UNIT 6 FOOD DIGESTION AND ASSIMILATION

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6.0 OBJECTIVES

After reading this unit, you will be able to:

- state the composition and functions of digestive juices;
- narrate the transfer mechanism of substances across membranes; and
- describe the method of digestion and absorption of nutrients in the body.

6.1 INTRODUCTION

The principal constituents of food, namely carbohydrates, lipids and proteins undergo digestion in the gastrointestinal tract to simpler compounds and are absorbed into the blood stream. Cooking of the food is necessary to make it palatable and digestive e.g., cooking is required for gelatinizing starch, as only cooked starch is rapidly digested. Further, cooking destroys harmful microorganisms present in the food and breaks cellwalls in vegetables, denatures proteins and converts collagen into gelatin. The digestion and absorption of food are described under the following heads: (1) The composition of digestive juices (2) Digestion and absorption of carbohydrates: (3) Digestion and absorption of fats and (4) Digestion and absorption of proteins.

6.2 THE COMPOSITION OF DIGESTIVE JUICES

The digestion of food begins in the mouth and is continued in the stomach and intestines. The composition of different digestive juices and the action of different enzymes are given in *Table 6.1* and are briefly described below.

6.2.1 Saliva

Saliva is a mixture of secretions from three pairs of salivary glands present in the mouth. The rate of secretion of saliva is controlled by nerve impulses and the stimuli for secretion are psychic (e.g. sight, smell and thought of food), mechanical (chewing of food) and chemical (stimulation of taste buds). The total flow of saliva in an adult has been estimated at 1 to 1.5 liters per day.

Table 6.1: Constituents of saliva and their action

Site of Secretion	Important constituents	Action
Saliva from Salivary glands like 1) Submaxillary 2) Sublingual and 3) Parotid gland	Mucin, Amylase (Ptylin)	Lubrication Cooked starch→ Dextrins + Maltose (Enzyme activity in the mouth is not important).

Enzyme

Saliva obtained from the parotid duct by cannula has been found to contain a number of enzymes including amylase, lysozyme, acid phosphatase, aldolase and choline esterase. Of these, only amylase and lysozyme are present in appreciable amounts and hence of physiological importance.

Functions of Saliva

- Moisten mouthparts and serve as lubricant
- Food solvent
- Medium for digestive enzymes and anti-coagulants

Saliva moistens dry food and facilitates swallowing by a lubricating action. Chewing mixes the food with saliva. It contains an α-amylase which rapidly digests cooked starch. The digestion of starch begins in the mouth. Since, food remains in the mouth for very short period, very little digestion takes place in the mouth. Saliva contains buffering substances, namely, bicarbonate, phosphates and mucin. It keeps the mouth at a neutral pH and thus protects the teeth from decalcification. It keeps the mouth and teeth clean. Presence of lysozyme facilitate to counter with bacteria.

6.2.2 Gastric Juice

Normal gastric juice is a thin, light coloured fluid which is strongly acidic. It contains about 0.45 per cent hydrochloric acid and the proteolytic enzyme pepsin. The quantity of gastric juice secreted in normal adults may range from 1500 to 2500 ml per day. The hormones that regulate the secretion of digestive juices are given in *Table 6.2*.

Hydrochloric Acid

This is secreted by the oxyntic cells (parietal cells). The functions of hydrochloric acid are as follows: (a) It provides the optimal pH (2 to 3) for digestion of proteins by pepsin (b) It converts inactive pepsinogen into active pepsin (c) It denatures food proteins, thus making them more readily digestible (d) It helps in the absorption of iron by converting food iron into inorganic form and by reducing ferric iron to ferrous form (e) It stimulates duodenum to secrete secretin (f) It helps to some extent to hydrolyse (inversion) sucrose to glucose and fructose and (g) It has a germicidal effect on micro-organisms and hence prevents their it growth in the stomach.

Table 6.2: Secretion from stomach and their action

Site of Secretion	Important constituents	Action
Gastric juice from Parietal cells	Hydrochloric acid	Pepsinogen → Pepsin, Bactericidal action, Reduces ferric iron to ferrous iron.
Chief cells	Pepsinogen Pepsin	Inactive form of pepsin, Protein → proteases → peptides → Polypeptides.
Columnar epithelium	Mucin	Lubrication, protects gastric and duodenal lining,
	Lipase	Emulsified fats → fatty acids, glycerol,
	Rennin(infants only)	Digestion of milk in infants.
	Intrinsic factor	Enables absorption of vitamin B_{12}.

Mucin

Mucin is a glycoprotein. It is secreted by the columnar cells on the surface of the gastric mucosa. It is also secreted by pyloric glands and cardiac tubular glands. The important function of mucin is to form a coating on the surface of gastric mucosa and thus help to protect the gastric mucosa from the acidity of gastric juice.

Pepsin

The chief cells (peptic cells) contain granules of pepsinogen (inactive form of pepsin called Zymogen). Pepsinogen is secreted into the stomach by peptic cells in response to vagal stimulation. It has a molecular weight of about 40,000 dalton. Pepsinogen is converted into active pepsin by the hydrochloric acid present in gastric juice. Pepsin has a molecular weight of 32,700 dalton. The process is autocatalytic and a mixture of peptides are removed from pepsinogen during its conversion to pepsin.

$$\text{Pepsinogen} \xrightarrow{\text{Hydrochloric acid}} \text{Pepsin + Peptides}$$

Pepsin converts food proteins mainly into a mixture of polyptiepdies. Recent studies indicate that pepsin is a mixture of enzymes (pepsin B, C and D).

Milk Clotting Activity of Pepsin: Pepsin in the presence of calcium ions can convert casein in milk to calcium paracaseinate at pH 5. This action of pepsin is similar to that of rennin described below:

$$\text{Casein} \xrightarrow[\text{(pH 5)}]{\text{Pepsin + Ca ions}} \text{Calcium paracaseinate + Peptides}$$

Rennin

This enzyme occurs in small amounts in the stomach of infants and not adult human beings. The optimum pH for its activity is 1.8. It is a powerful milk clotting enzyme. It hydrolyses casein to paracasein and peptides. Paracasein, in the presence of calcium ions, forms a thick curd of calcium para-caseinate.

$$\text{Casein} \xrightarrow{\text{Rennin} + Ca^{++}} \text{Calcium paracaseinate} + \text{Peptides}$$

Intrinsic Factor

This factor is essential for the absorption of vitamin B_{12} in the intestines. It is a mucoprotein having a molecular weight of about 50,000 dalton. The mucopolysaccharides present in the intrinsic factor contain hexosamine, hexoses and neuraminic acid. The intrinsic factor combines with vitamin B_{12} and helps in the absorption of B_{12} in the intestines.

Gastric Lipase

A weak lipase is present in the gastric juice. The optimal pH of the lipase is 5.5 to 7. Hence, the enzyme is not active at the pH (2 to 3) of the stomach contents.

Check Your Progress 1

1) Define Ptylin.

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2) Saliva is secreted by ....

