DIGESTION AND ABSORPTION

Contents

1. DIGESTION AND ABSORPTION

1.1 Introduction

- The process of nourishing or being nourished, especially the process by which a living organism assimilates food and uses it for growth and for replacement of tissues.
- The science or study that deals with food and nourishment, especially in humans.
- **Nutrition** is derived from Greek word. Nutrine which means to nourish.
- It is the sum total of all the activities which are concerned with ingestion; digestion; absorption of digested food into blood or lymph; oxidation of simple food to produce energy for growth, repair, synthesis of biomolecules; and egestion.
- A primary necessity of all living organisms is to obtain energy and matter.
- Energy is required for the continuation of metabolic functions.
- The materials required by the living organisms to sustain their life are called nutrients and include oxygen, food and water.
- A specialist associated with the needs and problems of nutrition is called dietitian or dietetist.

1.2 Types of Nutrition

- On the basis of the method of getting food **,** the living organisms show of two modes of nutrition-

1.2.1 Autotrophic Nutrition (Gk. auto - self; trophe - nourishment)

- When organisms synthesize the organic compounds from inorganic compounds on its own it is known as Autotrophic nutrition.
- Autotrophic nutrition is classified into two types-
  - **Photosynthesis**
    - In the process of photosynthesis, CO_2 and water are combined in the presence of radiant energy of sunlight trapped by Mg^{2+} containing green pigment, chlorophyll.
    - Photoautotrophic nutrition is found in all green plants, some bacteria (example- *Chlorobium*) and some protists like *Euglena*, *Volvox* etc. called photoautotrophs.
    - The process of photosynthesis is represented as-

$$6CO_2 + 6H_2O \xrightarrow[Radiantenergyofsunlight]{Chlorophyll} C_6H_{12}O_6 + 6O_2$$

  - **Chemosynthesis**
    - Some non-green bacteria manufacture their organic food from inorganic substances in the presence of energy derived from the oxidation of simple inorganic compounds of iron, sulphur etc. examples- Sulphur bacteria and iron-bacteria.
    - This process is called chemosynthesis and organisms are called chemoautotrophs.
    - It is also found in nitrifying bacteria like *Nitrosomonas* and *Nitrobacter*.
    - Sulphur bacteria oxidise hydrogen sulphide while nitrifying bacteria oxidise ammonia to derive energy for chemosynthesis.

$$6CO_2 + 12H_2S \xrightarrow[Sulphur-bacteria]{Chemsynthesis} C_6H_{12}O_6 + 6H_2O + 12S$$

    - Both chemosynthetic and photosynthetic organisms are collectively called autotrophs.

1.2.2 Heterotrophic Nutrition (Gk. hetero - different; trophe - nourishment)

- All animals and fungi, some protists (example- *Trypanosoma*, *Paramecium*, *and Amoeba*), many bacteria (example- *Pseudomonas*) and some non-green plants (example- parasitic plants like *Cuscuta*) are Heterotrophic.
- They do not have chlorophyll so cannot trap the radiant energy of sunlight.
- Therefore they take readymade organic food from other plants or animals.

- On the basis of nature of food, heterotrophic nutrition is of following types -

1.2.2.1 Holozoic nutrition

- Those organisms which feed exclusively on the solid organic food materials are known as Holozoic.
- The food may be a whole plant or whole animal or their parts.
- It is found in most of the free living animals including man.
- Depending upon the source of food, holozoic or holotrophs are of following types
  - Herbivore word is derived from Latin word herba which means herb and vorare means to eat. They are direct plant-feeding heterotrophs, examples -rabbit, cow, horse etc.
  - Carnivore word is derived from Latin word cornis which means flesh. The organisms which derive organic food from their animal food are known as carnivores. Examples- lion, tiger etc.
  - Omnivore is derived from Latin word omnis which means all. Organisms that take plant and animal food are called omnivores. Examples- human beings, cockroaches etc.
  - Cannibals eat upon the members of their own species, examples- some fishes, certain snakes, cockroach, etc.
  - Detritivores feed chiefly upon dead organic matters present in the mud, examples- earthworms.
  - Predators are the organisms when the larger animals feed upon the smaller animal species, examples- birds like eagle, kite etc.
  - Insectivores feed upon insects, examples- frog, lizards, small bats etc. Some insectivores are only ant-eaters, examples- *Echidna* (spiny ant-eater) and *Manis* (scaly ant-eater). Ant-eaters are always edentulous.
  - Scavengers or Carrion eaters are the animals feed upon other dead or decaying materials, examples- vultures, hyena, crow etc.
  - Piscivorous animals feed on fish, examples- Crocodile.
  - Grainivorous animals feed upon grains, examples- pigeon.
  - Coprophagus animals feed upon faeces, examples- pigs, dung beetles, etc.

1.2.2.2 Saprophytic or Saprozoic nutrition

- Organisms like fungi (yeasts, moulds, and mushrooms), many bacteria, a few angiosperms (example- *Neottia*) and animals (example- *Chilomonas*), take dissolved decaying organic materials from their environment.
- In this, the organism releases some enzymes to digest the dead organic food and then the nutrients are absorbed through the body surface.

1.2.2.3 Osmotrophic nutrition

- In this, the animals take predigested food materials by diffusion through their body wall , examples- *Trypanosoma*, *Taenia solium* etc.

1.2.2.4 Parasite nutrition

- In this, a smaller organism (parasite) derives food from another organism (host).
- It is shown by many bacteria, viruses, fungi, some non-green plants, examples- *Puccinia* (wheat and barberry plants), *Cuscuta* and many animals, examples- roundworms etc.
- It may be ectoparasitic, examples- *Trypanosoma* and malaria parasite (intracellular parasites) or *Taenia and Ascaris* (Coelozoic parasites) or Blood fluke and filarial worm (Histozoic-in body tissues).
- Certain green species of *Euglena*, examples- *E. viridis* and *E. gracilis* are autotrophic in the presence of light but become saprotrophic in dark.
- This dual mode of nutrition is called myxotrophic nutrition.

1.2.3 Size of Food
- On the basis of size of food, the animals are divided into two categories -

1.2.3.1 Microphagous
- These animals take small sized food particles, examples- earthworm.
- If food is ingested in liquid form, they are called fluid feeders, examples- aphids, mosquitoes, leeches, vampire bats, etc.

1.2.3.2 Macrophagous
- These animals take food from outside in the form of large pieces e.g. Hydra, Grasshopper etc.

1.2.4 Number of Amino Acids
- On the basis of number of amino acids required, the organisms are divided in two categories-

1.2.4.1 Mesotrophs
- Lower organisms need at least one type of amino acid to fulfil their N-requirement.

1.2.4.2 Metatrophs
- Higher organisms need several types of amino acids for their N-requirement.

1.3. Process of Nutrition
- The process of nutrition involves following steps
    - Ingestion is intaking of food.
    - Digestion is breaking of complex food components into simple soluble components.
    - Absorption is passing of digested food through the wall of small intestine into the blood or lymph.
    - Assimilation is use of simple food components in the synthesis of complex components in different body cells.
    - Egestion is elimination of undigested food as faeces.

1.4. Food
- Man, like other animals, is heterotrophic and depends upon ingested food to provide energy.
- Food is formed of a number of inorganic and organic compounds which are divided in two categories on the basis of their size, solubility and diffusibility

1.4.1. **Diffusible** or **absorbable food**
- Diffusible food includes water, minerals, simple sugars, amino acids, and vitamins etc. which are micro-biomolecules, readily soluble in water and diffusible through the wall of small intestine into blood or lymph.
- These need no digestion.

1.4.2. **Non-diffusible** or **non-absorbable food**
- Non-Diffusible food includes proteins, polysaccharides and oligosaccharides, fats and nucleic acids which are complex macro-biomolecules, insoluble or slightly soluble in water and cannot diffuse into blood or lymph. So these need digestion.
- These food components are divided into two categories
    - Food proper (which provide energy examples- carbohydrates, proteins and fats) Food accessories (which do not provide energy examples- vitamins and inorganic salts).

- Most of our foods are formed of complex and non-diffusible components which cannot be used as such unless they are converted into simple and soluble form.
- These complex biomolecules are polymeric organic compounds formed by interlinking of a large number of specific kind of monomers by **anhydro bonds** formed by loss of water molecules between monomers.

1.5. Ingestion

- Ingestion in liquid feeders occurs by **diffusion** in parasitic protozoans (example- *Trypanosoma*); or by **pinocytosis** or cell drinking; or by **blood sucking** in Sanguivorous animals (example- leeches, mosquitoes, etc.); or by **sucking sap** of plants (example- aphids).
- Ingestion in Filter-feeders (Microphagous animals) occurs by maintaing water current which brings microscopic organisms like bacteria, diatoms, protozoans, unicellular algae, planktons, etc. It is found in animals like sponges, corals, barnacles and bivalve-molluscs, tadpoles, mosquito larvae etc.
- In Macrophagous animals these feed on large animals or plants or their parts and have different structures to capture and ingest the food, example-tentacles with batteries of cnidoblasts in coelenterates, example- *Hydra*; eversible and sticky tongue to capture insects in frogs, toads, wall lizard etc; different types of mouth parts in insects; beaks in the birds; with differently adapted teeth, example- well developed incisors in rabbit and well developed canines (tearing teeth) in carnivores like lion, tiger etc.

1.6. Digestion

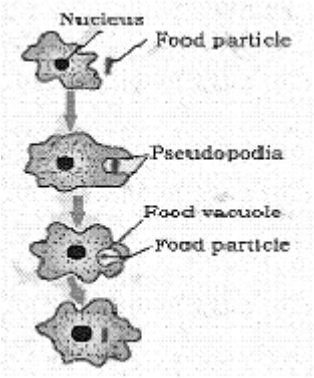
- Digestion is the process by which food is converted into substances that can be absorbed and assimilated by the body.
- It is accomplished in the alimentary canal by the mechanical and enzymatic breakdown of foods into simpler chemical compounds.
- Digestion is a catabolic process by which non-diffusible complex biomolecules are changed into simple and diffusible biomolecules by the process of hydrolysis which involves the breaking of anhydro bonds of complex polymeric compounds in the presence of digestive enzymes (bio-catalysts), called hydrolases, present in the digestive juices secreted by the digestive glands.

