Human Physiology-Digestion and Absorption

Introduction

* Food is the basic requirement of all living organisms as it provides energy and organic materials for growth and repair of tissues.
* Major components of food - carbohydrates, proteins and fats.
* Minor components of food - vitamins and minerals.
* Water plays an important role in metabolic processes and prevents dehydration of the body.

Important definitions and concepts

* **Thecodont dentition**: Each tooth is embedded in a socket of the jawbone.
* **Diphyodont dentition**: Teeth in humans are as two sets temporary teeth (Deciduous or lacteal teeth) and permanent teeth.
* **Heterodont teeth**: Presence of different type teeth.
* **Dental Formula**: Arrangement of teeth in each half of upper and lower jaws.
* **Deglutition** means swallowing the food.
* **Mesothelium**: Epithelium of visceral organs.
* **Payer’s patches**: Lymph nodules found in the wall of ileum.
* **Epiploic appendages**: Small fat filled connective tissue pouches on the outer surface of colon along its length.
* **Simple diffusion**: Passage of substances depending on concentration gradient.
* **Active transport**: Transport of substances against the concentration gradient, hence requires energy.
* **Facilitated diffusion**: Substances are absorbed using a carrier ion like Na+.

Digestive system

* It consists of digestive tract or alimentary canal and associated glands.
* **Gastro intestinal tract or GI tract** in man technically refers only to stomach and intestine.
* Total length of alimentary canal in man is 30 feet.

Alimentary canal

* Begins with mouth and opens out through anus.
* Mouth leads into the buccal cavity or oral cavity. It is followed by pharynx, oesophagus, stomach, small intestine and large intestine.

Oral Cavity or Mouth

* It includes teeth, salivary glands and tonsils as accessory organs.
* Oral cavity is bounded by lips anteriorly, fauces (openings) posteriorly, cheeks laterally, palate superiorly and tongue inferiorly.
* It is lined by stratified squamous epithelium.
* It has a number of teeth and a muscular tongue.
* Vestibule of the oral cavity is bounded externally by cheeks and lip and internally by gum and teeth

**Teeth**
* In human beings dentition is thecodont, heterodont and diphyodont.
* Teeth are derived both from ectoderm and endoderm.
* There are four types of teeth - incisors (I), canines (C), premolars (PM) and molars (M).
* Canines and wisdom teeth are vestigial in man.
* There are no premolar teeth in milk dentition.
* Dental formula in human adult is $\frac{213}{2123} \times 2 = 32$ while milk dentition is $\frac{2102}{2123} \times 2 = 20$.
* Teeth are made mainly of dentine while the chewing surface of the teeth helps in mastication of food.
* Enamel is the hardest substance of the body. (Teeth of armadillos and sloths lack enamel)
* Enamel is made of calcium carbonate and calcium phosphate.
* It is secreted by ameloblasts of pulp cavity.
* Dentine is harder than bone and is secreted by odontoblasts which line the pulp cavity.

**Type of teeth:**
* **Acrodont dentition:** When the teeth are not embedded in sockets but they are part of some bone as maxillary teeth and vomerine teeth of frog
* **Thecodont dentition:** When teeth are separate entities and are embedded in the teeth sockets as in mammals and crocodiles
* **Diphyodont dentition:** When two sets of teeth are produced in the life time i.e. milk teeth and permanent teeth, as in Mammals
* **Polyphyodont dentition:** When teeth can be replaced many times in life as in frogs
* **Homodont dentition (Isodont):** When teeth are a like as in frog
* **Heterodont dentition:** When there are different types of teeth present, like incisors canines, premolars and molars as in Mammals
* **Pleurodont dentition:** When the sides of teeth are fixed over the lateral surface of jaws as in reptiles
* **Bunodont dentition:** When there are low cusps present made by ridges of the teeth as in man
* **Solenodont:** When the cusps are crescentic as in sheep, etc
* **Secodont:** In carnivores such as cat, dog, lion, etc. Cusps are pointed and are used in cutting
DENTAL FORMULAE

