

1.1 Comparative study of nutritional apparatus (Structure and Function)

All living organisms require energy and nutrients for their growth and sustenance. Plants and animals differ in their mechanism to seek them. Animals generally ingest, digest, absorb and assimilate the food. Their food contains mainly carbohydrates which is a readymade source of energy, fats are a reserved source of energy and proteins provide amino acids, the building blocks of the body. They also derive minerals and vitamins from the food they ingest. Plants are capable of synthesizing their own food. Nutrition in plants and animals therefore differs grossly as described below.

1. Autotrophic nutrition - Organisms that synthesize their own food from simple substances are called autotrophs. Autotrophs are differentiated into the following types:

a) Photosynthetic autotrophs - Plants and some organisms like *Volvox* and *Euglena* are able to synthesize complex food material from simple inorganic substances like carbon dioxide and water using the energy of sunlight by a process called photosynthesis. They are called photosynthetic autotrophs.

b) Chemosynthetic autotrophs - Some bacteria and flagellates like *Chilomonas* synthesize complex food material using chemical energy derived from oxidation of compounds such as hydrogen sulphide, ammonia, iron and sulphur. They do not require sunlight as a source of energy. They are called chemosynthetic autotrophs.

2. Heterotrophic nutrition - Organisms that are unable to synthesize their own food material and depend on other plants and animals for their food are called heterotrophs. Heterotrophs are differentiated into different types viz. holozoic, parasitic and saprophytic.

a) Holozoic nutrition - Organisms exhibiting holozoic nutrition obtain nourishment by feeding on other organisms. Complex organic substances are ingested without being digested or decomposed. After ingestion, the complex substances are digested, absorbed and assimilated. Depending on the diet they are herbivorous, carnivorous, and omnivorous. All animals from protozoans to mammals exhibit holozoic nutrition.

b) Parasitic nutrition - Parasites obtain nutrients from another living organism which is the host. They are called **ectoparasites** when they live on the body surface of the host and

obtain nourishment by sucking blood. e.g. leech, bed bug, lice. They are called **endoparasites** when they live inside the body of the host. e.g. hookworm and tapeworm.

c) Saprophytic nutrition - Organisms that obtain their food from decomposing dead matter exhibit saprophytic nutrition and are called saprophytes. They secrete enzymes outside their body, break down the complex food material and absorb the soluble simple products. e.g. fungi and bacteria. Animals, from simple to complex, live in diverse environments and obtain their nourishment in different ways. The type of the feeding apparatus correlates with the habitat and the type of food available to the organism. Following are some examples.

1.1.1 *Amoeba* - Food vacuole:

Amoeba is a simple unicellular organism. It lives in fresh water and feeds on particulate matter like bacteria, diatoms, flagellates, ciliates, rotifers etc. It is able to distinguish between organic matter and inorganic sand particles and also exhibits a preference to certain types of food in spite of its simple organization. Nutrition is holozoic. Since there is no mouth, *Amoeba* takes in food particles through the cell membrane in one of the following ways :-

1. Circumvallation
2. Circumfluence
3. Import
4. Invagination

In **circumvallation**, an active and mobile prey is taken in by pseudopodia, cell 'extensions', which enters the cytoplasm. This process is also referred to as **phagocytosis**.

In **circumfluence** too, pseudopodia are formed that engulf the food particles to form a food vacuole. However, in contrast to circumvallation, the prey is motionless and maintains a close contact with pseudopodia.

Import is taking in of food particles by the cell membrane passively. The food particle sinks into the cytoplasm at the point of contact and forms a food vacuole.

In **invagination**, the prey which comes in contact with the cell membrane is first rendered inactive by toxic secretions and is then engulfed to form a food vacuole. Formation of pseudopodia is not necessary. The digestion is intracellular and takes place in food vacuole. Lysosomes containing digestive enzymes attach to the food vacuole, pour their enzymes and accomplish chemical breakdown of the food material until it is in the form of small, soluble

molecules that can be absorbed into the cytoplasm. The undigested wastes are extruded from the cell.