3) Discuss the functions of saliva.

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4) Define Mucin.

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5) Cooking of food is necessary to make it...................... and ....

6) Digestion of food begins in the ....

7) The quantity of gastric juice secreted in normal adult ranges from .... to .... ml/day.

6.2.3 Secretions of Small Intestine, Liver, Pancreas and their Functions

Two types of juices are secreted in the intestines — (1) Duodenal juice and (2) Intestinal juice.

Duodenal Juice : It is secreted by Brunner's glands present in duodenum. It is an alkaline juice containing mucin, a weak proteolytic enzyme and enterokinase. Its principal function is to protect the mucosa of the duodenum against injury by acid chyme from the stomach. The enterokinase activates trypsinogen to trypsin.

Intestinal Juice and Intestinal Mucosa: The intestinal juice is an alkaline fluid secreted by the small intestines. It contains mucus, sodium bicarbonate, enterokinase and erepsin. The quantity of intestinal juice secreted in an adult may vary from 2000 to 3000 ml per day. Many important enzymes are present in the intestinal mucosa. These includes peptidases, disaccharidases, nucleinases, phosphatases and phospholipases.

Pancreatic Juice

The pancreas has dual functions: (1) It secretes the pancreatic juice which contains proteases, amylase and lipase for the digestion of food and (ii) The islets of langerhans present in the pancreas secrete the hormones, insulin and glucagon which are essential in carbohydrate metabolism. The pancreatic juice is a colourless, transparent, viscous fluid which has an alkaline reaction (pH 8.4) due to the presence of sodium bicarbonate (0.3 to 0.65 per cent). The quantity of pancreatic juice secreted in adult human beings may range from 600 to 800 ml per day. The proteases present in pancreatic juice are trypsin, chymotrypsin, collagenase, elastase and carboxypeptidases.

Table 6.3: Secretion from small intestine, Liver, Pancreas and their functions

Site of Secretion	Important constituents	Action
Pancreas:		
Pancreatic juice	Thin, watery, alkaline, juice	Neutralises acid chyme.
	Amylase	Starch→Maltose and Isomaltose.
	Chymotrypsinogen	Inactive form of Chymotrypsin
	Chymotrypsin	Proteins→ Proteases → Peptones→ Polypeptides
	Trypsinogen	Inactive form of Trypsin.
	Trypsin	Proteins→Proteases→ Peptones → Polypeptides.
	Peptidase	Polypeptides→ Smaller peptides and amino acids.
	Lipase	Fats→ monoglycerides, fatty acids, glycerol.
	Collagenase	Hydrolyses Collagen.
	Elastase	Hydrolyses Elastin
	Ribonuclease	Hydrolyses RNA to Nucleotides.
	Deoxyribonuclease	Hydrolyses DNA to Nucleotides.

Liver: Bile	Bile salt Bile acids Bile pigments Cholesterol Mucin	Neutralises acid chyme Emulsifies fats for action of lipase Facilitates absorption of fats and fat soluble vitamins.
Small intestine: Intestinal juice (succus entericus, small intestine)	Enterokinase Peptidases Nucleinase	Trypsinogen→ Trypsin Polypeptides→ Amino acids Nucleic acid→Nucleotide→ Nucleosides + phosphoric acid.
Within Mucosal cells of small Intestine	Lecithinase Sucrase (invertase) Maltase Lactase Isomaltase Lipase Cholesterolesterase	Lecithin→Diglycerides +Choline + Phosphate Sucrose→ Glucose+ Fructose. Maltose→Glucose + Glucose. Lactose→Glucose + Galactose Isomaltose→ Glucose + Glucose Fat→ Monoglycerides + Fatty acids and glycerol. Cholesterol→Cholesterolesters + Fatty acids.

Bile

Bile is essential for the digestion of fat. It is secreted from the hepatic cells into the bile capillaries. It passes into the hepatic ducts which join to form the common bile duct. Between periods of digestion, bile is diverted through the cystic duct into the gall bladder where it is concentrated and stored. About 300 to 1200 ml of bile are formed daily in adult human beings.

The gall bladder has a capacity of 60 ml in adult humans. It secretes mucin, which gives bladder bile its viscid ropy character. Gall bladder concentrates and alters the composition of bile. Its mucosa rapidly removes water and electrolytes but not bile salts, bile pigments or cholesterol.

Bile Acids

Bile acids are synthesized from cholesterol exclusively to the liver and represents one of the major end products of cholesterol metabolism. The bile acids can be considered as being derived from the parent called cholanic acid. The different bile acid are hydroxy derivatives of cholanic acid.

Conjugation of Bile Acids with Glycine or Taurine

Before bile acids are excreted in the bile, they are conjugated with glycine or taurine (obtained from cysteine) to form glycocholates or taurocholates. Glycocholic acid is present in larger amounts than taurocholic acid in the bile.

Functions of Bile Salts

Bile salts present in the bile have several important functions: (1) They act as emulsifying agents and help to emulsify fats thereby increasing surface area and making fat miscible with water. This facilitates the hydrolysis of fat by pancreatic lipase; (2) They activate the enzymes, pancreatic lipase and cholesterol esterase; (3) They combine with free fatty acids and monoglycerides to form minute particles called *miscelles* and help in their absorption in the intestines; (4) They stimulate intestinal peristalisis; (5) They stimulate bile production in liver. Since they are excreted in the bile and are reabsorbed to a considerable extent in the intestines (enterohepatic circulation) and returned to the liver, they ensure continuous secretion of bile by the liver and (6) They keep cholesterol in solution in gall bladder bile.

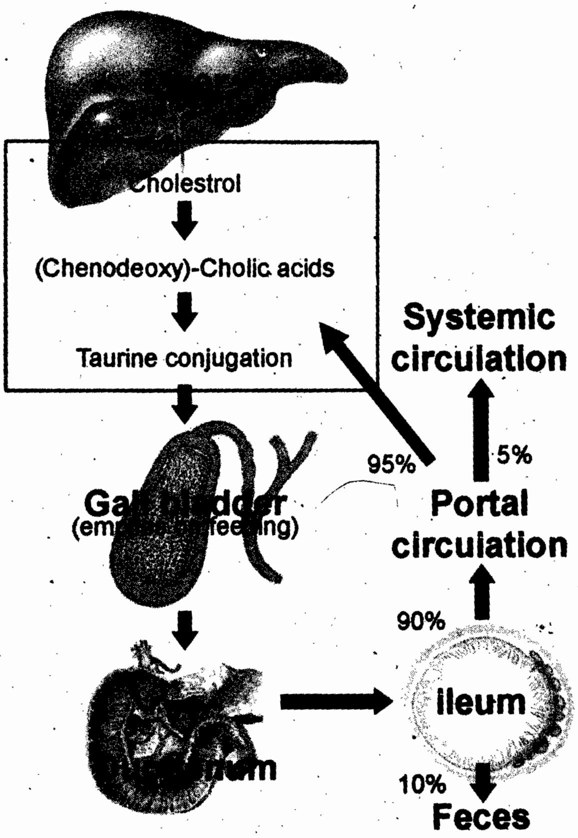

Fig. 6.1: Circulation of Bile Acids

Bile Pigments

Bile pigments are excreted in the bile. They have no physiological role.

