Food is the basic and essential requirement of human for his very existence. The food we eat consists of carbohydrates, proteins, lipids, vitamins and minerals. The bulk of the food ingested is mostly in a complex macromolecular form which cannot, as such, be absorbed by the body.

Digestion is a process involving the hydrolysis of large and complex organic molecules of foodstuffs into smaller and preferably water-soluble molecules which can be easily absorbed by the gastrointestinal tract for utilization by the organism. Digestion of macromolecules also promotes the absorption of fat soluble vitamins and certain minerals

Gastrointestinal tract

Digestion as well as absorption are complicated processes that occur in the gastrointestinal tract (GIT) involving many organs. The diagrammatic representation of GIT is depicted in Fig.5.2, and the essential organs with their respective major functions are given in Table 5.1. The digestive organs possess a large reserve capacity. For instance, pancreas secretes enzymes 5-10 fold higher than required for digestion of foods normally ingested. The digestion and absorption of individual foods, namely carbohydrates, proteins and lipids is described here.

Table (5-1)

Organs of gastrointestinal tract with their major functions in digestion and absorption	
Organ	*Major function(s)*
Mouth	Production of saliva containing α-amylase; partial digestion of polysaccharides
Stomach	Elaboration of gastric juice with HCl and proteases; partial digestion of proteins
Pancreas	Release of $NaHCO_3$ and many enzymes required for intestinal digestion
Liver	Synthesis of bile acids
Gall bladder	Storage of bile
Small intestine	Final digestion of foodstuffs; absorption of digested products
Large intestine	Mostly absorption of electrolytes; bacterial utilization of certain non-digested and/or unabsorbed foods

CARBOHYDRATES

The principal dietary carbohydrates are polysaccharides (starch, glycogen), disaccharides (lactose, sucrose) and, to a minor extent, mono saccharides (glucose, fructose).

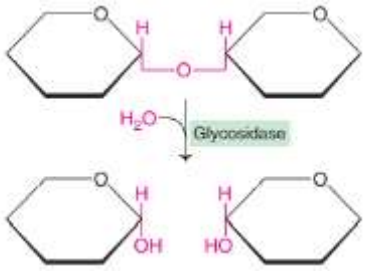

Figure 5-1: Hydrolysis of a glycosidic bond

Digestion

The digestion of carbohydrates occurs briefly in mouth and largely in the intestine. The polysaccharides get hydrated during heating which is essential for their efficient digestion. The hydrolysis of glycosidic bonds is carried out by a group of enzymes called glycosidases (Fig.5.1). These enzymes are specific to the bond, structure and configuration of monosaccharide units. Digestion in the mouth : Carbohydrates are the only nutrients for which the digestion begins in the mouth to a significant extent. During the process of digestive , salivary α-amylase (ptyalin) acts on starch randomly and cleaves α 1,4-glycosidic bonds. The products formed include α -limit dextrins, (containing about 8 glucose units with one or more α -1,6-glycosidic bonds) maltotriose and maltose.

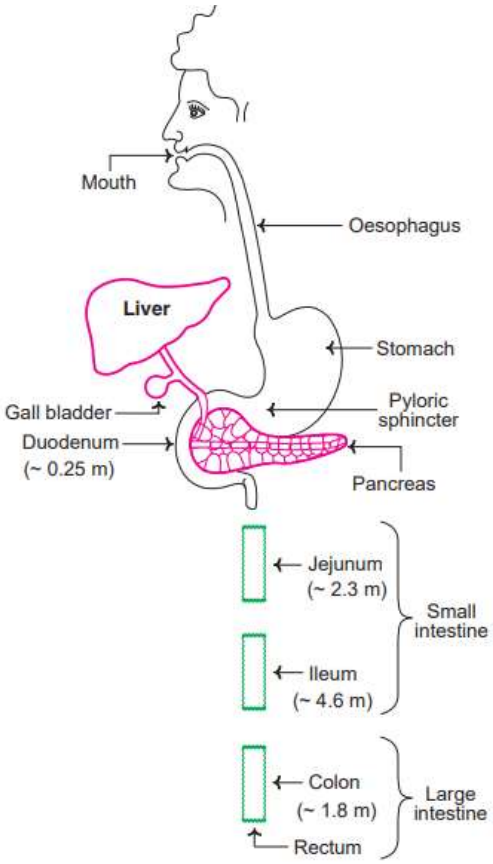

Figure 5-2: Diagrammatic representation of gastrointestinal tract

Carbohydrates not digested in the stomach : The enzyme salivary amylase is inactivated by high acidity (low pH) in the stomach. Consequently, the ongoing degradation of starch is stopped.

Digestion in the small intestine :

The acidic dietary contents of the stomach, on reaching small intestine, are neutralized by bicarbonate produced by pancreas. The pancreatic α -amylase acts on starch and continues the digestion process. Amylase specifically acts on α 1,4-glycosidic bonds and not on α 1,6-bonds. The resultant products are disaccharides (maltose, isomaltose) and oligosaccharides. The final digestion of di- and oligosaccharides to monosaccharides (Fig.5.3) primarily occurs at the mucosal lining of the upper jejunum. This is carried out by oligosaccharidases (e.g. glucoamylase acting on amylose) and disaccharidases (e.g. maltase, sucrase, lactase). The enzyme sucrase is capable of hydrolysing a large quantity of table sugar (sucrose). In contrast, lactase (E-galactosidase) is the rate limiting, and, consequently, the utilization of milk sugar (lactose) is limited in humans.

