UNIT 6 PHYSIOLOGY OF GASTROINTESTINAL SYSTEM

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6.1 INTRODUCTION

In this unit we shall focus on the gastrointestinal system. The gastrointestinal system, you would realize, is also referred to as the *digestive system* or the *alimentary system*, which deals with the food we eat.

Food, as we all know, is needed as the source of energy, for growth and repair of tissues. As the food passes through the gastrointestinal tract, it is broken down by some physical factors and enzymes until it is in a form suitable for absorption into the blood. After being absorbed, food is utilized in the body. There are some substances which are neither digested nor absorbed. These are excreted in the form of faeces.

What are the organs which form the gastrointestinal tract? What are their functions? What is the mechanism of absorption of the food we eat? These are a few issues discussed in this unit.

Objectives

After studying this unit, you will be able to:

- illustrate the structure and describe the functions of different parts of the digestive system,
- discuss the secretory and digestive functions of salivary glands, stomach, pancreas, liver and intestine, and
- explain the mechanism of absorption of carbohydrates, proteins and fats.

6.2 DESCRIPTION OF THE GASTROINTESTINAL TRACT

You may be familiar with the gastrointestinal tract in our body. The gastrointestinal tract is a long tube which starts at the mouth and ends at the anus. Can you list the organs which form the gastrointestinal tract? List them one by one and tally your responses with the list of organs presented herewith.

- Mouth
- Pharynx
- Oesophagus
- Stomach
- Small intestine
- Large intestine
- Rectum, and
- Anus

Figure 6.1 illustrates the structure of the gastrointestinal tract. Identify the different organs, as mentioned above, here in Figure 6.1.

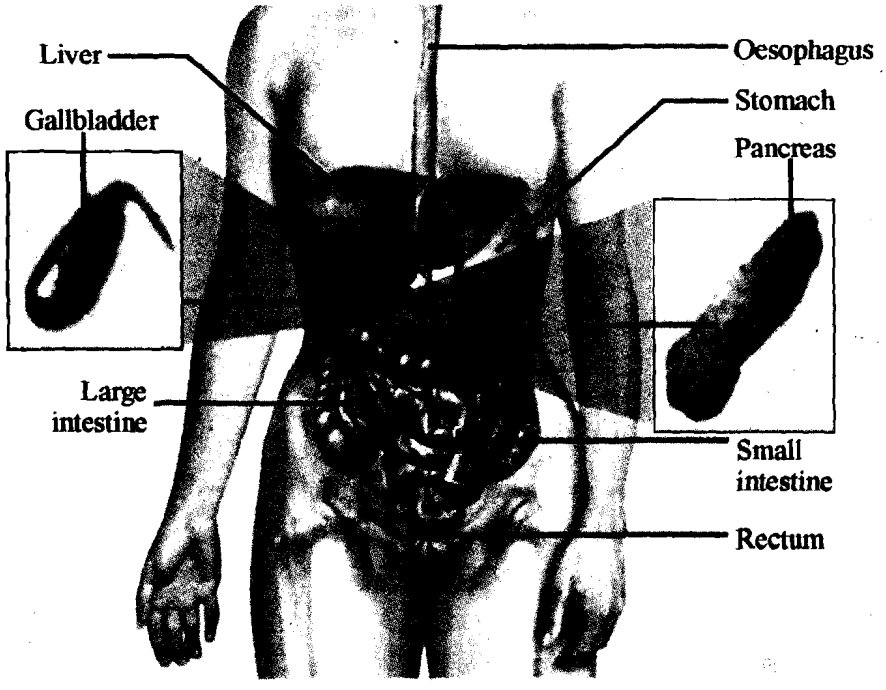

Figure 6.1: Organs of the gastrointestinal tract

As you read on, you will find that some of the functions are common to all parts e.g. the onward movement of the ingested food. But some of the functions of these

organs are very specialized e.g. absorption of products of digestion by the small intestine. Similarly, there is a general structural plan throughout the length of the tract. But in some organs it is modified because of its specific function. Let us first learn about the general structural plan of the gastrointestinal tract. This will help us to understand their function better.

General Structural Plan of the Gastrointestinal Tract

The wall of the gastrointestinal tract consists of four layers of tissue. These are:

- adventitia or outer covering
- muscle layer
- submucous layer, and
- mucous membrane lining

Let us discuss each of these.

1) *Adventitia or outer covering:* In the thorax, the outer covering is made up of loose fibrous tissue and in the abdomen, the organs are covered by a serous membrane called *peritoneum*. The peritoneum is the largest serous membrane of the body.

2) *Muscle layer:* This layer consists of two layers of smooth muscle. The outer layer is a longitudinal muscle layer and the inner layer is a circular muscle layer. But there are some exceptions in some organs.

   Between these two muscle layers, there is a network of nerves called the *myenteric plexus*. It contains both sympathetic and parasympathetic nerves.

   The contraction of this smooth muscle layer is called *peristalsis*. You would realize that it is by peristalsis that the food contents of the gastrointestinal tract are pushed onwards.

3) *Submucous layer:* This layer consists of loose areolar connective tissue. There are lymph vessels, plexuses of blood vessels and nerves. The nerve plexus is *meissner's plexus* which contains both sympathetic and parasympathetic nerves.

4) *Mucous membrane*: This layer is lined by the epithelial cells. Parts of the tract which are subject to mechanical injury, the layer consists of stratified squamous epithelium. Parts of the tract which secrete digestive juice and absorb food materials, the layer consists of columnar epithelium. This layer has three main functions – *protective, secretory* and *absorptive*.

Next, let us learn about the nerve supply of the gastrointestinal tract.

Nerve Supply of the Gastrointestinal Tract

The gastrointestinal tract is supplied by nerves from both sympathetic and parasympathetic nervous system. The parasympathetic supply is provided by cranial nerves, the *vagus nerve*. The sympathetic supply is provided by numerous nerves which emerge from the spinal cord in the thoracic and lumbar regions.

There are a few accessory organs which help in digestion. We shall get to know them now.

Accessory Organs which help in Digestion

The gastrointestinal tract receives various secretions. Some are secreted from the glands in the lining membrane of the organs, e.g. gastric juice by the glands of the stomach.

But some secretions are poured by glands located outside the tract. These are called *accessory organs of digestion*. Their secretions pass through ducts and reach the gastrointestinal tract. They consist of:

- three pairs of salivary glands
- pancreas, and
- liver, gall bladder and biliary tract.

We shall journey through these and the other organs of the gastrointestinal tract next. We shall start our journey from the mouth.

6.3 MOUTH

In this section we shall learn about the mouth and other organs present within, which help in digestion. We shall first look at the structure of the mouth.

Structure

The mouth or oral cavity is a cavity bounded by muscles and bones. The mucous layer of the mouth consists of *stratified squamous epithelium* containing small mucus secreting glands. Superiorly (upper side), the mouth is bounded by a palate. Touch the upper portion of your mouth with your thumb. The hard part you feel is the *palate*. Actually, the palate is divided into the anterior part called the 'hard palate' and posterior part called the 'soft palate'. Figure 6.2 illustrates the structure of the mouth and the parts within. Now open your mouth wide. Can you see that little flap of skin visible at the back of your mouth? This is the *uvula* as you can also observe it in Figure 6.2. It is a curved fold of muscle covered with mucous membrane which hangs down from the soft palate.

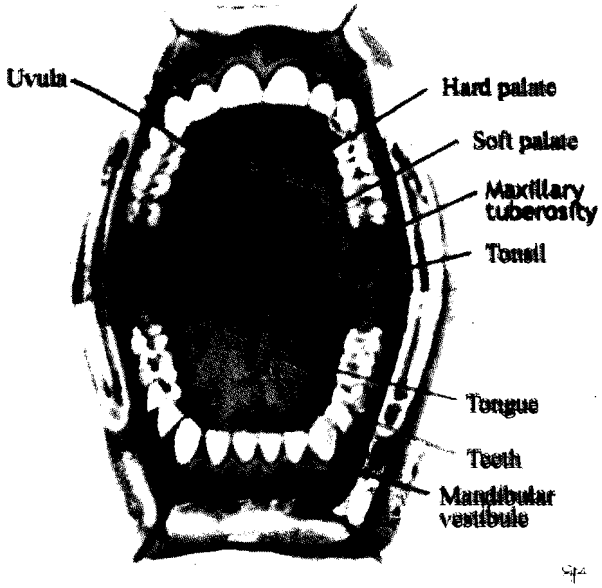

Figure 6.2: Structure of the mouth

In the structure above, you would have noticed that the mouth contains the teeth and the tongue. What is their role in the mouth? We are already aware of their functions. Let us get to know them a little better.

Function

The mouth contains tongue and teeth which take part in mastication (chewing) and *deglutition* (swallowing) and thus help in digestion.

We shall get to know more about these two important parts next. We shall begin with the tongue.

6.3.1 Tongue

The tongue is an important organ. You will agree that the tongue accurately reflects the state of our digestive system. How? Well, you may have experienced that some times when we suffer from stomach upset or discomfort in the abdomen, our tongue too is soar, red or sometimes ulcerated. You may have found yourself looking at your tongue in the mirror, looking for the affected area. As a whole, the tongue has a high value as a diagnostic tool. What is the tongue made up of? Let's find out.

Structure

The tongue is a muscular organ. It is covered with a mucous membrane. The tongue is attached by its base to the hyoid bone and by a fold of its mucous membrane covering called the *frenulum*. The superior surface of the tongue is covered by stratified squamous epithelium with little projections called *papillae* (small nodules of tissue). Papillae contain the taste buds (small and large) as shown in Figure 6.3 and the nerve endings of the sense of taste. There are three types of papillae. These are:

a) *Circumvallate papillae:* These are the largest of the papillae, about 8 to 12 in number. These are arranged in a V-shape.

b) *Fungiform papillae:* These are situated mainly at the tip and the edges of the tongue. They have a flat, rounded head like fungus. The fungiform papillae are rich in blood vessels and have a marked red colour.

c) *Filiform papillae:* These are long and slender and are the smallest of the three types of papillae. They are found to be most numerous on the edges and anterior two thirds of the tongue

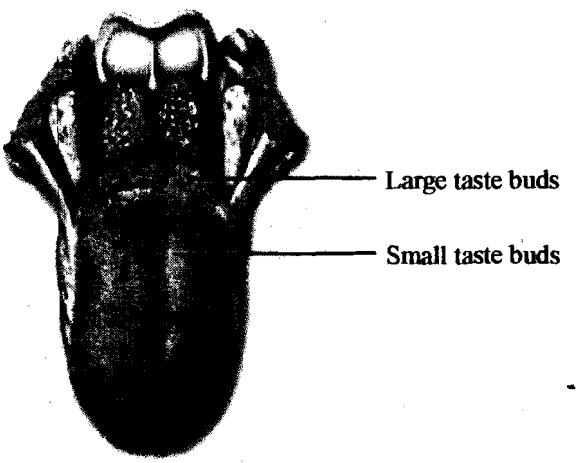

Figure 6.3: Tongue

Our tongue can sense different tastes. Do you know which are the basic tastes and the areas where these are sensed?

In humans, there are four basic tastes – *sweet, sour, bitter and salt* – as you may already know. Bitter substances are tasted on the back of the tongue, sour along the edges, sweet and salty tastes are appreciated mainly at the tip of the tongue. Sour and bitter substances are also tasted on the palate along with some sensitivity to sweet and salt. All four modalities can also be sensed on the pharynx and epiglottis. Having studied about the structure, let us now look at the functions of the tongue.

The tongue plays an important part in mastication or chewing, deglutition or swallowing and in speech. It is the organ of taste. Taste buds are found in the papillae of the tongue.

Now, we move on to the study of the teeth – where are these placed and what are the different types.

6.3.2 Teeth

The teeth are placed in the mandible (the lower jaw bone) and maxillae (the upper jaw bone) as shown in Figure 6.4. Each person has two sets of teeth, the temporary or deciduous or milk teeth and the permanent teeth.

At birth, teeth of both dentitions are present in immature form.

Temporary teeth are 20 in number, 10 in the upper jaw and 10 in the lower jaw. These teeth begin to erupt when the child is about 6 months old and usually are all present by the end of one year. After six years, they begin to fall. Their distribution in both jaws is given in Table 6.1.

Table 6.1: Temporary teeth

Jaw	Molars	Canine	Incisors	Incisors	Canine	Molars
Upper	2	1	2	2	1	2
Lower	2	1	2	2	1	2

The permanent teeth begin to replace the temporary teeth in the sixth year and the dentition is completed by twenty four years. Permanent teeth are 32 in number. Their distribution in upper and lower jaw is indicated in Table 6.2 and illustrated in Figure 6.4.