1.7 Types of Digestion

- The digestion is classified into two main types on the basis of site of digestion of food
    - Intracellular digestion
    - Intercellular digestion

1.7.1. Intracellular digestion

- It is simplest type of digestion which occurs inside the food vacuoles in the cytoplasm of the cells.
- Such vacuolar digestion is found in the protozoans and sponges.
- The secondary intracellular digestion is found in the gastrodermal cells of the coelenterates (example- *Hydra*), echinoderms (example- star fish) and cephalochordates (example- *Amphioxus*).
- In this type of digestion the foreign food is engulfed by endocytosis into a food vacuole, endosome. Example- ingestion of microbes by WBCs of blood by the process of phagocytosis.
- Primary lysosome with hydrolases fuses with endosome for vacuolar digestion.
- Medium in the food vacuole is first acidic and then alkaline as in the gut of higher animals.
- The digested food diffuses into the cytoplasm.
- The intracellular digestion is always associated with Microphagous mode of feeding.



1.7.2 Inter- or Extracellular digestion

- Here digestion of food takes place in the lumen of digestive tract outside the cells and is a characteristic feature of higher animals, example- annelids, crustaceans, insects, cephalopods and chordates.
- It is more complex type of digestion in which the glandular cells secrete digestive juices in the alimentary canal to digest the complex food and then only the digested food is absorbed into the blood via the intestinal cells.
- Animals showing intercellular digestion are always Macrophagous.
- The intercellular digestion is more efficient as alimentary canal shows regional differentiation in which different parts are specialized differently to perform different functions.
- In this, there is no mixing of digested food and indigestible food. On the basis of physiological division of labour, the alimentary canal can be divided into four zones-
    - Ingressive zone is involved with intake and mastication of food and includes mouth, lips, buccal cavity, teeth, tongue etc.
    - Progressive zone is for conduction and early digestion of food and includes the pharynx, oesophagus and stomach.
    - Degressive zone is an area of final digestion and absorption of food. It includes small intestine.
    - Egressive zone is to temporarily store the faeces and finally their expulsion to outside through the anus. It includes the large intestine (rectum, anus etc.).

Differences between Autotrophic and Heterotrophic nutrition

Characters	**Autotrophic nutrition**	**Heterotrophic nutrition**
Source of energy	Sunlight or chemical energy.	Readymade food.
Source of food	Photosynthesis or chemosynthesis. $6CO_2 + 6H_2O \xrightarrow[sunlight]{Chlorophyll} C_6H_{12}O_6 + 6O_2$	Dead or living plants or animals.
Occurrence	Found in green plants, blue-green algae; certain chemosynthetic bacteria example- Nitrosomonas.	Found in animals, parasitic plants, fungi and most bacteria.

Differences between Holozoic and Saprozoic nutrition

Characters	Holozoic nutrition	Saprozoic nutrition
Nature of food	Whole plant or animal or their parts. Solid food is ingested.	Feed upon decaying organic matter. Liquid digested food is taken.
Site of digestion	Always inside body, either intracellularly or intercellularly.	Always outside the body, as enzymes are released on the food outside the body.
Occurrence	Found in human beings, rabbit, vulture, cockroach, owls, lizards etc.	Found in fungi.

Differences between Intracellular and Extracellular digestion

Characters	Intracellular digestion	Extracellular digestion
Site of digestion	Digestion occurs inside a food vacuole in the cells. Digested food diffuses into the cytoplasm.	Digestion occurs in the alimentary canal and outside the cell. Digested products are absorbed into the cells.
Efficiency	Less efficient and no regional differentiation.	More efficient. Gut shows regional differentiation.
Occurrence	Found in lower forms.	Found in higher forms.

1.8. Digestive System

- It is concerned with all the activities related to food. Primarily, the digestive system is formed of two parts -
  - Alimentary canal is a tube of varying diameter and may be incomplete (example- in flatworms and coelenterates) or complete (example- higher invertebrates and vertebrates). It is the path for food from ingestion to egestion. Though the detailed structure of alimentary canal differs widely in different animals yet it is basically similar in structure and function. It is formed of three parts-
    - Foregut or stomodaeum is ectodermal in origin. In man, it includes mouth and buccal cavity.
    - Midgut or Mesenteron is endodermal in origin. It includes the parts from pharynx to colon.
    - Hindgut or proctodaeum is also ectodermal in origin. It includes rectum and anus.
  - Digestive glands are exocrine glands located either in the wall of alimentary canal or associated with it. These secrete digestive juices which contain digestive enzymes which increase the rate of digestion. These include gastric and intestinal glands in the mucosa of stomach and intestine respectively. Liver and pancreas are also associated with it.

1.9. Human Digestive System

- Digestive system of man consists of two parts
  - Alimentary canal
  - Digestive glands

1.9.1. Alimentary canal

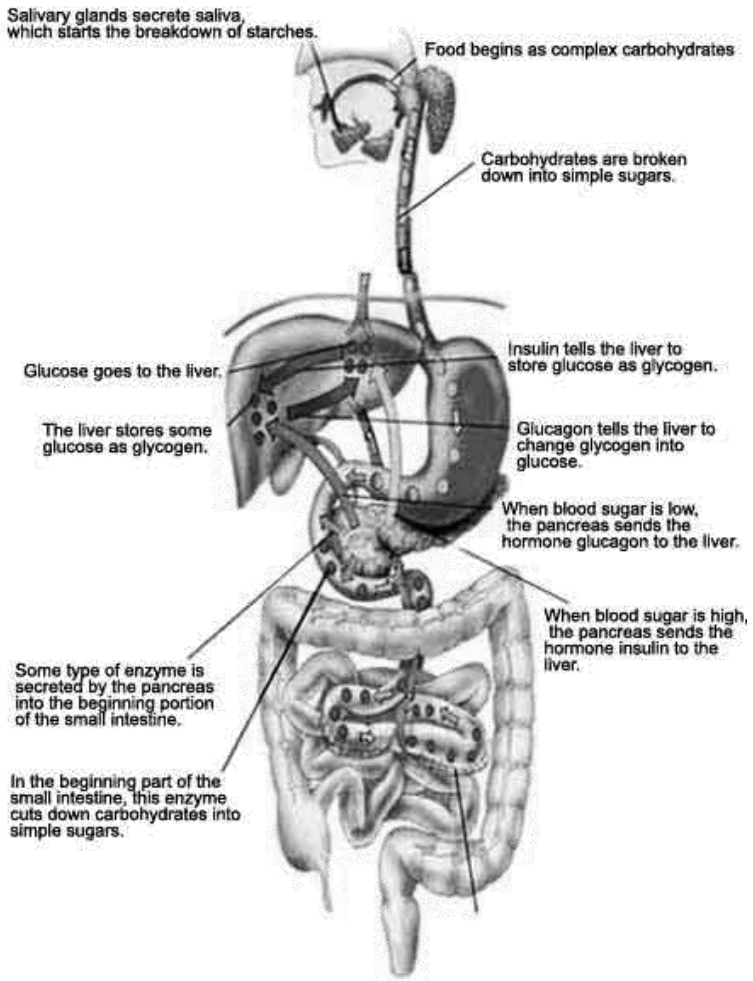
- Alimentary canal is a long sized (about 8-10 metres in length) tube of varying diameter and is complete (extends from mouth to anus). It is formed of following parts

1.9.1.1. Mouth

- Mouth is a slit-like transverse aperture, bounded by two soft movable lips (labia).
- Mouth is meant for ingestion of food.

1.9.1.2. Buccopharyngeal cavity

- The space bounded dorsally by skull and ventrally by throat is known as Buccopharyngeal cavity.
- It can be divided into three parts -



1.9.1.2.1. Vestibule

- Vestibule is the space bounded by lips and cheeks externally and the gums and teeth internally.
- It is meant for temporary storage of food.

1.9.1.2.2. Buccal (oral) cavity

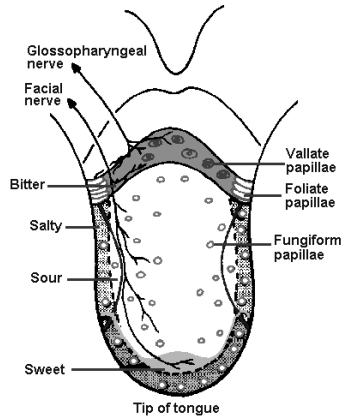
- Buccal cavity is the space bounded dorsally by palate, ventrally by throat and laterally by alveolar processes of jaws having teeth.
- It has following structures-

1.9.1.2.2.1. Palate

- Palate forms the roof of buccal cavity and separates buccal cavity from nasal chamber.
- In man, it is a secondary palate and is divisible into anterior hard plate supported by bony processes and having palatine rugae to grip the food during mastication and posterior soft palate.
- Posterior free flap of soft palate is called uvula or velum palati which closes the internal nares during swallowing of food bolus.

1.9.1.2.2.2. Tongue or Lingua

- It is a thick, musculo-sensory organ present on the floor of buccal cavity.
- It is greatly protrussible.
- The posterior part of tongue is attached to the floor of buccal cavity by a soft ligamentous fold called frenulum.
- The dorsum of tongue is lined by a stratified epithelium and has three types of lingual papillae
- Circumvallate papillae are 8 to 12 in number, largest in size, circular in outline and lie in A-shaped manner at the back of the tongue.
- Fungiform papillae are numerous in number, mushroom-shaped and distributed on the tip and sides of the tongue.
- Filliform papillae are most abundant, smallest sized, conical-shaped and present on anterior two-third part of the tongue.

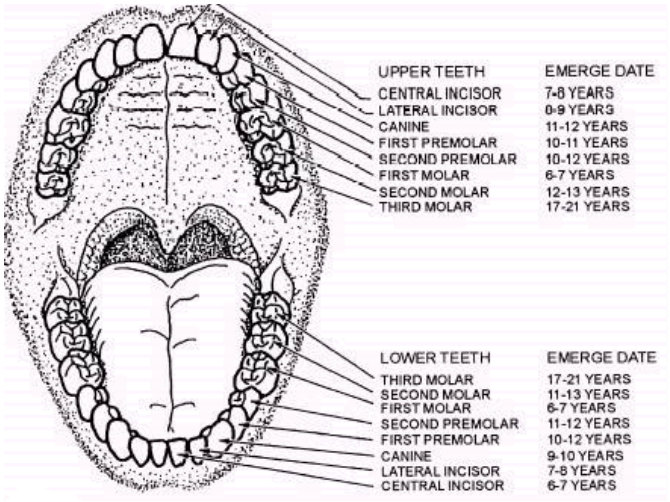


1.9.1.2.2.3. Teeth (Dentes)

- In human being teeth are present in both the jaws and the thecodont i.e. embedded in jaw-sockets, called alveoli, of mandible and maxilla bones of lower and upper jaw respectively.
- The teeth are developed in two sets-milk (or temporary or deciduous) teeth and permanent (or successional) teeth.
- Milk teeth start erupting after six months of birth and appear between 6 to 24 months. These are smaller, weaker and temporary.
- These are replaced by the permanent teeth between 6 to 12 years.
- There are twenty temporary teeth, ten in each jaw.
- The formula showing the number and arrangement of teeth in one half of each jaw, is called dental formula.
- Dental formula of milk teeth is

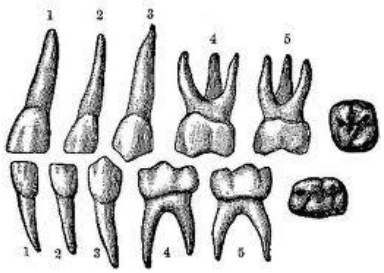
  i 2/2, c 1/1, pm 0/0, m 2/2 or 2102/2102 = 20.

  i, c, pm and m denote incisors, canines, premolars and molars.