Fig 1.1.1 Formation of food vacuole in *Amoeba*

1.1.2 *Hydra* - Gastrovascular cavity/Coelenteron:

Hydra belongs to a group of organisms called Cnidarians. It lives in a fresh water and feeds on minute crustaceans, insects and even fresh embryos. It possesses an internal cavity called **gastro vascular cavity (GVC)** or **coelenteron**. The GVC has only one opening at the anterior end, the mouth, which serves to ingest food as well as egest undigested waste materials. *Hydra* thus, has an incomplete digestive cavity and shows both extracellular and intracellular digestion. The mouth is encircled by tentacles which are organs for food capture, offense and defense. The tentacles are long and flexible, armed with stinging cnidoblasts. These seize and immobilize prey like small insects, which is taken into the GVC through the mouth. Once the prey reaches the GVC the process of digestion begins at once. The GVC is lined by gastroderm made up of flagellar cells, gland cells and amoeboid cells. The flagellar cells ensure the circulation of food in the GVC. Extracellular digestion takes place in the GVC. The gland cells secrete enzymes which first kill the prey and then disintegrate it. The digestive enzymes partly digest protein and fat. The partially digested food is now in the form of small fragments that can be engulfed by the nutritive amoeboid cells by phagocytosis for further digestion. Final digestion takes place in the food vacuoles. Thus, digestion is both, extracellular in the GVC and intracellular in the nutritive cells. Proteins, carbohydrates and fats are digested in *Hydra*. The products of digestion are distributed to all cells by diffusion. Additionally, some gastrodermal cells containing food vacuoles may get detached and distribute food to the cells. Reserve food in the form of glycogen and fats may be stored in the gastrodermal cells. The undigested wastes are eliminated through the mouth.

Fig.1.1.2a : Diagrammatic sketch of *Hydra* capturing prey

Fig.1.1.2.b : L.S. of *Hydra*

1.1.3 Cockroach

An incomplete digestive system has a major disadvantage. A single opening for ingestion and egestion result in all activities of digestion getting mixed up in a single open cavity. Enzymes needed for digestion must be poured into the entire cavity and the entire cavity must be able to absorb digested food. A digestive system would be more effective if there was a tubular digestive tract with parts having specialized functions. For such a system, two openings are needed, one to take in food and the other to expel the wastes.

Such a complete digestive system, with two openings, a mouth and an anus is seen in the insect, cockroach. Cockroach is a common nocturnal pest belonging to Class Insecta of Phylum Arthropoda. It is omnivorous, feeds on various types and sizes of food. The digestive system comprises of the mouth parts, the digestive tract and the digestive glands.

The mouth parts of feeding appendages are adapted to the varied diet of cockroach and are of the capturing and cutting type. It is the most basic type of the mouth parts and includes appendages on the head that serve that serve as crushing teeth, grasping jaws and a probing and tasting tongue. A pair of mandibles is present one on either side of the mandible. These are serrated and used to cut food into pieces. A pair of maxillae is present one on either side of the mandible. The maxillae help to hold the food and thus assist in ingestion. The digestive tract is divisible into three regions; the foregut or **stomodaeum**, the midgut or **mesenteron** and the hindgut or **proctodaeum**.

The foregut includes the mouth, pharynx, oesophagus, crop and gizzard. The mouth marks the beginning of the alimentary canal. It is a small aperture between the maxillae and mandibles on either side and leads into a small buccal cavity. A small tongue or hypopharynx is present on the floor of the buccal cavity. The buccal cavity opens into a short pharynx which leads into the oesophagus. The oesophagus is narrow, thin-walled and continues into the **crop**. The crop is the largest part of the foregut, occupies the entire space in the thorax, and extends into the anterior part of the abdominal region too. It is thin-walled and acts as a temporary reservoir for ingested food. The last part of the foregut is the **gizzard** or the **proventriculus**. It is thick, biconvex and invested with a thick layer of muscle cells. The inner wall of the gizzard is differentiated into an anterior part which has six chitinous teeth and a posterior part with cushion-like pads covered with bristles. The teeth serve to crush the food while the bristles act as a strainer to filter the food.