Table 6.2: Permanent teeth

Jaw	Molars	Pre-molars	Canine	Incisors	Incisors	Canine	Pre-molars	Molars
Upper	3	2	1	2	2	1	2	3
Lower	3	2	1	2	2	1	2	3

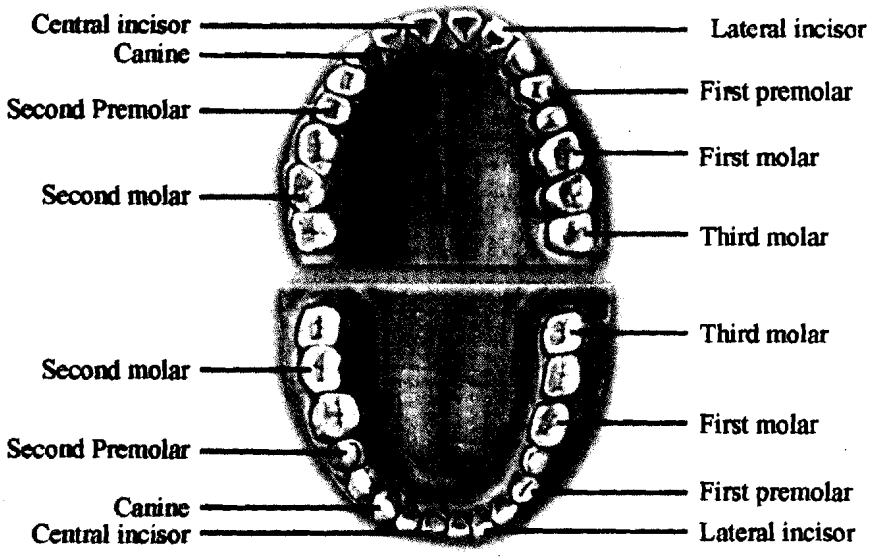

Figure 6.4: Dental anatomy

What is the tooth made up of ? Let's get to know.

Structure of a tooth

The structure of a tooth includes dentin, pulp and other tissues, blood vessels and nerves embedded in the bony jaw as illustrated in Figure 6.5. Above the gum line, the tooth is protected by the hard enamel covering. As shown in Figure 6.5, the tooth consists of the following parts:

- the crown which protrudes from the gum,
- the root which is embedded in the bone,
- the neck which is the slightly constricted part where the crown merges with the root,
- the pulp cavity which contains blood vessels, lymph vessels and nerves in the centre of the tooth,
- the dentine, a hard substance, which forms the main body of the tooth,
- the enamel, which is a thin layer of hard substance outside the dentine of the crown, and
- the cement, which covers the root of the tooth and fixes it in its socket.

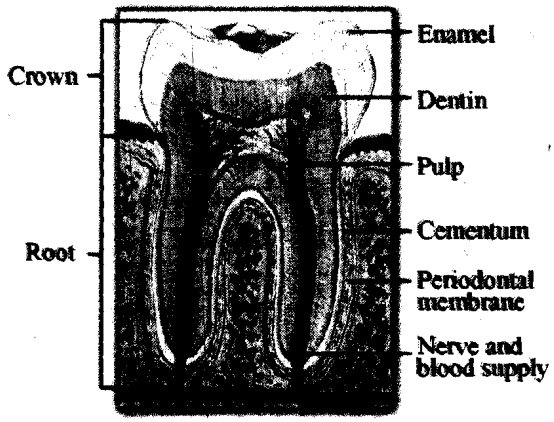

Figure 6.5: Parts of a tooth

Next, let us look at the functions of the different teeth described above.

Functions

The incisors and canine teeth are the cutting teeth and are used for biting off pieces of food. Premolar and molar teeth are used for chewing the food.

Having studied the structure of the mouth and its parts, we shall move on to the salivary glands.

6.4 SALIVARY GLANDS

Salivary glands are *the accessory glands of digestion*. They lie outside the gastrointestinal tract. Their function is to secrete saliva, which is conveyed to the mouth by ducts.

There are three pairs of salivary glands. The salivary glands include the large parotid glands (one pair) as illustrated in Figure 6.6 and the smaller sub-mandibular glands (one pair) and sublingual glands (one pair). Let us get to know each of these structures.

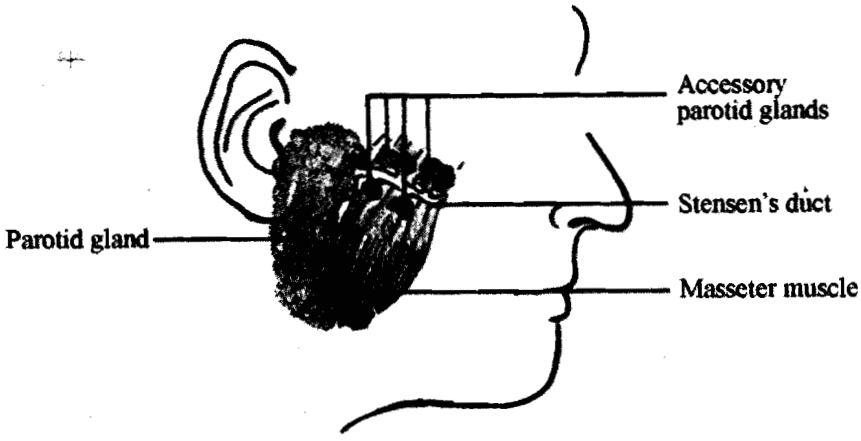

Figure 6.6: Salivary gland

a) *Parotid glands:* These are situated one on each side of the temporal region of face as shown in Figure 6.6. Each gland opens at the level of second upper molar tooth by a duct known as *Duct of Stensen.*

b) *Submandibular glands:* These lie on one on each side of the face under the angle of the jaw. The submandibular or submaxillary gland opens by *Wharton's duct.*

c) *Sublingual glands:* They lie under the mucus membrane of the floor of the mouth in front of the submandibular glands. They have numerous small ducts which open in the mouth. They are called *Ducts of Rivinus.*

Let us learn about the structure of the salivary glands in greater details.

Structure

Salivary glands are compound racemose (resembling a bunch of grapes as shown in Figure 6.6) glands. They consist of a number of lobules which are made up of small alveoli lined with the secretory cells.

The gland cells are of two types – *serous* and *mucous*. The parotid gland is composed entirely of serous cells. The sublingual gland is predominantly of mucous cells. The submandibular gland is a mixed type and contains serous and mucous both. The serous cells contain *zymogen granules* and *mucous cells* which contain mucinogen granules. The secretion of serous gland is watery, rich in enzyme (such as starch-splitting enzyme, amylase) and poor in solid. The secretion of mucous cells is thick and contains much mucus.

Now, let us get to know the composition of saliva.

Composition of Saliva

Saliva is a combined secretion from the salivary glands and the small mucus secreting glands of the lining of the oral cavity. It is slightly cloudy due to the presence of cells and mucin. Usually it is slightly acidic (pH 6.02–7.05). It consists of 99.5% of water and 0.5% of solid. Of the solids, 0.2% is inorganic salts and 0.3% is organic constituents. What are the inorganic and organic constituents present in saliva? Let's find out.

Inorganic constituents: The inorganic salts such as sodium chloride, potassium chloride, sodium phosphate, potassium phosphate etc. are present.

Organic constituents: The organic constituents present in saliva include:

- enzymes (salivary amylase or ptyalin, lysozyme, carbonic anhydrase, phosphatase etc),

- mucus (added by the glands in mouth),
- cellular constituents (bacteria, desquamated epithelial cells etc), and
- small amount of urea and citrate.

The functions of the saliva are elaborated next.

Functions of saliva

Saliva serves many roles, some of which are important to all species and others to only a few. Let us study about these functions which are significant to us.

- *Digestion of food:* Salivary amylase or ptyalin acts on cooked starches (polysaccharides) and changes them into maltose as shown herewith.

  Boiled starch ⟶ Soluble starch ⟶ Erythrodextrin and Maltose

  Achrodextrins and Maltose ⟶ Isomaltose and Maltose.

  The action of amylase is not complete in the mouth but it continues in the stomach until the reaction of the bolus has been made strongly acid by hydrochloric acid in the stomach. The pH of gastric juice is between 1.5 and 1.8. The pH of saliva is between 6.02 and 7.5.

- *Lubrication of food:* Dry food enters the mouth. It is moistened and lubricated by the saliva, before it can be made into a bolus ready for swallowing.

- *Cleansing:* Saliva is necessary to keep the mouth clean and to keep the structures within the mouth soft and pliable. In fever, when the salivary secretion is reduced, the food bolus is not properly washed away and bacteria multiply. This can cause tooth decay.

- *Taste:* Food substances, mixed with saliva stimulate the taste buds. Saliva acts as a solvent and is essential for the sensation of taste.

- *Articulation:* Saliva helps in the smooth delivery of speech because it keeps the mouth moist. By facilitating movements of the tongue and lips, saliva makes rapid articulation possible. Decrease in salivary secretion in nervousness or fever may impair the speech.

- *Heat loss:* This is found in dog, sheep etc. who do not have sweat glands. In very hot climate, they secrete more saliva (panting) causing greater heat loss.

- *Bacteriolytic action:* Saliva contains lysozyme. It destroys cell walls of many bacteria.

  Having looked at the functions of saliva, let us also get to know how the saliva secretion is controlled.

Control of salivary secretion: The autonomic control of saliva secretion occurs in two ways, as unconditioned and conditioned reflex. What are these? Let's find out.

- *Unconditioned reflex:* This response occurs due to the presence of an object in the mouth.

- *Conditioned reflex:* This response occurs due to some previous experience. Sight, smell and even the thought of appetizing food results in salivation.

Parasympathetic stimulation of the glands causes copious salivary secretion. Atropine blocks the response and makes mouth dry. Many drugs / toxic substances can also be secreted in saliva.

Check Your Progress Exercise 1

1) Fill in the blanks

a) The sympathetic nervous supply to the gastrointestinal tract is provided by nerves from ..... and .....region while parasympathetic nervous supply is provided by ..... and the ..... nerve.

b) The accessory organs of digestion are ....., ... and ..... .

c) A curved fold of muscle covered with mucus membrane which hangs down from the soft palate is called the ..... .

d) The three types of papillae in the tongue are ....., ... and ..... .

e) The saliva is composed of organic constituents such as ....., mucus, cellular constituents, urea and citrate.

2) Enumerate the general structural plan of the gastrointestinal tract.

.....

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.....

3) Name the different types of tooth and list their functions.

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.....

4) List the functions of saliva.

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5) Match the following:

	A		B
a)	Parotid gland	i)	Mucus Cells
b)	Sublingual gland	ii)	Serous Cells
c)	Submandibular gland	iii)	Mixed Cells
d)	Tongue	iv)	Enamel
e)	Tooth	v)	Circumvallate papillae

6.5 THE PHARYNX

You may recall that we studied about the pharynx in the last unit on respiration. We learnt that it is divided into three parts – *the nasopharynx, the oropharynx* and *the*

laryngopharynx. Well, the *oropharynx* and *naso pharynx* are related to the gastrointestinal tract, hence the discussion here. Food passes from the mouth to the oropharynx and then to the laryngopharynx before it enters the oesophagus. We shall get to know about the oesophagus next.

6.6 THE OESOPHAGUS

The oesophagus or the food pipe is the narrowest part of the gastrointestinal tract as can be seen in Figure 6.1. It lies in front of the vertebral column and behind the trachea and the heart. It is continuous with the pharynx above and the stomach below.

Let us look at the structure of the oesophagus.

Structure of the Oesophagus

Histological study reveals that there are four layers of tissue in the oesophagus. The outer covering consists of elastic fibrous tissue, the muscle layer consists of inner circular and outer longitudinal muscle fibres. In the upper portion, the muscles are voluntary, in the middle portion both voluntary and involuntary and in the lower portion only smooth muscles (involuntary) are found. The submucous layer consists of areolar tissue, blood vessels, lymph vessels, nerves etc. The inner lining consists of stratified squamous epithelium.

What is the role of oesophagus in our body? Read and find out next.

Function of the Oesophagus

The oesophagus passes the food from the pharynx to the stomach by *peristaltic movements* (natural contractions of the muscular walls of the organ that moves the food contents forward) as illustrated in the Figure 6.7. This is the main function of the oesophagus.

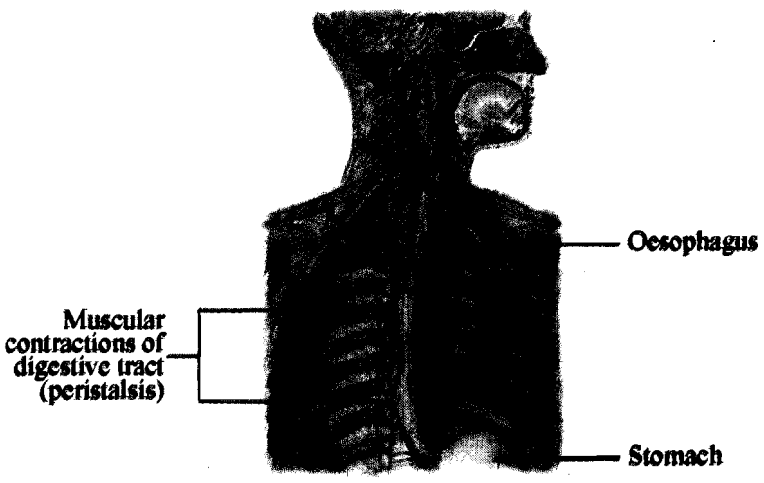

Figure 6.7: Peristalsis

From the oesophagus, the food enters the stomach. Let us learn about the structure of the stomach next.