Cholesterol

Bile contains fairly large amounts of cholesterol. The cholesterol is kept in solution by bile salts. If the concentration of bile salts becomes less, cholesterol gets precipitated, leading to the formation of gall stones. Cholesterol is excreted through the bile. Some of it may be reabsorbed to the intestinal tract.

Check Your Progress 2

1) Define pancreatic juice.

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2) ....enzyme plays important role in hydrolysis of Lecithin.

3) ....and .... are the important secretions of small intestine.

4) Discuss about few functions of bile salts.

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6.3 HORMONES OF THE GASTROINTESTINAL TRACT

As already mentioned in this chapter, the secretion of digestive juices are regulated by certain hormones produced in the gastrointestinal tract. These are listed in *Table 6.4*.

Table 6.4:Hormones that regulate activities of the digestive tract

Hormone	Site production	Action
Gastrin	Pyloric and duodenal mucosa	Stimulates flow of gastric juice.
Enterogastrone	Duodenum	Inhibits secretion of gastric juice; reduces motility
Cholecystokinin	Duodenum	Contraction of gall bladder and flow of bile to duodenum
Secretin	Duodenum	Secretion of thin, alkaline, enzyme-poor pancreatic juice
Pancreozymin	Duodenum; Jejunum	Secretion of thick, enzyme-rich pancreatic juice
Enterocrinin	Upper small intestine	Secretion by glands of intestinal mucosa
Hepatocrinin	Duodenum	Stimulates liver to secrete more bile

6.4 TRANSFER OF SUBSTANCES ACROSS MEMBRANES

Food after digestion is absorbed from the small intestines into the circulation. The different nutrients absorbed are glucose, amino acids, vitamins, minerals and emulsified and finely divided lipids as chylomicrones and lipoproteins. The cells of different tissues obtain their nutrient requirements in the form of glucose, amino acids, vitamins, minerals and lipids (free fatty acids and lipoproteins). The passage of water and nutrients across the intestinal membranes, blood capillaries and cell membranes is a highly complex physico-chemical process.

6.4.1 Transport Mechanisms

The transfer of substances across cell membranes is effected by two types of mechanisms: (1) Passive transport and (2) Active transport.

Passive Transport

There are three major types of passive transport: (i) Simple diffusion (ii) Facilitated diffusion and (iii) Exchange diffusion.

Simple Diffusion: Simple diffusion occurs along a concentration gradient of an electrical gradient from a high concentration or potential to a lower one. No energy is required for the process. The major deterrent to penetration by diffusing molecules is the lipoprotein present in the membrane. If a molecule is passing from the water phase of the environment into the membrane, all the hydrogen bonds of the water should be broken when entrance into the lipid phase is gained. Compounds like sugars, containing three or more polar groups, will enter more slowly. If the molecule entering is non-polar in character, the factor limiting the rate of diffusion is the entry of the molecule (e.g., vitamin A, cholesterol and fatty acids) from the membrane into the cytoplasm.

Facilitated Diffusion: One means of facilitating the passage of substances across the cell membrane is by the provision of a carrier to link with the substance and carry it along with it. This type of transport is called facilitated diffusion. This does not require energy. The carrier is presumably present in the membrane. The substance gets attached to the carrier at one surface of the membrane and gets released at the opposite side and enters the cytoplasm. The carrier is able to move freely from one surface to other surface of the membrane.

Exchange Diffusion: Another type of carrier dependent transport has been shown to operate in the passage of certain ions and amino acids. This is called exchange diffusion. For each molecule or ion transported into the cell, a similar molecule is transported out of the cell on the return trip of the carrier. This type of diffusion is responsible for the major exchange of labeled ions and molecules for non-labeled ions.

Active Transport

A greater part of the transport of nutrients across the intestinal mucosa and cell membranes takes place by "active transport". The term "active transport" means movement of substances across the cell membrane against a concentration or electrochemical gradient. Energy is required for active transport. Further, active transport is carrier-mediated and the carrier is a specific transport protein that is present in the membrane. ATP provides the energy required for the active transport. "Active transport" is essential for the transport of sodium ion out of the cell and potassium ion into the cell, and for the absorption of glucose and amino acids across the intestinal mucosa. The transport of glucose and amino acids into the cell by active transport mechanism is accompanied by the simultaneous movement of sodium ion along with them and it is carrier dependent. The movement of sodium ion out of the cell and potassium ion into the cell is constantly going on by active transport mechanism and the concentration of these ions out of the cell is maintained at constant level. The active mechanism functions in the (i) maintenance of high potassium content in RBC and other cells; (ii) movement of sodium, potassium, calcium ions in nerve cells;

(iii) secretion of digestive juices; (iv) absorption and secretion by kidney tubules and (v) secretion of hormones by endocrine glands.

Check Your Progress 3

1) The transfer of substances across cell membrane is by .... and .... mechanisms.

2) Name the types of passive transport.

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3) Discuss exchange diffusion.

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6.5 DIGESTION AND ABSORPTION OF NUTRIENTS

The process of digestion and absorption of different nutrients like carbohydrates, proteins and fats are not same because of the difference in their chemical nature. Thus the digestion and absorption of these nutrients are discussed below under different heading:

6.5.1 Digestion and Absorption of Carbohydrates

The carbohydrates of the diet consist predominantly of the starch together with varying amounts of sucrose and lactose from milk and glycogen from meat or liver. The diets also contain varying amounts of indigestible carbohydrates such as cellulose, hemicellulose, and pentosans. The digestion and absorption of carbohydrates are briefly described below:

Digestion of carbohydrates

Mouth: The digestion of cooked starch by salivary amylase begins in mouth. But the food remains for a short period in the mouth and hence very little digestion takes place in the mouth. The digestion of starch by salivary amylase continues in the stomach for 10-15 minutes till the food gets mixed with gastric juice and the action of amylase ceases due to high acidity.

Stomach: Hydrolysis (inversion) of some of the sucrose present in the food may take place in the stomach by the action of hydrochloric acid.

