DIGESTION

- Digestion is the breakdown of large, complex organic matter into smaller molecules that can be absorbed and used by the body. Molecules need to be small enough to diffuse across membranes
- Mechanical Digestion: Physical breakdown of food in the mouth and churning in stomach. Smaller pieces of food have greater surface area for action of digestive enzymes
- Chemical Digestion: Enzymes break down food substances into their simplest form.
  - Starch: In mouth and small intestine
  - Protein: Stomach and small intestine
  - Fat: only in small intestine

Steps in Digestion

- Ingestion: Consumption or taking in of nutrients
- Digestion: Chemical breakdown of large complex molecules into smaller components Absorption: Delivery of digested nutrients to body tissues
- Assimilation: Conversion of absorbed food into biomolecules in the body Egestion: Elimination of waste materials from the body

Mouth	• Ingests food • Teeth masticates food into small pieces to increase surface area for digestion Saliva (pH 7) moistens and softens food (Water + Mucus + Salivary Amylase) **Starch to Maltose by Salivary Amylase** **Salivary Glands** • Parotid Glands: Serous, watery secretion (25%) • Sub Maxillary: Serous, mucus secretion (70%) • Sub Lingual: Predominantly mucus (5%) • Buccal Glands secrete only mucus **Enzymes** • Salivary Amylase: starch to maltose • Maltase: Maltose to Glucose • Lingual Lipase: Lipid digesting enzyme. Hydrolyses Triglycerides into Fatty Acids and diacylglycerol • Lysozyme: kills bacteria in mouth

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	• Lactoferrin, IgA also have anti-microbial properties • Mucin lubricates the mucus membrane of the mouth **Importance of Saliva** • Preparation of food for swallowing • Initial digestion of starch to maltose by salivary amylase • Role in speech • Regulation of body temperature and water balance • Detection of taste: Dissolves compounds in food so that they can stimulate the taste receptors
Oesophagus	• Approximately 10" long • Secretes mucus • Moves food to stomach using muscle movement called peristalsis
Stomach	• J shaped muscular bag • Gastric Juice is highly acidic - pH 0.9 to 1.2 • Breakdown of Proteins and Lipids. Acid kills bacteria. Buffers the food if it is too alkaline • Peristaltic movements mix the bolus with gastric juice. Food in stomach is called chyme • Controls the amount of food leaving the stomach for small intestine • Produce **Intrinsic Factor** important in $\mathbf{B_{12}}$ absorption at the small intestine • G cells secrete hormone **Gastrin**: Helps in Pepsin and HCl production in stomach and bile production in liver • D cells secrete Somatostatin which inhibits acid • Parietal Cells: Secrete HCl, Intrinsic factor. Parietal cells have receptors for histamine, Acetylcholine, Gastrin, Somatostatin etc. which stimulate the secretion of Acid. • Chief Cells: Pepsinogen, Chymosin (Rennin) • Enter-chromaffin like cells: Histamine **Secretions of the stomach** • Hydrochloric Acid: Provides an acidic medium for enzymes to be activated • Pepsin: Pepsinogen is converted to Pepsin by HCl (optimum pH for activation is <6). Also causes curdling of milk • Rennin: Proteolytic enzymes that curdle milk • **Gastric Lipase**: Weak Lipolytic enzyme compared to Pancreatic lipase. Active only in pH 4-5 and becomes inactive below pH 2.5 • **Gastric Amylase** • Gelatinase • Mucus: Protects the stomach wall from digestive action of pepsin. Also protects gastric mucosa from HCl action • Histamine
Small Intestine	• Roughly 7m long — Duodenum, Jejunum, Ileum • Site for majority of digestion and absorption

- Lining of intestine walls has finger like projections called villi to increase the surface area.
- Villi are further covered in microvilli which further increases surface area for absorption
- Duodenum: Majority of chemical digestion occurs here. Chyme is acidic due to HCl in the stomach, so it needs to be neutralised
- Presence of Chyme in the small intestine triggers the conversion of **Pro-secretin to Secretin,** which is absorbed into the blood stream and carried to the pancreas.
- Jejunum: Majority of the absorption takes place. The inner walls have tiny finger like projections called Villi.
- Ileum: Fewer Villi. Compacts the leftovers to pass through the Caecum into the large intestine.
- Small intestine absorbs 80% water, vitamins, minerals, mono saccharides, amino acids and fatty acids

Secretions of Small Intestine

- Intestinal Juice is called Succus entericus - intestinal enzymes, mucus. Water and electrolyte secreted by epithelial cells of intestines (Crypts of Liberkuhn)
- Enterokinase from brush border cells. Converts Trypsinogen to Trypsin
- Peptidases: Convert Peptide to Amino Acid
- Disaccharidases: Di to Monosaccharide
- Brush Border Enzymes: Dextrinase, Glucoamylase, Maltase, Sucrase, Lactase (convert saccharides to simple sugars)
- Brunner's Gland: Thick alkaline and mucoid secretion. Prevent HCl and Chyme from damaging intestinal mucosa
- Goblet Cells: Secrete mucus. Protect mucosa and lubricate chyme.

