritivorous: Animals feed chiefly upon organic matters present in the humus. **e.g.** earthworm.

(6) Coprophagus or pseudorumination or refaecation: Animals which feed on their own faeces. **e.g.** rabbit, guinea pig.

Feeding Mechanism

(1) Feeding mechanism in liquid feeders (fluid feeders): This is as follows -

(i) Diffusion: Many parasitic organisms (protozoans, tapeworm) absorb the dissolved organic food through general body surface.

(ii) Pinocytosis (cell drinking): Ingestion of liquid food by invagination through surface of body. Pinocytosis channels are formed at body surface to enclose the fluid food from surrounding medium. Lower ends of channels are pinched off as pinocytic vesicle or pinosomes.

(iii) Blood sucking: Their mouthparts are modified for sucking blood. **e.g.** vampire bat, female mosquitoes

(2) Feeding mechanism in microphagous animals (filter feeders): The food of such animals (paramecium, sponges, corals, bivalves, tadpole etc.) is suspended in water and they have filtering devices (clusters of pseudopodia, cilia, flagella, sheets of mucus etc.) for selective feeding on small microscopic animals.

Steps of Animal Nutrition

The process of nutrition in animals involves following steps:

1. **Ingestion:** Intake of food.
2. **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.It is of two types –
   (i) Intracellular: When the process of digestion occurs within the cell in the food vacuole. **e.g.** Protozoa, Porifera, Coelenterata and free living platyhelminthes.
   (ii) Extracellular: When the process of digestion occurs outside the cell. **e.g.** Coelenterates and Platyhelminthes to Chordata.
3. **Absorption:** Passing of digested food through the wall of small intestine into the blood or lymph.
4. **Assimilation:** Use of simple food components for the synthesis of complex components in different body cells or to get energy.
5. **Egestion:** Elimination of undigested food as faeces (or defaecation).

Resonate the Concept
• If above steps occur at cellular level then this phenomenon is called as phagocytosis.

❖ Human Digestive System

Digestive system is a system of organs and glands which are involved in obtaining food, its crushing digestion, absorption, assimilation and egestion of indigestible matter. Human digestive system consists of an alimentary canal (GIT) and digestive glands.

Alimentary Canal or Gastro-Intestinal Tract

It is a long hollow, coiled muscular and glandular tube of variable diameter that contains a number of specialised sections and extends from mouth to anus. The length is 6-9 m. The various parts of alimentary canal or digestive tract are mouth, vestibule, oral cavity, pharynx, oesophagus, stomach, small intestine, large intestine and anus.

Parts of alimentary canal and its histology

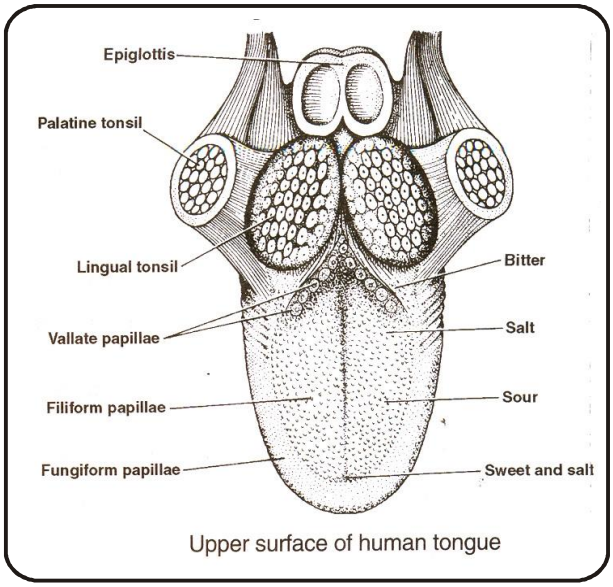
1. **Mouth:** The mouth is a transverse slit bounded by two movable lips or labia, upper lip and lower lip. Upper lip has small ridges on the sides. a tubercle in the middle and a vertical groove (philtrum) above.

2. **Buccal cavity / Bucco pharyngeal cavity:** It has two parts:
   - **(i) 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.
   - **(ii) Oral cavity:** The part of buccal cavity which is surrounded by teeth is called oral cavity. It is lined by non keratinized stratified squamous epithelium.

- Main structure of buccopharyngeal cavity are:

A. Palate: The roof of buccal cavity is called palate. It distinguished into three regions -
   - **a. Hard palate:** Anterior, bony portion formed of maxilla and palatine bones in humans. Hard palate has 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.
   - **b. Soft palate:** Posterior soft part, made up of connective tissue and muscles.
   - **c. Velum palati/uvula:** Posterior most part of soft palate, which hangs in the region of pharynx. It closes the internal nostrils during degglutition.

B. Tongue (lingua):



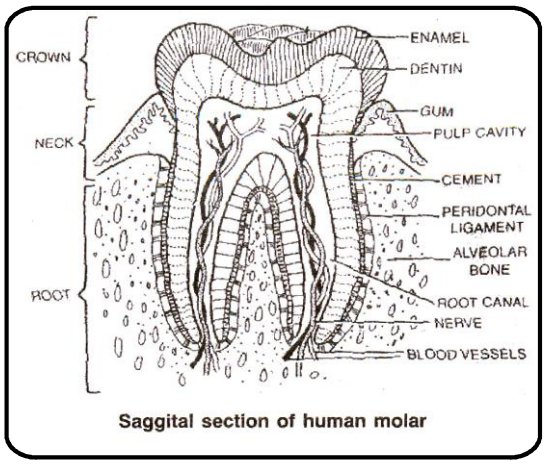
Upper surface of human tongue

- It is highly muscular and protrusible structure present on the floor of buccopharyngeal cavity and is lined by stratified squamous epithelial cells.
- The upper surface of the tongue has small projections called papillae. Some of which bear taste buds.
- The papillae are of the following types:
   - **a. Circumvallate:** They are circular, 8 to12 in number, present in the posterior part of the tongue extending from one side to another. They possess around 100 taste buds on each. These are the largest of all the papillae.
   - **b Fungiform:** They are mushroom shaped, numerous, present at the tip and anterior margins of the tongue.They also contain around five taste buds on each.
   - **c. Foliate:** They are leaf like flat, 8-10 in number, present at the posterior margin of the tongue. They are absent in humans and are found in rabbit. (Degenerate in early childhood in human).
   - **d. Filiform:** They are conical shaped, smallest and most numerous and are distributed throughout the tongue. They are devoid of the taste buds, however possess tactile receptors.

- Hence, taste, in humans, is recognized with the help of circumvallate and fungiform taste papillae. In man the anterior end of the tongue perceives sweet taste, basal part perceives bitter taste, lateral sides perceive sour taste and its dorsum perceives salty taste.
- **Functions of the tongue:** It
  (i) acts as universal toothbrush, as it helps in teeth cleaning.
  (ii) helps in speaking.
  (iii) helps in deglutition.
  (iv) helps in mixing of saliva in food.
  (v) helps in taste perception.
  (vi) helps in regulation of body temperature in dogs (through panting).

C. Teeth : Ectomesodermal structures which are helpful in mastication (chewing). Upper jaw teeth are called maxillary teeth as present on maxilla bone & lower jaw teeth are attached to mandible bone so called mandibular teeth.

- **Structure of a tooth:** A tooth is divided into three parts:
  (i) Root: Inner most part, attached to the bone with the help of cement (containing hyaluronic acid).
  (ii) Neck: Middle part covered over by the gum which provides support to the tooth.
  (iii) Apex or crown: External exposed part of tooth. It is white in colour.