Small Intestine: A greater part of the starch and glycogen of the food is digested by the pancreatic amylase in the small intestines into a mixture of maltose and isomaltose.

$$\text{Starch and glycogen} \xrightarrow[\text{Amylase}]{\text{Pancreatic}} \text{Maltose + Isomaltose}$$

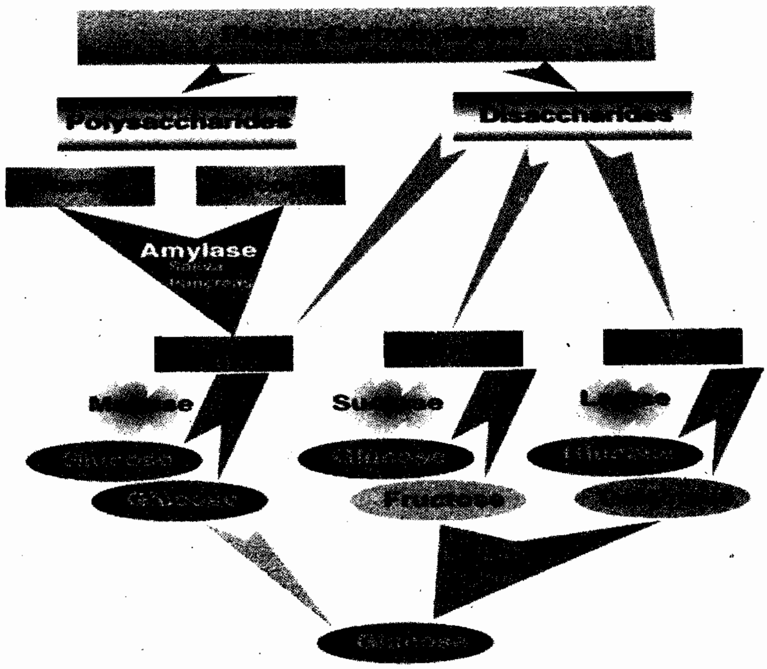

Fig. 6.2: Utilization of Glucose

(Utilization of the glucose by the cells to produce energy, stored as glycogen, or, through metabolic pathways, converted into fat)

The resulting disaccharides are maltose (mainly) and isomaltose along with sucrose and lactose of diet are digested by the different enzymes present in the intestinal mucosa into the corresponding monosaccharides as indicated below:

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

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{2 molecules of Glucose}$$

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

$$\text{Isomaltose} \xrightarrow{\text{Isomaltase}} \text{2 molecules of Glucose}$$

The resulting monosaccharides namely glucose (most abundant), fructose and galactose are absorbed in the small intestine. Some quantity of pentoses present in the diet or liberated from the digestion of nucleic acid are also absorbed.

Metabolism of carbohydrates

Glucose, galactose and fructose absorbed in the small intestines pass through the portal circulation to the liver. In the liver, a part of the glucose and the entire galactose and fructose are converted into glycogen. A part of the glucose passes into the general circulation and to the various tissues for being oxidised and used as energy. A small part of glucose is stored in liver and muscle as glycogen and some portion of the glucose is converted into fat and stored in adipose tissue. The oxidation of glucose in the tissues occurs in two stages as indicated below:

(1) $\text{Glycogen} \longrightarrow \text{Glucose} \xrightarrow{\text{Glycolysis}} \text{Pyruvic acid}$

(2) $\text{Pyruvic acid} \xrightarrow{\text{Oxidation}} CO_2 + H_2O$

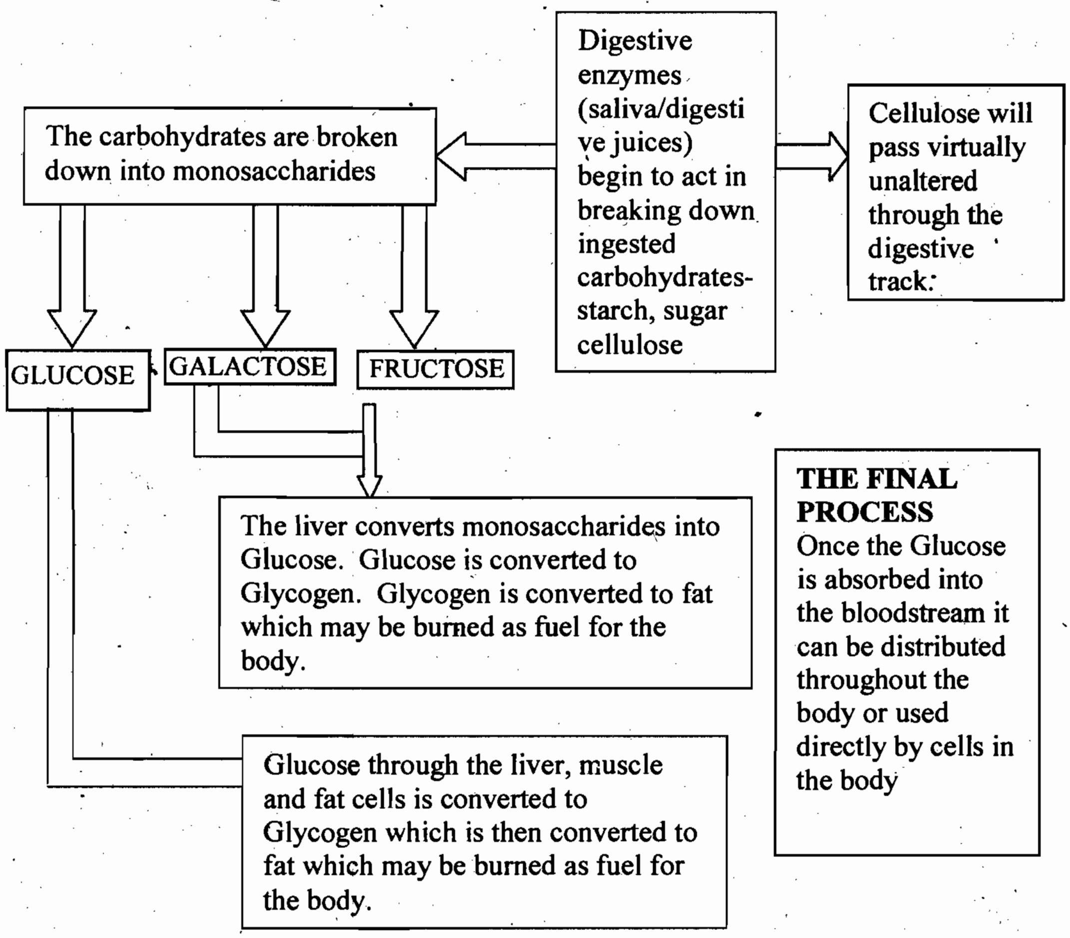

Fig. 6.3: Carbohydrate Metabolism

The first stage is called 'glycolysis'. The oxidation of pyruvic acid takes place in mitochondria and it involves a number of steps such as linked reaction, Kreb's cycle and electron transport chain.

Absorption of Monosaccharides

The rate of absorption of different monosaccharides, taking glucose as 100, is as follows: Galactose (110), glucose (100), fructose (43), Xylose (15) and arabinose (9). It is evident that glucose and galactose are absorbed at a faster rate than fructose and pentoses. It has been found that the high rate of absorption of glucose and galactose is due to the fact that they are actively transported while fructose and pentoses are absorbed by diffusion (*Table 6.5*).

Table 6.5: Sugars Actively Transported

Actively transported	Not actively transported
Glucose Galactose	Fructose Mannose Xylose Arabinose Sorbitol

Transport of monosaccharides in the intestines

Active Transport: When a substance has to be transported against a concentration gradient or electrochemical gradient, energy has to be supplied from cellular metabolism for the purpose. For example, glucose can be absorbed when its concentration in mesenteric blood is higher than that in the gut lumen. Active transport is carrier-mediated and the carrier is a specific transport protein which is an integral part of the membrane to the traversed.