6.7 THE STOMACH

The stomach is a J-shaped dilated portion of the gastrointestinal tract situated in the abdominal cavity between the oesophagus and the small intestine, as you may have noticed in Figure 6.1. The junction of the oesophageal mucosa with that of the stomach is abrupt. The opening by which the oesophagus communicates with the stomach is known as the *cardiac orifice*. The stomach opens into the duodenum through the *pyloric orifice*. The capacity of the average human stomach is about 1.12 - 1.70 litres.

Let us study about the structure and parts of the stomach.

6.7.1 Structure of the Stomach

The stomach is described as having two curvatures – lesser and greater curvature as can be seen in Figure 6.8. The lesser curvature is short and lies on the posterior surface of the stomach. As it can be observed from Figure 6.8, it is a continuation of the posterior part of the oesophagus. The greater curvature is on the anterior surface of the stomach.

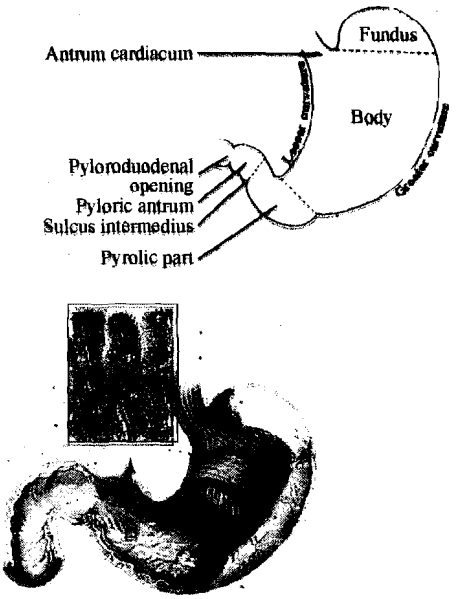

Figure 6.8: Stomach

The stomach is divided into 3 parts – the *fundus*, the *body* and the *pylorus* (pyloric part) as shown in Figure 6.8. The part of the stomach above and left of the cardiac orifice is called the *fundus*. The main part is the *body* of the stomach and the lower part which curves to the right is the *pylorus*. The pyloric orifice communicates with the duodenum, and its position is usually indicated on the surface of the stomach by a circular groove, the duodenopyloric constriction.

There are four layers of tissue which form the walls of the stomach. Figure 6.9 illustrates the layers of tissue which form the walls of the stomach. The outermost layer is a *serous* covering. The *muscle layer* (muscularis externa) consists of an outer longitudinal, middle circular and inner oblique layer. The *submucous layer* consists of areolar tissue, blood, lymph vessels and nerves. The innermost *mucous layer* consists of *columnar epithelium* and *goblet cells.*

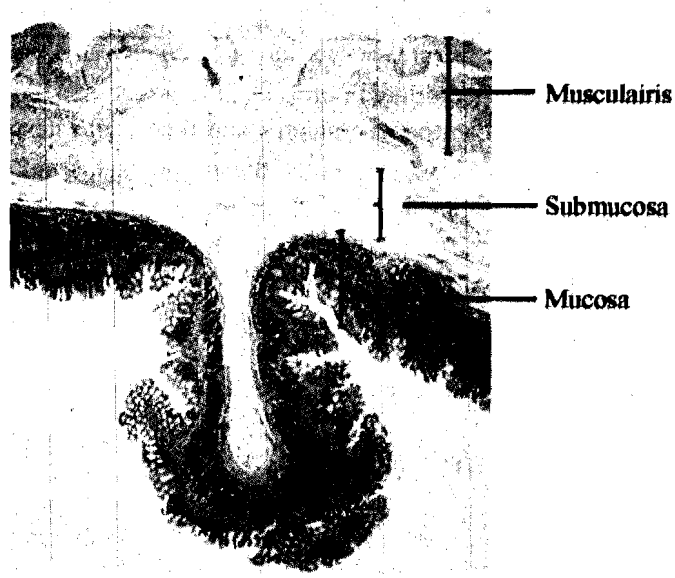

Figure 6.9: Layers of tissue which form the walls of the stomach

Within the *mucous membrane*, there are *gastric glands*. The gastric glands consist of *mucous neck cells* which secrete *mucus*, *chief cells* or *peptic cells* which secrete *pepsinogen* (the precursor of the enzyme pepsin), oxyntic cells or *parietal cells* which secrete *hydrochloric acid. Enteroendocrine cells* (G-cells) secrete the hormone gastrin. Figure 6.10 illustrates the gastric gland.

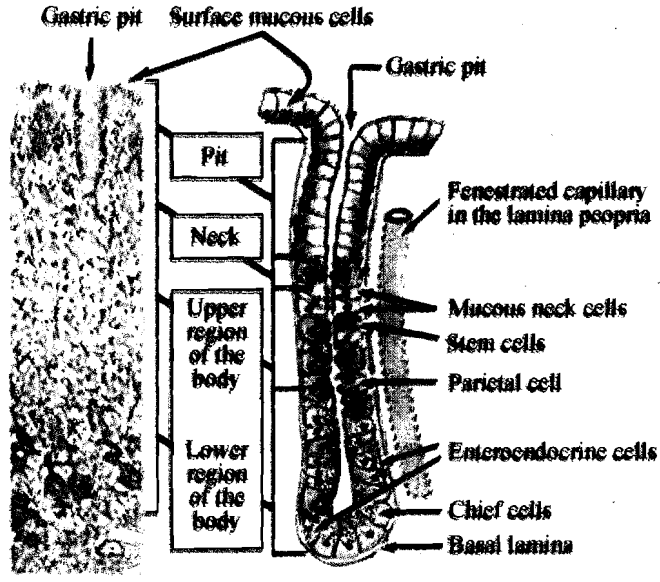

Figure 6.10: Gastric gland

The combined secretion of different types of cells of above glands forms the gastric juice.

In the fundus and the body of the stomach, the glands are straight and slender with a narrow lumen. In the pyloric region, the glands are fewer in number and shorter in length. Gastric glands in the pylorus do not contain oxyntic cells.

Next, we shall learn about the functions of the stomach.

6.7.2 Functions of the Stomach

The functions of stomach are many. We shall get to know them one by one.

- *Reservoir function:* The stomach acts as a temporary reservoir for food. It allows the gastric juice to act on different food substances.

- *Mechanical function:* Muscular action of the stomach helps in the mixing of food with the digestive juices and also helps to propel the food into the duodenum.
- *Secretory function:* The stomach secretes gastric juice. Hydrochloric acid secreted from the stomach creates the acidic medium necessary for the digestion of protein. Also, hydrochloric acid acts as an antiseptic agent. Intrinsic factor secreted from the stomach is necessary for vitamin B_{12} absorption.
- *Digestive function:* Gastric juice begins the digestion of protein. Gastric rennin coagulates milk. Iron in the food is dissolved in the stomach in presence of hydrochloric acid.
- *Absorptive function:* Absorption takes place to a limited degree in the stomach. Water, glucose, alcohol and some drugs are absorbed through the walls of the stomach into the venous circulation.

We have learnt above about the digestive function of the stomach and seen how the gastric juice is important for this function. Let us look at the composition of gastric juice next.

6.7.3 Composition and Functions of Gastric Juice

In resting condition, the secretion of gastric juice is little in amount and is about 10-15 ml. After taking each meal, the amount of secretion begins to increase. The total secretion per day starts from 1500-2000 ml. Its pH is strongly acidic, i.e. 2.3. Its specific gravity is 1.002-1.004.

Gastric juice contains 99.45% of water and 0.55% solid. Of the solids, organic constituents are 0.4% and inorganic constituents are 0.15% of total gastric juice. Table 6.1 presents the composition of organic and the inorganic constituents present in gastric juice.

Table 6.1: Organic and the inorganic constituents present in gastric juice

Organic Constituents	Inorganic Constituents
Pepsin (the proteolytic enzyme), mucin, intrinsic factor (a mucoprotein, necessary for absorption of Vitamin B_{12}), gastric rennin (not present in human adults), and other gastric enzymes (lysozyme, carbonic anhydrase etc)	Free hydrochloric acid, lactic acid and other fermenting acid, sulphates, chlorides, phosphates of sodium, potassium, calcium and magnesium, and bicarbonates.

After understanding the composition, let us move on to the functions of gastric juice.

Functions of Gastric Juice

Gastric juice performs many vital functions as discussed herewith:

- *Digestive function:* As the gastric juice contains water, it further liquefies the food swallowed. The hydrochloric acid acidifies the stomach contents and terminates the action of salivary amylase (ptyalin). Pepsinogen is converted to active pepsin by hydrochloric acid.
- *Enzyme action:* Pepsin begins the chemical digestion of proteins. It converts proteins to peptones. The enzyme rennin present in infants curdles the milk and changes the soluble caseinogen into insoluble casein. This casein is converted by pepsin into peptones.
- *Antiseptic action:* Hydrochloric acid in the gastric juice acts as a barrier to the passage of certain microorganisms harmful to the human system.

- *Haemopoietic function:* Gastric juice contains the intrinsic factor, which is necessary for the absorption of vitamin B_{12}. Vitamin B_{12} present in food combines with intrinsic factor of the gastric juice. It is absorbed through the walls of the small intestine and stored in the liver. It is required for red blood cell maturation in the bone marrow.
- *Protective function:* Large quantity of mucin is secreted by gastric glands. Mucin lubricates the food bolus (a mass of chewed food) and also gives a protective layer over the gastric mucosa.
- *Excretory function:* Certain toxins, heavy metals like lead and some alkaloids are excreted through the gastric juice.

Next, we shall study about the mechanism of gastric juice secretion and the phases involved.

6.7.4 Mechanism of Secretion of Gastric Juice

There is always a small quantity of gastric juice present in the stomach even when there is no food in the stomach. This is known as *fasting juice.* Secretion of gastric juice is divided into three phases. These include:

a) *Cephalic phase or neural phase:* 45% of the total gastric secretion is discharged in this phase. The flow of juice occurs before food reaches the stomach. Sight of food, taste, smell and even the thought of an appetizing meal produces secretions by the reflex stimulation of vagus nerve. If vagus nerves are cut, this phase of gastric secretion stops. Through the vagus nerve, the parietal cells are stimulated.

b) *Gastric phase:* Another 45% of the gastric secretion is discharged in this phase. The mechanical presence of food in the antrum of the stomach stimulates the production of a hormone, *gastrin.* Gastrin is secreted from the G cells of the antral mucosa and passes directly into the circulating blood. This hormone activates the parietal cells of the stomach to secrete more gastric juice. This gastric juice contains more acid, but little pepsin or mucus.

c) *Intestinal phase:* Rest 10% of the total gastric secretion is discharged in this phase.

When partially digested contents of the stomach reach the duodenum, presence of certain food substances in the small intestine excites gastric secretion. These are meat extract, alcohol etc. Some substances inhibit gastric secretion. These are alkali and fat. If the intestinal food material contains a considerable amount of fat, a hormone *enterogastrone* is produced. It inhibits gastric secretion and gastric motility that is why after taking a fatty meal (paranthas) you don't feel hungry for about 3-4 hours again. By slowing down the emptying rate of the stomach the contents in the small intestine are thoroughly mixed with bile and pancreatic juice.

You must have read about the acid being one of the constituents of gastric juice. How is the acid secreted in our body? Let's get to know, next.

Mechanism of secretion of hydrochloric acid

Sodium chloride (NaCl) solution is present in the extracellular fluid. It is ionized as NaCl ($Na^+ + Cl^-$).

Both at rest and during acid secretion, the mucosal surface of the body of the stomach is electronegative to serosal surface. Therefore secretion of chloride must take place against an electrical gradient as well as a concentration gradient (from 107 mmol/l in the intracellular fluid to 170 mmol/l in the canaliculus). Movement of chloride ions across the membrane requires an active transport mechanism.

An unlimited supply of hydrogen is available from intracellular water ($H_2O \rightarrow H^+ + OH^-$). Accumulation of hydroxyl ions (OH^-) within the parietal cell results in the

rise of intracellular pH sufficient to interfere with the cell metabolism. Hydroxyl ions are to be removed. Carbon dioxide is formed during metabolism of carbohydrate in the cells. It combines with water under the influence of carbonic anhydrase (present in the parietal cells) to form carbonic acid.

$$H_2O + CO_2 \xrightarrow{\text{Carbonic Anhydrase}} H_2CO_3$$

$$H_2CO_3 + OH^- \rightleftharpoons H_2O + HCO_3$$

Accumulation of OH^- ions is thus prevented. Bicarbonates are transported into the blood. Chloride ions diffuse down against concentration gradient and enter the parietal cells. Its entry into the cell is facilitated by a carrier mechanism. In the same way, chloride ion is coupled with hydrogen ion to form hydrochloric acid.

$$H^+ + Cl^- \longrightarrow HCl$$

Next, we shall get to know about our pancreas.