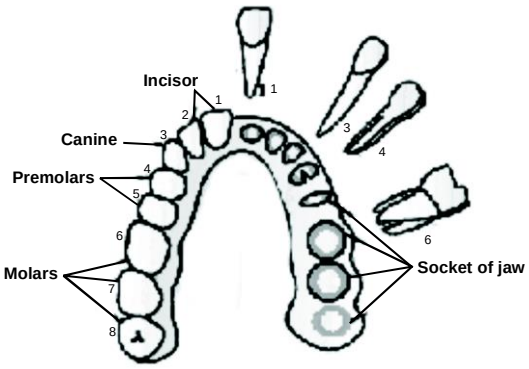


Saggital section of human molar

- A small cavity present inside teeth is called as pulp cavity. It contains blood vessels, lymphatic vessels, nerve fibres, connective tissue etc. and provides nutrition to odontoblasts or osteoblasts.
- The odontoblasts 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%) and surrounds the odontoblasts. It is mesodermal in origin.
- **Enamel** is secreted by ameloblasts/enameloblasts, 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.
- **Differentiation of teeth:** Morphologically, teeth can be distinguished as homodont or heterodont.
  (i) Homodont teeth are structurally and functionally similar.
  (ii) Heterodont teeth are structurally and functionally different. They are further distinguished into four types: incisors, canines, premolars and molars.
    (a) Incisors are single-rooted monocuspid and long, curved and sharp-edged. They are adapted for cutting or cropping and biting.
    (b) Canines, next to the incisors, are pointed in each half of upper and lower jaws. They are meant for piercing, tearing and offence & defence. They are single rooted and monocuspid.

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

(d) Molars have more than two roots (upper molars have three roots and lower molars have two roots) and have four cusps (tetracuspid).



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

- **Attachment of teeth:** On the basis of the attachment of teeth with the jaw bones, teeth can be differentiated into-
  - **(i) Acrodont:** Teeth are attached to the free surface of the jaw bone, as in a shark and frog. Such teeth are prone to break off easily but are replaced.
  - **(ii) Pleurodont:** In this condition, teeth are attached to the inner side of jaw bone by their bases as well as one side. **e.g.** lizards
  - **(iii) Thecodont:** Such teeth are characteristic of mammals and crocodile. Teeth have well developed roots implanted in deep individual pits or sockets called **alveoli or theca,** in the jaw bone.

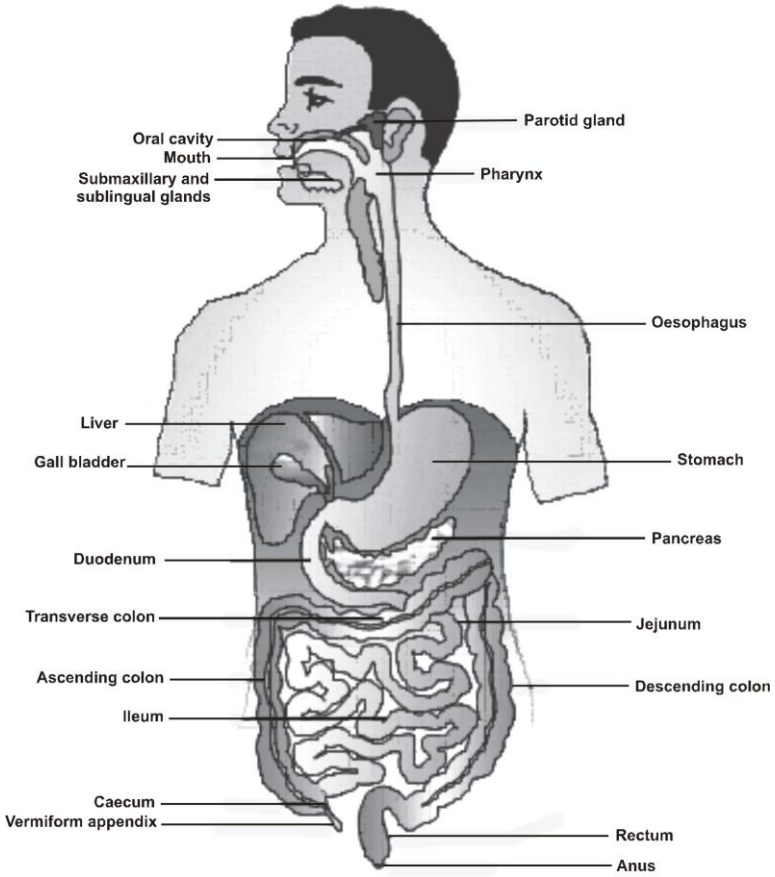
- **Succession of teeth:** According to their replacement (succession), teeth can be divided into 3 categories:
  polyphyodont, diphyodont and monophyodont.
  - **(i) Polyphyodont:** In lower vertebrates, teeth can be replaced for indefinite number of times during life. e.g. Fishes, Amphibians, Reptiles.
  - **(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 primary teeth or milk teeth or lacteal teeth** whereas the second set is called **permanent or secondary teeth.**
  - **(iii) Monophyodont:** In some mammals only one set of teeth develops known as monophyodont condition.

Note: Milk 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). In human, molar teeth are monophydont.

- **Dental formula:** Formula that expresses a definite number and arrangement of teeth and has taxonomic importance as this varies in species.

  Human (milk set) $\frac{2102}{2102} \times 2 = 20$

  Human (adult set) $\frac{2123}{2123} \times 2 = 32$

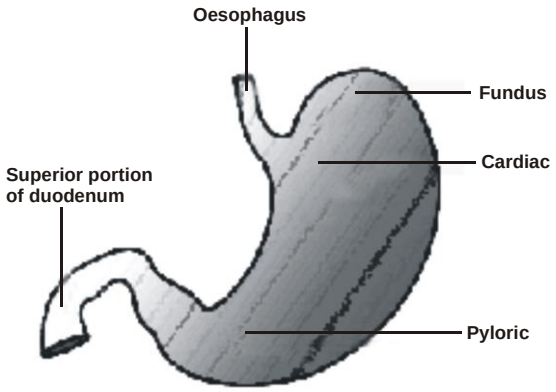


The human digestive system

3. **Pharynx:** Oral cavity leads into a short pharynx which is a vertical canal beyond the soft palate. This serves as a comman passage for food and air. A cartilaginous flap called **epiglottis** prevents the entry of food into glottis (opening of wind pipe) during swallowing. Pharynx is divided into three parts; Nasopharynx, Oropharynx and Laryngopharynx.

4. **Oesophagus (food pipe):** Its opening is called gullet.
   Morphology: Single, posterior 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.

5. **Stomach**



Anatomical regions of human stomach

Structure:

- Single oval, elongated, unilobed and **J** shaped and present within abdominal cavity below diaphragm.
- It consists of three parts as cardiac (anterior part) into which oesophagus opens, fundic (middle part), pyloric (posterior part) which opens into the first part of small intestine. Middle part i.e. fundic act as the main gastric gland which contains peptic cells (secrete enzymes), oxyntic cells (secrete HCl), mucus cells or goblet cells (secrete mucus), argentaffin cells etc. These cells play a very important role in digestion.
- Two types of sphincters are present in the stomach viz.**cardiac sphincter** (gastro-oesophageal sphincter) between oesophagus and stomach and **pyloric sphincter** between stomach and duodenum.

Resonate the Concept

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

Resonate the Concept

Ruminant Stomach/Compound Stomach

In ruminants, the stomach is differentiated into four chambers:

(i) Rumen: Largest part of stomach for churning, breaking of food with the help of cornified surface of villi. In this part symbiotic microorganisms (anaerobic bacteria like *Rumenococcus* and cilates like *Entodinium caudatum)* are present which are related with the fermentation of cellulose.