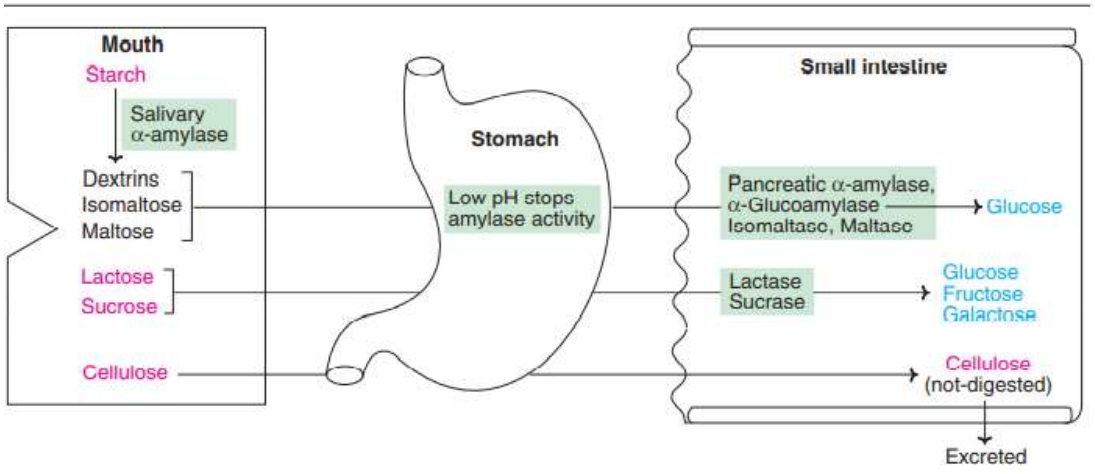

Figure 5-3: Overview of digestion of carbohydrates

Absorption of monosaccharides

The principal monosaccharides produced by the digestion of carbohydrates are glucose, fructose and galactose. Of these, glucose accounts for nearly 80% of the total monosaccharides. The absorption of sugars mostly takes place in the duodenum and upper jejunum of small intestine There exists a considerable variation in the absorption of different monosaccharides. The relative rates of absorption of important monosaccharides in comparison with glucose are given below

(Glucose — 100 , Galactose — 110 , Fructose — 43 , Mannose — 20

Xylose — 15 , Arabinose — 9)

It is observed that hexoses are more rapidly absorbed than pentoses. Further, among the monosaccharides, galactose is most efficiently absorbed followed by glucose and fructose. Insulin has no effect on the absorption of sugars.

PROTEINS

The proteins subjected to digestion and absorption are obtained from two sources— dietary and endogenous The intake of dietary protein is in the range of 50-100 g/day. About 30-100 g/day of endogenous protein is derived from the digestive enzymes and worn out cells of the digestive tract. The digestion and absorption of proteins is very efficient in healthy humans, hence very little protein (about 5-10 g/day) is lost through feces. Dietary proteins are denatured on cooking and therefore, easily digested. Proteins are degraded by a class of enzymes— namely hydrolases— which specifically cleave the peptide bonds, hence known as peptidases. They are divided into two groups

1. Endopeptidases (proteases) which attack the internal peptide bonds and release peptide fragments, e.g. pepsin, trypsin.

2. Exopeptidases which act on the peptide bonds of terminal amino acids. Exopeptidases are subdivided into carboxypeptidases (act on C-terminal amino acid) and aminopeptidases (act on N-terminal amino acid).

The proteolytic enzymes responsible for the digestion of proteins are produced by the stomach, the pancreas and the small intestine. Proteins are not digested in the mouth due to the absence of proteases in saliva.

I. Digestion of proteins by gastric secretion

Protein digestion begins in the stomach. Gastric juice produced by stomach contains hydrochloric acid and a protease proenzyme namely pepsinogen. Hydrochloric acid : The pH of the stomach is < 2 due to the presence of HCl, secreted by parietal (oxyntic) cells of gastric gland. This acid performs two important functions-denaturation of proteins and killing of certain microorganisms. The denatured proteins are more susceptible to proteases for digestion. Pepsin : Pepsin (Greek : pepsis—digestion) is produced by the serous cells of the stomach as pepsinogen, the inactive zymogen or proenzyme. Pepsinogen is converted to active pepsin either by autocatalysis, brought about by other pepsin molecules or by gastric HCl (pH < 2). Removal of a fragment of polypeptide chain (44 amino acids in case of pig enzyme) makes the inactive enzyme active after attaining a proper conformation.

Pepsin is an acid-stable endopeptidase optimally active at a very low pH (2.0). The active site of the enzyme contains 2 carboxyl groups, which are maintained at low pH.