The midgut or the mesenteron is undivided. It is tubular, lined with columnar epithelium that secretes digestive enzymes. Food is digested and absorbed here. At the junction of the foregut and midgut are present eight slender blind tubules, the **hepatic caecae**. These open into and increase the surface area of the midgut and also secrete digestive juices. The midgut is lined by a **peritrophic** membrane which protects the lining of the midgut but is permeable to enzymes and digested food.

The hind gut or the proctodaeum is divisible into the ileum, colon and rectum. The ileum is short and narrow. At the junction of mesenteron and the ileum are present numerous, about 80-90, yellowish, hair-like processes called **Malpighian tubules**. These open into the ileum and are excretory in function. The ileum continues into a long, coiled colon which further continues into a broad rectum. The rectal wall shows special glands called rectal glands that serve to absorb water from the undigested food and converts it into almost solid faeces. The rectum finally opens to the exterior through the anus through which the faeces are egested.

Fig.1.1.3a Digestive system of Cockroach

Fig.1.1.3b Cockroach-T.S. of Gizzards

The digestive glands include the salivary glands, inner lining of mesenteron and the hepatic caecae. A pair of salivary glands is situated on either side of the crop in the thoracic cavity. The salivary ducts from each gland unite to form a common salivary duct and open into the pharynx. They secrete saliva which contains digestive enzymes.

Physiology of digestion

Cockroach is omnivorous and feeds on all types of matter. Food is sensed by the antennae and picked up by the maxillae. The mouth parts are of the capturing and cutting type and mastication is done by the mandibles. During mastication, the food is mixed and moistened by saliva. Saliva contains amylase that hydrolyze carbohydrates. The food passes through the oesophagus into the crop. In the crop, digestion continues by enzymes from the midgut that ascends into the crop through the gizzards. These enzymes include amylases, proteases and lipases. The gizzard grinds the food particles and filters it. The food entering the midgut is thus very fine. The digestive enzymes of the hepatic caecae and mesenteron help to digest the food further. The digested food is absorbed by the mesenteron. Undigested food is

stored in the rectum where water is absorbed and almost solid faeces are formed that is egested through the anus.

1.1.4 AMPHIOXUS-Filter feeder

Animals with tubular alimentary tract and a complete digestive system may ingest food in the form of fluids, microscopic or near microscopic solids and solids of greater size. Many aquatic animals live on microscopic solid food. Ingestion here, takes the form of **filter feeding**. This type of ingestion is common in burrowing and sessile animals. An example of this type is *Amphioxus* which lives in tropical and temperate seas. It is found near the shore, where it burrows in sand and conceals all but its anterior ends. It feeds on diatoms, desmids, small protozoans and other microorganisms.

The digestive system consists of an alimentary canal and digestive glands. The alimentary canal includes the oral hood and vestibule, wheel organ, velum, mouth, pharynx or branchial sac, oesophagus, intestine and anus. At the anterior tip of the rostrum is an aperture which is surrounded by a frill-like membrane, the **oral hood**. The margins of the hood are edged with oral or **buccal cirri** which are sensory in function and help to assess water quality. In feeding, the cirri are folded over the entrance to the oral hood, excluding large particles. The oral hood encloses a funnel-shaped cavity called **vestibule** that receives water and food particles. The inner lining of the vestibule shows several ciliated finger-like projections from a horse-shoe shaped base. This represents a **wheel organ**. It produces whirling currents of water to sweep the food particles into the mouth.

Behind the base of the wheel organ is a vertical membrane, the velum. It separates the vestibule from the pharynx. The mouth is an opening in the velum, and may be closed by circular muscle fibres that surround it. Twelve slender, sensory velar tentacles protect the mouth, and when folded across it, act as a strainer. The mouth leads into the pharynx, a wide tube extending nearly half the body length. The lateral wall of the pharynx is perforated by gill slits. Surrounding the pharynx is a large cavity, the atrium. It is closed anteriorly but opens into the exterior through an aperture, the atriopore. On the floor of the pharynx is present the **endostyle**. It is a ciliary and glandular groove which contains tracts of ciliated cells alternating with bands of mucus-secreting cells.