(ii) Reticulum: It is lined by keratinised epithelium.

(iii) Omasum: This is for mechanical churning and breaking of food, absorption of fluid and electrolytes. **Omasum is absent in camel.**

(iv) Abomasum: This part secretes gastric juice and shows chemical digestion of food.

Rumen and reticulum have diverticula or water pockets for temporary storage of food. Small part of food is broken down in rumen which is sent back to the buccal cavity for further chewing. Then, It comes in abomasum for chemical digestion, so it is considered as **true stomach of ruminants.**

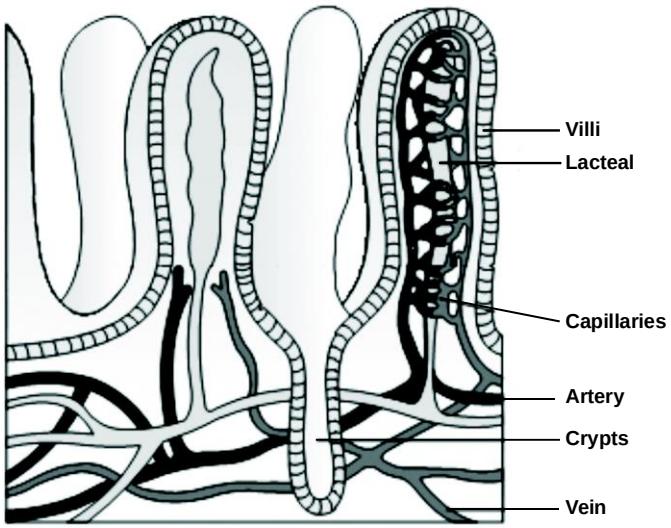
6. Small intestine

Structure: Longest part of alimentary canal present in the abdominal cavity, supported by a peritoneal membrane called mesentery.

- It is approximately 6.25 m in humans. 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; head of pancreas lies in the loop.	About 2-2.5 m long and about 4 cm wide. The wall is thicker and more vascular. The villi are thicker and tongue-like.	About 3.5 m long and about 3.5 cm wide. The wall is thinner and less vascular. The villi are thinner and finger like.

- Wall of jejunum and ileum has circular or spiral internal folds called **folds of kerckring or valvulae conniventes or plicae circulares.**
- Also numerous finger like projections called villi project from the wall of lumen, increasing internal surface area about ten times.
- The distal end of ileum leads into the large intestine by ileo-caecal valve in humans.
- Ileum has lymph nodes called peyer's patches.



A section of small intestinal mucosa showing villi

Function: Digestion and absorption of food.

7. Large intestine: The name of large intestine is due to large diameter (4-6 cm).

Structure: Approximately 1.5-1.75 m long.

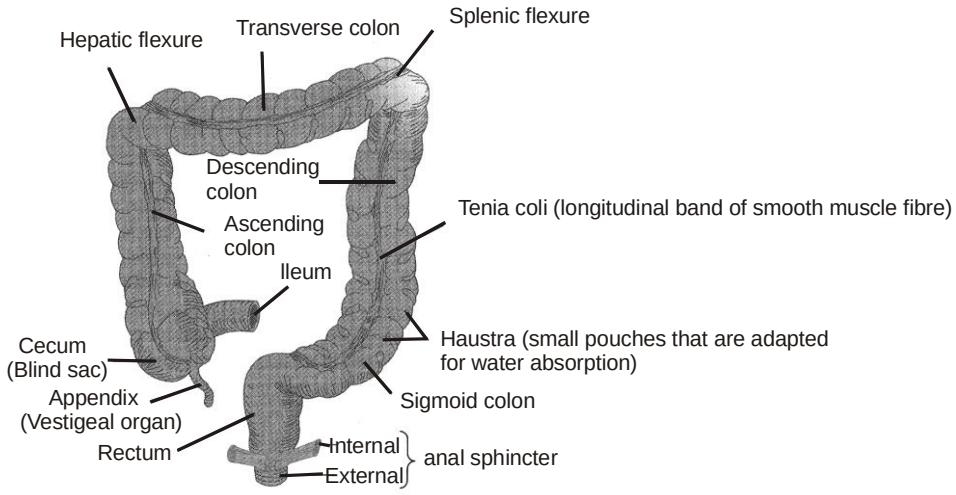
Parts: They are following:

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

(ii) Colon: Single endodermal approximately 1.3 m long in humans distinguished into four limbs as ascending, transverse, descending and pelvic or sigmoid limb. Colon has three longitudinal bands called taeniae coli and small pouches (haustra).

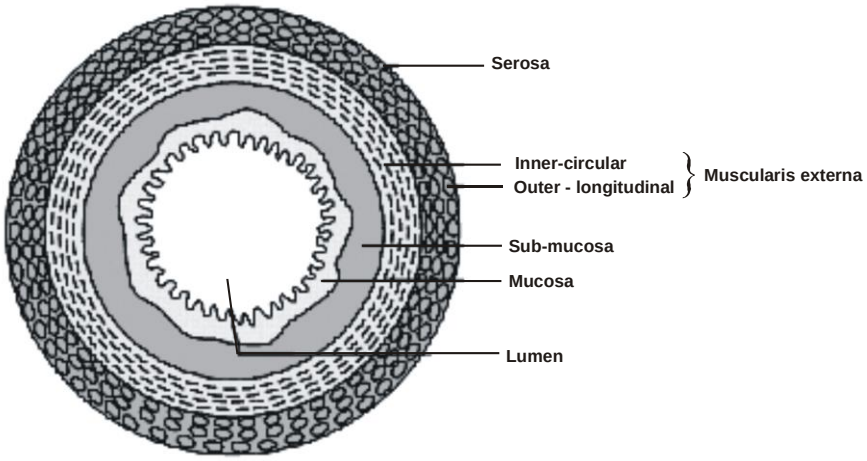
(iii) Rectum: Single small dilated sac like in human. It is concerned with storage of faeces. Rectum has strong sphincter muscle in its wall. The **sphincter** keeps the canal as well as anus, closed when not used for defecation.

(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, bounded by internal (involuntary) & external (voluntary) spinicter.



The human colon

- **Histology of Gut:**



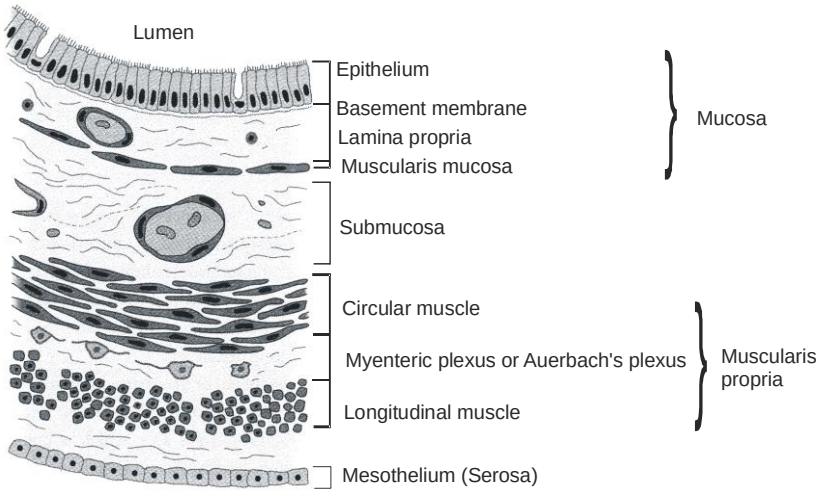
Diagrammatic representation of transverse section of gut