Ionic Dependence: The absorption of monosaccharides depends on the presence of sodium ions and probably also on the Sodium: Potassium concentration ratio.

Transmural Electric Potential: In the absence of glucose, the serosal surface of the intestines is 1-5 mV positive relative to the luminal surface. When glucose is added to the luminal surface, the transmural potential can increase to 12 mV. This increase is due to the active transport of glucose which involves supply of energy from cellular metabolism.

Career Hypothesis: In order to explain the active transport of sugars, it has been postulated that the sugar (glucose or galactose) combines with a carrier (a specific transport protein) that has individual binding centers for it. According to Crame (1965), glucose associates with a carrier and with sodium ion in the microvilli and the complex travels to the inner side of the membrane where it dissociates, releasing glucose and sodium ion into the cytoplasm. The carrier returns back and functions again. The sodium ion is then actively transported out of the cell.

Check Your Progress 4

1) Why the absorption rate of glucose is higher than that of fructose?

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2) Sucrose is converted into glucose and fructose by the enzyme..................

3) Pancreatic amylase converts starch and glycogen into ....and

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6.5.2 Digestion and Absorption of Fat

Digestion of Fat

Fat is not digested in the stomach. The presence of fat in the diet delays the emptying of the food from the stomach. Fats are hydrolysed by the pancreatic and intestinal lipases in the intestines into a mixture of diglyceride, monoglycerides and fatty acids. Bile is essential for the digestion and absorption as it helps to emulsify fat before digestion. The products of digestion pass into the cells of the intestinal wall, where synthesis of new glycerides takes place. The resynthesised lipids pass through the lacteals of the small intestines to the thoracic duct and then to the blood stream in the form of fine particles known as chylomicrons. A greater part of the cholesterol present in the diet is absorbed while phytosterols present in vegetable fats and oils are not absorbed.

Absorption of Cholesterol: Cholesterol esters are hydrolysed to free cholesterol in the intestines by the enzyme cholesterol esterase secreted in the pancreatic juice. It is absorbed as free cholesterol. In the intestinal mucosa, cholesterol is re-esterified and passes along with neutral fat in the form of chylomicrons into the lacteals, and then into lymph vessel. About 85 to 90 per cent of the cholesterol in the thoracic lymph is in the esterified form.

Absorption of Phospholipids: A major portion of the ingested phospholipid undergoes complete hydrolysis in the intestinal lumen into fatty acids, glycerol, phosphate and the free base (choline or ethanolamine or serine). They are absorbed along with the products of digestion of neutral fat. Some of the phospholipids may be absorbed as such. The phospholipids are resynthesised in the intestinal mucosa and form part of the chylomicrons during the passage of fat to the lymph.

Factors Affecting the Absorption of Lipids: The three important factors influencing lipid absorption are: (1) Activity of pancreatic lipase; (2) Secretion of sufficient bile; and (3) The lipid synthetic activity of intestinal mucosa. If sufficient quantity of pancreatic lipase is not secreted, the hydrolysis of fats is not complete. If sufficient quantity of bile is not available, formation of micelles with monoglycerides and soap (sodium salt of fatty acid) does not take place and absorption of fat is reduced. The third factor, which influences the absorption from the intestinal lumen, is the activity of lipid synthesizing enzymes in the intestinal mucosa. Unless the system rapidly converts absorbed monoglycerides and fatty acids into triglycerides, absorption of fat is reduced.

Metabolism of Fat: Fatty acids are oxidised by certain enzymes in the tissues to carbondioxide and water.

$$\text{Palmitic acid (1 molecule)} \longrightarrow \text{Acetic acid (8 molecule)} \xrightarrow{\text{Oxidation}} 16CO_2 + 16H_2O$$

The oxidation takes place through the tricarboxylic acid cycle. Fat is also

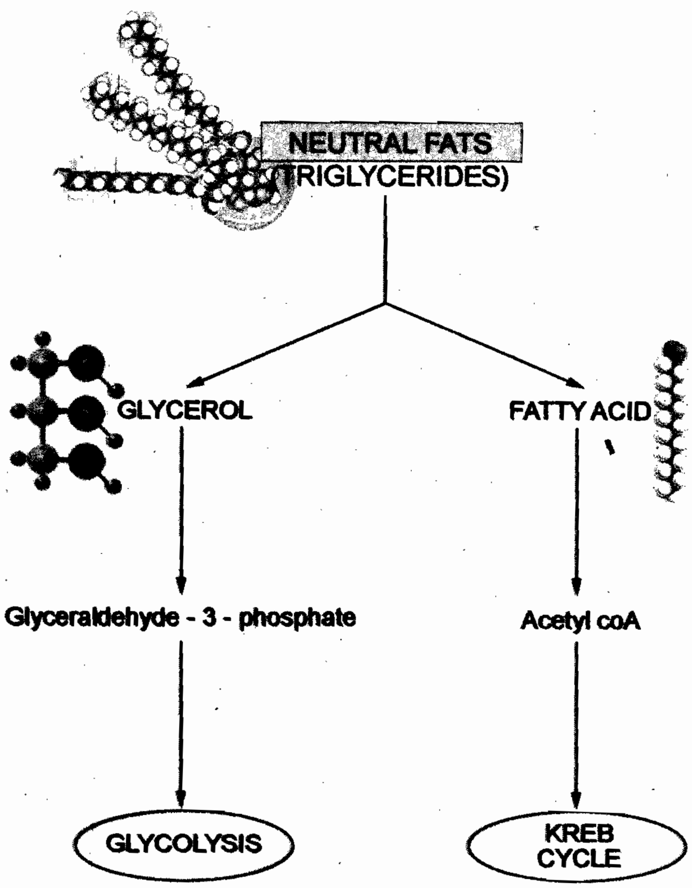

Fig. 6.4: Metabolism of fat

Check Your Progress 5

1) During digestion, fats are emulsified by .... salts.
2) ....is not digested in stomach.
3) Cholesterol is absorbed as ....
4) Write the factors which influence the absorption of lipids.

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6.5.3 Digestion and Absorption of Proteins

Digestion of Proteins:

The hydrolysis of proteins in the gastrointestinal tract is accomplished by proteases secreted in gastric juice and pancreatic juice and by proteases present in the intestinal mucosa.