Fig.1.1.4 Digestive system of *Amphioxus*

The pharynx continues into a short oesophagus which further continues into the midgut. At the junction of the oesophagus and midgut is present the **hepatic diverticulum** which produces digestive enzymes. The intestine is a straight, ciliated tube divided into the midgut and hindgut. The midgut narrows posteriorly into the iliocolon ring beyond which is the narrow intestine or hindgut that opens out through the anus. The digestive glands include the epithelial gland cells that are scattered in the epithelium of the whole intestine and the hepatic diverticulum that secrete digestive enzymes.

Physiology of digestion

The oral cirri, wheel organ and the velar tentacles help in filtration of the food laden water. The food is carried into the mouth with the current of water produced by cilia on the gills. In the pharynx, the endostyle secretes abundant mucus. Food particles brought by the water current get entangled in the mucus. The food laden mucus enters the oesophagus in the form of a cord, called food cord. In the iliocolon ring the food cord is rotated by action of cilia. This helps in fragmentation of food particle and also ensures mixing of food with the digestive enzymes. Digestion takes place extracellularly as well as intracellularly in the midgut. Absorption of digested food takes place partly in the midgut and completely in the hindgut. Elimination of faeces is through the anus by strong ciliary action.

1.1.5 Pigeon

The digestive system of birds is well developed and modified for aerial mode of life. A large surface area, high temperature and increased metabolic activity of birds demand a high food intake. The food is efficiently utilized inspite of passing rapidly through the gut. Birds are able to convert one-third of their food into energy as opposed to mammals who can convert only one-tenth of their food into energy. Pigeon is **graminivorous** and its diet chiefly consists of cereals, pulses and seeds. The digestive system is complete and includes the alimentary canal and digestive glands. The alimentary canal is short and comprises the foregut, midgut and hindgut. The foregut consists of mouth, buccal cavity, pharynx, oesophagus and stomach. The mouth is wide opening bounded by the upper and lower horny jaws. The jaws are modified into a beak. The mouth leads into the buccal cavity. It contains the tongue,

internal nares and salivary glands. Teeth are absent. The tongue is flat, fleshy, non-muscular, narrow in front and bifid behind. It has taste buds and mucus glands and helps in swallowing food. Situated behind the buccal cavity is the pharynx which leads into the oesophagus. The oesophagus is a narrow, distensible tube. In the neck region, it enlarges to form a bilobed sac, the **crop**. It stores the food which is swallowed whole and enables the bird to ingest a considerable quantity of grains quickly. The crop contains glands that secrete mucus which helps to moisten is regurgitated and fed to the young. It is produced by the disintegration of the epithelial cells of the crop itself and is termed '**pigeon's milk**'. Its secretion is controlled by the hormone prolactin. The stomach has two distinct chambers, the anterior **proventriculus** and posterior **ventriculus** or **gizzard**. The proventriculus is tubular, thick-walled, glandular and contains gastric glands. The ventriculus or gizzard is large, hard, flattened laterally forming a biconvex structure. The walls of the gizzard are muscular and its cavity is small. The cavity contains small pebbles, stones, grit called gastroliths which are swallowed by the bird. This helps to crush the food material and thus acts as a grinding mill. The lining of the gizzard contains tubular glands the secretion of which is thick, horny, yellowish or green. The gizzard opens into the small intestine by a pyloric opening guarded by a sphincter called pyloric valve.

The midgut includes the small intestine and is differentiated into anterior duodenum and posterior ileum. the duodenum leaves the gizzard dorsally, close to the entry of the proventriculus and forms a U-shaped loop posteriorly. The pancreas is present between the two limbs. The duodenum receives three pancreatic ducts and two bile ducts. Its wall is thrown into folds called villi and contains glandular cells called **crypts of Leiberkuhn** and goblet cells. These cells secrete intestinal juice and mucus respectively. The ileum is a long, coiled tube lined by villi that help to increase surface area of absorption.