6.8 THE PANCREAS

From the stomach, the semi-liquid mass of partially digested food (called *chyme*) enters the small intestine. When the chyme enters the small intestine, it is mixed with the pancreatic juice and bile and then with the intestinal juice. Let us get to know our pancreas. We start with the structure.

6.8.1 Structure of the Pancreas

Pancreas lies outside the alimentary tract and is an accessory gland of digestion as you may recall reading earlier in this unit. It is a pale yellowish grey gland situated in the abdominal cavity. Figure 6.11 illustrates the pancreas. As you can see, it consists of a broad head. The head lies in the curve of the duodenum, a body which lies behind the body of the stomach and a narrow tail which lies left to the kidney.

The *exocrine part* of the pancreas is a compound tubular gland. The *secretory portion* consists of a number of lobules. Lobules are made up of alveoli lined with secretory cells. These alveoli are serous alveoli containing *zymogen* granules. Zymogen granules contain pro-enzymes. The pro-enzymes become activated to form enzymes. These enzymes are responsible for digestion of proteins, fats and carbohydrates.

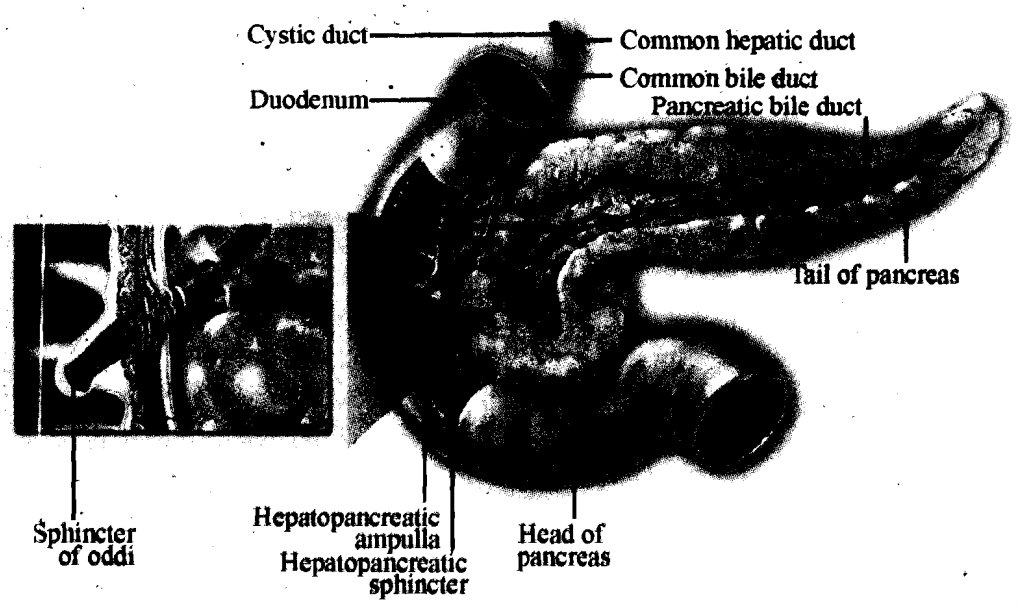

Figure 6.11: Pancreas

Each lobule has a small duct. This duct unites with other ducts and joins the main pancreatic duct which passes the whole length of the gland to open into the duodenum.

Just before entering the duodenum, the pancreatic duct joins the bile duct to form *ampulla of the bile duct* as shown in Figure 6.11. The duodenal opening is controlled by sphincter of oddi.

The *endocrine* part of the pancreas consists of collection of cells distributed throughout the substances of the pancreas. These collections of cells are called '*Islets of Langerhans*'. The secretion produced by the islets of Langerhans is passed directly into the circulating blood and consists of hormones insulin and glucagon.

So the pancreas secretes the pancreatic juice and also secretions produced by the islets of Langerhans i.e. insulin and glucagon. What is the composition of the pancreatic juice? Let's find out.

Composition of pancreatic juice

Pancreatic juice is the secretion of the exocrine part of the pancreas. It is alkaline in reaction. Its pH is 8.0 – 8.3. It consists of:

- water
- mineral salts (high bicarbonate, salts of sodium, potassium, magnesium, calcium and zinc), and
- enzymes (trypsinogen, chymotrypsinogen, procarboxypeptidase, pancreatic lipase, pancreatic amylase etc).

What is the role of the secretions and juices produced by the pancreas? We shall learn about this next.

6.8.2 Functions of the Pancreas

Pancreatic juice contains, as you have already learnt, many enzymes and so performs many vital jobs. The functions of pancreas are many-fold and include:

- *Neutralising action:* Pancreatic juice is alkaline in nature and acid chyme is rendered alkaline by the strong alkalinity of the pancreatic juice. This alteration of reaction is important for an effective action of pancreatic secretion.
- *Digestive action: Trypsinogen* and *chymotrypsinogen* are the inactive proteolytic enzymes of the pancreatic juice. When they come in contact with *enterokinase* of the intestinal juice, they are converted to trypsin and chymotrypsin, respectively as illustrated herewith. You may recall reading about this also in the Nutritional Biochemistry Course in Unit 5.

$$\text{Trypsinogen} \xrightarrow{\textit{Enterokinase}} \text{Trypsin}$$

$$\text{Chymotrypsinogen} \xrightarrow{\textit{Enterokinase}} \text{Chymotrypsin}$$

$$\text{Procarboxypeptidases} \xrightarrow{\textit{Trypsin}} \text{Carboxypeptidases}$$

Trypsin and chymotrypsin, you know are the enzymes that act on partially digested proteins. This means that they convert peptones (formed in the stomach) into peptides and polypeptides. Other enzymes called *ribonuclease* and *deoxyribonuclease*, act on two types of nucleic acids (ribonucleic acid and deoxyribonucleic acid).

Pancreatic amylase, the other enzyme of the pancreas, converts all polysaccharides (starches) to disaccharides. Starches, not affected by ptyalin, are digested here. Pancreatic lipase converts fats into fatty acid and glycerol. Bile salts emulsify the fats and breakdown fat into smaller globules and thus help the enzyme to act.

We have studied about the digestive function of pancreas, next, let us learn about the mechanism of pancreatic secretion.

6.8.3 Mechanism of Pancreatic Secretion

The pancreatic secretion consists of two phases – nervous phase and hormonal phase.

Let's get to know about these mechanisms.

a) *Nervous phase:* When stomach secretes gastric juice in cephalic phase and gastric phase, nerve impulses are simultaneously transmitted along the vagus nerves to the pancreas. This results in the secretion of moderate quantity of pancreatic enzymes.

b) *Hormonal phase:* After food enters from the stomach to the duodenum, pancreatic secretion starts increasing. Two hormones are responsible. One is *secretin*, another is *cholecystokinin - pancreozymin (CCK-PZ).*

Let us understand the role of these hormones in the digestive process.

Role of secretin: Secretin is a polypeptide containing 27 amino acids. It is present in the mucosa of the upper small intestine in an inactive form *prosecretin.* When food mixed with hydrochloric acid enters the duodenum, secretin is released from prosecretin. Secretin causes the pancreas to secrete large quantities of fluid containing a high concentration of bicarbonate ion. This copious flow of fluid is called *hydrelatic secretion* because it is mainly a thin watery solution containing almost no enzymes. Pancreatic juice containing large quantity of sodium bicarbonate is helpful to neutralize the acid content of substances emptied into the duodenum from the stomach. The reaction is as follows:

$$HCl + NaHCO_3 \longrightarrow NaCl + H_2CO_3$$

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

(carbonic acid)

Carbonic acid dissociates into water and carbon dioxide. Carbon dioxide is absorbed into the body fluids. A neutral solution of sodium chloride is left.

Bicarbonate secretion also provides an appropriate pH for the action of pancreatic enzymes.

Role of cholecystokinin - pancreozymin (*CCK-PZ*): The presence of food in the upper small intestine also causes another hormone, CCK-PZ to be released. It is a polypeptide containing 33 amino acids, secreted from the intestinal mucosa.

Presence of peptones, fats and also acids in the small intestine are stimuli for cholecystokinin – pancreozymin secretion. Cholecystokinin-pancreozymin acts on pancreas via blood. It causes secretion of large quantity of digestive enzymes. This type of secretion is called *ecbolic secretion.*

Having gone through the discussion above, you would have got a fairly good idea about the digestive function of pancreas and the mechanism of pancreatic secretions. Now, try answering the questions given next and check your understanding of the topic.

Check Your Progress Exercise 2

1) Fill in the blanks:

   a) The three parts of pharynx are ....., ... and ..... .

   b) The layers of tissue in the oesophagus are ....., ..., ... and ..... .

   c) The different types of cells in the walls of stomach are ....., ..., ..., ... and ..... .

   d) Small amount of gastric juice present in the stomach even in the absence of food is termed as ..... juice.

   e) The oesophagus opens into the stomach at .....while stomach opens into the duodenum through ..... .

2) Describe the structure of stomach.

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3) List the functions of gastric juice.

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4) Enumerate the mechanism of secretion of:

   a) Gastric juice

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   b) Pancreatic juice

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5) Give the role of following hormones in the digestive process:

   a) Secretin

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   b) CCK-PZ

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6.9 THE LIVER AND BILIARY SYSTEM

The liver is the largest gland in the body. It weighs about 1500 g. It is situated in the upper part of the abdominal cavity. The liver secretes bile. The biliary system comprises of the gall bladder and the bile ducts. Let's first learn about liver, its structure and functions.

6.9.1 Liver – Structure and Functions

The liver is enclosed in a thin capsule and is completely covered by a peritoneum. The liver is described as having four lobes. As you can see in Figure 6.12, only two lobes are visible - the left and the right lobe. The *right lobe* is the largest. The *left lobe* is smaller and wedge-shaped. The *quadrate* lobe is almost square in outline and the *caudate lobe* is tail-like in appearance. The latter two lobes can only be distinguished by viewing the liver from behind.

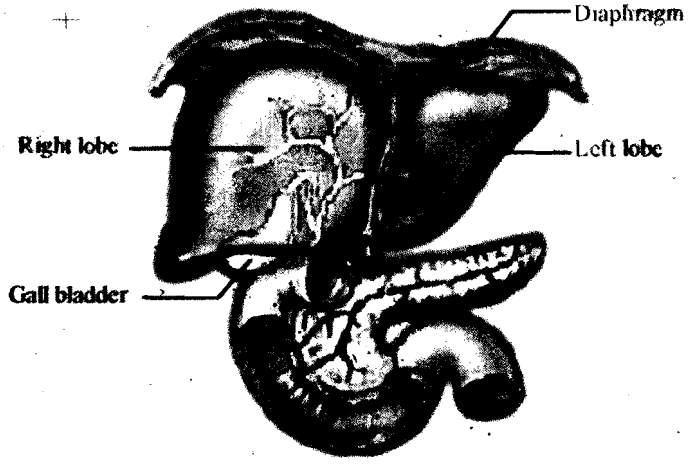

Figure 6.12: Liver

The lobes of the liver are made up of tiny lobules. These lobules are hexagonal in outline. They are formed by cubical shaped cells arranged in columns which radiate from a central vein. Between the columns of cells, there are *sinusoids* (blood vessels with incomplete walls) which contain a mixture of blood from the tiny branches of the portal vein and hepatic artery. Thus oxygenated blood and blood with a high concentration of nutritional materials come in direct contact with the cells of the liver. Blood drains into central vein. Central veins from all the lobules join up and unite to form hepatic veins which drain blood from the liver and empty into inferior vena cava. What are the functions of the liver? Certainly, you may be aware of the important functions the liver performs in the body. Read the functions enumerated next and refresh your knowledge about the functions of the liver.

Functions of the liver

The liver has the following functions:

- *Secretion of bile:* The liver cells are able to synthesize bile. All constituents of bile are not present in the liver. Liver cells use different substances from mixed venous and arterial blood in the sinusoids.
- *Glycogenesis and glycogenolysis:* The liver converts glucose to glycogen in the presence of insulin and changes the liver glycogen back to glucose when required. You would recall reading about glycogenolysis and gluconeogenesis in the Nutritional Biochemistry Course. If not, we suggest you get back to this Course, look up Unit 6 and understand this concept.

- *Deamination of protein:* The nitrogenous portion of the amino acid is removed and urea is formed by the liver. Look up Unit 8 of the Nutritional Biochemistry Course for more details about the deamination reaction. Further, nucleoproteins are broken down to uric acid which is excreted in the urine. Liver also forms urea from the protoplasm of worn-out cells.

- *Storage of vitamin A, D, E, K and B_{12}:* The liver stores vitamin A, D, E, K. It also stores vitamin B_{12} until it is required by the bone marrow for the formation of red blood cells.

- *Formation of plasma proteins:* Serum albumin, serum globulin, prothrombin and fibrinogen and other coagulation factors are synthesized in the liver from the available amino acids.

- *Storage of iron:* The liver stores iron from the diet and from the breakdown of red blood cells in the spleen.