Liver

- Produces Bile from Hepatocytes, which is stored in **Gall Bladder** till it is needed in the small intestine Bile is 97.5% water and 2.5% salts
- Bile constituents: Bile salts, Pigments (Bilirubin and Biliverdin), Cholesterol, Phospholipids, Lecithin (pH 8 to 8.6)
- Presence of Lipids in the small intestine triggers the release of **Cholecystokinin** which triggers the release of bile from the Gall Bladder
- Bile salts emulsify fats (breaks them into small droplets) which can be digested (Bile is NOT an enzyme)

Functions of Liver

- Regulation of Blood Glucose concentration: Too much glucose in blood — insulin is secreted — Liver converts glucose into Glycogen — Blood glucose concentration decreases
- Production of Bile
- Iron Storage: RBCs are destroyed in the spleen and their haemoglobin is sent

to the liver to be broken down. Iron released is then stored in the liver. Breakdown of Hb also provides for formation of bile pigments
- Synthesis of proteins like Albumin, Globulin, Fibrinogen
- Deamination of Amino Acids (when they are in excess): Carbon group is converted to glucose, Amino group to Urea

Functions of Bile salts

- Emulsification of Fats: Bile salts emulsify the fats by reducing surface tension due to their detergent action
- Absorption of Fats: Bile salts combine with fats and make complexes of fats (Micelles). Micelles can be easily absorbed
- Choleretic Action: Stimulate secretion of bile from liver
- Cholagogue Action: Stimulate secretion of Cholecystokinin which causes contraction of gall bladder and release of Bile into the intestine
- Laxative Action: Stimulates peristalsis in the intestine
- Prevention of Gallstone formation: by keeping cholesterol and Lecithin in solution. In absence of Bile salts, Cholesterol precipitates along with Lecithin and forms Gall stones.
- Inhibit growth of certain bacteria in lumen of intestine by its natural detergent action

Hormones secreted by Liver

- Insulin Like Growth Factor 1: Stimulus for proceeding with cell cycle
- Angiotensinogen: Precursor for Angiotensin which plays a role in maintaining blood pressure Thrombopoietin: Stimulates precursor cells in the bone marrow to differentiate into megakaryocytes, which generate platelets
- Hepcidin: Blocks please of Iron, thereby helping in Iron homeostasis Betatrophin: Stimulates proliferation of Insulin secreting ß cells of the Pancreas

Gall Bladder

- Stores bile in between meals
- Secretes bile to the Duodenum through the bile duct during meal time

Pancreas

- Located towards the posterior of the gut cavity
- Sits behind the stomach, Duodenum loops around the head of the Pancreas Partly endocrine (insulin and glucagon) and partly exocrine (pancreatic juice)

Pancreatic Secretion

- Pancreatic secretion is highly alkaline - pH 8 to 8.3
- Secreted by Acinar and Epithelial cells of the duct system (Exocrine function)
- **Secretin** — Pancreas — releases a solution containing bicarbonate ions into the small intestine which neutralises the acidic chyme and raises the pH from 2.5 to 9 — leads to inactivation of **Pepsin Pancreatic Amylase**: Break carbohydrate chains into disaccharides (small intestine releases enzymes which breaks them into monosaccharides)
- **Trypsinogen** from Pancreas is converted to **Trypsin** in the small intestine (by **Enterokinase** secreted by brush bordered cells of Duodenal Mucus membrane).
    - Breaks down large protein chains into smaller chains. Trypsin is the most powerful proteolytic enzyme.
    - Curdling of milk (Caseinogen to Casein) Activates several other pancreatic enzymes
        - Chymotrypsinogen to Chymotrypsin Proelastase to Elastase Procarboxypeptidase to Carboxypeptidase
- **Chymotrypsin:** Trypsin coverts Chymotrypsinogen to Chymotrypsin. Converts Proteins to polypeptides and digests Caseinogen faster than Trypsin.
- **Carboxy-Peptidase:** Splits the first amide bond at the C end of protein
- **Pancreatic Lipase:** Most powerful lipolytic enzyme (digestion of 80% fat). Converts Triglycerides to Monoglycerides and Fatty Acids. Activity of Pancreatic Lipase is accelerated in the presence of Bile.
    - Bile Salts help in emulsification of fats
    - **Co-lipase:** Co-enzyme necessary for Lipolytic action of Pancreatic Lipase
- **Phospholipase**
  Cholesterol Esterase