The hindgut includes the large intestine which is differentiated into rectum and cloaca. The ileum continues as the rectum. The rectum is short and has the same diameter as the ileum. At the junction of the two are present a pair of small blind pouches, the **colic caecae**. They absorb water from the food. The rectum opens into the cloaca, the terminal part of the alimentary canal, by an anal sphincter. The digestive and associated glands in pigeon include the buccal glands, tubular glands, gastric glands, liver, pancreas and intestinal glands. The

buccal glands secrete mucus that softens the food. The gastric glands secrete gastric juice that contains peptic enzymes. The liver is large, bilobed and dark red in colour. It secretes bile which is carried by two bile ducts to the duodenum. Gall bladder is absent. The pancreas is a compact, pinkish gland situated in the loop of the duodenum. It secretes pancreatic juice which is by the three pancreatic ducts to the duodenum. The intestinal glands in the wall of the intestine also secrete digestive enzymes. The secretion of the tubular glands lining the gizzard makes the food acidic.

Fig.1.1.5 Digestive system of Pigeon

Physiology of digestion

The food, mainly grains, is picked up by the beak, softened in the mouth by mucus secreted by buccal glands and is swallowed whole. It is stored in the crop where it is further softened by mucus and bacterial action. The food passes into the proventriculus where it mixes with gastric juice and acted upon by peptic enzymes. It enters the gizzard where it is mechanically broken down by grinding action and is also made acidic by the secretion of the tubular glands. The partially digested food, chyme, passes through the pylorus into the duodenum. In the duodenum it mixes with bile, pancreatic juice and intestinal juice. The enzymes present in these juices help to digest the carbohydrates, proteins and fats. Bile helps in the digestion and absorption of fats. Digestion, absorption and assimilation occur in the small intestine. The undigested remains pass into the rectum where water from the remains is absorbed. The faecal matter is semisolid and passes into the cloaca and egested through the cloacal aperture.

1.1.6 Ruminant stomach

The stomach of mammals presents many variations in form, of which the most pronounced are seen among the ungulates, especially the ruminants. **Ruminants** are herbivores that feed on plant material with a high fibre content. The stomach of the ruminant is the most specialized organ of the digestion of plants material. They are unable to digest the cellulose directly since they lack the enzymes that breaks down the cellulose in the cell wall. They depend on microbes for cellulose digestion. Digestion in ruminants occurs sequentially in a

four chambered stomach. The four chambers are rumen, reticulum, omasum or psalterium and abomasum.

Rumen: The food from the oesophagus enters the rumen. It is the largest chamber with an inner wall resembling a turkish towel. The unmasticated food is stored here. This allows the animal to gulp more and sufficient food in a shorter time. The food is softened by mucus and undergoes bacterial fermentation. Microbes in the rumen digest cellulose. The great size of rumen allows food to accumulate and ensures that sufficient time is allowed for slow breakdown of cellulose.

Reticulum - This is the next chamber. Its wall has a honeycomb like structure and is subdivided into cavities in which the food is made up into small masses or boluses; these are regurgitated into the oral cavity, to be chewed at leisure. A small fold of tissue separates the rumen and reticulum. The two chambers are collectively called rumino-reticulum.

Omasum or **Psalterium** - This is the third chamber. The wall bears numerous folds, like the pages of a book. The regurgitated cud when swallowed enters this chamber. Here it is filtered so as to remove water from the cud.

Abomasum - This is the true stomach and bears gastric glands. Hydrochloric acid and digestive enzymes are secreted into the abomasum.

Fig.1.1.6 Ruminant stomach

Physiology of digestion

Rumen and reticulum contain microbes mainly anaerobic bacteria and protozoans which share a symbiotic relationship with the ruminants.