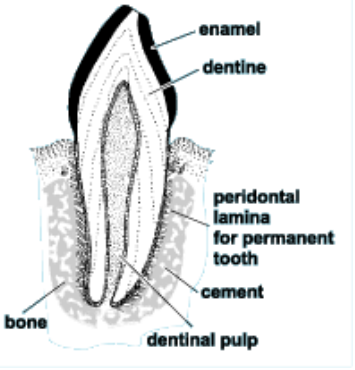


- **Permanent teeth**
- These replace the temporary teeth at about the age of six years and by 14th year about 28 teeth erupt while the dentition is complete by 24 years of age.
- Dental formula of adult man is
  i 2/2, c 1/1, pm 2/2, m 3/3 or 2123/2123 = 32

- Third pair of molars of permanent set erupts between the eighteenth and twenty-fifth year and sometimes never erupt. These are called wisdom teeth.
- Development of teeth in man in two sets is called diphyodont.
- **Types of teeth**
  - In human being permanent teeth are of four types on the basis of their function
    - Incisors,
    - Canines,
    - Premolars
    - Molars
  - This condition is called Heterodont.
  - Incisors (or cutting teeth) are sharp, pointed, chisel-shaped and are used to cut vegetable food. Canines (or tearing teeth) are dagger-shaped.
  - These are used to tear the flesh. Premolar and molars are also called grinding or cheek teeth.
  - These have 2 to 4 cusped crown and are used to grind the food.
  - Although the shape of different teeth varies, but all the teeth have a similar basic structure, so teeth show homology.
  - A tooth is formed of three parts –
    - Crown
    - Neck
    - Root
  - Crown is the exposed part of tooth and is formed of shining, whitish and hard substance called enamel. It is mainly formed of hydroxy apatite [$Ca_3(PO_4)_2$]. $Ca(OH)_2$.
  - Neck is usually covered by fleshy skin called gum or gingiva.
  - Root is embedded in the socket of jaw bone and is fixed by a bone like cementum and a thick fibrous peridontal membrane.



- Tooth is mainly formed of a bone-like material, called dentine.
- In the centre of dentine, there is a pulp canal which is filled with a soft, gelatinous and vascular connective tissue, called pulp.
- Pulp canal is lined by a layer of dentine-forming cells, called odontoblasts, which give branched and fine cytoplasmic processes in the fine canaliculi of dentine.



- Teeth help in mastication of food with the help of hard chewing surface formed of enamel which increases its surface area for the better action of enzymes.
- Mastication is aided by jaw muscles.

1.9.1.2.3. Pharynx

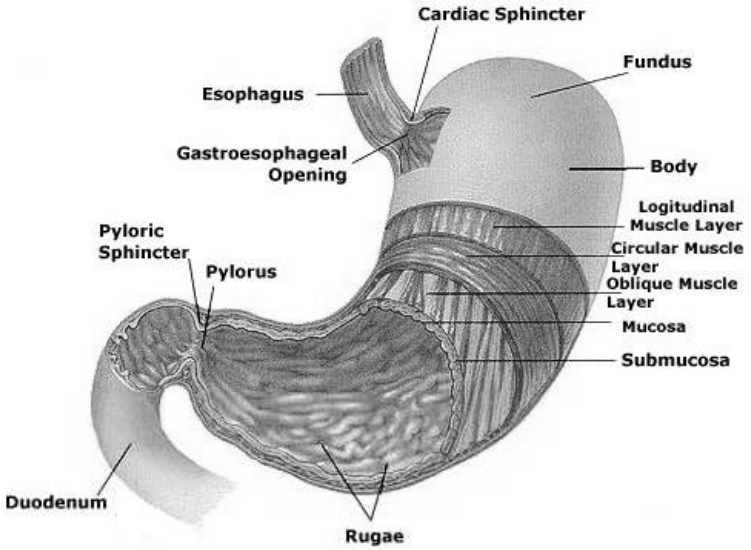
- It is posterior-most part of buccopharyngeal cavity.
- It is small sized, conical part where food and air passages cross each other.
- It is divided into three parts **-**
  - Nasopharynx lies behind the nasal chambers and has internal nares in its roof, oval-shaped openings of Eustachian canals on the sides and two masses of lymphoid tissues called pharyngeal tonsils in the child upto 7 years of age.
  - Oropharynx lies behind the buccal cavity and is the passage for food-bolus.
  - Laryngopharynx is the lowest part of pharynx. It has two apertures anterior slit like glottis and posterior gullut. Glottis leads into trachea or wind pipe and can be closed by a bilobed leaf-like cartilage, the epiglottis, during the swallowing of food-bolus. Gullut leads into oesophagus or food pipe. It is normally closed.

1.9.1.3. Oesophagus

- It is a long (22-25 cm) narrow, muscular and tubular structure.
- It runs downward through the neck behind the trachea, passes through the diaphragm and opens in the stomach in the abdomen.
- Its inner mucosa is raised into longitudinal folds, oesophageal rugae, which close it to prevent the entry of air and also expand it receive the food-bolus.
- It conducts the food to stomach by peristalsis.

1.9.1.4. Stomach

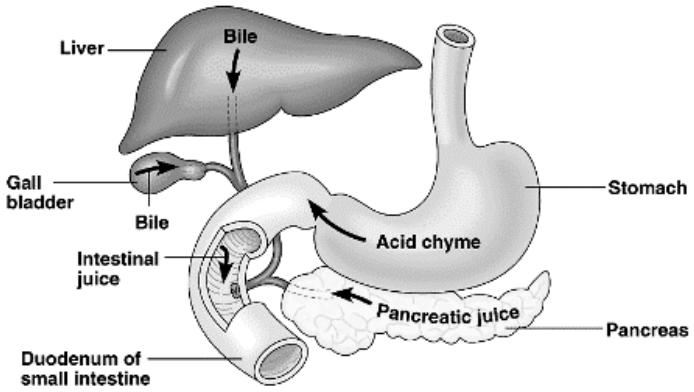
- The stomach is most distensible portion of the alimentary canal.
- It is J-shaped, thick, muscular organ present on the left side of upper part of abdominal cavity below the diaphragm.
- It is formed of three parts -
  - Cardiac stomach is connected to the oesophagus through cardiac aperture guarded by a cardiac sphincter which prevents regurgitation of food.
  - Fundic part is raised part that projects above the cardiac aperture and often contains gas or air.
  - Pyloric antrum is lower and narrow part which opens in the duodenum by pyloric aperture or pylorus and is guarded by a pyloric sphincter which prevents the predigested food to enter the duodenum.



- Inner mucosa of stomach is raised into large number of longitudinal folds called gastric rugae.
- These rugae dilate the stomach to store the food and also increase the surface area of digestion.
- Stomach helps in mechanical churning and chemical digestion of food. It also acts as food reservoir.

1.9.1.5. Small Intestine

- It is the longest part (about 20 ft or 6 metres) of alimentary canal. It is narrow and tubular part occupying the central and lower parts of abdominal cavity. It is divided into three parts -
  - Duodenum is the widest, shortest (about 25 cm) and most flexed part of small intestine. It forms a C-shaped curve. It receives the bile-pancreatic duct.
  - Jejunum is the middle part and is about 8 ft long.
  - Ileum is longest part (12 ft.) of small intestine. It finally opens in the caecum in the lower part of the abdominal cavity. The opening is guarded by an ileo-caecal valve which prevents the regurgitation of food from caecum. Both ileum and jejunum are greatly coiled.



- Inner mucosa of small intestine is raised into about four millions of minute finger-like projections called villi.
- Villus is the unit of absorption of food.
- The free surfaces of these cells have numerous electron microscopic evaginations, called microvilli, which form a brush border.
- Villi and microvilli increase the surface area of digestion and absorption of food.
- Small intestine is the main region where digestion and absorption of food occurs.

Differences between Jejunum and Ileum

Characters	**Jejunum**	**Ileum**
Size	About 2.4 m long	About 3.6 m long
Nature of wall	Thicker and more vascular.	Thinner and less. Vascular.
Nature of villi	Villi thicker and tongue-like.	Villi thinner and finger-like.
Plicae circulares	Best developed	Less developed.
Peyer's patches	Absent.	Present.

1.9.1.6. Large Intestine

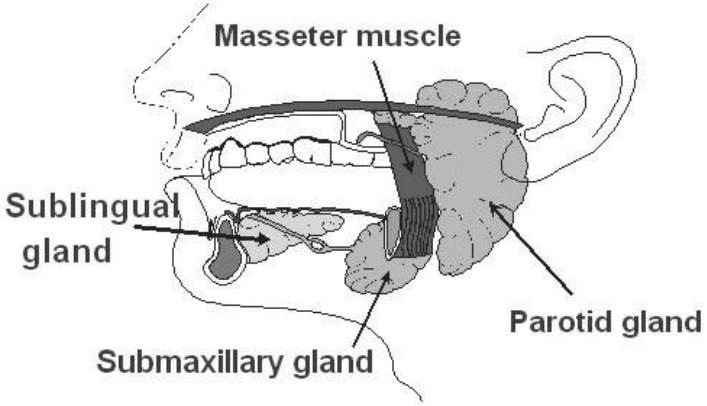
- It is about 5 feet (1.5 metres) long, shorter but wider than small intestine which forms an arc around the small intestine. It is formed of three parts **-**
  - Caecum is a small, pouch-like structure which ends into a tubular structure (13 cm long) called vermiform appendix. Caecum and vermiform appendix are vestigial in function as these are not involved in cellulose digestion.
  - Colon is long sized, sacculated structure which is differentiated into four regions : ascending colon extending upto liver on the right side then bends (called hepatic flexure) to become transverse colon which crosses the abdominal cavity below the pancreas; descending colon running downward on the left side, and sigmoid or pelvic colon which is S-shaped, enters the pelvis and joins the rectum.
- It is concerned with conservation of water, sodium or other minerals and formation of faeces.
- Rectum is slightly dilated part, and concerned with temporary storage of faeces. It leads into an anal canal which opens out by anus present at the base of trunk and guarded by two anal sphincter muscles.