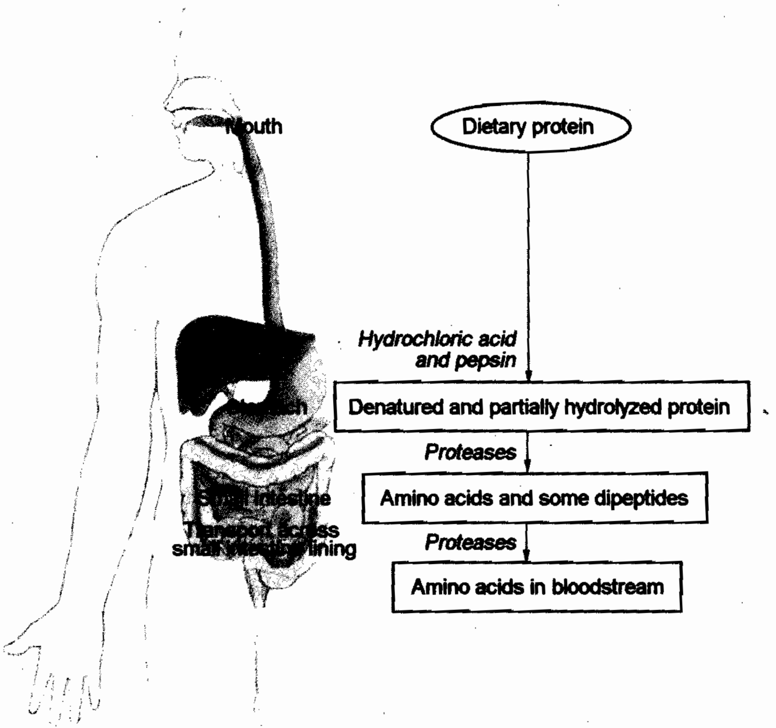

Fig. 6.5: Digestion and absorption of protein in the gastrointestinal tract.

Gastric Digestion: The proteolytic enzyme present in gastric juice is pepsin. Its optimum pH is about 2.0. Pepsin is an endopeptidase and it can hydrolyse peptide bonds in the interior of the protein molecule. It hydrolyses mainly peptide bonds containing phenylalanine, tyrosine or tryptophan and also peptide bonds containing leucine and acidic amino acids. Since food remains in the stomach for a limited time, pepsin hydrolyses dietary proteins mainly into mixture of polypeptides.

$$\text{Dietary protein} \xrightarrow{\text{Pepsin}} \text{Polypeptides}$$

If gastric hydrochloric acid production is low and not adequate to maintain the pH of the stomach contents between two and three, protein digestion in the stomach may be negligible. This will happen in achlorhydria, achylia gastrica (both pepsin and hydrochloric acid absent) or in pernicious anemia. Pepsin has a strong clotting action on milk. This is of considerable importance in the digestion of milk proteins in infants.

Proteolysis in the Intestines: The main digestion of polypeptides produced in the stomach takes place in the intestines. The proteases involved in the digestion are trypsin, chymotrypsin and carboxypeptidase secreted in pancreatic juice and amino peptidases present in the intestinal mucosa. Trypsin and chymotrypsin act at pH 7.4 to 8.0. Trypsin hydrolyses mainly peptide linkages containing arginine or lysine and chymotrypsin hydrolyses peptide linkages containing tyrosine or phenylalanine.

$$\text{Proteins and polypeptides} \xrightarrow[\text{chymotrypsin}]{\text{Trypsin}} \text{Peptides + Amino acids}$$

Carboxy peptidase: Carboxy peptidase hydrolyses the end group in peptides containing aromatic or aliphatic amino acid, thus releasing free amino acids. Carboxy peptidase B hydrolyses peptides containing arginine and lysine residues. The intestinal mucosa contains a group of amino peptides which complete the hydrolysis of peptides to amino acids. The intestinal mucosa also contains tripeptidase, dipeptidase, which hydrolyse tri- and di-peptides.

$$\text{Peptides} \xrightarrow{\text{Carboxy peptidase}} \text{Amino acids}$$

$$\text{Peptides} \xrightarrow{\text{Amino peptidase}} \text{Amino acids}$$

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

$$\text{Tripeptides} \xrightarrow{\text{Tripeptidase}} \text{Amino acids}$$

The ultimate products of digestion of proteins are amino acids, which are absorbed.

Absorption of Amino Acids: Absorption of amino acids takes place in the small intestines. This process requires energy. Studies with everted sacs of rat intestines have shown that (1) L-isomer (natural isomers) of amino acids are more rapidly absorbed than D- amino acids (2) The neutral amino acids are more rapidly absorbed than the basic amino acids and (3) Amino acids compete with one another for absorption. Vitamin B_6 is essential for amino acid absorption.

Carrier System for Amino Acid Absorption: Studies with mixture of amino acids have shown that more than one transport or carrier system functions in the absorption of amino acids. The active carrier system for neutral amino acids shares a common membrane carrier. The basic amino acids lysine, arginine and histidine share a carrier system with cystine. The dependence of amino acid transport on Sodium ion suggests a direct interaction between the carrier and Sodium ion. This is similar to that observed in the absorption of glucose. According to the available information, the amino acid associates with the carrier and sodium ion in the microvilee and the complex travels to the inner side of the membrane where it dissociates, releasing the amino acid and Sodium ion into the cytoplasm. The carrier returns back and functions repeatedly. The Sodium ion is then actively transported out of the cell.

6.5.4 Digestion and Absorption of Nucleoproteins and Nucleic Acids

Nucleoproteins: The acidity of gastric juice brings about the cleavage of nucleoproteins present in many foods into proteins (histones, protamines) and nucleic acid.The proteins undergo hydrolysis to amino acids in the same way as the dietary proteins by the proteases present in the digestive juices.

Nucleoproteins —Hydrochloric acid→ Nucleic acids + Proteins

Nucleic Acids: Nucleic acids are hydrolysed consecutively by three groups of enzymes (i) Nucleases (ii) Nucleotidases and (iii) Nuceeosidases to purine or pyrimidine base, pentose and phosphoric acid.

Nucleases: The nucleases may be broadly grouped under two heads: (i) Ribonucleases and (ii) Deoxyribonucleases. The former group hydrolyses RNA while the later hydrolyses DNA. A number of deoxynucleases and ribonucleases occur. Some are endoenzymes hydrolyzing internucleotide bonds throughout the DNA and RNA molecule converting them to smaller fragments called oligonucleotides. These are hydrolysed into nucleotides by exoenzymes which hydrolyse the end nucleic acid linkages step by step. The end product of hydrolysis of DNA and RNA by nucleases are nucleotides.

Nucleotidases: Nucleotidases hydrolyse nucleotides into nucleoside and phosphoric acid.