Mouse $\frac{1003}{1003} = 16$  
Man Temporary $\frac{2102}{2102} = 20$

Squirrel $\frac{1003}{1013} = 18$  
Permanent $\frac{2123}{2123} = 32$

Rabbit $\frac{2033}{1023} = 28$  
Bear $\frac{3142}{3142} = 40$

Cat $\frac{3133}{3120} = 32$  
Horse $\frac{3143}{3143} = 44$

Opossum $\frac{5134}{4134} = 50$

Dental diseases

* Pyorrhoea: Inflammation of periodontal ligaments and gums.
* Dental caries: Tooth decay due to acids produced by bacteria.
* Lactobacillus acidophilus and streptococcus mutans are associated with tooth decay.
* Periodontal disease: Inflammation and degradation of periodontal ligaments, gingiva and alveolar tissue.
* Halitosis: Bad breath due to pyorrhoes or periodontal disease.
* Diet should contain vitamin D, calcium and phosphorus for the healthy teeth.

Tongue

* Tongue is freely movable, muscular organ attached to the floor of the oral cavity by frenulum.
* Tongue has striated extrinsic and intrinsic muscles.
* Terminal sulcus is the groove that divides the tongue into two parts.
* The anterior two thirds is covered by lingual papillae, those are with taste receptors.
* Four types of papillae are found on human tongue - circumvallate, fungiform (mushroom shaped), filliform (filament shaped) and foliate (leaf like).
* Tongue possesses Nuhn’s glands (glandular lingugles anteriores).

Pharynx

* It is about 12cm long.
* It is a short passage for food and air.
* Structures that open into the pharynx are oesophagus and trachea (wind pipe).
* It is divided into naso, oro and laryngopharynx.
* During the swallowing, entry of food into the wind pipe is prevented by epiglottis.
* a cartilaginous flap.
* Pharynx leads into oesophagus through aperture, gullet.
**Oesophagus**
* The part of alimentary canal which passes through neck, thorax and diaphragm is oesophagus.
* It is 25cm, narrow muscular tube lined by stratified squamous epithelium contain mucus glands
* Upper part of this is with striated muscle, middle part a mixture of striated and smooth and lower part purely smooth muscle
* Opening of oesophagus into the stomach is regulated by gastro-oesophageal sphincter also known as cardiac sphincter.
* Oesophagus opens into the stomach.

**Stomach**
* Stomach is located in the upper left portion of the abdominal cavity.
* It is J-shaped.
* It is about 30cm long and 15cm wide
* It has three parts cardiac, fundic and pyloric portions.
* Stomach leads into small intestine.
* Opening of stomach into duodenum is guarded by pyloric sphincter.

**Compound stomach:**
* Ruminant animals such as cattle, buffalo, sheep, goat and camel have a **compound stomach**
* Compound stomach consists of four chambers, viz, **rumen, reticulum, omasum and abomasum**
* Some reminants like camel and deer do not have omasum
* Rumen is the largest and first of the four chambers
* Rumen and reticulum are the sites of cellulose digestion these harbour numerous bacteria and protozoa which carry out extensive fermentation of cellulose
* Omasum concentrates the food by absorbing water and bicarbonates
* Fourth chamber, abomasum is the **true stomach** as it secretes gastric juice and HCl

**Small intestine**
* It is bout six meters in adults and it has three parts duodenum, jejunum and ileum.
* Duodenum is 25cm inches long and is U-shaped.
  * Pancreas lies between the two limbs of duodenum.
* It receives hepato-pancreatic duct formed by the union of bile duct and pancreatic duct
* Jejunum is 2.4 meters long and is a coiled part.
* Ileum is highly coiled and 3.6 meters long.
* Wall of ileum has **Payer’s patches** which produce lymphocytes.
* The distal end of ileum has a small dilated spherical sac called **sacculus rotundus** in rabbit
* Lining of small intestine bears a series of transfers folds called **plica circuris** or valves of kerkering
* Their internal lining is with villi
Small intestine leads into large intestine.