We have looked at the functions of the liver above. Now we shall go on to the study of the gall bladder and the bile ducts.

6.9.2 The Gall Bladder and the Bile Ducts

The gall bladder is a pear shaped sac attached to the liver by connective tissue. It is divided into three parts – fundus or expanded end, body or main part and a neck which is continuous with the cystic duct, as shown in Figure 6.13.

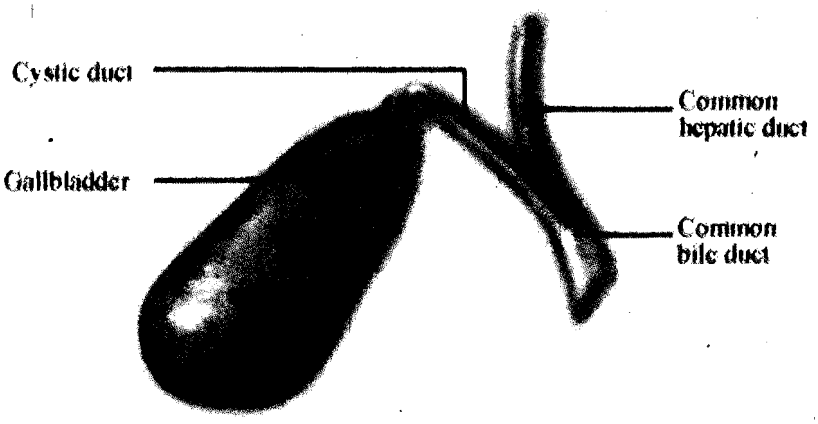

Figure 6.13: Gall bladder and bile ducts

There is a right and a left hepatic duct which join to form the common hepatic duct. As can be seen in the Figure 6.13, the common hepatic duct passes downwards and joins the cystic duct from the gall bladder at an acute angle. The cystic duct and common hepatic duct joins to form the bile duct. It passes downwards and joins the main pancreatic duct at the ampulla of the bile duct. The two together open into the duodenual papilla and its orifice is guarded by the *sphincter of oddi.*

Very briefly let us look at the tissues of the gall bladder. The surface of the gall bladder, not attached to the liver, is covered by a *peritoneum.* The *middle layer* is a smooth muscle layer which contains longitudinal, circular and oblique fibres. The innermost lining is of *mucous membrane.* There are rugae in the gall bladder when it is empty. The rugae disappear when the organ is distended with bile.

Let us learn about the functions and the factors controlling the movement of the gall bladder next.

Functions of the gall bladder

Bile from the liver passes through the cystic duct to the gall bladder. The gall bladder acts as a reservoir of bile. By the absorption of water, the bile is concentrated in gall bladder. When a meal is taken, the gall bladder contracts. Then the bile passes through the cystic duct again and then down the bile duct and enters the duodenum. Bile enters the duodenum only when the sphincter of oddi is relaxed.

Next, the factors that influence the movement of gall bladder are enumerated.

Factors Controlling Movements of Gall Bladder

Contraction of gall bladder can be controlled by reflex action, by the presence of foodstuff in the duodenum and by the hormone *cholecystokinin*. Let us discuss each of these control mechanisms.

- *Reflex control:* During digestion, reflex stimulation of gall bladder takes place. Entry of acid into the duodenum reflexly stimulates the gall bladder to contract and sphincter of oddi to relax. The stimulus may arise when the food is present in the mouth and stomach.
- *Presence of foodstuffs:* Fatty foods particularly cream, fatty acids and proteins to a less extent, stimulate the contraction of gall bladder. Bile is expelled from the gall bladder when these foodstuffs are eaten. Fatty meal is given to the patient to examine gall bladder movements during X-ray of gall bladder (referred to as *cholecystography*).
- *Cholecystokinin:* Active contraction of gall bladder during digestion is due to the hormone cholecystokinin. Acid extracts of the duodenal mucosa stimulate the secretion of cholecystokinin from the cells of the mucosa in the upper intestine.

So we have seen that the gall bladder stores the bile. Do you know what the composition of the bile is? Let's find out.

Composition of bile

Bile is a complex fluid. It is yellowish green in colour and bitter in taste. It contains:

- water
- mineral salts (chloride, carbonate and phosphate of sodium, potassium and calcium)
- mucus
- bile salts (sodium taurocholate, sodium glycocholate)
- bile pigments (bilirubin and biliverdin)
- cholesterol, and
- traces of fatty acids

There is a slight difference between the composition of bile produced by the liver and bile stored in the gall bladder. Liver bile is alkaline (pH 7.7) and gall bladder bile is neutral or slightly alkaline (pH 7.0 - 7.6). The differences in the composition of bile produced by the liver and bile stored in the gall bladder are highlighted in Table 6.2.

Table 6.2: Constituents of bile

Constituents	Gall bladder bile %	Liver bile %
Water	89.0	98.0
Solids	11.0	2.0
Inorganic salts	0.8	0.75
Bile salts	6.0	0.9
Mucin and Pigments	3.0	0.4
Cholesterol	0.38	0.06

From Table 6.2 it must be evident that bile in the gall bladder is concentrated as compared to the bile produced in the liver. What functions does the bile perform in the body? Let's find out.

Functions of Bile

The main function of the bile is digestive function. The digestive functions are many. These are:

- *Emulsification:* The bile salts, sodium taurocholate and sodium glycocholate are active in emulsifying fats in the duodenum. Bile salts break up the fat into tiny droplets. The fine globules of fat have a larger surface area for the enzyme to act. This is called *emulsification*. Due to this, digestion is quickened.
- *Activation of enzyme:* Bile salts activate pancreatic lipase. Lipase, as you already know, is a fat – splitting enzyme and splits fat into fatty acids and glycerol. Bile salts combine with fatty acids to make them soluble and enable them to be absorbed.
- *Cholagouge action:* Bile acts as its own stimulus. Bile salts are absorbed from the intestine, carried to the liver and stimulate further bile secretion.
- *Absorptive function:* Presence of bile in the small intestine is needed for the absorption of vitamin K and digested fat.
- *Laxative action:* Bile salts stimulate peristalsis and hence have a laxative action.
- *Maintenance of pH:* Bile neutralises the hydrochloric acid and helps to maintain a suitable pH. This prevents the injurious effects of acids on gastric mucosa. Mucin of bile acts as a buffer and as a lubricant.
- *Excretory function:* Bile pigments (bilirubin and biliverdin) are the waste products of the breakdown of red blood cells and bile is their route of excretion. Also some metals (like copper, zinc) and toxins are excreted by bile.
- *Colouration of faeces:* The iron-free breakdown products of haemoglobin (i.e. bilirubin and biliverdin) oxidize to brown stereobilin. This stereobilin gives the faeces their characteristic brown-yellow colour. Thus bile colours the faeces. Dark coloured stools in jaundice patients indicate lot of RBC destruction and formation of more bile pigments.

What is the mechanism of bile secretion? The mechanism is discussed next.

Mechanism of secretion of bile

Bile secretion is independent of neural influence. The normal stimuli for bile secretion are bile salt itself and some foodstuffs.

Substances which increase the output of bile from the liver are known as *choleretic agents*. Substances those which increase the volume of bile are called *hydrocholeretic agents*.

An excellent correlation exists between the bile flow and bile salt excretion. The secretion of bile salts into the *biliary canaliculus* is the most important factor promoting bile flow. This bile-salt dependent active secretion carries the bile pigments, organic anions and water with it. The passages of osmotically active bile salts generate water flow. The bile salts are present as micelles. A change in micellar size influences osmotic activity. This may be the regulatory mechanism for the flow of water into the bile.

There is also bile-salt independent flow. But it is only a small fraction of total bile flow. This fraction may be linked to active sodium transport. Substances like phenobarbitone or cortisol increase bile flow without enhancing bile salt secretion.

Fat and protein rich foods stimulate bile secretion. Carbohydrates exert no such effects. Bile secretion increases about one hour after meal.

Flow in the bile duct is controlled by the hormone 'secretin'. Ductular flow may serve to flush bile salts from the lower end of the common bile duct following gall-bladder contraction.

Earlier we looked at the constituents of bile. We learnt that bile is composed of cholesterol, bile salts, pigments etc. We shall now see how these individual constituents of bile are formed.

Formation of individual constituents of bile

Let us understand how the following individual constituents of bile are formed.

- *Cholesterol:* Cholesterol is an extremely important compound, a constituent of most cell membranes and the precursor of bile acids and steroid hormones. Synthesis takes place mainly from acetate in microsome. The liver is particularly concerned with the production of cholesterol for export, largely as bile.
- *Bile salts:* The liver is the site for synthesis of bile salts. The amino acid glycine is synthesized in the body. Taurine is derived from the sulphur-containing amino acid cysteine. Glycocholic acid and taurocholic acid (i.e. bile salts) are formed by the combination of glycine and taurine with cholic acid respectively (cholic acid is a bile acid synthesized in the liver).
- *Bile pigments:* The red blood cells are broken down when they are old (life span of red blood cell is 120 days). They are taken up by the reticuloendothelial system. Haemoglobin is released and by degradation, opening of the porphyrin ring system occurs. The degraded compound is known as 'verdohaemoglobin.' This is broken down to haem and globin. Globin is broken down to amino acids and enters the general amino acid pool of the body. Iron is stored in the body as apoferritin, haemosiderin which is re-utilized to form new haemoglobin. The rest of the haem is converted to yellow pigment called as *bilirubin.* Bilirubin is oxidised to green pigment *biliverdin*. The bilirubin then combines with plasma albumin. When it enters the liver cells, it is conjugated with glucuronic acid.

  It is to be noted that bilirubin, present in blood (haemobilirubin) is not the same as the bilirubin present in bile (cholebilirubin). Haemobilirubin remains combined with serum albumin and cholebilirubin remains in combination with glucuronic acid.

Finally, before we end our discussion on bile, we must talk about the enterohepatic circulation of bile. What do we mean by the enterohepatic circulation of bile? Read the following section and find out.

Enterohepatic Circulation of Bile

Any compound which is secreted in bile and subsequently reabsorbed from the small intestine, returns to the liver and is then resecreted in the bile. This is called *enterohepatic circulation of bile*. The enterohepatic circulation is a physiological conserving mechanism. The efficiency with which compounds recirculate may vary.

Bile salts are efficiently reabsorbed. Only a minute proportion escapes into the systemic circulation. Cholesterol and phospholipids are much less efficiently absorbed.

Let us study about the pathways of bile circulation. There is both a *portal and extraportal pathway* for the enterohepatic circulation. Bile acids undergo recirculation through the portal vein. Phosopholipids and cholesterol undergo an extraportal enterohepatic circulation. Various exogenous compounds such as antibiotics, barbiturates and digitalis undergo an enterohepatic circulation, which may be both portal and extraportal.

Compounds which undergo portal enterohepatic circulation are first secreted by the liver. Then they are passed into the intestine, then reabsorbed from the intestine and then transported back to the liver through the portal vein.

Compounds with an extraportal enterohepatic circulation are absorbed from the small intestine into the lymphatics which then drain into superior vena cava. These compounds then enter the systemic circulation and are transported throughout the body where they may be partially excreted e.g. by kidney or by skin. They then pass back to the liver where they are re-excreted in bile.

Check Your Progress Exercise 3

1) What are the important functions of liver?

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2) List the factors controlling the movements of gall bladder.

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3) Give the composition and functions of bile.

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4) What do you mean by the terms 'choleretic agent' and 'hydrocholeretic agent'?

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6.10 THE SMALL INTESTINE

The small intestine is continuous with the stomach at the pyloric sphincter and leads into the large intestine at the ileocolic valve. It is about 21 feet long. It lies in the abdominal cavity. It is surrounded by the large intestine.

The small intestine is divided into three parts – duodenum, jejunum and ileum as shown in Figure 6.14. Let us study about these parts:

- *Duodenum:* The first part of the small intestine is called the *duodenum.* It is about 10 inches in length. At the mid-point of the duodenum, there is a common opening of the pancreatic duct and the bile duct called *papilla.* It is guarded by the sphincter of oddi as you have seen earlier in Figure 6.11.

- *Jejunum:* The jejunum as illustrated in Figure 6.14, is the middle part of the small intestine and is about 8 feet in length.
- *Ileum:* The ileum is the last part of the small intestine. It is about 12 feet long. It terminates at the ileocolic valve. This controls the flow of material from the ileum to the large intestine and from the large intestine to the ileum.