1.9.2. Human digestive glands

- Digestive glands are those glands which secrete digestive juices for the digestion of food. These are of following types –

1.9.2.1. Salivary glands

- These are three pairs of glands which secrete about 1-1.5 litre of saliva per day.
- The saliva is carried to buccal cavity by the salivary ducts.

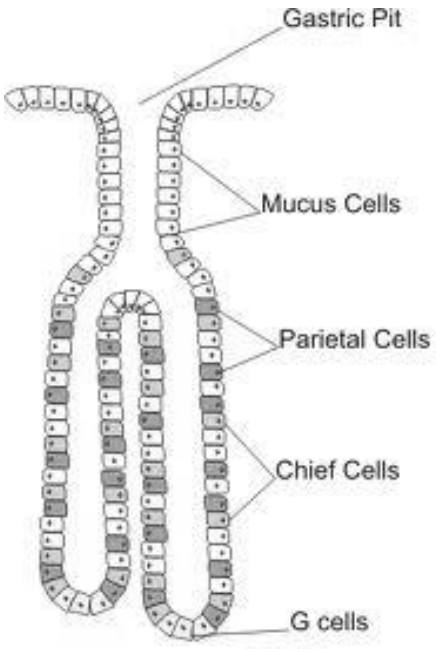


- These are of three types -
  - Parotid glands are largest salivary glands present just below the external ear. Saliva is carried by the parotid ducts.
  - Submaxillary or Submandibular glands lie beneath the jaw angles. Their secretion is carried by submaxillary ducts.
  - Sublingual glands are smallest sized and lie beneath the tongue and open at the floor of buccal cavity by a number of small sublingual ducts.

    The function of these salivary glands is to secrete saliva.

1.9.2.2. Gastric glands

- These are numerous, simple or branched tubular glands present in the mucosa of the stomach.



- These are of three types –
  - Cardiac glands (secrete an alkaline mucus)
  - Pyloric glands (secrete alkaline mucus)
  - Fundic glands. Each fundic gastric gland has four types of cells

- Chief or peptic (zymogen) cells which secrete two proenzymes ; pepsinogen and prorennin, and an enzyme gastric lipase.
- Oxyntic (parietal) cells secrete HCl and intrinsic factor of Castle (which helps in absorption of vitamin B_{12}).
- Goblet cells secrete mucus.
- Argentaffin cells mainly lie in pyloric glands and secrete gastrin hormone.

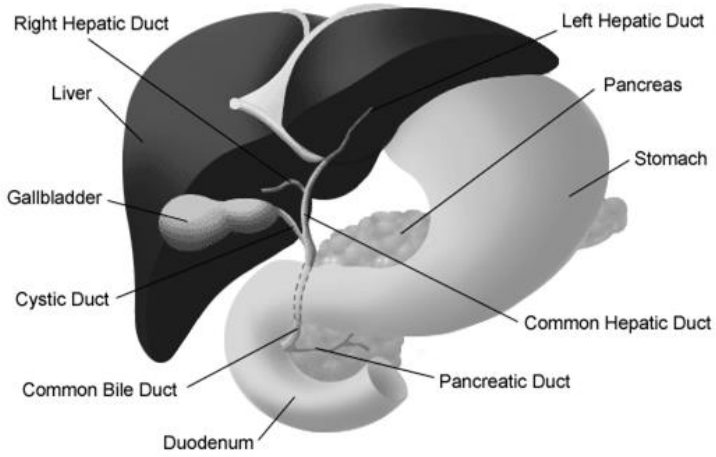
Differences between Small intestine and Large intestine

Characters	**Small intestine**	**Large intestine**
Size	Long sized (about 20 ft.)	Small sized (about 5 ft.)
Divisions	Three parts – Duodenum, jejunum and ileum.	Four parts – Caecum, colon, rectum and anal canal.
Mucosa	With circular folds called **plicae circulares** and finger-like villi.	Plicae circulares and villi are absent.
Peyer's patches	Present.	Absent.
***Taeniae coli* and haustrae**	Absent.	Present.
Function	Completion of digestion and absorption.	Formation, storage and expelling of faeces.
Peristalsis	Faster.	Least.

- All these juices collectively form gastric juices.
- Daily secretion is 2-3 litres/day.
- These work at 1.2-1.8 pH.
- HCl forms about 0.05 to 0.3 per cent of gastric juices.
- Secretion of gastric juices is under nervous as well as hormonal control.

1.9.2.3. Liver

- Liver is the largest sized, reddish brown exocrine gland of body and weighs about 1.5 kg in adult man.
- It is present in the posterior concavity of the diaphragm in the right upper part of abdomen.
- It is attached to diaphragm by a suspensory ligament.



- Liver is a multi-lobulated gland. It is formed of two main and two small lobes.
- Two main lobes are-larger right and smaller left lobe, while two small lobes are-quadrate and caudate lobe. Each liver lobe is formed of hexagonal lobules surrounded by a connective tissue sheath called Glisson's capsule.

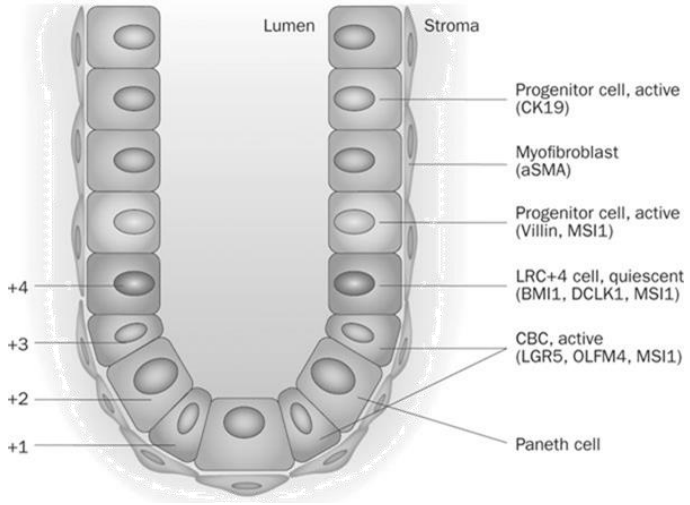
- Hepatic lobules are structural and functional units of liver. These contain hepatic cells in the form of radiating cords, called hepatic laminae, having spaces, called hepatic lacunae, between them.
- Present on the lower surface of right liver lobe, there is a thin walled, pear-shaped sac, called gall bladder. It concentrates and stores the bile (about 60 ml) secreted by the liver. Bile is drained from the liver by a bile duct which is formed by the joining of a cystic duct from the gall bladder and a common hepatic duct from different liver lobes.
- Just near the duodenum, the bile and pancreatic ducts join to form hepato-pancreatic duct which swells to form hepato-pancreatic ampulla or ampulla of Vanter just before opening into duodenum. The opening of hepato-pancreatic ampulla in the duodenum is guarded by a sphincter of Oddi. Daily secretion of bile is about 600-1200 ml.
- Liver is largest gland and performs many functions. It controls metabolism in a number of ways -
  - Hepatocytes of liver secrete a non-enzymatic digestive juice called bile. Bile helps in digestion of food by providing an alkaline medium (8.0 pH); and emulsifies the fats for their proper digestion.
  - Liver regulates the blood sugar level either by the process of glycogenesis (conversion of excess of glucose into glycogen) or by glycogenolysis (breakdown of glycogen into glucose).
  - Liver also controls lipogenesis (conversion of excess of glucose and amino acids into the fats. Fats are stored in liver cells).
  - Liver changes the excess and harmful amino acids of blood into toxic NH_3 by the process of deamination.
  - In liver cells, toxic NH_3 is combined with CO_2 to form less toxic urea by the process of detoxification.
  - Liver changes haemoglobin of dead RBCs into bile pigments like biliverdin and bilirubin which are egested out along with faeces. So liver helps in excretion.
  - Liver produces an anticoagulant, heparin, which prevents blood clotting inside the blood vessels.
  - Liver also produces two proteins Prothrombin and fibrinogen which help in clot formation at injury to check excess bleeding.
  - Liver acts as an erythropoeitic organ (forms RBCs) in the embryo.
  - Liver also acts as haemolytic organ (breaks old RBCs).
  - Kupffer cells of liver sinusoids act as phagocytes which eat up the dead cells and bacteria.
  - Liver is the seat of vitamin-A synthesis from the carotenes of carrots in the presence of enzyme carotenase.
  - Liver also stores minerals like copper and iron; vitamins like A, D, E and B_{12}, glycogen and fats.

1.9.2.4. Pancreas

- Pancreas is the second largest gland in human body.
- Pancreas is yellow in colour, 12-15 cm long and a compound racemose gland.
- It is present in the loop of duodenum.
- Pancreas is formed of head, body and tail.
- Pancreas is a heterocrine gland.
- Its exocrine part is formed of large number of lobules or acini.
- Each acinus of pancreas consists of a number of glandular cells which secrete the pancreatic juices (pH 8.8).
- Pancreatic juices are drained by a pancreatic duct which joins bile duct as described in the liver.
- About 1500 ml of pancreatic juice is secreted per day.

1.9.2.5. Intestinal glands

- These are numerous, microscopic glands present in the mucosa of small intestine.



- These are of two types -
  - Crypts of Lieberkuhn are multicellular, simple, straight, tubular glands present throughout the mucosa of small intestine between the villi. These secrete digestive enzymes and mucus.
  - Brunner's glands are compound tubular glands which are found only in the sub-mucosa of duodenum. These secrete alkaline watery and enzyme-free mucoid fluid which protects the duodenal mucosa from acidic chyme coming from the stomach.
- The secretions of both types of glands are collectively called intestinal juices or succus entericus (pH 8.3).
- Daily secretion is about one litre per day.
- Besides above five types of glands, whole mucosa of alimentary canal is lined by goblet cells.
- These secrete mucus which lubricates the alimentary canal and food so helps in peristalsis and protects the gut mucosa from injury.

1.9.3. Histology of Gut

- Histologically, the gut wall (especially of intestine) is formed of 4 coats**;** each of which has different types of cells

1.9.3.1. Visceral peritoneum of serosa

- It is outermost coat and is formed of a squamous epithelium.
- It is protective in function.