DIGESTION IN SMALL INTESTINE

- **Carbohydrates**
    - Polysaccharides to Disaccharides (Pancreatic Amylase from Pancreas) Disaccharides to Monosaccharides (Disaccharidases from Small Intestine)
- **Proteins**
    - Polypeptides to Protein Fragments (Trypsin, Chymotrypsin) Protein

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	Fragments to Amino Acids (Amino Peptidase) • **Fats** ○ Fats to Monoglycerides and Fatty Acids (Pancreatic Lipase) Facilitated by Bile Salts and Co-Lipase **ABSORPTION IN SMALL INTESTINE** • **Glucose, Fructose** and **Galactose** are absorbed by microvilli by active transport, then leave the cell and enter the capillary • **Amino Acids** cross the epithelial cell membranes by active transport, then enter the capillary • **Water, Vitamins** and **Minerals** are absorbed by diffusion without digestion **Villus** • Contains a capillary network along with a lacteal • End products of protein and fat digestion enter capillary End products of fat synthesis move into the Lacteal • The lacteal is a vessel of the Lymphatic system **Absorption of Amino Acids and Glucose** • Molecules pas into epithelial cells • Through walls of capillaries in the villus into the blood stream • Capillaries join to form veins, from where they move into Hepatic Portal Vein Carried in blood to liver • Liver stores or alters the products of digestion • Products are released from liver into general blood circulation **Absorption of Fats** • Products of digestion (fatty acids and monoglycerides) pass into epithelial cells Recombine into fats again in the Epithelial cells • Fats enter the Lacteals Lymph + Fat = Chyme • Lymphatic vessels discharge Chyme into blood stream
Large Intestine	• About 5ft long • Accepts what small intestines don't absorb • Large intestines absorb water from waste material Produces Vitamin K and Vitamin B using helpful bacteria
Rectum	• Short term storage which holds faeces before it is expelled
Anus	• External opening of the Rectum. • Opening/Closing is controlled by Sphincter muscles

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	Carbohydrate	Proteins	Fats
Mouth	• Starch to Maltose by Salivary Amylase		• Lingual Lipase breaks down Triglycerides into FA + diacylglycerol
Stomach	• Salivary Amylase continues working till HCl comes up (about 30 min) • When pH decreases, amylase activity stops	• Pepsin splits proteins to Proteases, Peptones and Polypeptides • HCl is needed for converting Pepsinogen to Pepsin (optimum pH 2)	• Gastric Lipase converts TG to FA
Small Intestine	• Pancreatic Amylase • released in duodenum in alkaline medium Converts polysaccharides (starch and glycogen) to • Oligosaccharides (maltose and dextrin) • Brush border enzymes - Dextrinase, maltase, sucrase, lactase - convert dextrin, maltose, sucrose and lactose to Glucose **Absorption** • From mucosal surface of jejunum and upper ileum • Glucose and Galactose by Na dependent active transport • Fructose by facilitated diffusion • Pentose by simple diffusion	• Pancreatic proteases digest protein to dipeptides, tripeptides and polypeptides • Brush border peptidases — dipeptidase, polypeptidase, nuclease • Final digestion to amino acids by intracellular peptidases **Absorption** • Into intestinal epithelial cells • Na dependent active transport mechanism • From Epithelial cells to interstitial space by simple and facilitated diffusion. • From interstitial space, passes into Capillaries by simple diffusion	• Emulsification of fat by bile salts • Lecithin helps in emulsification Hydrolysis of fat droplets by pancreatic and intestinal lipolytic enzymes • Fat digestion is accelerated by Micelle formation. • Pancreatic Lipase hydrolyses almost all fats to Fatty Acids and Monoglycerides • Cholesterol esterase breaks down cholesterol molecules • Phospholipase hydrolyses Phospholipids and operates Fatty Acids from them **Absorption** • Mostly in Duodenum • Transported as micelles to brush

			border membrane • Diffuse across the enterocyte basal membrane • Formation and exocytosis of Chylomicrons from Enterocytes • Chylomicrons merge to form larger droplets, diffuse into lacteals and then into lymphatic circulation

Nutritive Requirements

- Carbohydrates: 250-850g/day
- Protein: 0.5-1g/kg/day
- Fats: 25-160g/day
- Vitamins
- Minerals

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