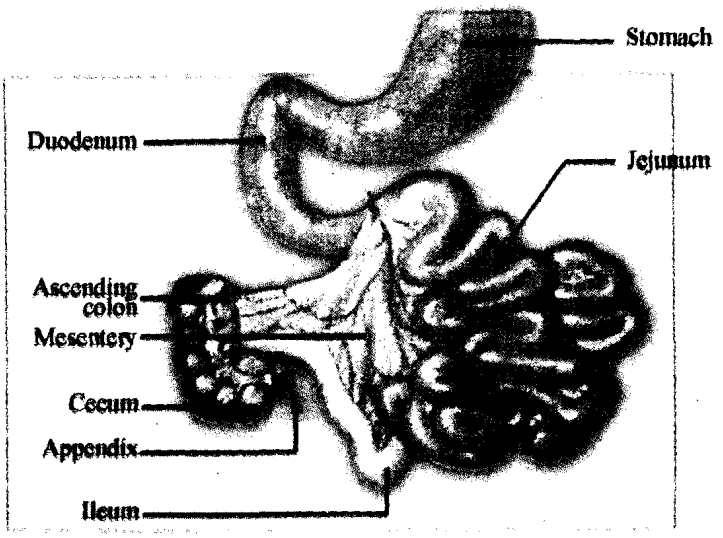

Figure 6.14: Parts of the human intestines

Let us also learn about the histological structure of the small intestine. There are four layers of tissue forming walls of the small intestine, same as you learnt earlier under the section on stomach. The outer covering of *peritoneum* is called as 'mesentery'. The next, *muscle layer,* consists of smooth muscle fibres – longitudinal and circular muscle fibres. The *submucous layer* consists of blood vessels, lymph vessels and nerves. The *mucous membrane* consists of circular folds and villi as you can see in the Figure 6.15.

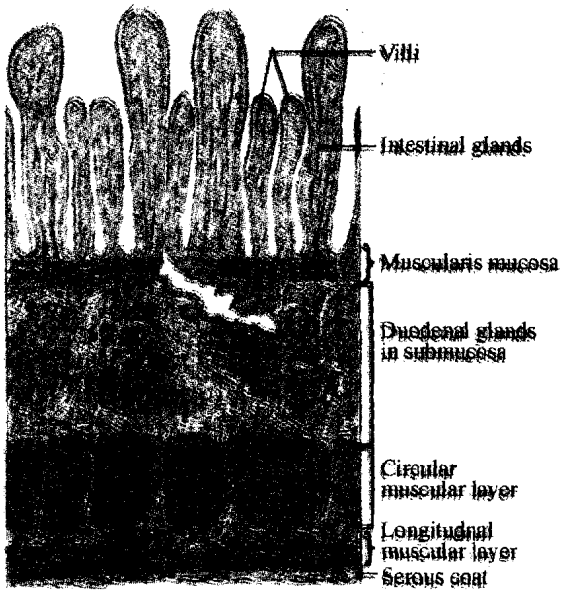

Figure 6.15: Structure of small intestine

Villi, as you may already know, are *tiny finger-like projections into the lumen of the organ*. The walls of the villi are composed of columnar epithelial cells which enclose a network of blood and lymph capillaries. The lymph capillaries are called *lacteals*. Nutrient materials are absorbed through the walls of villi. Fat is absorbed through lacteals.

There are *intestinal glands* between the villi. They secrete intestinal juice. *Brunner's glands* are present in the duodenum. There are numerous lymph nodes in the mucus membrane. The smaller ones are known as *solitary lymphatic nodules*. The larger ones are known as *aggregated lymphatic nodules* or *Peyer's patches*. They are situated towards the distal end of the ileum.

Next, let us get to know about the functions of small intestines.

Functions of small intestine

What functions does the small intestine perform? Can you list a few? Tally your responses with the functions enumerated herewith.

- The small intestine secretes intestinal juice.
- Intestinal juice containing enzymes completes the digestion of carbohydrates, proteins and fats.
- The small intestine protects the body against infection by bacteria with the help of solitary lymph nodes and aggregated glands.
- The walls of villi of the small intestine are able to absorb glucose, amino acid, fatty acid, glycerol etc. These are the end-products of carbohydrate, protein and fat metabolism, as you may have already studied in the Nutritional Biochemistry Course. Glucose and amino acids are absorbed through blood capillaries. Fatty acids and glycerol are absorbed into lacteals or lymph capillaries. The surface area for absorption of nutrients is vastly increased by the circular folds of the mucus membrane and by the large number of villi.

The main function of the small intestine, as you may have read above, is to secrete intestinal juices which help in digestion. What substances/constituents are present in the intestinal juice? Can you tell? How does it aid in digestion? These are a few aspects discussed next.

What are the constituents of the intestinal juice?

Intestinal juice is also called *succus entericus*. The word *succus* means juice and *entericus* means intestinal. The digestive juice completes the digestion of carbohydrate, protein and fat. It is secreted by glands lying between intestinal villi.

The total quantity of intestinal juice per day is about 1-2 litres. It is alkaline in reaction (pH 8.0). The intestinal juice contains: water - 98.5% and solids - 1.5%. Of the solids, there are:

- inorganic constituents (salts of sodium, potassium, calcium, magnesium with chloride, bicarbonate and phosphate), and
- organic constituents: The organic constituents present in the juice include the proteolytic enzyme, carbohydrate-splitting and fat-splitting enzymes and some other enzymes. A brief review of these organic constituents present in the intestinal juice follows.

  a) Proteolytic enzymes: The proteolytic enzymes help in the digestion of proteins.

     These include: trypsin (a mixture of enzymes containing dipeptidases and amino peptidases) and nuclease (acts on different fractions of nucleic acid)

b) Carbohydrate-splitting enzymes, namely amylase (acts on starch and dextrin), sucrase or invertase (acts on cane sugar), maltase (acts on maltose and isomaltase) and lactase (acts on lactose)

c) Fat-splitting enzyme, the lipase

d) Activating enzyme, the enteropeptidase or enterokinase (activates trypsinogen to trypsin)

e) Other enzymes (alkaline phosphatase, cholesterol esterase etc), and

f) Mucin

What are the functions of the intestinal juice?

As already discussed, the main function of the intestinal juice is to aid in digestion. Other functions include protective, absorptive and regulatory functions. Let us learn about these functions.

- *Digestive function:* Enzymes in succus entericus help in digestion of carbohydrates, proteins and fats present in our food. Let us get to know the enzymes involved.

  Enterokinase activates trypsinogen and chymotrypsinogen as highlighted herewith.

$$\text{Trypsinogen} \xrightarrow{\textit{Enterokinase}} \text{Trypsin}$$

$$\text{Chymotrypsinogen} \xrightarrow{\textit{Enterokinase}} \text{Chymotrypsin}$$

  Carbohydrate splitting enzymes act on disaccharide to form monosaccharides, as shown in the reaction herewith.

  Sucrase acts on cane sugar, sucrose.

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

  Maltase acts on beet sugar, maltose

$$\text{Maltose} \xrightarrow{\textit{Maltase}} 2\ \text{Glucose}$$

  Lactase acts on milk sugar, lactose

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

  Protein-splitting enzyme peptidase act on peptides (products of digested protein by trypsin of pancreatic juice) to form amino acids.

$$\text{Peptides} \xrightarrow{\textit{Peptidase}} \text{Amino Acids}$$

  Fat-splitting enzyme lipase acts on fats to form fatty acid and glycerol.

$$\text{Fat} \xrightarrow{\textit{Lipase}} \text{Fatty Acid} + \text{Glycerol}$$

- *Protective function:* Succus entericus protects the intestinal epithelium from the corrosive action of bile, as well as, acid chyme.
- *Absorptive function:* Nutrient materials are absorbed by small intestine in the presence of succus entericus.

- *Regulation of water balance:* Secretion of intestinal juice regulates water balance in the body.

Next, we shall look at the mechanism of the secretion of the intestinal juice.

Mechanism of secretion of succus entericus

The mechanism of secretion of succus entericus involves two factors. These include:

- *Local factors:* Presence of nutritional materials in the small intestine increases the flow of intestinal juice. Distention of the small intestine and the presence of chyme regulate intestinal secretion by various local reflexes.
- *Hormonal factors:* When chyme enters the small intestine, the hormone *enterocrinin* stimulates intestinal juice secretion.

6.11 THE LARGE INTESTINE

The large intestine or colon is about five feet long. It begins at the caecum as can be seen in Figure 6.16 and terminates at the rectum and anal canal.

It is divided into a number of parts – caecum, ascending colon, transverse colon, descending colon, pelvic colon, rectum and anal canal. Figure 6.16, illustrates these different parts of the large intestine. Now, let us study about these parts.

- *Caecum:* This is the first part of the colon. Ileocolic valve opens from the ileum on the medial aspect of the caecum. The vermiform appendix is a fine tube which leads from the caecum. It has the same structure as the walls of the colon but contains more lymphoid tissue.
- *Ascending colon:* The ascending colon passes upwards from the caecum to the level of the liver where it bends acutely to the left to become transverse colon.
- *Transverse colon:* This is a loop of colon which extends transversely across the abdominal cavity in front of the duodenum and the stomach.
- *Descending colon:* This part of the colon passes down the left side of the abdominal cavity.
- *Rectum:* This is a slightly dilated part of the colon. It leads from the pelvic colon.
- *Anal canal:* This is a short canal which leads from the rectum to the exterior. There are two sphincter muscles which control the anus. The internal sphincter consists of smooth muscle fibre and is under the control of autonomic nervous system. The external sphincter is formed by striated muscle. It is under voluntary nerve control.

Next, let us learn about the tissues of the large intestine.

Like other parts of the gastrointestinal tract, the large intestine also consists of four layers. Can you recall these four layers? Yes, the outermost covering is a *peritoneum* consisting of fibrous tissue. The next layer is a *muscle layer*. It consists of two layers of smooth muscle fibres. The longitudinal fibres are collected into three bands called *taeriae coli*. These bands of muscle tissue are slightly shorter than the total length of the colon. They give a puckered appearance to the organ. The circular muscle fibres form a thin layer surrounding the colon. The sphincters are formed by thickening of these circular fibres. Next is the *submucous layer* which consists of areolar tissue, blood vessels, lymphoid tissue and nerves. The *mucous membrane* consists of columnar epithelium with numerous goblet cells.

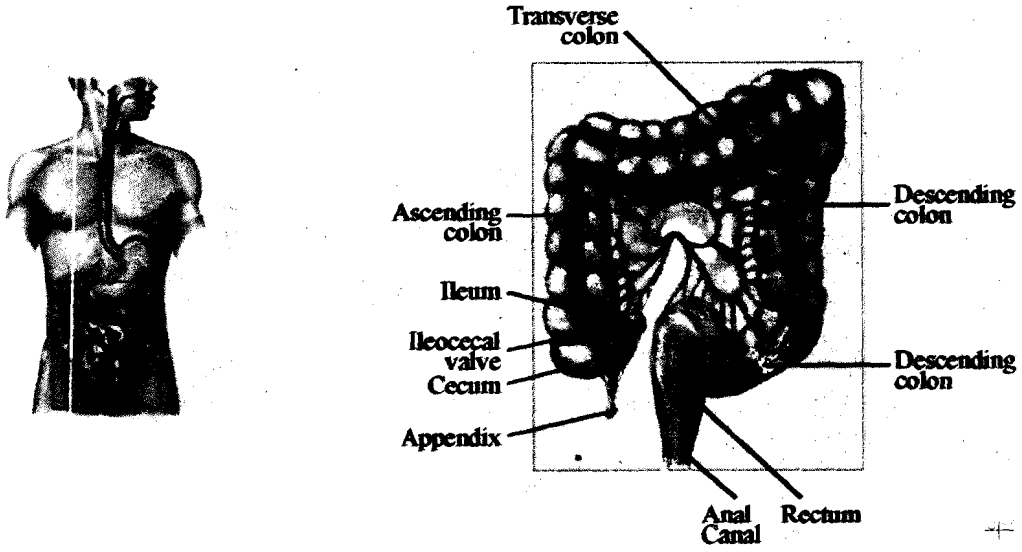

Figure 6.16: Large intestine

Next, let us get to know the functions of the large intestine. These functions are highlighted herewith.

Functions of the large intestine

The multiple functions of large intestine include:

- *Absorption:* The large intestine helps in the absorption of saline, glucose, water, alcohol and drugs at a slow rate.
- *Secretion:* It secretes large quantity of mucin.
- *Bacterial action:* Coarse cellular material cannot be digested in the alimentary tract. In the large intestine, they are broken down by the bacterial action.
- *Synthesis:* A large number of bacteria in the large intestine possess the power to synthesize vitamin B complex and folic acid. It is, however, doubtful whether these vitamins are reabsorbed.
- *Defaecation:* The undigested and waste matter in the intestine is called *faeces*. The process of evacuation of faecal matter from the rectum is called *defaecation*.

Defaecation is one of the most important functions of the large intestine. Let us learn about this function in greater details.

The rectum is normally empty. The faecal matter is stored in the pelvic colon. When there is a mass movement, it forces the contents of the pelvic colon into the rectum. As soon as the matter enters the rectum, there is a desire of defaecation. Nerve endings in the walls of the rectum are stimulated. Nerve impulses are conveyed to the brain and the brain can inhibit the reflex until a suitable time and place is available to defaecate. The colon contents pass into the anal canal and are finally removed from the body. Defaecation involves involuntary contraction of the muscle of the rectum and relaxation of internal anal sphincter and voluntary relaxation of external anal sphincter. Contraction of the abdominal muscles and lowering of diaphragm increases the intra-abdominal pressure. This helps in the process of defaecation. Remember, in infants, defaecation cannot be controlled and occurs by reflex action.