**Large intestine**
* Large intestine consists of caecum, colon and rectum.
* It is about 1.5mt long.
* Caecum is a small blind sac, which has some symbiotic micro organisms.
* A vistigal organ arises from the caecum called vermiform appendix - three inches in length.
* Caecum opens into the colon.
* Colon is 5 feet and is divided into three parts as **ascending**, **transverse** and **descending** part.
* Constrictions on the wall of the colon form a series of pockets called **haustra**.
* Three median longitudinal muscle cords on colon are called **Taeniae coli**.
* Descending part of colon passes into the rectum.
* Rectum is about 7-8 inches long, the terminal one inch is as anal canal.
* Anal canal opens out through the anus

**Histology of Alimentary canal**
* Wall of the alimentary canal has 4 layers.
* **Serosa** - Outer most layer and is made up of mesothelium and some connective tissue.
* **Muscularis** - Smooth muscles consisting of outer longitudinal and circular muscles. In some regions oblique muscles are also present.
* **Submucosa** - Loose connective tissue and contains nerves, blood vessels and lymph vessels.
  * In duodenum submucosa has ‘Brunner’s’ glands.
* **Mucosa** - It is the inner lining layer of alimentary canal. Forms ‘**rugae**’ which are irregular folds in stomach.
  * It also forms villi which are small finger like foldings in small intestine.
  * Cells lining villi bear microvillus which is seen as a ‘**brush border**’.
  * Microvilli increase surface area of absorption enormously.
* Villi have capillaries and large lymph vessel called **lacteal**.
* Goblet cells of mucosa secrete mucus for lubrication during food passage.
* **Digestive glands of stomach** and **crypts of Lieberkuhn of intestine** are formed by mucosa.
* **Plexus of Aurebach**: Network of nerve cells and parasympathetic nerve fibres between layers of longitudinal and circular muscles*  **Plexus of meissner**: Nerve cells and parasympathetic nerve fibres between circular muscles and submucosa
Digestive glands
* The digestive glands associated with alimentary canal include salivary glands, liver, pancreas, and intestinal glands

Salivary glands
* Human beings have three pairs of salivary glands. 1. Parotids (cheek), 2. Submaxillary or submandibular (lower jaw), 3. Sub linguals (below the tongue).
* Infra orbital or zygomatic glands or absent in man
* Saliva (pH 6.9) contains enzyme ptyalin (amylase).
* Ptyalin acts on starch and converts it to maltose in the presence of chloride ions.
* Smallest salivary glands are sublingual glands and the largest are parotid glands.
* Parotid glands are compound tubulo-alveolar glands whereas submandibular and sublingual are compound alveolar glands.
* “Mumps” is a viral disease caused by Paramyxo virus causing inflammation of parotid glands.
* Secretions of perotid glands is pored into buccal cavity through stenson’s duct
* Duct of submaxillary riches buccul cavity through wharton’s duct
* Ducts of sublingual gland is duct of Bartholin and duct of Rivinus

Liver
* It is the largest reddish brown gland of the body.
* It weighs 1.2 to 1.5 kg in an adult human.
* It is located below the diaphragm in the abdomen.
* It is attached to the posterior concavity of diaphragm by a fold called coronary ligament.
* It is also attached to the anterior abdominal wall by falciform ligament.
* It has two lobes.
* Structural and functional units of liver are hepatic lobules.
* Hepatic cells are arranged in the form of cords.
* The connective tissue that covers each lobule is called Glisson’s capsule.
* Hepatic cells secrete bile (pH 7.6)
* Bile is stored and concentrated in a thin muscular sac called the gall bladder.
* The duct of gall bladder is called cystic duct.
* Bile duct (ductus choledocus) of liver joined combine cystic duct and form, common bile duct
* The common hepato-pancreatic duct opens into the duodenum and opening is guarded by a sphincter called Sphincter of Oddi.
* Kupffer’s cells are hepatic macrophages present between hepatic cords
* Breaking down gall stones by use of ultra sonic vibration is called lithotripsy.
* Surgical removal of the gall bladder is called Cholecystectomy.
* Retarded function of liver can cause jaundice.
Functions of Liver:
* Liver performs variety of functions
* Glycogenesis: Extra glucose is converted to glycogen
* Glycogenolysis: Glycogen is converted into glucose
* Glucogenesis: Synthesis of glucose from other carbohydrates
* Lipogenesis. Extra protein and carbohydrates are converted into lipid
* Deamination of protein
* Ornithine Cycle. NH₃ is converted into urea
* Cori Cycle. Lactic acid formed in muscle is converted back to glycogen
* Synthesis of substance like Vitₐ From carotene Vit₅D from cholesterol or ergocalciferol, Heparin Insulin-like growth factor
* Detoxification of substances
* Storage of glycogen, Vitamin like Vitₐ, Vit₅D, Vit₈K, Vit₆B₁₂ and folic acid etc.; Fe and Cu
* It acts as thermoregulatory organ