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

1. **Serosa:** It is the outermost layer and is made up of a thin mesothelium (epithelium of visceral organs) with some areolar connective tissues. Part of oesophagus above diaphragm has areolar connective tissue only, so called tunica adventitia.
2. **Muscularis:** It is formed by smooth muscles usually arranged into an inner circular and an outer longitudinal layers. An oblique muscle layer is present in some regions like stomach. In between longitudinal and circular muscle fibres, there is a network of parasympathetic nerve fibre called Auerbach's plexus (Myentric plexus), which control peristalsis.
3. **Submucosal layer:** It is formed of loose connective tissue containing nerves, blood and lymph vessels. In duodenum, glands are also present in submucosa. A network of sympathetic nerve fibre, called Meissner's plexus is present here, which control secretion of intestinal juice.
4. **Mucosa:** The innermost layer lining the lumen of the alimentary canal is the mucosa. This layer forms irregular folds (rugaes) in the stomach and small finger-like folds 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).
- Mucosa is composed of three layers:
  - **(i)** The **muscularis mucosa** consists of outer longitudinal and inner circular muscle fibres, both are unstriped.
  - **(ii)** The **lamina propria** consists of loose connective tissue, blood vessels, glands and some lymphoid tissue.
  - **(iii)** The **epithelium** forms gastric glands in stomach, and villi and intestinal glands in small intestine.

    In upper one third of the oesophagus both Auerbach and Meissner's plexuses are absent.



Organization of the wall of the intestine into functional layers

Test your Resonance with concept

1. Digestive enzymes are
(1) Hydrolase (2) Oxido-reductase (3) Transferase (4) Isomerase

2. The hardest substance of vertebrate body is
(1) Keratin (2) Enamel (3) Dentine (4) Chondrin

3. In the wall of alimentary canal which of the following sequence is correct from outer to inner
(1) Serosa, longitudinal muscle, mucosa, sub mucosa
(2) Mucosa, serosa, longitudinal muscle
(3) Serosa, longitudinal muscle, circular muscle, sub-mucosa, mucosa
(4) Serosa, longitudinal muscle, sub-mucosa, mucosa

4. Main part of the tooth is compose of
(1) Enamel (2) Dentine (3) Bony socket (4) Cementum

5. Distinct microvilli are present on all of the following except
(1) Cells lining the proximal convoluted tubules of the kidney
(2) Follicular cells of the thyroid gland
(3) Absorptive cells of the intestinal epithelium
(4) Mucous cells of the salivary glands

Answers

1. (1) **2.** (2) **3.** (3) **4.** (2) **5.** (4)

❖ 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.

1. Salivary glands:

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

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

(ii) 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.

(iii) Sub-lingual: One-pair, present in the floor of buccopharyngeal cavity. 6-8 ducts arise from the gland. These ducts are called as **Ducts of Rivinus or Bartholin's ducts** and open below tongue on the floor of buccopharyngeal cavity.
Sub-lingual and sub-mandibular salivary glands secrete salivary amylase and mucus. Salivary amylase is absent in herbivores.

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 which is called Aptylism and may lead to dental problems).
(5) Chemical composition: Water (99.5%), mucous (acts as lubricant), salts (NaCl, $NaHCO_3$ etc.), enzymes (ptyalin, lysozyme) etc.

Functions of Salivary juice and its enzymes:

(1) Saliva makes the medium slightly acidic for the action of its enzyme.
(2) This helps in taste perception, deglutition, speaking etc.

2. Gastric glands

There are approximately 35 millions of gastric glands present in human stomach which are following

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

(ii) Middle part (Fundic): Main gastric glands in humans have four distinct types of cells:

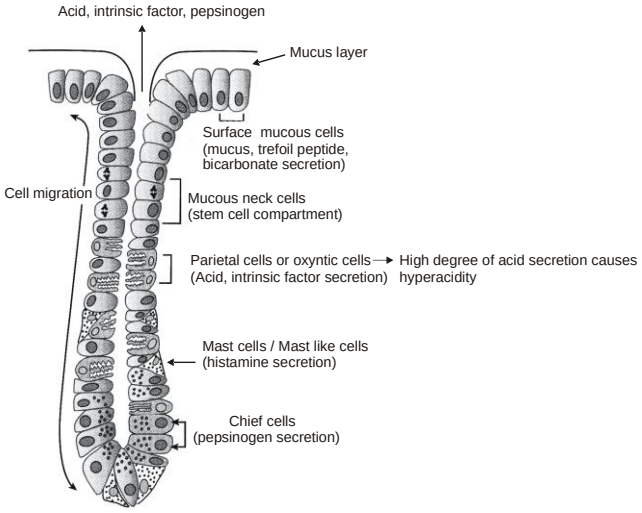
A. Peptic or zymogenic or chief or central cells: Secrete two digestive proenzymes pepsinogen and prorennin (prorennin is secreted in children but not in adults). They also produce some amount of gastric lipase which is related with fat digestion.

B. Oxyntic or parietal cells: Secrete HCl and Castle's intrinsic factor required for the absorption of vitamin B_{12}. Hyperacidity is abnormally high degree of acidity due to the secretion of large quantity of HCl in gastric juice.

C. Mucous neck cells: Secrete alkaline mucus.

D. Argentaffin cells or Kultchitsky or Enterochromaffin cells: Responsible for the secretion of vasoconstrictor serotonin and vasodialator histamine. These play a role in regulation of muscular movements.

(iii) Posterior part: (Pyloric) The cells present in this region are mucous neck cells secreting mucus 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.



Structure of a gastric gland from the fundus

The gastric glands secrete gastric juice.

Gastric juice

(1) Amount: 2-3 liters/day.
(2) Chemical nature: Highly acidic
(3) pH: 1.0 - 2.5 (due to presence of HCl). pH of infant's gastric juice is 5.
(4) Control of secretion: This is regulated by gastrin hormone.
(5) Chemical composition: Water (99%), mucus, inorganic salts, Castle's intrinsic factor, HCl (0.5%) and enzymes prorennin, pepsinogen & gastric lipase.

Functions of gastric juice and its enzymes

(1) It inactivates the action of ptyalin.
(2) It makes the medium acidic for the action of gastric enzymes.
(3) HCl kills micro organisms.
(4) HCl kills the ingested living organisms (prey etc.).

Resonate the Concept

- **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.
- **Galactosemia:** It is a metabolic disorder in which gene coding for uridyl transferase enzyme become recessive due to mutation. In this disease galactose is not converted to glucose which lead to accumulation of galactose. Deposition of galactose hampers nervous system.

3. Intestinal glands

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

(i) The **crypts of Lieberkuhn** are simple, tubular structures which occur through-out the small intestine between the villi. They secrete digestive enzymes and mucus. The mucus is secreted by **goblet cells** (= mucous cells) whereas water and electrolytes are secreted by **enterocytes** present on the intestinal crypts. These crypts have at the base paneth cells. **Paneth cells** are found particularly in the duodenum. These cells are present in the bottom of crypts of Liberkuhn. These cells are rich in zinc and contain acidophilic granules. The function of these cells is not certain but there is evidence that they secrete lysozyme (antibacterial substance). Paneth cells are also capable of phagocytosis.

(ii) The **Brunner's glands** are *found only in the duodenum* and are located in the submucosa. They secrete a little enzyme and mucus. The mucus protects the duodenal wall from getting digested. Digestion of most of nutrients takes place in the duodenum under the action of various enzymes. The Brunner's glands open into the crypts of Lieberkuhn.

All these parts of small intestine are related with the secretion of intestinal juice which is also called as succus entericus.