Do you know what the composition of faeces is? Faeces contain undigestible cellular material, such as:

- dead and living microorganisms
- epithelial cells from the intestinal wall
- some fatty acids, and
- mucus

Faeces are brown in colour due to the presence of bile pigments.

With the discussion on the large intestine, we come to an end of our study on the different organs of the gastrointestinal tract. We shall now look at the movement of the gastrointestinal tract, which you would realize, is basic for performing the various functions of the organs of the gastrointestinal tract as discussed above.

6.12 MOVEMENTS OF THE GASTROINTESTINAL TRACT

Unless some kind of movement is present in the gastrointestinal tract, it will not be able to perform its digestive and absorptive functions. What do we mean by *movement*? You have studied about mastication, swallowing, peristalsis process earlier in the unit. These are the movements of the gastrointestinal tract. Movements are necessary to propel the food mass onwards, to bring the food in contact with different digestive juices and also for mixing and churning. Defaecation, the process of evacuation of the faecal matter, is also performed by contraction of muscle of the large intestine.

When food is taken in the mouth, two types of movements – *mastication* and *deglutition* are important. What do you understand by these terms? Let's get to know about them.

a) *Mastication:* Mastication or chewing means the grinding of food with the teeth. Teeth are designed for chewing. You learnt earlier in sub-section 6.3.1 that incisors and canine are cutting teeth. Premolar and molar are grinding teeth.

   We know that chewing of food is important for digestion of all foods, but it is especially important for fruits and vegetables. Indigestible cellular membranes of fruits and vegetables must be broken before the food can be utilized. The total surface area of the foodstuff is increased during mastication. This enables the digestive enzymes to act faster on a large surface area.

   Chewing is a reflex process. When the food bolus is present in the mouth, it first causes reflex inhibition of the muscles of mastication. This allows lower jaw to drop. The sudden drop, in turn, initiates a stretch reflex of the jaw muscles that leads to a rebound contraction. This automatically raises the jaw to cause closure of the teeth. But it also compresses the bolus against the lining of the mouth. The process is repeated again and again.

b) *Deglutition:* Deglutition or swallowing is a complicated mechanism. In general, it is divided into three phases – *the voluntary stage, the pharyngeal stage* (involuntary) and the *oesophageal stage* (involuntary). Let us look at these processes.

   - During *voluntary stage*, the food bolus is thrown back to the pharynx by the upward elevation of the tongue.
   - In *pharyngeal stage*, when the food bolus is pushed backward in the mouth, it stimulates swallowing receptors around the opening of the pharynx. Impulses from these receptors reach the brain stem to initiate a series of automatic pharyngeal muscular contraction. The soft palate elevates, the nasal opening is closed and the larynx is pulled down. The food bolus reaches the pharyngeal cavity.
   - In *oesophageal stage*, the laryngeal opening is closed by a covering cartilage and the vocal cords are closed with each other. The food bolus is thrown into the oesophagus.

Along with chewing and swallowing, there are two other basic types of movements in the gastrointestinal tract – *mixing movement* and *propulsive movement*. What are these movements? Let's learn about these, next.

c) *Mixing movement:* This movement helps the intestinal contents to be thoroughly mixed at all times. It is usually caused by the local contractions of small segments of the gut wall. Movements are modified in different parts of the gastrointestinal tract for performance of respective work. Let us understand the mixing movement now.

Gastric secretion comes into contact with the stored food in the stomach. When the stomach is filled, mixing waves move along the stomach wall approximately once in 20 seconds. Mixing movement by these waves tend to move the gastric secretions and the food gradually towards the antral part of the stomach. On entering the antrum, the waves become stronger. The food and gastric secretions become progressively mixed with a greater degree of fluidity.

In the small intestine, rhythmic contractions proceed at a rate of 11 to 12 per minute when the chyme enters the duodenum. In this way, there is a progressive mixing of solid food particles with the secretions from the small intestine.

Mixing movements also occur in the large intestine. Contractions are called *haustral contractions*. By this movement, the faecal material is gradually exposed to the surface of the large intestine and the fluid is progressively absorbed. These contractions also help to move the faecal contents of the cecum and ascending colon into the transverse colon.

Next, let us learn about the propulsive movement.

d) *Propulsive movement:* The basic propulsive movement of the gastrointestinal tract is *peristalsis*. Peristalsis *is the movement by which the gastrointestinal canal, having both longitudinal and circular muscle fibres, help propel the contents.*

The usual stimulus for peristalsis is distention i.e. if a large amount of food collects at any point in the gut, the distention stimulates the gut wall 2 to 3 cm above this point. A contractile ring appears and a peristaltic movement starts.

Strong peristaltic waves occur about once every 20 seconds in the stomach. They become intense approximately at the *incisura angularis*, from which they spread through the antrum. The movement is necessary to propel the food mass onwards and to bring it in contact with the gastric juice.

Peristaltic movements take place in the large intestine also. It is called *mass movement*. Mass movement propels the faecal contents towards the anus. Let us take a break here before we move on to the gastrointestinal hormones and review what we have learnt so you.

Check Your Progress Exercise 4

1) Fill in the blanks:

   a) The three parts of the small intestine are ..... , ... and ..... .

   b) The mucus membrane consists of tiny finger-like projections called as ..... .

   c) The small intestine protects the body against bacterial infection with the help of ..... and ..... .

d) ..... and ..... are the two sphincter muscles which control the movement of anus.

e) The process of defecation involves the movements of ..... and ..... .

2) What is succus entericus? Give the functions of succus entericus.

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3) List the factors involved in the secretion of succus entericus?

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4) Which are the basic movements in the GI tract? Explain any one of these.

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6.13 GASTROINTESTINAL HORMONES

We have learnt earlier in the unit about the hormones present in the gastrointestinal tract which aid in digestion. Can you name these hormones? Yes, gastrin, secretin, CCK etc. What are hormones? Hormones, as we already know, are *the secretions from the ductless glands in the body and have a particular target organ where they perform the functions.* There are many types of hormones in our body. In this unit, we shall study about gastrointestinal hormones.

The digestive functions of the gastrointestinal system are dependent on gastrointestinal hormones. Gastrointestinal hormones are *the local hormones secreted by parts of gastrointestinal mucosa, transported in the blood circulation and influence the functions of the stomach, the intestine, the pancreas and the gall bladder.* Some of these gastrointestinal hormones namely secretin, CCK have been discussed earlier in this unit.

We will now study about gastrin and other gastrointestinal hormones here in this section.

Gastrin

Gastrin is secreted from G-cells of the glands of the mucosa of the antral portion of stomach. A significant amount of gastrin is also secreted by the duodenal mucosa.

Three types of gastrin have been isolated. The commonest form is called G17 containing 17 amino acids. Another form is G34, a big gastrin containing 34 amino acids. Gastrin containing 14 amino acids is called G14 or *minigastrin.*

The main functions of gastrin are stimulation of gastric acid and pepsin secretion. The substances that increase gastrin secretion include: peptides and amino acids, increased vagal discharge, calcium and epinephrine. The substances that inhibit gastrin secretion are: acid in the antrum, secretin, glucagon and calcitonin.

We have already studied about secretin and CCK in sub-section 6.8.3. Let us get to know about the other gastrointestinal hormones now.

Gastric inhibitory peptide (GIP): It inhibits gastric secretion and motility.

Enterogastrone: It inhibits gastric acid secretion and motility.

Motilin: It stimulates gastric acid secretion.

Vasoactive intestinal peptide (VIP): It stimulates intestinal secretion of electrolytes and hence water.

Our understanding of gastrointestinal tract shall not be complete without a discussion on the mechanism involved in the absortion and utilization of carbohydrates, proteins and fats in the GI tract. The next section summarizes the information.

6.14 ABSORPTION AND UTILIZATION OF CARBOHYDRATES, PROTEINS AND FATS

We have partly studied about the digestion of carbohydrates, proteins and fats earlier in section 6.10. Let us look at the digestion of these substances in greater details now. We start with carbohydrates.

6.14.1 Absorption and Utilization of Carbohydrates

The digestion of carbohydrates in the body and the digestive juices involved in this process are summarized in Table 6.5.

Table 6.5: Digestion of carbohydrates

Organ	Digestive juice	Enzymes and their action
Mouth	Saliva	Ptyalin acts on cooked starches and converts starch to maltose.
Stomach	Gastric juice	Hydrochloric acid stops the action of salivary ptyalin.
Small intestine	Pancreatic juice	Pancreatic amylase converts all starches to disaccharides.
Small intestine	Intestinal juice	Sucrase, maltase and lactase convert all sugars to monosaccharides, mainly glucose.

You would have noticed that the end products of carbohydrate digestion are monosaccharides, namely glucose, fructose and galactose. Let us learn how these are absorbed and utilized.

Absorption of glucose: Glucose is absorbed from the small intestine. The carrier for transport of glucose is present in the brush border of the epithelial cells. The carrier needs sodium-transport system for its action. Therefore, it is believed that the carrier has a receptor site for both glucose molecule and sodium ion. The energy to cause movement of the carrier from the exterior of the membrane to the interior is derived from the difference in sodium concentration between the outside and inside. As sodium diffuses to the inside of the cell, it drags the carrier and the glucose along with it. This is called *sodium gradient theory* for glucose transport. You can read more about the absorption of glucose in the Nutritional Biochemistry Course.

Transport of fructose: Fructose is converted to glucose after it is being transported. This occurs before entering the portal blood. The conversion occurs inside the cell. Fructose first becomes phosphorylated, then converted to glucose and finally released from the epithelial cell into the blood.

Utilization of glucose: A constant blood glucose level is maintained so that all body tissues have a constant supply. Excess glucose is converted to glycogen in the presence of insulin and stored in the liver and in the muscles. Remaining glucose is converted into fat and stored in the body. Glucose is used in the body to provide energy and heat. Oxygen helps in the process of breakdown of glucose. Waste products left are carbon dioxide and water.

6.14.2 Absorption and Utilization of Proteins

The digestion of proteins is summarized in Table 6.6.

Table 6.6: Digestion of proteins

Organ	Digestive juice	Enzymes and their action
Mouth	Saliva	No action.
Stomach	Gastric juice	Hydrochloric acid converts pepsinogen to pepsin. Pepsin converts all proteins to peptones.
Small intestine	Pancreatic juice	Enterokinase of intestinal juice converts trypsinogen to trypsin and chymotrypsinogen to chymotrypsin. Trypsin and chymotrypsin convert peptones to peptides and polypeptides.
Small intestine	Intestinal juice	Peptidases convert [illegible] to amino acid.

Let us have a look at the absorption and utilization of amino acid next.

Absorption of amino acid

Proteins are absorbed in the form of amino acids. Amino acid transport occurs only in the presence of simultaneous sodium transport. Carrier systems are present in the brush border of the epithelial cells. Amino acids are also transported by sodium gradient mechanism. The carrier has a receptor site for both an amino acid molecule and a sodium ion. Only when both sites are filled, the carrier will move to the interior of the cell. The sodium diffusion to the cell interior pulls the carrier and its attached amino acids to the interior where amino acids are trapped. They diffuse through the sides or base of the cell into the portal blood. There are four different carrier systems — one transports neutral amino acid, second one transports basic amino acid, third transports acidic amino acids and the fourth transports proline and hydroxyproline.

Utilization of amino acid

Amino acids are utilized in the liver to form plasma proteins like serum albumin, serum globulin, prothrombin and fibrinogen.

Amino acids, not required in the body, are deaminated in the liver. The nitrogenous part is converted into urea and excreted in the urine. The remaining part is used to provide energy and heat or deposited as fat. To learn more about this process, look up Unit 8 in the Nutritional Biochemistry Course.

Next, we shall move on to the fats.

6.14.3 Absorption and Utilization of Fats

The digestion and absorption of fats in the various organs of the body along with the enzymes involved is summarized in Table 6.7.

Table 6.7: Digestion of fat

Organ	Digestive juice	Enzymes and their action
Mouth	Saliva	No action.
Stomach	Gastric juice	No action.
Small intestine	Bile and pancreatic juice	Bile emulsifies fat. Lipase converts fats to fatty acids and glycerol.
Small intestine	Intestinal juice	Lipase completes the digestion of fats to fatty acids and glycerol.

Let us now study how these are absorbed and utilized in the body.

Absorption of fatty acid and glycerol

Free fatty acid and glycerol dissolve in lipid portion of the bile micelles. They are soluble in chyme. In this form, they are transported to the epithelial cells. As they are lipid soluble, they become dissolved in the membrane and diffuse to the interior of cells. As they diffuse through the cell membrane, bile acid micelles are left in the chyme. They then absorb more fatty acids and transport them to the epithelial cells. Thus, the bile acids perform a ferrying function.