1.9.3.2. Muscular coat

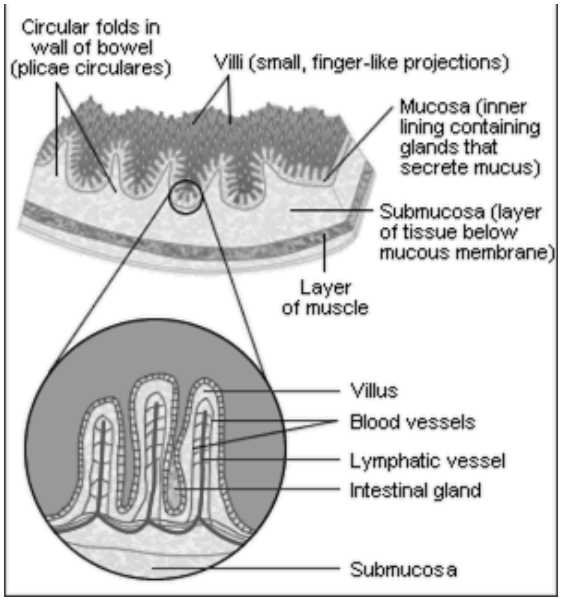
- It is formed of outer layer of smooth longitudinal muscle fibres and inner layer of smooth circular muscle fibres.
- These muscles help in peristalsis of food and mixing of food and digestive juices.

1.9.3.3. Sub-mucosa

- It is formed of areolar connective tissue and has blood capillaries, lymph capillaries (called lacteals), nerve fibres, etc.
- The largest lymph capillary is called central lacteal.

1.9.3.4. Mucosa

- It is innermost coat. In intestine, it is highly adapted to ensure maximum absorption
- It is raised into circular mucosal folds called folds of Kerckring.
- Mucosa is raised into about 4 million finger-like projections called villi.
- The free surface of each intestinal cell has electron microscopic evaginations called microvilli (3,000 per intestinal cell).Mucosa of intestine is differentiated into three parts -
  - Outermost muscularis mucosa-a thin sheath of smooth muscle fibres.
  - Middle lamina propria of reticular connective tissue and has blood and lymph capillaries.
  - Innermost epithelium of columnar cells which rests on the basement membrane and has two types of cells: Mucus-secreting goblet cells and absorptive cells having microvilli.
  - Intestinal wall has two types of intestinal glands (Discussed in intestinal glands)
- These four coats are differently modified in different parts of gut.



Differences between Intestinal and Stomach wall

Character	Intestinal wall	Stomach wall
Muscular coat	Thinner and contains two types of smooth muscle fibres.	Thick and is formed of three types of smooth muscle fibres**.**
Types of folds	Circular folds of Kerckring and finger-like villi.	Only gastric rugae.
Microvilli	Present on free surface of intestinal cells.	Not present of gastric cells.

1.10 Digestion of Food

- Alimentary canal of man, like that of other vertebrates, shows regional differentiation for physiological division of labour and is divided into four zones
  - Ingressive Zone
  - Progressive Zone
  - Degressive Zone
  - Egressive Zone

1.10.1 Ingressive Zone

- Ingressive Zone is involved with intake and mastication of food and includes the following parts-
  - Mouth and Lips- Mouth is the aperture for ingestion for which the food is carried to the mouth by hands which are adapted for grasping. Food is cut into pieces either by incisors or canines, depending upon the nature of food. Lips help in gripping of food, sucking and sipping of liquids.
  - Buccal Cavity- In buccal cavity following actions occur.
    - Tongue helps in the ingestion, chewing and swallowing of food. It also helps in tasting of food and saliva, speech etc.
    - Teeth (premolars and molars) help in mastication of food into smaller pieces with the help of mandibular muscles which cause jaw movements. This increases the surface area of food for the action of saliva enzymes.
  - Digestion in Buccal cavity is done by the mixing of food with saliva which is formed of 99.5% water, 0.2% minerals – Na^+, K^+, Cl^-,HCO_3^-, thiocyanate ions, etc., and 0.3% organic compounds like mucin and a starch-splitting enzyme ptyalin/salivary amylase. Daily secretion of saliva is about 1 to 1.5 litre and operates at 6.8 pH.
  - It hydrolyses α glycosidic bonds of starch into double sugars, maltose and isomaltose and small dextrins called 'limit' dextrins. The salivary amylase is most active at pH 6.8 and in the presence of Cl^-.

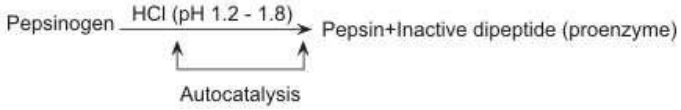
$$Starch \xrightarrow[6.8\,pH,Cl^-]{Salivary\,Amylase} Maltose + Isomaltose + Dextrin$$

  - Chewing and mastication in the buccal cavity help in mixing the food with salivary amylase which increases the rate of action of ptyalin.
  - The food-bolus from buccal cavity is immediately swallowed and the action of saliva is inhibited by acidic gastric juices in stomach, but the action of ptyalin continues in the stomach for about twenty minutes. So about 30 % of starch present in the food is hydrolysed by salivary amylase.
  - Proteins and fats are not digested in buccal cavity because saliva has neither proteolytic nor lipolytic enzyme.
  - Formation of Food Bolus is done by rolling up of masticated and partially digested food by tongue. The mucus of saliva helps in food bolus formation by sticking together of food particles.

1.10.2 Progressive Zone

- Progressive Zone involves conduction of food and early digestion of food and includes pharynx, oesophagus and stomach.
  - **Deglutition** involves the pushing of food bolus from buccal cavity into oesophagus via pharynx. It occurs in three phases-
    - **In first phase** of swallowing the food bolus is placed on the dorsal side of tongue and is then pushed backward into pharynx by lifting and striking the anterior part of tongue against the hard part.
    - **In second phase** of swallowing, the food bolus passes through the pharynx. In this, a number of involuntary actions occur for example uvula and soft palate are raised to close the internal nares to check the entry of food into nasal chambers; and larynx is raised upward so that glottis is closed by epiglottis. So during swallowing, expiration and inspiration processes are suspended temporarily.
    - **In third phase** of swallowing, constrictor muscles of the wall of pharynx contract to push the food bolus into oesophagus through the open gullut. In oesophagus, the food is mixed with mucus and passed on into stomach by the process of peristalsis. It involves involuntary movements of gut by which the food bolus is moved backwards in the gut.

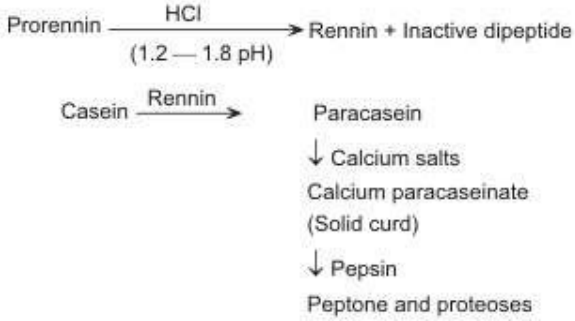
- **Digestion in stomach-** In stomach, the food is subjected to two types of actions
  - **Mechanical Action –** In mechanical action, the stomach undergoes alternate forceful contraction and relaxation which helps in both mechanical churning of food and mixing of food and gastric juices which increases the efficiency of digestive enzymes of gastric juices.
  - **Chemical Action-** In chemical action, digestion of both proteins and fats is started in stomach with the help of gastric enzymes in the presence of HCl.
    - **Gastric Phase of Proteins Digestion-**In stomach, the food is mixed with gastric juices of the gastric glands. Gastric juices contain mucus, HCl, two proenzymes- prorennin and pepsinogen and a weak gastric lipase enzyme.
      - **Role of HCl-** HCl forms about 0.05 to 0.3% of gastric juices. It helps in
        - Killing the bacteria in the food.
        - Stopping the action of saliva.
        - Activating the pepsinogen to pepsin and prorennin to rennin.
        - Providing optimum pH i.e., 1.2 to 1.8 pH for pepsin.
        - Softening of food.
      - Role of Pepsinogen- It is a proenzyme secreted by peptic cells of the gastric glands. It is most active in acidic medium and is capable of digesting all the dietary proteins, including collagen.



        Pepsin is an endopeptidase enzyme and hydrolyses the proteins into peptones and proteoses.

$$\text{Proteins} \xrightarrow[1.2 \text{ to } 1.8\ pH]{\text{Pepsin}} \text{Peptones and Proteoses}$$

      - Role of Prorennin-This proenzyme is first activated by HCl in acidic medium to rennin which is a very strong milk coagulating factor. It hydrolyses milk soluble protein casein to paracasein. Paracasein is precipitated spontaneously as calcium paracaseinate in the form of curd. This is called curdling of milk. Curdling of milk increases the period of action of pepsin on the milk-proteins, especially casein, in the stomach for their proper digestion.
        The food in stomach is thick, acidic and semi-digested and is called 'chyme'.



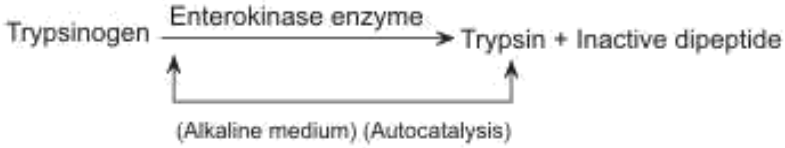
    - Gastric phase of fat digestion-Gastric juices of gastric glands of stomach has no fat-emulsifying enzymes but has a weak gastric lipase enzyme which hydrolyses a small amount of fats. It is so that gastric lipase has an optimum pH 4.0 to 5.0 and is inactivated by strong acidic conditions (1.2 to 1.8) provided by HCl. The gastric juices contain no carbohydrolase, so there is no digestion of carbohydrates in the stomach.