The ruminants are herbivorous. They graze or browse on various plant material which is partially chewed, mixed with saliva and goes to rumen through oesophagus. Saliva acts as pH stabilizer and also as lubricant which helps easy movement of the comparatively bigger particles of food from mouth to rumen through oesophagus. The ruminant food contains mainly fibres composed of complex carbohydrates, which are broken down into simple sugars or monosaccharides. This process of breaking down cellulose based fibres into sugar is carried out by the anaerobic symbiotic microbes present in the rumen and reticulum,

hence it is a biological process, involving **fermentation**. Since the ruminants graze hurriedly, the ingested food in rumen contains large pieces of plant parts, which may take many days to get completely digested. These large particles are brought back into the mouth by the animal when it is at rest for further chewing, during which they are converted into fine particles and more saliva is added to it forming the cud. This process is called regurgitation. The regurgitated cud then goes directly to the reticulum. Breaking the fibrous cellulose into fine particles, further accelerates the process of its degradation by the symbionts.

The symbiotic micro flora in the rumen and reticulum, secrete enzyme cellulase which converts cellulose into monosaccharides. The sugars are then subjected to fermentation which in turn results in the formation of lactic acid and fatty acids such as acetic acid, propionic acid, butyric acid and valeric acid, which are absorbed through the walls of rumen and reticulum and act as source of energy for the host. The protein digesting enzymes secreted by the symbionts, degrade proteins into amino acids, which are used by the symbiotic microbes for their growth and multiplication, thus maintaining their population in the rumen and reticulum. These rumen microbes are also capable of producing amino acids from available ammonia and urea, which is a special feature. This is very important, as the food of ruminants is poor in protein. Thus, the protein requirement is taken care of. The mixture of semi digested food and the symbiotic microbes then is passed into omasum, where water is absorbed and then it is further transferred to abomasum, where the microbes are digested to get back the amino acids, which are then absorbed by the host. Hence the amino acids are not lost, thus completing the protein digestion.

1.2 Physiology of digestion in man

The human digestive system resembles that of other vertebrates. Digestion is extracellular and involves the breakdown of food into forms that can be used by the body. Food is digested within the tube-like digestive tract, also called **gastrointestinal tract** (GI) or alimentary canal. The digestive tract is differentiated into different regions, each assigned specific functions. The processes involved in digestion may be grouped into mechanical and chemical. In addition, digestion is also dependent upon the secretions of three types of glands, the salivary glands, the liver, and the pancreas. Mechanical activities are mastication and muscular contractions of the digestive tract. Food is cut, masticated and

broken down into small particles by the teeth. Rhythmic contractions of the muscular walls of the GI tract result in peristaltic movement, ensuring the passage of the food through the tract. Peristaltic also serves to break down food mechanically and aids in mixing it with the secretions of the digestive tract so that chemical digestion is more efficient. Chemical digestion is with the help of enzymes that reduce large food molecules to smaller molecules by hydrolysis. These small molecules are absorbed into blood and transported to the cells by the body. The major macromolecules in the diet include the polysaccharides, triglycerides and proteins. Digestion is complete when each one of these macromolecules is hydrolyzed to monosaccharides, fatty acids and glycerol and amino acids respectively. The digestion occurs in the step-wise manner until the macromolecules are broken down into their smallest components which can be absorbed. Each of these steps is catalyzed by a specific enzyme and occurs in a particular area of the digestive tract. Carbohydrates are acted upon by carbohydrases, fats by lipases and proteins by proteases.

Digestion in the mouth

The process of the digestion begins in the mouth where the food is chewed and broken down by the teeth. As the food is chewed it is mixed with the saliva, secreted by the three pairs in the salivary glands in the mouth. Saliva consists of mucus and the digestive enzyme, salivary amylase or ptyalin. Ptyalin initiates chemical digestion of carbohydrates. It breaks down starch into disaccharides like maltose. Although lipids and proteins are also mixed with saliva, there is no chemical breakdown of these substance in the mouth. The pH of saliva ranges from 6.0 to 7.4, a necessary condition for effectiveness of ptyalin. After food is chewed, moistened and mixed in the mouth it forms a semisolid mass, or bolus. This enters the pharynx aided by the tongue and is swallowed into the oesophagus. The lining of the oesophagus secretes thick, lubricating mucus. There is no chemical digestion in the oesophagus since its secretions do not contain digestive enzymes. The bolus passes into the stomach.