Succus entericus (intestinal juice)

(1) Amount: 2 - 3 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%), mucus, inorganic salts, enzymes etc

Function of Intestinal juice and its enzymes:

(1) This juice inhibits the action of gastric enzymes.
(2) This makes the medium alkaline for the action of it's enzymes.
(3) The intestinal juice contains many enzymes - maltase, isomaltase, sucrase, lactase, α - dextrinase, enterokinase, aminopeptidase, dipeptidase, nucleotidase, nucleosidases and intestinal lipase.

4. Pancreas

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

Exocrine: It is the major part (about 99%) of pancreas. The exocrine tissue of the pancreas consists of rounded lobules (acini) which 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: It is minor part (1% only) of pancreas which consists of islets of Langerhans scattered in the exocrine part. It consists of four various types of cells, as α cells, β cells, δ cells and PP cells. α-cells secrete glucagon hormone, β-cells secrete insulin hormone and δ cells secrete somatostatin. The PP cells secrete pancreatic polypeptide hormone to control somatostatin. The secretion passes directly into the blood.

Pancreatic juice

(1) Amount: 1-1.5 l /day
(2) Chemical nature: alkaline
(3) pH: 7.1-8.2
(4) Control of secretion: This is regulated by hormonal and neural mechanisms. Secretin hormone stimulates the production of more alkaline pancreatic juice but lowers 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:

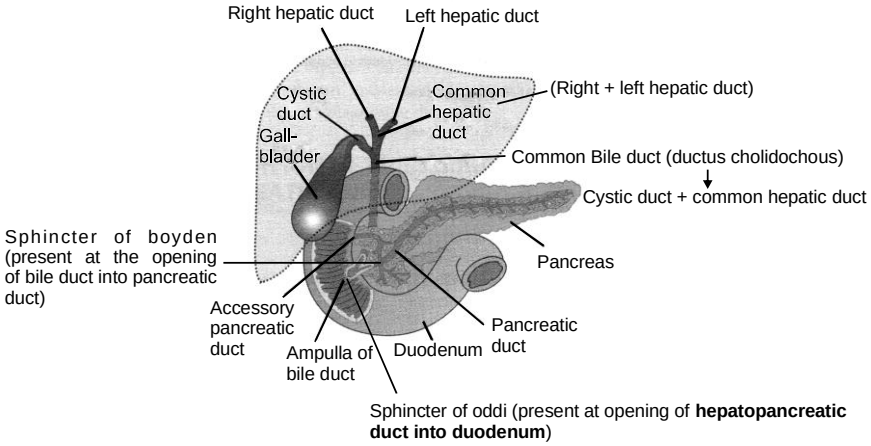
(1) The islets of Langerhans secrete insulin and glucagon hormones.
(2) The exocrine part of pancreas secretes pancreatic juice containing tripsinogen, Chymotrypsinogen, procarboxypetidase, pancreatic amylase (amylopsin), pancreatic lipase (Steapsin) and Nuclease.

5. 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 by 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 manner. Between the plates are radial blood sinusoids which are lined by scattered phagocytic **Kupffer cells** that eat bacteria and foreign substance.



Connections of the ducts of the gallbladder,liver and pancreas

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

- **(i)** 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.
- **(ii)** In the liver, haemoglobin of the worn out erythrocytes breaks down to form bile pigments bilirubin and biliverdin.
- **(iii)** Excess quantities of carbohydrates (glucose) are converted to glycogen **(glycogenesis)** in the presence of insulin in the liver cells, and stored therein.
- **(iv)** 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.
- **(v)** 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.**
- **(vi)** In the embryo, red blood cells are manufactured by the liver. In the adult, liver stores inorganic salts of iron, copper and vitamin B_{12} (anti-anaemic factor) and thus helps in the formation of red blood cells and haemoglobin.
- **(vii)** Fibrinogen, prothrombin and certain other blood coagulation factors are formed in the liver.
- **(viii)** The plasma proteins serum albumin and serum globulin are synthesized by the liver.
- **(ix)** 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 B_{12}.
- **(x)** The liver is the site of detoxification of different toxic substances either produced in the body or taken along with food.
- **(xi)** 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 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 are formed by bilirubin and biliverdin and provide colouration to faeces and urine respectively.

Test your Resonance with concept

1. Liver is the largest gland and is associated with various functions, choose which is not correct
(1) Metabolism of carbohydrate (2) Digestion of fat
(3) Formation of bile (4) Secretion of hormone called gastric

2. Prorennin is secreted by
(1) Zymogen cells (2) Islet of langerhans
(3) Sertoli cells (4) Hepatocytes

3. The pH of succus entericus is or in intenstine, pH value is
(1) 7.8 (2) 6.6 (3) 5.6 (4) 2.0

4. Islets of Langerhans are present in
(1) Pancreas (2) Ileum (3) Oesophagus (4) Stomach

Answers

1. (4) **2.** (1) **3.** (1) **4.** (1)

❖ Physiology of Digestion

The process of digestion is accomplished by mechanical and chemical processes.

1. **Digestion in buccal cavity:** The buccal cavity performs two major functions, mastication of food and facilitation of swallowing.
   - **i. Mastication:** Chewing of food is called mastication which converts large food particles into tiny food pieces. This is also called as mechanical digestion of food.
   - **ii. Chemical Digestion:** 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.

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

     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.

2. Digestion in stomach: The mucosa of stomach has gastric glands containing three major types of cells namely:

(i) mucous neck cells which secrete mucus
(ii) chief / peptic or zymogen cells which secrete the proenzymes ; pepsinogen and prorennin
(iii) parietal or oxyntic cells which secrete HCl and Castle's intrinsic factor (essential for the 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.

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

- HCl provides the acidic pH (pH 1.8), optimal for pepsin. This converts proteins into proteoses and peptones (peptides).

  Proteins $\xrightarrow[pH\ (1.8)]{Pepsin}$ Proteoses + Peptones

- **Rennin** is a proteolytic enzyme, found in the gastric juice of infants and helps in the digestion of milk proteins.

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

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

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

  Paracasienate $\xrightarrow[pH\ (1-3)]{Pepsin}$ Proteose + Peptones

- Small amounts of lipases are also secreted by gastric glands.
- 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.

3. Digestion in 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.

  Trypsinogen $\xrightarrow[Intestinal\ juice]{Enterokinase\ of}$ Trypsin

  Trypsinogen $\xrightarrow[Autocatalysis]{Trypsin}$ Trypsin

  Chymotrypsinogen $\xrightarrow{Trypsin}$ Chymotrypsin

  Procarboxypeptidase $\xrightarrow{Trypsin}$ Carboxypeptidase

- 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:

  Proteose + Peptones $\xrightarrow[Pancreatic\ protease]{Trypsin}$ Dipeptides + Oligopeptides

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

  Starch $\xrightarrow[(Pancreatic\ amylase)]{Amylopsin}$ Disaccharides

- The bile released into the duodenum contains bile pigments (bilirubin and biliverdin), 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**.

  Emulsified lipids $\xrightarrow[\text{(Pancreatic lipase)}]{\text{Steapsin}}$ Diglycerides + Monoglycerides

  Nucleic acids $\xrightarrow{\text{Nuclease}}$ Nucleotides + Nucleosides

  Nucleosides $\xrightarrow{\text{Nucleosidase}}$ Purines + Pyrimidines

  Polypeptides $\xrightarrow{\text{Chymotrypsin}}$ Oligopeptides

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

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

- 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 along with the bicarbonates from the pancreas protects the intestinal mucosa from acid as well as provides an alkaline medium (pH 7.8) for enzymatic activities. Submucosal glands (Brunner's glands) also help in this.
- 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.