1.10.3 Degressive Zone

- It involves completion of digestion and absorption.
  - Movement and Digestion in small intestine, two types of movements have been reported-
    - Rhythmic or segmentation movements – The stretches of small intestine under concentric contraction of circular muscles of muscular coat which helps in mixing the food with the digestive enzymes.
    - Peristaltic Movements – These are same as in oesophagus. In this, the gut expands in the region of food while contracts behind it to push the food forward. These occur at the rate of 0.5 to 2.0 cm/sec and are regulated by myenteric plexus.
  - Digestion in small intestine-In intestine, the chyme is mixed with three alkaline juices-Bile (8.0 pH) from liver, pancreatic juice (8.8 pH) from intestinal glands. These juices have following actions-
    - **Action of Bile in fat digestion**- Bile of liver is an alkaline, yellowish-green juice which has no enzyme and has no chemical action on food. It is formed of water (86%) , sodium bicarbonates, bile pigments biliverdin of green colour and bilirubin of yellow colour , two bile salts sodium glycocholate and sodium taurocholate.
      Fats are finely emulsified in the small intestine by the detergent action of bile salts, lecithin and monoglycerides. Bile salts alone are relatively poor emulsifying agents, but in the presence of the phospholipid and monoglycerides, particles 200 to 5000 nm in diameter is formed. The emulsification of fats involves breaking of large fat droplets into large number of small droplets which provide larger surface area to lipases.
    - **Role of Pancreatic juice in digestion**
      - **Starch Digestion**-Pancreatic juices contain pancreatic amylase which hydrolyses the remaining starch into disaccharides but operates in alkaline medium i.e., pH 8.8. The alkaline medium is provided by bicarbonates mainly present in pancreatic juices.

$$Starch \xrightarrow[pH\ 8.8]{Pancreatic\ Amylase} Maltose + Isomaltose + Dextrin$$

      - **Protein Digestion**- Pancreatic juices contain three alkaline proteases- Trypsinogen, Chymotrypsin and Carboxypeptidase.
      - Trypsinogen is a proenzyme and is firstly activated by enterokinase enzyme of intestinal juices.



      - Trypsin is an endoproteolytic enzyme and hydrolyses the peptones and proteoses into peptides.

$$Peptones\ and\ \text{Pr}oteoses \xrightarrow{Trypsin} Peptides$$

      - Trypsin also activates other proenzymes

$$Chymotrypsinogen \xrightarrow{Trypsin} Chymotrypsin$$

$$\text{Procarboxypeptidase} \xrightarrow{Trypsin} Carboxypeptidase$$

      - Chymotrypsin hydrolyses the proteoses and peptones to peptides

$$Peptones\ and\ \text{Pr}oteoses \xrightarrow{Chymotrypsin} Peptides$$

      - Carboxypeptidase is an exopeptidase and separates individual amino acids from C-terminus.

Differences between Proenzymes and Enzymes

Character	Proenzymes	Enzymes

Nature	Inactive or native form of enzyme.	Active form of enzyme.
Active sites	Their active sites are masked by an inhibiting fragment.	Their active sites are unmasked.
Activator	Is required to activate them.	Not required.
Examples	Pepsinogen and Trypsinogen	Pepsin and Trypsin.

- **Fat Digestion**-Pancreatic lipase is the principal fat-digesting enzyme and digests about two-third of the fats in stages.

$$Emulsified\ Fats \xrightarrow{Lipase} \text{Fatty Acids + Glycerol +Monoglycerides}$$

- So the pancreatic lipase hydrolyses the dietary fats and oils into glycerol, fatty acids, monoglycerides and diglycerides. During digestion of fats, only 50% fat is completely digested to fatty acids and glycerol while remaining 50% are mono- and di-glycerides.
- Pancreatic juice has also two more lipolytic enzymes: Phospholipase and Cholestrol-esterase which hydrolyse the phospholipids and free cholesterol respectively.
- **Nucleic Acid Digestion**- Pancreatic juice contains two nucleolytic enzymes: Ribonuclease and Deoxyribonuclease.
  - ✓ Ribonuclease (RNAse) hydrolyses RNA into ribonucleotides.
  - ✓ Deoxyribonuclease (DNAse) hydrolyses DNA into deoxyribonucleotides.

Differences between Pepsin and Trypsin

Character	**Pepsin**	**Trypsin**
Source	Produced by peptic cells of gastric glands of stomach.	Produced by acinal cells of pancreas.
Site of action	Acts in stomach	Acts in intestine
Medium of action	In acidic pH (about 1-2).	In alkaline pH (about 8.8).
Action	Hydrolyses proteins into proteoses and peptones.	Hydrolyses proteoses and peptones into peptides.

- **Role of Intestinal juice in digestion**
  - **Carbohydrate Digestion**-Intestinal juices (pH 8.3) contain a number of oligosaccharidases which hydrolyse the specific oligosaccharides into their monosaccharides as shown below

$$Starch \xrightarrow{Amylase} Maltose + Isomaltose$$

$$\text{Maltose} \xrightarrow{\text{Malt}ase} 2\ Glu\cos e$$

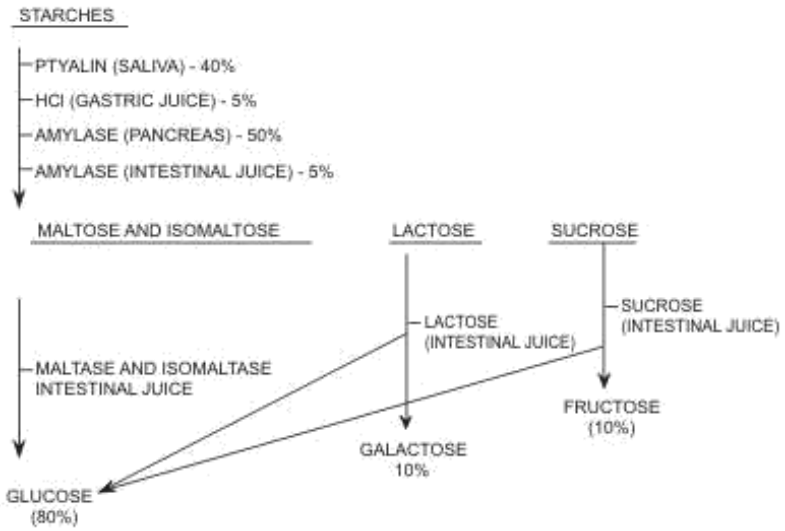
$$\text{Isomaltose} \xrightarrow{\text{Isomalt}ase} 2\ Glu\cos e$$

$$\text{'Limit' Dextrins} \xrightarrow{\text{'Limit' dextrinase}} Glu\cos e$$

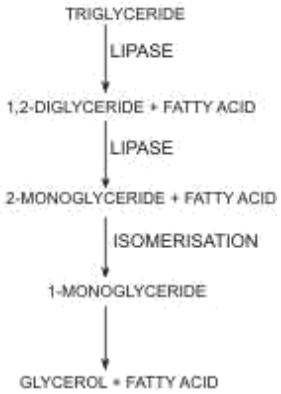
$$Sucrose \xrightarrow{\text{Sucr}ase} \text{Glucose} + Fructose$$

$$Lactose \xrightarrow{\text{Lact}ase} \text{Glucose} + Galactose$$

So glucose is the most abundant end product (80%) of carbohydrate digestion while each of galactose and fructose forms 10% of the end products. The monosaccharides so formed are diffusible.



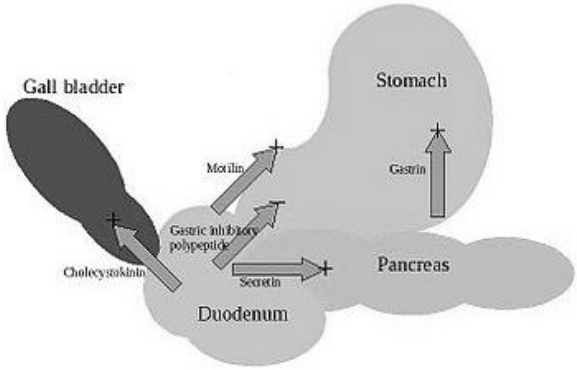
- **Protein Digestion**- Intestinal juices contain two alkaline proteases Aminopeptidases and Dipeptidase.
  - ✓ Aminopeptidases (Erepsin) hydrolyses the terminal peptide bond at N-terminus of the peptide chain to release the amino acids one by one.
  - ✓ Dipeptidase hydrolyses the Dipeptides to release the amino acids.
  - ✓ Intestinal juices also contain a non-digestive protease enterokinase which activates trypsinogen to trypsin.
  - ✓ Fat Digestion – Intestinal juice has intestinal lipase enzyme which generally operates intercellularly. It hydrolyses some triglycerides, diglycerides and monoglycerides to fatty acids and glycerol molecules.



  - ✓ **Nucleic Acid Digestion**- Intestinal juice contains three nucleolytic enzymes: Nuclease, Nucleophosphatases and Nucleosidases.
    Nuclease hydrolyses nucleic acids into their nucleotides.
    Nucleophosphatases hydrolyses nucleotides into nucleosides and phosphoric acid.
    Nucleosidases cleaves nucleosides into free nitrogen bases and pentose sugar.
    The fully digested and alkaline food present in the small intestine is called 'chyle', while semi-digested and acidic food present inside the stomach is called 'chyme'.

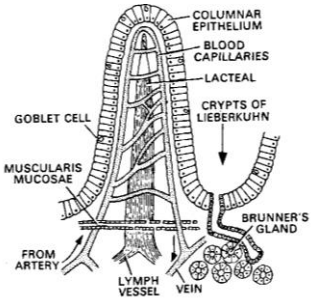
1.10.4 Egressive Zone

- It involves formation of faeces, their temporary storage and finally their expelling out of the body through anus and is called egestion or defaecation.
- The undigested food along with water (about 75%) and excess of digestive enzymes enter the large intestine.
- In man, the caecum is vestigial.
- Colon absorbs the water by osmosis and concentrates the undigested food into faeces.
- It also helps in active absorption of Na^+ ions.
- It also transports excess of certain ions like calcium, magnesium, iron and phosphorous from blood into large intestine to egest out with faeces.
- The undigested food is moved backward by peristaltic rush movements called bowel movements.
- The faeces are temporarily stored in rectum where more water is reabsorbed.
- The faeces are finally expelled out through the anus and involve the coordinated contraction of muscles of large intestine, abdominal muscles and diaphragm and relaxation of muscles of anal sphincters.
- Egestion is partly voluntary and partly involuntary process.
- The faeces are formed of water (75%) and solid matter (25%) which is further formed of undigested roughage (30%), fats (20%), inorganic matter (15%) proteins (3%) and bacteria (3%). Brown colour of faeces is due to stercobilinogen and stercobilin.



1.11 Absorption of Digested Products

- Absorption is a process by which diffusible nutrients are transferred from the gut into the blood or lymph by physic-chemical processes and active transport.
- Absorption of only certain drugs occurs in buccal cavity and very little absorption takes place in the stomach for example of alcohol, some water and salts, certain drugs like aspirin, etc.
- Practically, all absorption takes place through the small intestine. Small intestine is adapted to ensure complex absorption.
  - Enormous length of small intestine (6 meters).
  - Permanent circular folds on the mucosa and called plicae circulares.
  - Intestinal mucosa raised into four millions of finger-like projections, villi.
  - Each intestinal cell has numerous, electron microscopic evaginations, microvilli (3000 per cell).
- Each villus is with a lymph capillary called lacteal in the centre which is surrounded by a network of blood capillaries.
- The molecules of water, minerals, hexose sugars, amino acids and products of villi while the fatty acids and glycerol molecules are absorbed into the lacteals.