Digestion in the stomach

In the stomach, mechanical digestion continues by peristalsis. Distension of stomach due to food causes the release of a hormone, gastrin from the stomach wall. It is carried by blood

circulation to the stomach glands; where it stimulates release of gastric juice. Gastric juice contains mucus, hydrochloric acids and enzymes. Hydrochloric acid provides an acidic medium, acts as an antiseptic and activates pepsinogen. The major enzyme present is pepsin which is released in its inactive form, pepsinogen. Hydrochloric acid converts it to active pepsin. Pepsin hydrolyzes almost all proteins to large polypeptides. Presence of HCL makes the medium acidic in the stomach. The salivary amylase in the bolus is rendered inactive in acidic pH and hence there is no further carbohydrates digestion in the stomach. Lipase activity is low in the stomach. Nearly 99% of lipid digestion occurs in the small intestine. As peristalsis continues, the semi-liquid acidic mass called **chyme** moves towards the lower end of the stomach and passes through the pyloric sphincter into the small intestine.

Digestion in the small intestine

Chyme enters into the upper section of the small intestine, the duodenum, and causes the release of two hormones from the intestinal wall, secretin and cholecystokinin. Secretin stimulates the pancreas to secrete pancreatic juice, cholecystokinin stimulates the gall bladder to contract and release bile. The duodenal wall secretes mucus containing a large amount of bicarbonate ions making it alkaline and neutralizing the acidic chyme that enters the duodenum. This provides a suitable environment for the activity of the digestive enzymes in the duodenum. Digestive enzymes from the pancreas along with bile from the liver begin their breakdown of various substances. Pancreatic juice contains pancreatic amylase which acts on polysaccharides, not acted upon in the mouth, and hydrolyzes them to disaccharides. As the chyme moves along the small intestine, the digestion of disaccharides is complete by enzymes secreted by intestinal glands. Thus the final products of carbohydrate digestion are the monosaccharides viz. glucose, fructose and galactose. There are three major protein digesting enzymes in the pancreatic juice: trypsin, chymotrypsin and carboxypeptidase. These are secreted in their inactive forms and become active after they reach the duodenum. Trypsinogen, the inactive form is activated to trypsin by the initial enzyme, enterokinase. Trypsin is responsible for the activation of chymotrypsin and carboxypeptidase. Both trypsin and chymotrypsin hydrolyze proteins, peptones and proteoses to polypeptides. Carboxypeptidases hydrolyze polypeptides to dipeptides. The

initial wall secretes an enzyme, erepsin that hydrolysis the peptides into amino acids. The digestion of all proteins, then, releases free amino acids as the final product. Bile juice from the gall bladder is poured into the duodenum. Bile is not an enzyme and is not involved in chemical digestion. It however enhances digestion of fats by coating the fat globules, which lowers their surface tension. The bile salts aid in breaking fat globules into small particles. This is known as **emulsification**. The small particles thus formed facilitate chemical digestion by pancreatic lipases. The final products of lipid digestion are fatty acids and glycerol. At the end of the chemical digestion, a completely digested mass called **chyle** is formed. It is now ready to be absorbed and assimilated.

Table 1: Digestive enzymes involved in the digestion of food in man

Site of enzymatic action	Secretion	Glands	Enzymes	Substrate	Product
Oral cavity	Saliva	Salivary gland	Amylase (Ptyalin)	Starch	Maltose
Stomach	Gastric juice	Gastric glands	Pepsin, Renin	Protein Caseinogen	Polypeptide Casein
Duodenum	Bile	Liver	-	Fats (globules)	Emulsified fat (Fat droplets by bile salts)
	Pancreatic juice	Pancreas	Amylase	Starch	Maltose
			Trypsin	Protein	Polypeptides
			Peptidases	Polypeptides	Amino acids
			Lipase	Fats	Fatty acids & Glycerol
Small intestine	Intestinal juice	Intestinal glands	Enterokinase (Enteropeptidase)	Trypsinogen	Trypsin
			Amylase	Starch	Maltose

			Maltase	Maltose	Glucose
			Sucrase	Sucrose	Glucose & Fructose
			Lactase	Lactose	Glucose & Galactose
			Peptidases	Polypeptides	Amino acids