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

  Isomaltose $\xrightarrow{\text{Isomaltose}}$ Glucose + Glucose

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

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

  Dipeptides $\xrightarrow{\text{Dipeptidases}}$ Aminoacids

  Nucleic acids $\xrightarrow{\textit{Polynucleotidase}}$ Nucleotides

  Nucleosides $\xrightarrow{\text{Nucleosidase}}$ Nitrogenous bases

  Diglycerides + Monoglycerides $\xrightarrow{\text{Lipases}}$ Free fatty acid + Glycerol

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

4. **Digestion in large intestine:** No significant digestion occurs in the large intestine. The functions of large intestine include:
   (i) The absorption of water, vitamins, minerals and certain drugs
   (ii) The secretion of mucus which helps in adhering the waste particles together and lubricating them for an easy passage during defaecation.

- The undigested, unabsorbed substances called faeces finally enter into the rectum of the large intestine where they are temporarily stored in the rectum till defaecation.

❖ Regulation of digestion

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.

1. **Hormonal control of digestion:** All the hormones involved in regulation of digestion are polypeptide hormones. These hormones and their functions are following-

Gastrointestinal hormones in mammals

Hormone	Source	Stimulus for secretion of Hormone	Target organ of Hormone action	Action
Gastrin	Mucosa of pyloric stomach	Distension of stomach on food entry	Stomach	Stimulates secretion of gastric juice. Constricts cardiac sphincter.
Enterogastrone	Duodenal pithelium	Chyme entry into duodenum	Stomach	Slows gastric contractions to delay its emptying. Stops secretion of gastric juice.
Secretin	Duodenal epithelium	Acidic chyme entry into duodenum	Pancreas Liver Stomach	Release of sodium bicarbonate in pancreatic juice. Steps up secretion of bile. Inhibits secretion of gastrin.
Cholecystokinin (pancreozymin)	Duodenal epithelium	Presence of fats in duodenum	Pancreas Gall Bladder	Release of enzymes in pancreatic juice. Release of bile from gall bladder.
Villikinin	Intestinal epithelium	Food in small intestine	Intestine	Accelerates movements of villi.
Duocrinin	Intestinal epithelium (Duodenal mucosa)	Acidic chyme in intestine	Intestine (Brunner's gland)	Release of viscous mucous from Brunner's glands.
Enterocrinin	Intestinal epithelium (Duodenal mucosa)	Acidic chyme in intestine	Intestine (crypts of Lieberkuhn's)	Release of enzymes from Lieberkuhn's crypts.

2. **Neural regulation of digestion:** The gastrointestinal tract is innervated by an intrinsic/enteric as well as by extrinsic nerves.

   The **intrinsic neural system** consists of

   (i) The **Meissner's plexus** situated in the submucosa controls the secretion of digestive juices.

   (ii) The **Auerbach's plexus** situated in the muscular layer controls peristalsis.

   The enteric neural system controls most of the gastrointestinal functions like secretion and motility.

   The **extrinsic innervation** of the gut consists of parasympathetic and sympathetic nerves which can modify the activity of the intrinsic neural system in response to the reflex activity initiated from the GIT itself or from other parts of the body.

   This happens by the stimulation of vagus nerve. Feeling of hunger at a particular time, when regularly food is taken, is an example of **conditional reflex.**

❖ Absorption of digested products

- Absorption is a process, by which, the end products of digestion pass through the intestinal mucosa into the blood or lymph. It is carried out by active, passive or facilitated transport mechanisms.
- Small amounts of monosacharides like glucose, amino acids and some of the 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 some amino acids are absorbed with the help of the carrier ions like Na^+. This mechanism is called the facilitated transport. Fructose is also absorbed by facilitated diffusion.
- 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 and electrolytes like Na^+ are absorbed into the blood by this mechanism.
- **Absorption of Lipids**

All dietary lipids are absorbed via simple diffusion. Adults absorb about 95% of the lipids present in the small intestine; due to their lower production of bile, newborn infants absorb only about 85% of lipids. As a result of their emulsification and digestion, triglycerides are mainly broken down into monoglycerides and fatty acids, which can be either short-chain fatty acids or long-chain fatty acids. Although short-chain fatty acids are hydrophobic, they are very small in size. Because of their size, they can dissolve in the watery intestinal chyme, pass through the absorptive cells via simple diffusion, and follow the same route taken by monosaccharides and amino acids into a blood capillary of a villus.

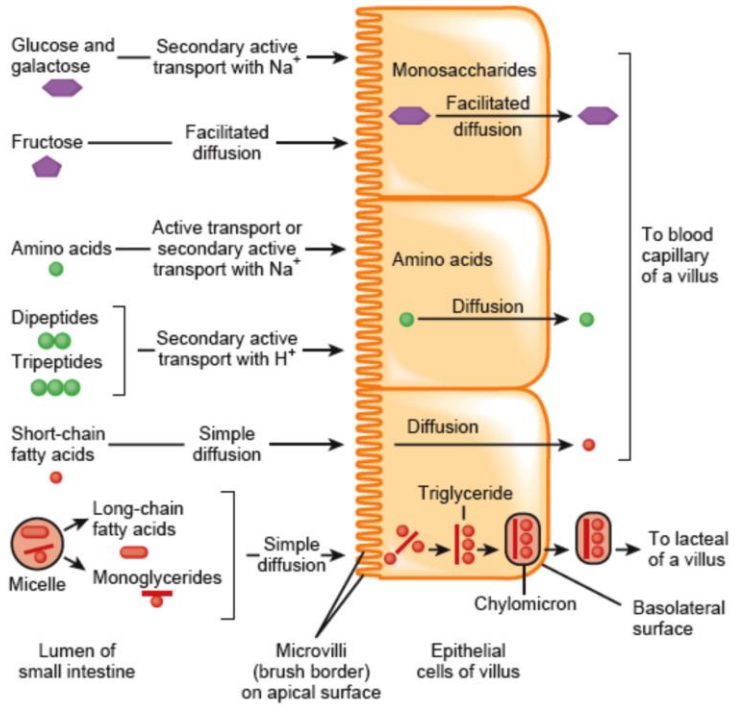


Fig. Mechanisms for movement of nutrients through absorptive epithelial cells of the villi

Long-chain fatty acids and monoglycerides are large and hydrophobic and have difficulty being suspended in the watery environment of the intestinal chyme. Besides their role in emulsification, bile salts also help to make these long-chain fatty acids and monoglycerides more soluble. The bile salts in intestinal chyme surround the long-chain fatty acids and monoglycerides, forming tiny spheres called micelles, each of which is 2–10 nm in diameter and includes 20–50 bile salt molecules. Micelles are formed due to the amphipathic nature of bile salts: The hydrophobic regions of bile salts interact with the longchain fatty acids and monoglycerides, and the hydrophilic regions of bile salts interact with the watery intestinal chyme. Once formed, the micelles move from the interior of the small intestinal lumen to the brush border of the absorptive cells. At that point, the long-chain fatty acids and monoglycerides diffuse out of the micelles into the absorptive cells, leaving the micelles behind in the chyme. The micelles continually repeat this ferrying function as they move from the brush border back through the chyme to the interior of the small intestinal lumen to pick up more long-chain fatty acids and monoglycerides. Micelles also solubilize other large hydrophobic molecules such as fat-soluble vitamins (A, D, E, and K) and cholesterol that may be present in intestinal chyme, and aid in their absorption. These fat-soluble vitamins and cholesterol molecules are packed in the micelles along with the long-chain fatty acids and monoglycerides. Once inside the absorptive cells, long-chain fatty acids and monoglycerides are recombined to form triglycerides, which aggregate into globules along with phospholipids and cholesterol and become coated with proteins. These large spherical masses, about 80 nm in diameter, are called chylomicrons. Chylomicrons leave the absorptive cell via exocytosis. Because they are so large and bulky, chylomicrons cannot enter blood capillaries—the pores in the walls of blood capillaries are too small. Instead, chylomicrons enter lacteals, which have much larger pores than blood capillaries. From lacteals, chylomicrons are transported by way of lymphatic vessels to the thoracic duct and enter the blood at the left subclavian vein.