After entry into the epithelial cell, the fatty acids are reconstituted by the endoplasmic reticulum into triglycerides. Almost all of the glycerol that is utilized for this purpose is synthesized from glycerophosphate. Once formed, the triglycerides collect into globule, along with the absorbed cholesterol, absorbed phospholipids and newly synthesized phospholipids. Each of these is then encased in a protein coat. Such globules are called *chylomicrons*. Read Unit 7 of the Nutritional Biochemistry Course for more details on this topic. Finally, globular mass along with the protein coat enters the intercellular space from the sides of the epithelial cells. From here, it passes into central lacteal of the villi.

From the lacteals of villi, the chylomicrons are propelled along the lymph through the thoracic duct and is emptied into great veins: superior vena cava and inferior vena cava. 80% to 90% of fat is absorbed from the gut and is transported to the blood in the form of chylomicrons.

Small quantities of short chain fatty acids from cow milk, butter etc. are absorbed directly into the portal blood. They are not converted into triglyceride and are not absorbed into the lymphatics. Actually, short chain fatty acids are more water soluble than long chain fatty acids. They are directly diffused from the epithelial cells into the capillary blood of the villus.

Next, let us learn how fatty acids are utilized.

Utilization of fatty acids

In the presence of oxygen, fatty acids are utilized to provide energy and heat. Waste products produced are carbon dioxide and water.

Fatty acids are stored as fat. When this stored fat is required in the body for oxidation, it must first be desaturated by the liver.

The discussion above presented a brief review on the digestion, absorption and utilization of nutrients in the GI tract. Finally, let us look at the disorders of the digestive tract. With this our study and understanding of the physiology of gastrointestinal tract will be completed.

6.15 SOME COMMON DISORDERS OF THE DIGESTIVE SYSTEM

Having understood the structure, functions of the various organs which constitute the gastrointestinal tract, you would now appreciate how important and crucial the functioning of this system is for good health. You may have sometimes experienced few common disorders related to the malfunctioning of the GI tract. What are these disorders? Read and find out.

Constipation: Constipation means *infrequent or difficult evacuation of faeces.* It is often associated with the large quantities of dry hard stool in the descending colon. One of the causes of constipation is irregular bowel habits, which may develop from the inhibition of the normal defecation reflex. Constipation can also result from spasm of a small segment of colon. Occasionally, a person develops constipation which is so severe that bowel movements occur only once in several weeks. This may be due to congenital lack of myenteric plexus. A large quantity of stool accumulates in the colon. The condition is called *megacolon.*

Intake of plenty of water, vegetable and roughage may relieve constipation.

Diarrhoea: Frequent evacuation of watery stool, you know, is called *diarrhoea.* There is a rapid movement of faecal matter from the large intestine. The major causes of diarrhoea may be infection or by parasympathetic stimulation of the large intestine.

Infection may be due to a bacteria or a virus. Usually the infection is extensive in the ileum and large intestine. Large quantity of fluid is lost in stool as it washes the infections agent toward the anus.

Psychogenic diarrhoea may occur due to nervous tension. There is excessive stimulation of the parasympathetic nervous system. It stimulates both motility and secretion of mucus in the distal colon resulting in diarrhoea.

There is excessive fluid and electrolyte loss. This loss can be compensated by taking fluid and salt. Infection should be treated.

Vomiting: Vomiting is *forcible ejection of contents of the stomach through the mouth.* The stimuli that cause vomiting may occur in any part of the gastrointestinal tract.

When the vomiting centre is sufficiently stimulated, the effects are deep breath, closing of the epiglottis, and lifting of the soft palate followed by a strong downward contraction of the diaphragm along with contraction of abdominal muscles. The gastroesophageal sphincter relaxes and gastric contents come out.

Obstructive jaundice: When bile duct is obstructed due to presence of stones, growth, pressing bile duct, bile pigments don't reach small intestine and regurgitate back to blood, leading onto excess of these pigments in blood. These have an affinity for elastic tissue in sclera of eye, skin in mucosa of tongue, hence these organs become yellowish - hence jaundice.

With a brief study of disorder, we come to an end of our study of the physiology of the gastrointestinal system.

Check Your Progress Exercise 5

1) What are gastrointestinal hormones? List any three gastrointestinal hormones.

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2) How are amino acids and fats utilized in our body?

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3) What is the role of pancreatic juice in the digestion of :

a) Carbohydrates

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b) Proteins

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4) Enumerate any two common disorders of the digestive tract.

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6.16 LET US SUM UP

In this unit, we studied about the digestive system and the organs involved. The digestive tract, as you know, is a long tube through which the food passes. It commences at the mouth and terminates at the anus.

We learnt in detail about the role of the different organs – mouth, oesophagus, stomach, pancreas, liver, gall bladder, small intestine, large intestine etc.– involved in the process of digestion and how they function to ensure the proper functioning of the digestive system.

We also got to know four major functions performed by the digestive system – ingestion, digestion, absorption and elimination.

Finally, we saw how the major components of food that is, carbohydrates, proteins and fats are metabolized in our body and what are the various digestive enzymes involved in the process. We also had a brief review on some of the major gastro-intestinal disorders such as diarrhoea, constipation and jaundice.

6.17 GLOSSARY

Antrum : a dilated portion of the pyloric part of the stomach.

Canaliculus : an extremely narrow tubular passage or channel.

Cephalic : pertaining to the head.

Cholagouge : an agent that stimulates gall bladder contraction.

Choleretic : stimulating bile production by the liver.

Chyme : a semi-liquid mass of partially digested food.

Deglutition : swallowing.

Haemopoietic : pertaining to blood making.

Hydrocholerectic : stimulating bile production with increased water output.

Ileocolic : pertaining to ileum and colon.

Myenteric Plexus : a plexus of unmyelinated fibers and postganglionic autonomic cell bodies in the muscular coat of the esophagus and stomach and intestines.

Peritoneum : the serous membrane living the walls of the abdominal and pelvic cavities.

Plexus : network of vessels and nerves.

Pylorus : the distal aperture of the stomach opening into the duodenum.

Sinusoids : resembling a sinus (i.e. cavity or channel).

Sphincter : a ring like muscle which closes a natural orifice or passage.

6.18 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1) a) thoracic, lumbar, cranial, vagus
   b) salivary glands, pancreas, liver and biliary tract
   c) uvula
   d) circumvallate, fungiform, filiform
   e) enzymes

2) The wall of the gastrointestinal tract consists of:

   - Adventitia or outer covering: made up of loose fibrous tissue and in the abdomen, the organs are covered by a serous membrane called peritoneum.

- Muscle layer: consists of two layers of smooth muscle. The outer layer is a longitudinal muscle layer and the inner layer is a circular muscle layer. Between these two muscle layers there is a network of nerves called the myenteric plexus. It contains sympathetic and parasympathetic nerves.
- Submucous layer: consists of loose areolar connective tissue. There are lymph vessels, plexuses of blood vessels and nerves.
- Mucous membrane: lined by the epithelial cells and consists of stratified squamous epithelium and columnar epithelium.

3) The different types of tooth and their functions are:
   - Incisors – biting off pieces of food
   - Canine – biting off pieces of food
   - Premolar – chewing
   - Molar – chewing

4) The functions of saliva include:

   Digestion of food, lubrication of food, cleaning, taste, articulation, heat loss, bacteriolytic action

5) a) – ii)

   b) – i)

   c) – iii)

   d) – v)

   e) – iv)

Check Your Progress Exercise 2

1) a) nasopharynx, oropharynx and laryngopharynx.

   b) outer covering, muscle layer, submucous layer and inner lining.

   c) columnar epithelium, goblet, mucous neck cells, chief cells, oxyntic cells

   d) fasting

   e) cardiac orifice, pyloric orifice

2) Stomach can be described as having two curvatures: the lesser curvature which is a continuation of the posterior part of the oesophagus and the greater curvature is on the anterior oesophagus and greater curvature is on the anterior surface of the stomach. It is divided into 3 parts:

   The fundus, which is a part of stomach above and left of the cardiac orifice, body, which is the main part of stomach and pylorus, lower part which curves to the right.

3) The functions of gastric juice are digestive function, enzyme action, antiseptic action, haemopoietic function, protective function and excretory function.

4) a) Secretion of gastric juice is divided into three phases:

- Cephalic phase or neural phase: The flow of juice occurs before food reaches the stomach. 45% of the total gastric secretion is discharged during this phase. Sight, taste, smell and even thinking of an appetizing meal produces secretions by the reflex stimulation of vagus nerve.

- Gastric phase: The mechanical presence of food in the antrum of the stomach stimulates the production of a hormone, gastrin. This hormone activates the parietal cells of the stomach to secrete more gastric juice. In this phase, another 45% of the gastric secretion is discharged.

- Intestinal phase: Rest 10% of the total gastric secretion is discharged in this phase. The presence of certain food substances in the small intestine excites gastric secretion. These are meat extract, alcohol etc. while certain substances inhibit gastric secretion such as alkali and fat.

b) The mechanism of secretion of pancreatic juice consists of the following phases:

- Nervous phase: When stomach secretes gastric juice, nerve impulses are transmitted along the vagus nerves to the pancreas. This results in the secretion of moderate quantity of pancreatic enzymes.

- Hormonal phase: After food enters the duodenum, pancreatic secretion increases. The hormones secretin and cholecystokinin are responsible for the secretion.

5) a) Secretin causes the pancreas to secrete large quantities of fluid containing a high concentration of bicarbonate ion. This fluid referred to as pancreatic juice, is helpful to neutralize the acid content of substances emptied into the duodenum from stomach.

b) The presence of food in the upper small intestine causes the release of CCK from the intestinal mucosa. It acts on pancreas via blood and cause secretion of digestive enzymes. Peptones, fats and acids in the small intestine stimulate its secretion.

Check Your Progress Exercise 3

1) The important functons of liver are secretion of bile, glycogenesis and glycogenolysis, deamination of protein, storage of vitamins A,D,E,K and B_{12}, formation of plasma proteins and storage of iron.

2) The movements of gall bladder are controlled by the factors such as reflex control, presence of foodstuffs and cholecystokinin.

3) Bile is a complex fluid. It is yellowish green in colour and bitter in taste.

It contains water, mineral salts (chloride, carbonate and phosphate of sodium, potassium and calcium), mucus, bile salts (sodium taurocholate, sodium glycocholate), bile pigments (bilirubin and biliverdin), cholesterol and traces of fatty acids.

Its functions are emulsification, activation of enzyme, cholagouge action, absorptive function, laxative action, maintenance of pH, excretory function, and coloration of faeces.

4) Substances which increase the output of bile from the liver are known as choleretic agents. Substances which increase the volume of bile are called hydrocholeretic agents.

Check Your Progress Exercise 4

1) a) duodenum, jejunum, ileum

   b) villi

   c) solitary lymph nodes, aggregated glands

   d) internal, external

   e) rectum, sphincters

2) Succus entericus is the intestinal juice. Its functions include digestion, protection, absorption and regulation of water balance.

3) The factors involved in the secretion of succus entericus are:

   - Local factors: Distention of the small intestine, presence of nutritional materials and chyme regulate intestinal secretion
   - Hormonal factors: with the entry of chyme in the small intestine, enterocrinin hormone is released, which stimulates intestinal juice secretion.

4) The basic movements in the GI tract are mastication, deglutition, mixing movement and propulsive movement. The mixing movement helps to keep the intestinal contents thoroughly mixed at all times. It is usually caused by the local contractions of small segments of the gut wall.

   These movements also occur in the small intestine where there is a progressive mixing of solid food particles with the secretions from small intestine. In the large intestine, these contractions expose the fecal material to the surface of large intestine and help to move it in the transverse colon.

Check Your Progress Exercise 5

1) Gastrointestinal hormones are local hormones secreted by parts of gastrointestinal mucosa, transported in the blood circulation and influence the functions of the stomach, the intestine, the pancreas and the gall bladder. Gastrin, secretin and CCK are three gastrointestinal hormones.

2) Amino acids are utilized in the liver to form plasma proteins - deaminated in the liver, nitrogenous part is converted into urine while the remaining part is used to provide energy and heat.

   Fatty acids are utilized to provide energy and heat and are stored as fat.

3) a) Carbohydrates: Pancreatic amylase converts all starches to disaccharides.

   b) Proteins: Enterokinase converts trypsinogen to trypsin and chymotryprsin converts peptones to peptides and polypeptides.

4) Any two of the following

   Constipation: Constipation means infrequent or difficult evacuation of faeces often associated with the large quantities of dry hard stool in the descending colon. One of the causes is irregular bowel habits developing from the inhibition

of the normal defecation reflex. It can also result from spasm of a small segment of colon. Intake of plenty of water, vegetable and roughage may relieve constipation.

Diarrhoea: Frequent evacuation of watery stool is called diarrhoea. There is rapid movement of fecal matter from the large intestine. The major causes may be infection or by parasympathetic stimulation of the large intestine.

Vomiting: Vomiting is forcible ejection of contents of the stomach through the mouth. The stimuli that cause vomiting may occur in any part of the gastrointestinal tract.

Obstructive jaundice: When bile duct is obstructed due to presence of stones, growth, pressing bile duct, bile pigments don't reach small intestine and regurgitate back to blood, leading onto excess of these pigments in blood – these have an affinity for elastic tissues.