Pancreas
* Pancreas is a compound racemose organ situated between the two limbs of duodenum.
* It is second largest gland
* It has both exocrine and endocrine cells.
* Exocrine portion secretes pancreatic juice (pH 8.8) containing enzymes.
* Endocrine portion secretes hormones insulin and glucagon.

Intestinal glands
* Submucosa of duodenum is with Brunner’s glands produces alkaline mucus
* In between the villi of ileum crypts of Lieberkühn are present
* Succus entericus is secreted by crypts of Lieberkuhn

Digestion of food
* Process of digestion involves mechanical digestion, chemical digestion and microbial digestion.
  Break down of food by the action of teeth and muscles is called mechanical digestion.
* Chemical digestion is by enzyme action.
* All enzymes are proteins.
* All digestive enzymes are hydrolytic.
* The major functions of buccal cavity are mastication of food and mixing food with mucus to help in swallowing.
* The food bolus formed is sent into oesophagus by deglutition.
* Saliva contains electrolytes, enzymes and lysozyme.
* pH of saliva is 6.8.
* Daily secretion of saliva in man is about 1 to 1.5 litres.
* Lysozyme is an anti bacterial agent.

**Digestion in stomach**
* Gastric glands have three major types of cells.
  1. **Mucus neck cells** which secrete mucus
  2. **Peptic or chief cells** that secrete pro enzyme pepsinogen.
  3. **Parietal or Oxyntic cells** which secrete HCl and intrinsic factor.
* pH of gastric juice is 1 to 3.5.
* Protein digestion starts in stomach.
* Food mixed with gastric juice in stomach is called **chyme**.
  HCl provides the acidic pH. Optimal pH for pepsin is 1.8.
  Rennin helps in digestion of milk.
* Another enzyme of the stomach is gastric lipase.
* Gastric lipase acts best at pH of 5 to 6.

**Digestion in small intestine**
* Three types of digestive juices are released into the small intestine.
  1. Bile, 2. Pancreatic and 3. Intestinal juice
* Bile and pancreatic juice are released through hepato - pancreatic duct or ductus choledochus.
* Daily secretion of bile is man is about 600ml.
* Bile is alkaline, yellow to green in colour and has pH of 7.8 to 8.6.
* Bile does not have any enzymes.
* Bile salts like sodium taurocholates and sodium glycocholates help in emulsification of fats.
* Bile salts also help absorption of fat soluble vitamins.
* Bile pigments like bilirubin and biliverdin are produced during break down of old RBCs.
* Bile also contains Cholesterol and phospho lipids.
* Bile also activates lipases.

**Pancreatic juices**
* Pancreatic juice is a complete digestive juice.
* It takes part in the digestion of proteins, carbohydrates and fats.
* Pancreatic juice contains trypsinogen, chymotrypsinogen, procarboxypeptidases, amylases, lipases and nucleases.
* Enterokinase secreted by intestinal mucosa converts inactive trypsinogen to active trypsin.
**Intestinal juice**
* Intestinal juice or succus entericus is mainly secreted by crypts of lieberkuhn.
* It is a clear yellow fluid, slightly alkaline with a pH of 7.8.
* The intestinal mucosal epithelium has goblet cells which secrete mucus.
* The secretions of brush border cells of the mucosa along with the secretions of the goblet cells constitute the succus entericus.
* Enzymes of intestinal juice are disaccharidases, dipeptidases, lipases, nucleosidases etc.
* Mucous along with bicarbonates forms the layer that protects the intestinal mucosa from acids.
* It also provides an alkaline medium for enzymatic functions.