- Absorption across the plasma membrane of intestinal cells depends upon two types of processes
  - **Passive Absorption**
    - In Passive absorption nutrients are absorbed along the concentration gradient i.e., higher concentration inside the lumen of the intestine while low concentration inside the intestinal cells.
    - It depends upon the physical processes like 'simple diffusion' for example of small and water soluble molecules like some of electrolytes like Cl^-, monosugars like glucose, fatty acids, cholesterol), 'osmosis' for example of water and alcohol.
    - 'Facilitated Diffusion' is movement of hydrophilic lipid in soluble molecules like fructose, mannose along concentration gradient with the help of some carrier ions like Na^+. It does not depend upon the energy so is a slow process.
    - It continues till the concentration becomes equal on both sides of cell membrane so the substances cannot be absorbed completely.
    - Water, some water soluble substances and fructose are absorbed by passive absorption.

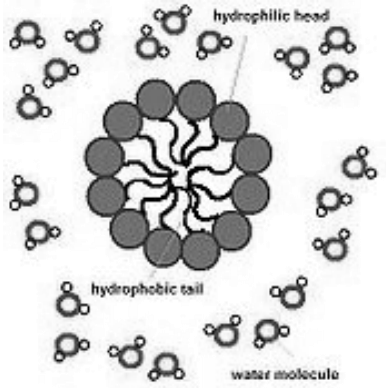
  - **Active Absorption**
    - In Active absorption, the nutrients are absorbed through the intestinal mucosa against concentration gradient.
    - This is a rapid process as it depends upon the energy provided by the ATP.
    - Active absorption occurs by two processes-
      - **Active Transport** is that active absorption which involves the carrier molecules called permeases or translocases which are generally proteinous in nature. Glucose, galactose, amino acids, Na^+ etc. are absorbed by active transport.
      - **Endocytosis** is an active absorption by which large sized liquid or solid nutrients are taken in some vesicles through the plasma membrane.

Differences between Passive Absorption and Active Absorption

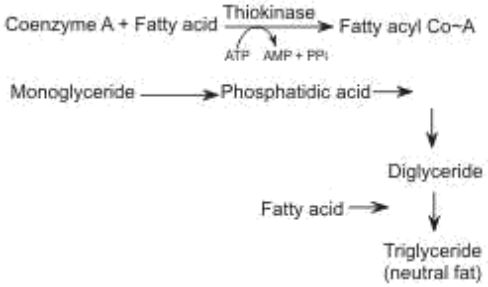
Characters	Passive Absorption	Active Absorption
Type of process	Passive absorption is a physical process.	Active absorption is a vital process.
Direction of Absorption	Direction of absorption is along concentration gradient.	Direction of absorption is against concentration gradient.
Energy	It does not depend upon the energy supply.	It depends upon the energy provided by ATP.
Speed of Absorption	Passive absorption is a slow process.	Active Absorption is rapid process.
Carrier Molecules	May or may not be involved in carrier molecules.	Always involved in carrier molecules.
Examples	Diffusion, osmosis and facilitated diffusion.	Active transport and endocytosis.

1.11.1 Mechanism of Absorption of Fats

- The end products of fats are a mixture of monoglycerides, fatty acids and glycerol.
- Glycerol is water soluble so is directly absorbed by the mucosal cells of intestine.
- The long chain fatty acids and monoglycerides are insoluble in water.



- In the intestinal lumen, fatty acids, monoglycerides and the bile salts aggregate to form small, spherical and water-soluble molecules called mixed micelles, each being 0.03 to 4 nm in diameter.
- Each mixed micelle has the bile salts in its outer part, whereas the hydrophobic fatty acids and cholesterol molecules from core of micelle.
- These micelles are taken by the intestinal mucosal cells generally by the process of pinocytosis.
- Inside the mucosal cells, fatty acids and monoglycerides react to form triglycerides as shown below-



- The neutral fat so formed is surrounded by a coat of β-lipoprotein to form water soluble fine globules called chylomicrons, each about 1 μ in diameter.
  Chylomicrons are milky in colour and are released in the lymph capillaries, called lacteals, by exocytosis, from where these are carried into the thoracic duct and then into systemic circulation.
- Short chain fatty acids are directly absorbed into the portal circulation.
- The bile salts are also released in the portal blood and are carried to the liver.
- Liver extracts the bile salts and uses them in bile formation and then again sent to the intestine. In this way, about 90% of bile salts are reabsorbed in ileum.
- This is called enterohepatic circulation of bile salts.

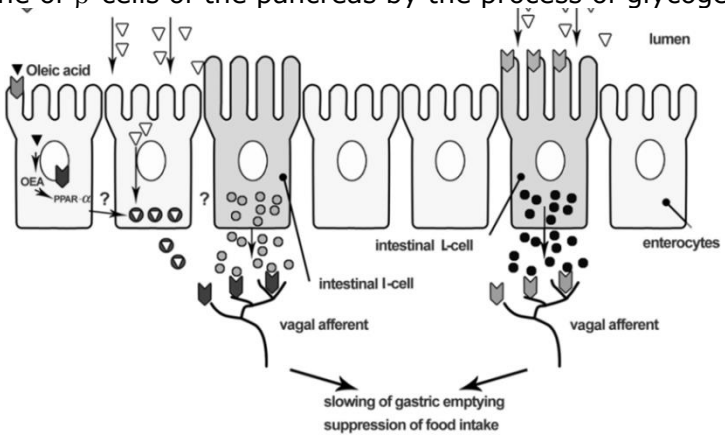
1.12 Assimilation and Storage

- Assimilation is an anabolic process by which simple nutrients are utilised to resynthesize the complex bio-molecules like proteins, carbohydrates, lipids and nucleic acids inside the cells.

  - **Amino Acids**

- Harmful and excess of amino acids are stored by the liver and are changed into urea by the ornithine cycle which involves oxidative deamination and detoxification.
- Most of amino acids are used in the protein-synthesis in the cellular ribosomes in the presence of intercellular enzymes. These proteins either act as structural proteins and help in growth and repair of body tissues, or act as enzymes and hormones to control metabolism.

- **Monosaccharides**
  - Most of glucose acts as the respiratory fuel and provides energy for metabolism.
  - Some sugar molecules are changed into amino acids or fats.
  - Excess of glucose is stored as glycogen in liver and muscle cells in the presence of insulin hormone of β-cells of the pancreas by the process of glycogenesis.



- **Fats**
  - Most of fats are used in the formation of cellular bio-membranes.
  - Some fasts act as respiratory fuels.
  - Excess of fats is stored in the liver, bones and adipose tissue.

1.13 Disorders of Digestive System

- The inflammation of the intestinal tract is the most common ailment due to bacterial or viral infections.
- The infections are also caused by the parasites of the intestine like tapeworm, roundworm, thread worm, hook worm, pin worm, etc.

1.13.1 Jaundice

- Jaundice is also known as icterus (attributive adjective: "icteric"), is yellowish discoloration of the skin, conjuctiva (a clear covering over the sclera, or whites of the eyes) and mucous membranes caused by hyperbilirubinemia the liver is affected; skin and eyes turn yellow due to deposit of bile pigments.

1.13.2 Vomiting

- Vomiting is the ejection of contents of stomach through the mouth.
- This reflex action is controlled by the vomit centre in the medulla.
- A feeling of nausea precedes vomiting.

1.13.3 Diarrhoea

- Diarrhoea is loose, watery stools.
- Diarrhoea can cause dehydration, which means the body lacks enough fluid to function properly.
- Acute diarrhoea is usually related to a bacterial, viral, or parasitic infection.
- Chronic diarrhea is usually related to functional disorders such as irritable bowel syndrome or inflammatory bowel disease.

- Diarrhoea may be accompanied by cramping, abdominal pain, bloating, nausea, or an urgent need to use the bathroom.
- Depending on the cause, a person may have a fever or bloody stools.

1.13.4 Constipation

- Constipation or costiveness, or irregularity, is a condition of the digestive system where a person (or animal) experiences hard faeces that are difficult to egest.
- It may be extremely painful, and in severe cases (*fecal impaction*) lead to symptoms of bowel obstruction.
- Causes of constipation may be dietary, hormonal, anatomical, a side effect of medications (example- some painkillers), or an illness or disorder.
- Treatments consist of changes in dietary and exercise habits, the use of laxatives, and other medical interventions depending on the underlying cause.

1.13.5 Indigestion

- Indigestion is a condition that is frequently caused by eating too fast, especially by eating high-fat foods quickly.
- It is caused by excessive acid accumulation in the stomach, over consumption of alcohol, Overeating.
- Symptoms of indigestion are pain or burning feeling in upper part of the stomach, heartburn, nausea.
- Indigestion can be treated by use of antacids, digestive enzymes capsule, activity modification and rest.

1.14 Malnutrition

- Adequate supply of nutrients in proper proportion in their diet for proper growth and development is required by every organism.
- There are two types of nutritional disorders like over-nutrition and under-nutrition.
- The under-nutrition, also called 'Malnutrition', is characterised by nutritional deficiency which may be both qualitative and quantitative.
- The nutritional deficiency of a nutrient for a long period causes the structural and functional disorders of some body parts.
- Such disorders caused by under-nourishment are called 'Deficiency diseases'.

1.14.1 Protein Energy Malnutrition

- Protein Energy Malnutrition (PEM) is characterized by dietary deficiency of proteins and total food calories.
- It is very common in a number of under-developed countries of South and South-East Asia, South America and Western and Central Africa.
- Two very commonly occurring diseases of infants and children are-

1.14.1.1 Kwashiorkor

- Kwashiorkor was for the first time reported from Africa but now it is prevalent in many parts of the world.
- It is commonly found in small children in the age group of 1 to 3 years, especially belonging to poor families.
- It is caused by severe protein deficiency.
- An actively growing child needs about 2 to 3.5 gms of proteins per kg of body weight.

- Main causes of Kwashiorkor are -
  - Diet mainly containing carbohydrates and fats.
  - Prolonged breast feeding by the mothers having inadequate proteins in their diet.
  - Starting supplementary food in very later age.
  - Very less gap between two children.
- Symptoms of Kwashiorkor are-
  - Deficiency of proteins causes stunted growth in the children.
  - Loss of appetite.
  - Anaemia.
  - Bulging eyes.
  - Protruded belly.
  - Darkening of the skin.
  - Repeated diarrhoea.
  - Atrophy of muscles.
  - Oedema of hands, feet and face.