Nucleosidases: Nucleosidases hydrolyse nucleosides into pyrimidine or purine base and pentose (ribose or deoxyribose). These are absorbed in the small intestines.There is evidence that certain amounts of nucleosides and pentose phosphates released by hydrolysis of nucleotides may also be absorbed. Most of the tissues contain nucleosidases which hydrolyse nucleosides absorbed from the intestines.The reactions are given in Fig. 6.6

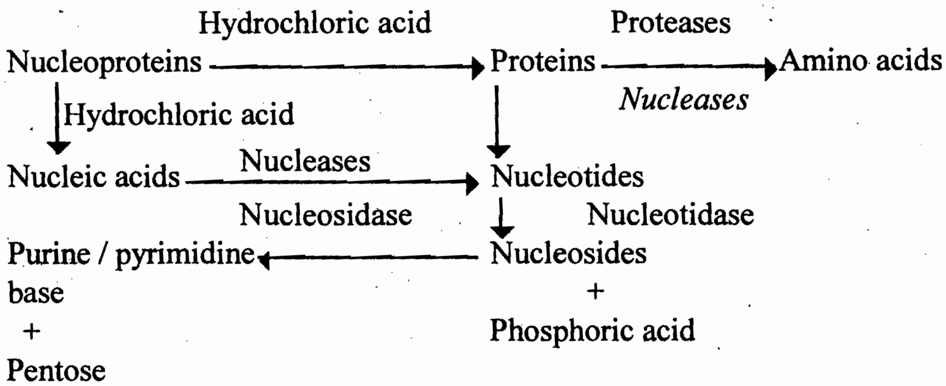

Fig. 6.6: Digestion of Nucleoproteins

Metabolism of Proteins : The metabolism of proteins may be conveniently discussed under the following heads: (1) Breakdown and synthesis of tissue proteins (2) Nitrogen balance and (3) Oxidation of amino acids.

Breakdown and synthesis of tissue proteins: Recent studies have shown that breakdown and synthesis of tissue proteins proceed simultaneously. A part of the tissue proteins is broken down continuously and is replaced by the formation of new tissue proteins from the amino acids supplied by the diet. The breakdown of tissue proteins is called catabolism and the formation of new tissue proteins is called anabolism.

Nitrogen balance: When a subject is on a protein-free diet, the oxidized proteins are broken down and the resulting amino acids are oxidized and the nitrogen is excreted in urine. The nitrogen lost in urine and faeces on a protein-free diet is called endogenous nitrogen which is derived from the body. When protein is taken in the diet, new tissue proteins are formed. When the nitrogen loss from the body is less than that of the nitrogen intake, the body is in positive nitrogen balance. In this case, the nitrogen is retained to form new tissues, as for example, during growth of the body. If the nitrogen loss from the body is higher than the nitrogen intake, the body is said to be in negative nitrogen balance. Under the above conditions, the body proteins are slowly depleted. Negative nitrogen balance occur in under-nutrition, fever, starvation, etc.

Oxidation of amino acids: The amino acids not utilized for the formation of tissue proteins are oxidized by enzymes in the liver, as indicated below:

$$\text{Amino acid} \xrightarrow{\text{Oxidation}} \text{Keto acids + Ammonia}$$

The ammonia thus formed is converted into urea in the liver and excreted in the urine. The keto acids are oxidised to yield energy.

Check Your Progress 6

1) Dietary protein gets hydrolyzed to polypeptide by ....

....

2) Polypeptides are converted to ....and .... by trypsin, chymotrypsin.

3) ....are converted to nucleic acid and proteins by ....

....

4) Amino acid get oxidized to .... and ammonia.

5) Explain the gastric digestion of proteins.

....

....

....

6.6 ABSORPTION OF WATER

In addition to the water contained in the ingested food, large amounts of water are present in the gastrointestinal secretions, namely saliva, gastric, pancreatic and intestinal secretions and bile. The water in these secretions may amount to five-seven liters per day in adults. Between 90 and 95 per cent of the ingested water is absorbed during the passage of digested food in the small intestine. The water content of the chyme that enters the large intestines is 0.4 to 0.5 liter per day in an adult and most of this is absorbed during passage through the large intestine so that the faeces contain only about 0.1 liter of water per day.

6.7 ABSORPTION IN THE LARGE INTESTINE

Absorption and Secretion in the Large Intestine: About 500 ml of chyme passes from the small intestines into the caecum each day in an adult. About

350 ml of water from the chyme is absorbed mainly in the caecum and ascending colon. Sodium chloride is readily absorbed from the colon. Large intestines secrete a small amount of mucus and a watery secretion. The mucus lubricates the faeces.

Bacteria of the Large Intestines: The large intestines of the new born baby are bacteriologically sterile. A day after birth, the intestine is invaded by bacteria through the mouth and anus. The bacterial flora consists of bacteroids, coliform bacilli and streptococci. These micro-organisms act on the undigested food proteins and carbohydrates causing putrefaction, decomposition and fermentation. The bacteria account for about 25 per cent of the dry weight of the faeces.

Action of Bacteria on Carbohydrates: Bacteria act on the undigested and unabsorbed carbohydrates. The process is called "Fermentation" and produces (1) Organic acids such as lactic acid, acetic acid and propionic acid and (2) Gases like methane, CO_2 and hydrogen. Though these products are not harmful, the production of excessive amounts of gas may cause distention of the abdomen and discomfort. The gases are usually eliminated as flatus.

Action of Bacteria on Proteins: Bacteria act on proteins and the process is known as "Putrefaction". The bacterial proteases decompose proteins and the other bacterial enzymes bring about reactions such as decarboxylation, deamination, oxidation and reduction producing amines and phenols which are toxic. Cystine, contain sulphur, undergoes a series of reactions to form mercaptans and hydrogen sulphide which add to the foul odour of the faeces. Tryptophan undergoes a series of changes to skatole and indole (*Table 6.7*). These two compounds are also responsible for the foul odour of the faeces.

Action of Bacteria on Fats: Bacterial enzymes act on choline present in lecithin producing toxic amines such as neurine and muscarine. The bacterial lipases hydrolyse neutral fats to fatty acids and glycerol.

Biosynthesis of Vitamins: Bacteria synthesise many B complex vitamins, namely riboflavin, folic acid, biotin and vitamin B_{12} and also vitamin K. A substantial portion of the daily requirements of vitamin K is derived from intestinal synthesis. Only a small percentage of the B vitamins synthesized are absorbed.

Table 6.7: Toxic products produced by Bacterial Action on Some Amino Acids

Amino acid	Toxic products
Tyrosine	Tyramin, Phenolic compounds
Tryptophan	Tryptamine, Indole and Skatole
Histidine	Histamine
Cystine	Mercaptans
Lysine	Cadavarine
Arginine	Putresine

6.8 FORMATION OF FAECES

The faeces consists of the food residue remaining in the large intestines after digestion and absorption of food together with intestinal secretions, mucus, desquamated epithelium and enormous number of bacteria. The quantity of faeces formed depends on the amount of roughage (cellulose and hemicelluloses) in the diet.

Table 6.8: Effect of fibre content of Wheat Flour on the weight of faeces passed in an adult human in 24 hours

Kind of flour	Fibre content %	Weight of moist faeces (g)	Weight of dried faeces (g)	Nitrogen (g)
Refined flour	0.7	133	25	2.2
Coarse flour	1.5	253	41	3.2
Whole wheat flour	2.8	315	76	3.8

Nitrogen Content of Faeces: The nitrogen content varies from two to four gram in adults, depending on the content of the diet. About half the nitrogen is derived from gastrointestinal secretions. The faecal bulk is high on diets based millets which are rich in fibre.