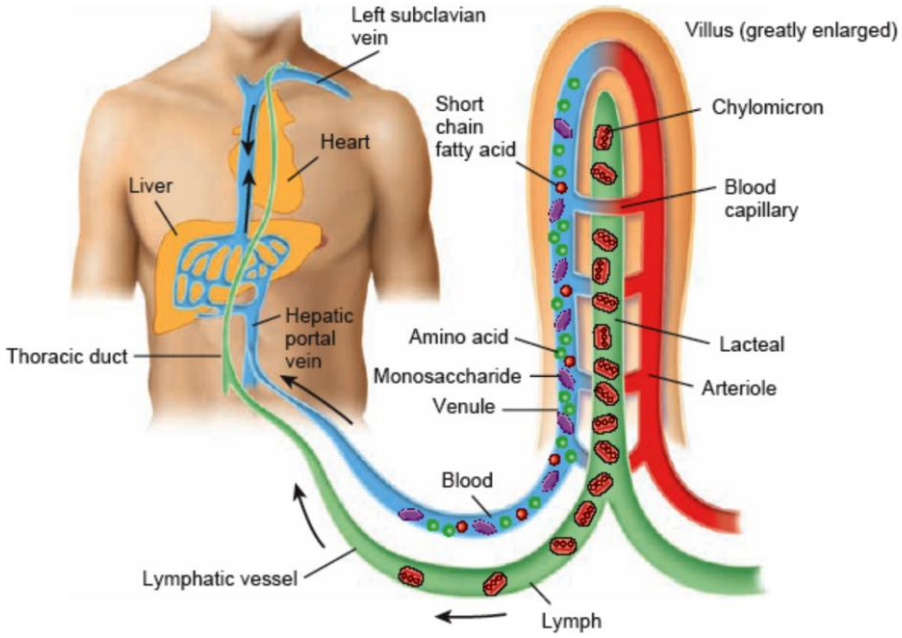
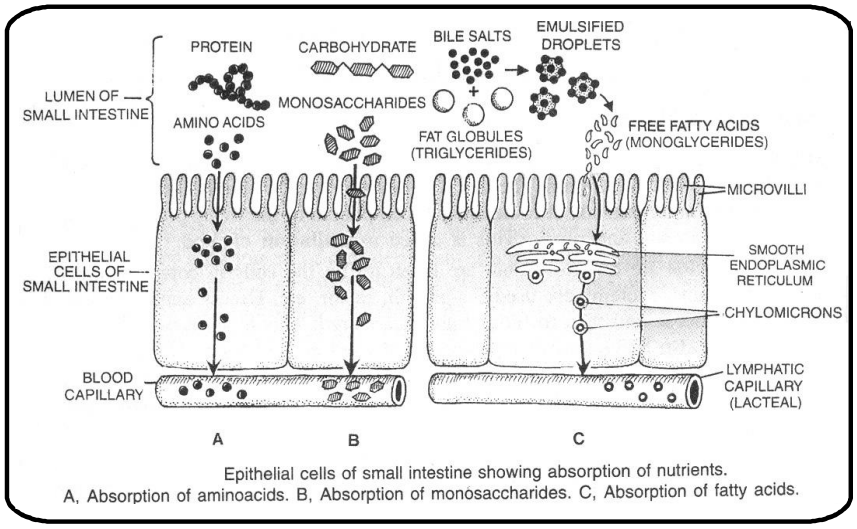


Fig. Movement of absorbed nutrients into the blood and lymph

- 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.**



Epithelial cells of small intestine showing absorption of nutrients.
A, Absorption of aminoacids. B, Absorption of monosaccharides. C, Absorption of fatty acids.

- A summary of absorption (sites of absorption and substances absorbed) is given in following table.
- The absorbed substances finally reach the tissues which utilise them for their activities. This process is 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.

❖ Disorders of digestive system

1. **Gastroenteritis:** The inflammation of the intestinal tract is the most common ailment due to bacterial or viral infections. The infections are also caused by the intestinal parasites like tape worm, round worm, thread worm, hook worm, pin worm, etc.
2. **Jaundice:** The liver is affected; skin and eyes turn yellow due to the deposition of the bile pigments.
3. **Vomiting:** It is the ejection of stomach contents through the mouth. This reflex action is controlled by the vomiting centre in the medulla. A feeling of nausea usually precedes vomiting.
4. **Diarrhoea:** The abnormal frequency of bowel movements and increased liquidity of the faecal discharge is known as diarrhoea. It reduces the absorption of food.
5. **Constipation:** The faeces are retained within the rectum as the bowel movements occur irregularly.
6. **Indigestion:** In this condition, the food is not properly digested leading to a feeling of fullness. The causes of indigestion are inadequate enzyme secretion, anxiety, food poisoning, over eating and spicy food.

Test your Resonance with concept

1. Salivary amylase, a digestive enzyme begins digestion of
(1) Proteins (2) Fats (3) Carbohydrates (4) All of these

2. Some of the free fatty acids and monoacyl glycerols aggregate in ileum to form the water soluble substance for the absorption. This is known as
(1) Chyle (2) Cargo (3) Micelles (4) Chylomicrons

3. Most digestion and absorption of food takes place in
(1) Stomach (2) Small intestine (3) Large intestine (4) Caecum

4. The hormone 'secretin' stimulates secretion of
(1) Pancreatic juice (2) Bile juice
(3) Salivary juice (4) Gastric juice

Answers

1. (3) **2.** (3) **3.** (2) **4.** (1)

APPENDIX

❖ Balanced diet

- The diet containing the different nutrients to meet various needs of our body, is called the "balanced diet". The proportion of carbohydrates, proteins and fats to fulfill energy requirement is 4 : 1 : 1 i.e. 65% of energy should be obtained from carbohydrates and 10-20% each from proteins and fats. This amount of energy is fulfilled by the intake of 400-600 g of carbohydrates, 80-100 g of proteins and 50-60 g of fats. The balanced diet must also contain sufficient amount of minerals and vitamins.

❖ Metabolic rates

1. **Basal Metabolic Rate:** It is the amount of energy required daily by a person to maintain its basal metabolism and is about 1600 kcal/day.
2. **Routine Metabolic Rate:** It is the amount of energy required daily by a person to do his routine work. It is about 2800 kcal/day for males and 2300 kcal/day for female.
3. **Active Metabolic Rate:** It is the amount of energy required daily by a person to maintain its high metabolic rate during heavy physical work and is about 4000 to 6000 kcal/day for males and 4500 kcal/day for females. It has been scientifically determined that a child of 4-6 years approximately requires 1500 kcal/day, a child of 13-15 years requires 2500 kcal/day and a youth of 16-18 year requires 3000 kcal/day.

❖ Calorific value

- The energy required to raise the temperature of 1gm of water by 1°C at normal atmospheric pressure is known as one **calorie (cal)**. Similarly the energy required to raise the temperature of 1kg of water by 1°C is called **kilocalorie (kcal).** One calorie is equal to 4.18 Joules.
- The amount of heat liberated due to the complete combustion of 1 gm food in a **bomb calorimeter** (a closed metallic chamber filled with O_2) is its calorific value.
- **Gross calorific values** of carbohydrates, proteins and fats are 4.1kcal/g, 5.65 kcal/g and 9.45 kcal/g respectively.