**Process of digestion**
* Proteins, proteoses and peptones are partially hydrolysed proteins of chyme.
* Trypsin, chymotrypsin and carboxy peptidase act on proteins, peptones and proteoses and convert them to dipeptides.
* Pancreatic amylase hydrolyse carbohydrates in the chyme into disaccharides.
* Lipases act on fats and convert them to di and monoglycerides.
* Nucleic acids are converted to nucleotides and nucleosides by nucleases in the pancreatic juice.
* Enzymes of succus entericus act on end products of the above reactions.
* Biomolecule break down occurs in duodenum of the small intestine.
* The regions of absorption of digested food are jejunum and ileum.
* The undigested and un absorb substances pass into large intestine.
* Functions of large intestine include
  1.absorption of water, minerals and drugs.
  2.secretion of mucus that adheres to the waste particle and helps in their easy passage.

**Chemical digestion in buccal cavity**
\[
\text{Starch} \xrightarrow{\text{salivary amylase}, \text{CT}} \text{maltose}
\]

**In stomach**
\[
\begin{align*}
\text{proteins} & \xrightarrow{\text{pepsin at pH 1–3.5}} \text{proteoses} + \text{peptones} \\
\end{align*}
\]

**In small intestine pancreatic juice action**
\[
\begin{align*}
\text{Tripsinogen} & \xrightarrow{\text{enterokinase}} \text{trypsin} \\
\text{chymotrypsonogen} & \xrightarrow{\text{trypsin}} \text{chymotrypsin} \\
\text{proteins, peptones, proteoses} & \xrightarrow{\text{trypsin, chymotrypsin}} \text{dipeptides} \\
\text{polysaccharides(starch)} & \xrightarrow{\text{amylase}} \text{disaccharides}
\end{align*}
\]
Fats $\xrightarrow{\text{lipases}}$ diglycerides $\rightarrow$ monoglycerides

Nucleic acids $\xrightarrow{\text{nucleases}}$ nucleotides $\rightarrow$ nucleosides

**Action of enzymes of succus entericus**

Dipeptides $\xrightarrow{\text{dipeptidases}}$ amino acids

Maltose $\xrightarrow{\text{maltase}}$ glucose + glucose

Sucrose $\xrightarrow{\text{sucrase}}$ glucose + fructose

Nucleotides $\xrightarrow{\text{nucleotidases}}$ nucleosides

Nucleosides $\xrightarrow{\text{nucleotidases}}$ sugars + bases

Di & monoglycerides $\xrightarrow{\text{lipases}}$ fatty acids + glycerol

* Undigested, unabsorbed substances called faeces enter into the caecum of the large intestine through ileo-caecal valve.
* Ileo-caecal valve prevents back flow of faecal matter.
* Faecal matter is temporarily stored in the rectum till defaecation.

**Neural control on GI tract**

* Secretion of saliva is stimulated by sight, smell or presence of food in the oral cavity.
* Neural signals stimulate gastric and intestinal secretions.
* Through CNS and local stimulation, muscular activities of different parts of alimentary canal can be moderated.

**Hormonal control on GI tract**

* Control of secretion of digestive juice is carried out by the local hormones produced by gastric and intestinal mucosa.
* Gastrin, enterogastrone, cholecystokinin (CCK), secretin, pancreozymin and enterocrinin are the hormones which act on the GI tract.

**Absorption of digested products**

* End products of digestion pass through intestinal mucosa into blood or lymph.
* Substances absorbed by simple diffusion are Monosaccharides like glucose, amino acids, some of the electrolytes like chloride ions.
* Substances absorbed by facilitated diffusion are Fructose, some amino acids, with the help of carrier ions like Na+.
* Transport of water depends on osmotic gradient.
* Substances absorbed by active transport are Amino acids, Monosaccharide and electrolytes like Na+.