Lipids: The lipid content varies from 10 to 20 per cent of the dry weight of the faeces. The fat is derived both from endogenous sources and from the diet. About one-third of the fat consists of cholesterol or coprosterol and bile acids. The remainder consists of fatty acids, neutral fat and phospholipids. The presence of excess fat in faeces is known as steatorrhoea, a condition due to impaired absorption of fat as in hepatic disorders, biliary obstruction, celiac disease sprue.

Pigments: The principal pigment in faeces is stercobilin which is chemically identical with the urobilin of urine. The pigments present in the diet e.g. chlorophyll present in green leafy vegetables will alter the colour of the faeces.

Odour: The foul odour of faeces is mainly due to indole and skatole formed from tryptophan and also due to mercaptans and hydrogen sulphide formed from cystine by bacterial action.

Examination of Faeces for Clinical Purposes: The examination of faeces for the presence of parasitic infection such as hookworm, tapeworm and roundworm is of considerable clinical importance. The estimation of lipids is of considerable diagnostic importance in celiac disease and sprue.

Check Your Progress 7

1) Define Faeces

....

....

....

....

2) Color of faeces is due to ....

3) Odour of faeces is due to ....

4) Bacteria synthesises ....

and .... vitamins.

6.9 LET US SUM UP

The principal constituents of food namely carbohydrates, lipids and proteins undergo digestion in the gastrointestinal tract to simple compounds and are absorbed into the blood stream. The process of digestion begins in the mouth where food is chewed by the teeth and mixed with saliva. While the food is still in mouth, it is acted upon by an enzyme, amylase which acts only on cooked carbohydrates and partially digests them or breaks them up into smaller units. The chewed food mixed with saliva then passes into the stomach. Where it gets mixed with the digestive juice present in the stomach called gastric juice. Gastric juice contains hydrochloric acid which makes it acidic in nature. It also contains an enzyme which acts on proteins and bring about their partial digestion. The partially digested mass of food passes from stomach into the small intestine. The small intestine contains intestinal juice and secretions from liver and pancreas. The secretion from the liver is called bile and from pancreas is known as pancreatic juice. Bile assists in the digestion and absorption of fats. Both pancreatic and intestinal juices contain enzymes that break down fats, proteins and carbohydrates into simpler substances which reach the blood stream. The food which is not absorbed in the small intestine along with large amount of water passes onto the large intestine. Most of excess water is reabsorbed and the remaining water and solid matter is eliminated from the body as faeces.

6.10 KEY WORDS

Active transport	:	Movement of substances through membrance against a concentration.
Diffusion	:	Spreading or scattering.
Digestion	:	Dissolving of the food in the stomach.
Dissociation	:	Separation.
Emulsification	:	Mixing of water and oil
Impulses	:	Force suddenly and momentarily communicated.
Lubricating	:	To make smooth or slippery.
Precursor	:	A fore runner or predecessor.
Stimuli	:	Anything that causes to action.
Swallowing	:	To engulf.

6.11 SOME USEFUL BOOKS

Khader, V. (2003). *Foods-Nutrition and Health.* 1st Ed. Kalyani Publishers, New Delhi.

Robinson, C.H. (1978). *Fundamentals of Normal Nutrition.* 3rd Edition. Mac Millaon Publishing Co. inc New York.

Swaminathan, M. (1985). *Essentials of Food and Nutrition.* Vol.I. 2nd Edition. The Bangalore Printing and Publishing Co. Ltd, Mysore Road, Bangalore.

6.12 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1) Ptylin: It is amylase present in the saliva. It can hydrolyze starch to maltose, isomaltose and low molecular weight dextrins.

2) Salivary gland.

3) Function of saliva are listed below:
   - Moisten mouth parts and serve as lubricant
   - Food solvent
   - Medium for digestive enzymes and anti-coagulants

4) Mucin: Mucin is a glycoprotein. It acts as a lubricant which facilitates swallowing of food. It also forms a coating on the surface of gastric mucosa and helps to protect gastric mucosa from the acidity of gastric juice.

5) Palatable, digestible

6) Mouth

7) 1500-2500 ml / day

Check Your Progress 2

1) **Pancreatic juice:** Pancreatic juice is a colourless, transparent viscous fluid which has an alkaline reaction (pH 8.4) due to the presence of Sodium bicarbonate. The pancreatic juice contains proteases, amylase and lipase for digestion of food.

2) Lecithenase.

3) Duodenal juice, intestinal juice.

4) Bile salts present in bile have several functions:
   i) Bile salts act as emulsifying agent and help to emulsify fats thereby increasing surface area and making fats miscible with water. This facilitates hydrolysis of fats by pancreatic lipase.
   ii) These activate enzymes, pancreatic lipase and cholesterol esterase.
   iii) These combine with free fatty acids and monoglycerides to form minute particles called micelles and help in their absorption in the intestines.
   iv) These stimulate intestinal peristalsis.
   v) These stimulate bile production in liver. Since these are excreted in the bile and are reabsorbed to a considerable extent in the intestines and returned to the liver, they ensure continuous secretion of bile by the liver.
   vi) These keep cholesterol in solution in gallbladder bile.

Check Your Progress 3

1) Passive transport and active transport

2) Simple diffusion, facilitated diffusion and exchange diffusion.

3) **Exchange Diffusion:** A type of carrier-dependent transport has been shown to operate in the passage of certain ions and amino acids. This is called

exchange diffusion. For each molecule or ion transported into the cell, a similar molecule is transported out of the cell on the return trip of the carrier. This type of diffusion is responsible for the major exchange of labeled ions and molecules for non-labeled ions.

Check Your Progress 4

1) Absorption rate of glucose is higher than that of fructose because glucose is transported actively whereas fructose is absorbed by diffusion.
2) Sucrase
3) Maltose, Isomaltose

Check Your Progress 5

1) Bile.
2) Fat.
3) Free cholesterol.
4) Activity of pancreatic lipase, secretion of bile and lipid synthetic activity of intestinal mucosa are the factors which influence the absorption of lipids.

Check Your Progress 6

1) Pepsin
2) Peptides, aminoacids
3) Nucleoproteins, hydrochloric acid
4) Keto acids
5) Gastric Digestion: The proteolytic enzyme present in gastric juice is pepsin. Pepsin can hydrolyse peptide bonds in the interior of the protein molecule. It hydrolyses mainly peptide bonds. Since food remains in the stomach for a limited time, pepsin hydrolyses dietary proteins mainly into mixture of polypeptides.

$$\text{Dietary protein} \xrightarrow{\text{Pepsin}} \text{Polypeptides}$$

If gastric hydrochloric acid production is low and not adequate to maintain the pH of the stomach contents between two and three, protein digestion in the stomach may be negligible. Pepsin is of considerable importance in the digestion of milk proteins in infants.

Check Your Progress 7

1) Faeces: The faeces consist of the food residue remaining in the large intestines after digestion and absorption of food together with intestinal secretions, mucus, desquamated epithelium and enormous number of bacteria. The quantity of faeces formed depends on amount of roughage in the diet.
2) Stercobilin
3) Indole and skatole.
4) Riboflavin, folic acid, Biotin, Vitamin B_{12}