1.14.1.2 Marasmus

- It is a type of Protein Energy Malnutrition in which there is simultaneous deficiency of proteins and total food calories.
- It is more common in infants below one year of age.

- Main causes of Marasmus are-
  - Early replacement of mother's milk by other foods deficient in proteins and calorific value.
  - Less spacing between the children.
- Symptoms of Marasmus are -
  - Shrievelled Appearance of child as the stored fats and tissue proteins are catabolised for energy production.
  - Extreme thinning of the limbs.
  - Ribs become prominent as the fat-layer beneath the skin disappears.
  - Skin becomes dry and wrinkled.
  - Physical and mental growth retarded.
  - Atrophy of digestive glands and intestinal mucosa.
  - Digestive disorders and repeated diarrhoea.

1.15 Points to Remember

- Organisms which obtain energy by the oxidation of reduced inorganic compounds are called Chemoautotroph.
- Heterotrophic nutrition includes Saprophytic, Parasitic and carnivorous.
- Saprophytes feed on dead and decaying organisms.
- Animals eating their own faecal matter are Coprophagus.
- Saprobiotic and parasitic modes of nutrition are found in Bacteria and Fungi.
- Microphageal nutrition occurs in *Paramecium*.
- Passive food ingestion in *Amoeba* occurs by import.
- Digestive process in human being is extracellular.
- The digestive system of humans consists of an alimentary canal and associated digestive glands.
- Human digestive juices lack cellulase.
- The alimentary canal consists of the mouth, buccal cavity, pharynx, oesophagus, stomach, small intestine, large intestine, rectum and the anus.
- The accessory digestive glands include the salivary glands, the liver and the pancreas.
- Carbohydrates are digested and converted into monosaccharides like glucose.
- Cellulose is most abundant organic compound on the earth.
- Proteins are finally broken down into amino acids.
- Gluconeogenesis is the formation of glucose from protein.
- Chylomicrons are fat droplets coated with glycoproteins.
- The fats are converted to fatty acids and glycerol.
- Fat is digested in ileum of small intestine.
- Emulsification is the first process in digestion and assimilation of fats.
- Maximum energy is available on complete oxidation of fat.
- In ruminants, cellulose is digested by symbiotic bacteria.
- Enzymes help in regulating metabolism.
- Hydrolytic enzymes which act in low pH are called as Hydrolases. They are digestive enzymes.
- Lipase hydrolyses triglycerides to fatty acids and glycerol.
- Gastric enzymes are Pepsinogen, Prorenin and Gastric lipase. Pepsinogen is secreted by chief cell.
- The gastric juice contains proteins-splitting enzymes Pepsin and Renin.
- Enzyme Renin is secreted from stomach. Rennin helps in digestion of milk.
- Cyanocobalamine is essential for the formation of RBCs.
- Cellulose of boiled potatoes is digested by enzyme cellulase.
- Amylase, rennin and Trypsin are all proteins.
- Trypsinogen is converted into trypsin by enterokinase.
- Enzyme Pepsin acts in acidic medium in stomach.
- Lactase is found in intestinal juice.
- Starch is converted into maltose by the action of Amylase.
- Amino-peptidase digests peptides releasing amino acids one by one.
- Caloric value for carbohydrates is 4.1 Kcal, proteins is 5.65 Kcal and for fats is 9.45 Kcal.
- Vitamins are organic catalysts.
- Vitamin –A is needed for rhodopsin formation.
- Vitamin-A (Retinol) is fat soluble and its deficiency causes night blindness. Vitamin A is antioxidant.
- Vitamin-B is water-soluble. Biotin and Pantothenic acid belong to Vitamin-B Complex.
- Vitamin B_1 (Thiamine) is involved in the catalysis of link reaction during aerobic respiration. Deficiency of Vitamin B_1 causes Beri-Beri, damage to nerve and heart.
- Vitamin B_2 (Riboflavin) is required by the body to use oxygen and the metabolism of amino acids, fatty acids, and carbohydrates.

- The Vitamin-B_3 (Niacin) nicotinamide can be synthesized in our body from Tryptophan.
- Deficiency of Vitamin-B_3 causes damage to skin and lining of intestine.
- Deficiency of Vitamin $-B_5$ causes Pellagra, in which patient develops swollen lips, thick pigment skin and legs, irritability.
- Deficiency of Vitamin $-B_6$ causes peripheral neuropathy.
- Vitamin B_{12} is also called Cyanocobalamine.
- Richest source of Vitamin B_{12} are rice and hen's egg.
- Deficiency of Vitamin $-B_{12}$ causes Pernicious anaemia.
- Vitamin C (Ascorbic acid) is helpful in wound healing. Vitamin-C is water soluble and antioxidant.
- Deficiency of Vitamin-C causes scurvy.
- In human body Vitamin-D (Calciferol) is produced by skin. It is fat soluble.
- Deficiency of Vitamin-D causes Osteomalacia in human adults.
- Tocopherol stands for Vitamin-E. It is fat soluble. It is antioxidant vitamins
- Vitamin–K is required for synthesis of Prothrombin and is helpful in blood clotting. It is fat soluble.
- In mammals the digestion of starch starts from mouth.
- Inside the mouth the teeth masticates the food, the tongue tastes the food and manipulates it for proper mastication by mixing with the saliva.
- Crown of teeth is covered by enamel.
- Dental formula of man is 2123/2123, while adolescent human below 17 years of age normally has dental formula as 2122/2122.
- The total number of canines in the permanent dental set of human is 4.
- Premolars and molars are bunodont teeth.
- Dental formula of Rat is 1003/1003 and Rabbit is 2033/1023.
- The Number of teeth which grow twice is 20.
- The Number of teeth which grow once in human life is 12.
- Mammals (Rabbit) has Thecodont, Heterodont and Diphyodont teeth.
- Bulk of tooth in a mammal is formed of dentine.
- A dental disease characterized by mottling of teeth is due to excess of fluorine.
- Diastema is associated with absence of certain teeth.
- Tusk of elephants are modified incisors.
- The food then passes into the pharynx and enters the oesophagus by peristalsis into stomach.
- In stomach mainly protein digestion takes place.
- Absorption of simple sugars, alcohol and medicines also takes place in stomach.
- Quantity of gastric juice secreted by human stomach during 24 hours is about 2000 to 2500 ml. pH of gastric juice in stomach is 1.5 to 3.0.
- Gastrin hormone is secreted by stomach.
- Pepsin digests proteins in stomach. Pepsinogen is secreted by Zymogen cells.
- The inhibition of gastric juice secretion is brought by Enterogasterone.
- The chyme (food) enters into the duodenum portion of the small intestine and is acted on by the pancreatic juice, bile and finally by the enzymes in the succus entericus, so that the digestion of carbohydrates, proteins and fats is completed.
- Digestion of protein is completed in Duodenum.
- Brunner's Glands are present in Duodenum, which secrete two hormones Secretin, Cholecystokinin.
- Argentaffin cells are found in Gastric glands.
- Function of Gall bladder is storage of bile.
- During digestion lymphatics of intestine become filled with fat globules giving white colour to lymph. This lymph is called chyle.
- Rumen is the place of digestion in ruminants.

- The food then enters into jejunum and ileum portions of the small intestine.
- Auerbach's plexus is found in Gastro-intestinal tract. It controls the peristaltic movement of intestine.
- The digested end products are absorbed into the body through the epithelial lining of the intestinal villi.
- The absorption of glycerol, fatty acids and monoglycerides takes place by Lymph vessels within the villi.
- The lacteals are found in villi. The main function of lacteals in the villi of small intestine is the absorption of Fatty acids and glycerol.
- Epithelial cells of the intestine involved in food absorption have microvilli on their surface.
- Nutrients absorbed by the blood capillaries in intestinal villi first to go into liver through hepatic portal vein.
- Microvilli are present for the absorption of digestive materials, structures present in epithelium of digestive tract.
- *Escherichia coli* is non-pathogenic bacteria of colon.
- The undigested food (faeces) enters into the caecum of the large intestine through ileo-caecal valve, which prevents the back flow of the faecal matter.
- Most of the water is absorbed in the large intestine.
- The undigested food becomes semi-solid in nature and then enters into the rectum, anal canal and is finally egested out through the anus.
- In Buccal Cavity, the food is mixed with saliva which is formed of 99.5% water. 0.2% minerals (Na^+, K^+, Cl^-, HCO_3^-, thiocyanate ions) and 0.3% organic compounds like mucin and a starch-splitting enzyme.
- Saliva contains a starch digestive enzyme, salivary amylase that digests the starch and converts it into maltose. Salivary amylase is also known as Ptyalin.
- Sublingual gland is a salivary gland.
- Amount of saliva secreted per day is 1100 ml. pH of saliva is 6.8. A lubricant mucin in saliva is of Glycopolysaccharide.
- Liver is the largest gland of human body. Kupffer cells are found in Liver.
- Glisson's capsule is found in Liver of mammals.
- Liver is the organ in the human body where glycogenolysis takes place. Heparin is produced by Liver cells. Liver is able to manufacture vitamin A. Liver in our body stores Vitamin- A, B_{12} and D. Liver stores glucose in the form of Glycogen.
- Due to malfunction of liver stool will be of whitish grey colour.
- The level of glucose in the blood is controlled by liver.
- Crypts of Lieberkuhn secrete Succus entericus.
- Duct of Wirsung is associated with Pancreas.
- Release of pancreatic juice from pancreas is stimulated by secretin.
- Proteolytic enzymes present in the pancreatic juice are Elastase and Chymotrypsin.
- Pancreatic juices contain three alkaline proteases -
  - Trypsinogen is activated by enterokinase enzyme of intestinal juice and gives trypsin.
  - Chymotrypsin hydrolyses the proteoses and peptones to peptides.
  - Carboxypeptidase separates individual amino acids from C-terminus.
- A person deficient in the visual pigment rhodopsin should be advised to take more of carrot and papaya.
- Continued consumption of a diet rich in butter, red meat and eggs for a long period may lead to Hyper-cholestrolemia.
- Marasmus is caused by prolonged starvation.
- Obesity is due to extra consumption of carbohydrates and fats.
- Excessive stimulation of vagus nerve in man may lead to peptic ulcers.
- People recovering from long illness are often advised to include the alga *Spirullina* in their diet because it is rich in proteins.