**Absorption of end products of fat digestion**

* Fatty acids and glycerol are insoluble and cannot be absorbed into the blood.
* They are first converted to micelle which then moves into the intestinal mucosa.
* In the intestinal cells they are converted into very small protein coated fat globules called chylomicrons which are transported into lacteals of the villi.
* Lymph vessels carry chylomicrons into blood stream.

**Summary of absorption in different parts of digestive system**
* **Mouth** - Certain drugs coming in contact with the mucosa of mouth on lower surface of tongue are absorbed into blood capillaries lining them.
* **Stomach** - Water, simple sugars and alcohol.
* **Small intestine** - Principal organ for absorption of nutrients. Glucose, fructose, fatty acids, glycerol and amino acids.
* **Large intestines** - Water, minerals and drugs.

**Assimilation**
* Utilization of the absorbed substances by the tissues is called assimilation.

**Defecation**
* Digestive waste, seen as faeces in the rectum initiates a neural reflex causing an urge or desire for its removal.
* Defecation is a voluntary process and is carried out by a mass peristaltic movement.
* Faeces is egested to the outside through the anal opening.

**Peristalsis**
* Peristalsis occurs usually in oesophagus, stomach and intestine.
* Least peristalsis occurs in rectum.
* Peristalsis is a part of mechanical digestion.
* Stimulation of parasympathetic nervous system results in the increase of gut peristalsis.
* Reverse peristalsis in the stomach produces vomiting.

**PEM**
* **Protein - energy malnutrition (PEM)** may affect large sections of the population during drought, famine and political turmoil.
* PEM affects infants and children to produce Marasmus and Kwashiorkor.
* **Marasmus** is produced by a simultaneous deficiency of proteins and calories. It is found in infants less than a year in age, if mother’s milk is replaced too early by other foods which are poor in both proteins and caloric value.
* This often happens if the mother has second pregnancy of childbirth when the older infant is still too young.
* **Symptoms:** Emaciation, thinning of limbs skin becomes dry, thin and wrinkled, growth rate and body weight decline.
* **Kwashiorkor** is produced by protein deficiency unaccompanied by calorie deficiency.
* It results from the replacement of mother’s milk by a high calorie-low protein diet in a child more than one year in age.
* **Symptoms:** Wasting of muscles, thinning of limbs, failure of growth and brain development, fat is still left under the skin: extensive oedema swelling of body
DISORDERS OF DIGESTIVE SYSTEM

* Nausea – discomfort preceding vomiting
* Anorexia – loss of appetite
* **Haemorrhoids**: Enlargement of rectal vein which causes piles.
* **Dyspesis**: Indigestion due to defective diet.
* **Pavlov pouch** was fabricated by Pavlov to study the effect of feeding on gastric secretion
* Hiatal hernia or diaphragmatic is the opening in the diaphragm. The part of the stomach is pushed into the thoracic cavity.
* Peptic ulcer is an erosion of the stomach or duodenal mucosa.
* Cirrhosis of the liver – The liver appears orange.
* Some people cannot digest milk and milk consumption in them causes diarrhea and gas generation because they do not produce lactase.
* Removal of stomach produces **dumping syndrome**.
* Abnormal metabolism of fats causes **Gaucher’s disease**.
* The **vermiform** contain numerous **lymphatic nodules** and is subjected to inflammation – **appendicitis**.
* Most common disorder is inflammation of the intestinal tract due to bacterial and viral infections.
* Parasites like tapeworm, roundworm, thread worm, hook worm, pin worm etc cause infections of alimentary canal.
* **Jaundice** - Liver is affected, skin and eyes become yellow due to deposition of bile pigments.
* **Diarrhoea** - Abnormal frequency of bowel movement and increased liquidity of the faecal discharge is known as diarrhoea.
* **Constipation** - Faeces are retained within the rectum, as bowel movements are irregular.
* **Indigestion** - Food is not properly digested leading to a feeling of fullness.