❖ Physiologic value

- The actual amount of energy liberated in the human body due to combustion of 1 g of food is the physiologic value of food. It is always less than gross calorific value measured by bomb calorimeter. The physiologic values of carbohydrates, proteins and fats are 4.0 kcal/g, 4.0 kcal/g and 9.0 kcal/g respectively.

❖ Regulation of food intake

- **Hunger:** It is defined as the intrinsic, involuntary desire or craving for food.It is associated with a number of objective sensations e.g. food deprivation for many hours. It causes intense rhythmic hunger contractions in the stomach, which in turn, results in intense pain (hunger pangs).It eventually sends sensory impulses to **"hunger or feeding centre"** located in the lateral regions of the hypothalamus.
- When glucose levels fall in the blood, hunger centre is stimulated.The latter transmits impulses to the wall of the stomach initiating its contractions or hunger pangs. After taking meal, the satiety centre which is located in the hypothalamus, gets stimulated resulting in stoppage of feeding. During high fever, a patient doesn't like consuming meal (anorexia or loss of appetite) because high temperature inhibits the hunger centre.
- **Thirst:** It refers to the subconscious desire for intake of water. It is induced by the hypothalamic "thirst centre". When the amount of water decreases in body fluids (like blood, lymph, tissue fluid, cerebrospinal fluid etc.) due to fever, exercise and sweating, copious urination, diarrhoea, etc. This induces the feeling of thirst. Presumably, a fall in the glucose level in the blood also induces thirst.

❖ Vitamins

- **Definition:** Vitamins are complex organic compounds needed daily in minute quantities and act as growth and metabolic regulatory substances.
- **Sources:** Vitamins can be synthesized by green plants, hence animals depend for their vitamin requirement on the plants. Human body manufactures vitamin D using ultraviolet rays of sunlight and can store A, D, E, K and B_{12} the chemical structures of vitamins are known and it is possible to synthesize them.
- **Importance:** The vitamins are not a sources of energy. They regulate the various metabolic processes. They mostly act as the constituents of coenzymes in the cells.
- **Types**
  - **A. Fat soluble vitamins:** A, D, E and K.
  - **B. Water soluble vitamins:** B complex and C

Vitamin	Mojor Dietary Sources	Major Functions in the Body	Symptoms of Deficiency
Water Soluble Vitamins			
B_1 (Thiamine)	Pork, legumes, peanuts, whole grains	Coenzyme used in removing CO_2 from organic compounds	Beriberi (tingling, poor coordination, reduced heart function)
B_2 (Riboflavin)	Dairy products, meats, enriched grains, vegetable	Component of coenzymes FAD and FMN	Skin lesions, such as cracks at corners of mouth
B_3 (Niacin)	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, delusions, confusion
B_5 (Pantothenic acid)	Meats, dairy products, whole grains, fruits, vegetables	Component of coenzyme A	Fatique, numbness, tingling of hands and feet
B_6 (Pyridoxine)	Meats, vegetable, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia
B_7 (Biotin)	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
B_9 (Folic acid)	Green vegetables, oranges, nuts, legumes, whole grains	Coenzyme in nucleic acid and amino acid metabolism	Anemia, birth defects
B_{12} (Cobalamin)	Meats, eggs, dairy products	Production of nucleic acids and red blood cells	Anemia, numbness, loss of balance
C (Ascorbic acid)	Citrus fruits, broccoli, tomatoes	Used in collagen synthesis; antioxidant	Scurvy (degneration of skin and teeth), delayed wound healing
Fat-Soluble Vitamins			
A (retinol)	Dark green and orange vegetables and fruits, dairy products	Component of visual pigments; maintenance of epithelial tissues	Blindness, skin disorders, impaired immunity
D	Dairy products, egg yolk	Aids in absorption and use of calcium and phosphorus	Rickets (Bone deformities) in children, bone softening in adults
E (Tocopherol)	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membranes	Nervous system degeneration
K (Phylloquinone)	Green vegetables, tea; also made by colon bacteria	Important in blood clotting	Defective blood clotting

❖ Minerals

They form approximately 4% of body weight. They are essential to regulate the various metabolic activities of the animals. The various types of minerals are grouped into two categories as minor elements. e.g. - Ca, S, P, Na etc. and trace elements e.g. - Cu, Zn, Mn etc. Some of these minerals are described as follows-

	Mineral	Major Dietary Sources	Major Functions in the Body	Symptoms of Deficiency
More than 200 mg per day required	Calcium(Ca)	Dairy products, dark green vegetables, legumes	Bone and tooth formation, blood clotting, nerve and muscle function	Impaired growth, loss of bone mass
	Phosphorus(P)	Dairy products, meats, grains	Bone and tooth formation, acid base balance, nucleotide synthesis	Weakness, loss of minerals from bone, calcium loss
	Sulfur(S)	Proteins from many sources	Components of certain amino acids	Impaired growth, fatigue, swelling
	Potassium (K)	Meats, dairy products, many fruits and vegetables, grains	Acid-base balance, water balance, nerve function	Muscular weakness, paralysis, nausea, heart failure
	Chlorine (Cl)	Table salt	Acid-base balance, formation of gastric juice, nerve function, osmotic balance	Muscle cramps, reduced appetite
	Sodium (Na)	Table salt	Acid-base balance, water balance, nerve function	Muscle cramps, reduced appetite
	Magnesium (Mg)	Whole grains, green leafy vegetables	Enzyme cofactor; ATP bioenergetic	Nervous system distrubances
Iron (Fe)		Meats, eggs, legumes, whole grains, geen leafy vegetables	Component of hemoglobin and of electron carriers; enzyme cofactor	Iron-deficiency anemia, weakness, impaired immunity
Fluorine (F)		Drinking water, tea, sea food	Maintenance of tooth structure	Higher frequency of tooth decay
Iodine (I)		Seafood, iodized salt	Component of thyroid hormones	Goiter (enlarged thyroid gland)

❖ Few important points

- In carnivores, last premolars in upper jaw and first molars in lower jaw may have very sharp cusps for cracking bones and shearing tendons. These are called carnassial teeth.
- Elephant's tusk is an upper incisor.
- Pyorrhoea refers to the infected gums and sockets of teeth.
- The respective numbers of teeth appearing once and twice during life time of a man are 12 and 20 respectively.
- Jacobson's or vomeronasal organs serve the purpose of perception of sensation of smell. They also help in recognising enemies and locating mates etc. They are found in lizards, snakes and *Sphenodon*.
- Gastritis refers to an inflammation of stomach
- The study of digestive system is called gastroenterology.
- Carnivores, cattles and other cud-chewing mammals lack ptyalin enzymes in their saliva.
- Trypsin is called universal enzyme as it is found in organisms starting from protozoans to mammals.
- Pancreatic juice is called as "complete digestive juice" as its proteases can digest variety of proteins.
- Blood is digested by trypsin.
- Cholecystectomy refers to the surgical removal of the gall bladder.
- The obstructive jaundice is due to obstruction of hepatic or common bile duct.
- The foul smell of the faeces is due to the presence of gases such as CH_4, NH_3., H_2S, CO_2 etc. and presence of indole, skatole and mercaptone amines formed due to decarboxylation of tryptophan amino acid.
- Most of the B-complex vitamins act as coenzymes.
- Somatostatin is secreted by salivary and Brunner's glands and plays a role in growth, repair and regeneration.
- The absorption of glucose, galactose and fructose occurs through the mucosal cells. If the absorption of glucose is assumed to be 100, then the absorption of galactose and fructose is 110 and 43 respectively.
- During prolonged fasting, human body first uses carbohydrates followed by fats and lastly proteins.
- Antioxidants decrease oxidative damage to tissues. The vitamins E, C and A act as antioxidants.