II. Digestion of proteins by pancreatic proteases

The proteases of pancreatic juice are secreted as zymogens (proenzymes) and then converted to active forms. These processes are initiated by the release of two polypeptide hormones, namely cholecystokinin and secretin from the intestine (Fig.8.6).

Release and activation of zymogens :

The key enzyme for activation of zymogen is enteropeptidase (formerly enterokinase) produced by intestinal (mostly duodenal) mucosal epithelial cells. Enteropeptidase cleaves off a hexapeptide (6 amino acid fragment)

from the N-terminal end of trypsinogen to produce trypsin, the active enzyme. Trypsin, in turn, activates other trypsinogen molecules

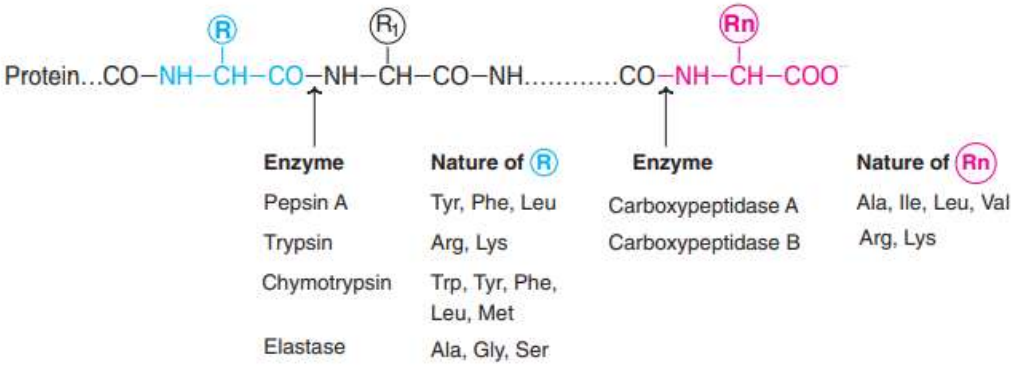

Figure (5-4): Digestion of proteins—Specificity of enzyme cleavage of peptide bonds. (R1 can be from any amino acid)

(autocatalysis). Further, trypsin is the common activator of all other pancreatic zymogens to produce the active proteases, namely chymotrypsin, elastase and carboxypeptidases (A and B). Specificity and action of pancreatic proteases : Trypsin, chymotrypsin and elastase are endopeptidases active at neutral pH. Gastric HCl is neutralized by pancreatic NaHCO3 in the intestine and this creates favourable pH for the action of proteases.

III. Digestion of proteins by small intestinal enzymes

The luminal surface of intestinal epithelial cells contains aminopeptidases and dipeptidases. Aminopeptidase is a non-specific exopeptidase which repeatedly cleaves N-terminal amino acids one by one to produce free amino acids and smaller peptides. The dipeptidases act on different dipeptides to liberate amino acids (Fig.5.5). Absorption of amino acids and dipeptides

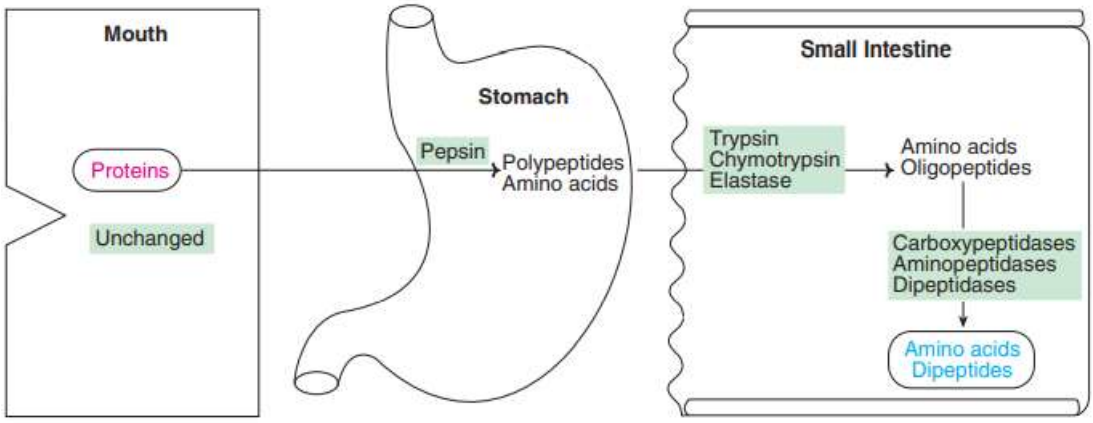

Figure 5-5: Overview of digestion of proteins

The free amino acids, dipeptides and to some extent tripeptides are absorbed by intestinal epithelial cells. The di- and tripeptides, after being absorbed are hydrolysed into free amino acids in the cytosol of epithelial cells. The activities of dipeptidases are high in these cells. Therefore, after a protein meal, only the free amino acids are found in the portal vein The small intestine possesses an efficient system to absorb free amino acids. L-Amino acids are more rapidly absorbed than D-amino acids. The transport of L-amino acids occurs by an active process (against a concentration gradient), in contrast to D-amino acids which takes place by a simple diffusion.