Chapter 9

HUMAN DIGESTIVE SYSTEM

STUDENTS'LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Describe the mechanical and chemical digestion in the oral cavity
- Explain swallowing and peristalsis.
- Illustrate with a diagram the structure of the stomach and relate each component with the mechanical and chemical digestion in the stomach.
- Identify the role of the nervous system and gastrin hormone on the secretion of gastric juice.
- Describe the major actions carried out on food in the three regions of the small intestine.
- Trace the absorption of digested products from the small intestine lumen to the blood capillaries and lacteals of the villi.
- Describe the component parts of large intestine with their respective roles.
- Correlate the involuntary reflex for egestion in infants and the voluntary control in adults.
- Explain the storage and metabolic role of the liver.
- Describe composition of bile and relate the constituents with respective roles.
- Outline the structure of pancreas and explain its function as an exocrine gland.
- Relate the secretion of bile and pancreatic juice with the secretin hormone.

Digestion is the process by which the body breaks down food into smaller, absorbable components. Digestion is crucial for converting food into energy and raw materials required for growth, repair and maintenance of body functions. It supports the immune system, provides essential nutrients and ensures overall health. Efficient digestion prevents nutrient deficiencies, supports metabolism and maintains energy levels, making it vital for sustaining life.

9.1-ANATOMY AND PHYSIOLOGY OF DIGESTIVE SYSTEM

The human digestive system is composed of the **gastrointestinal** (GI) tract and accessory digestive organs. The GI tract is a continuous tube that extends from mouth to anus. It includes oral cavity, pharynx, oesophagus, stomach, small intestine and large intestine. The accessory digestive organs include the salivary glands, liver, gallbladder and pancreas.

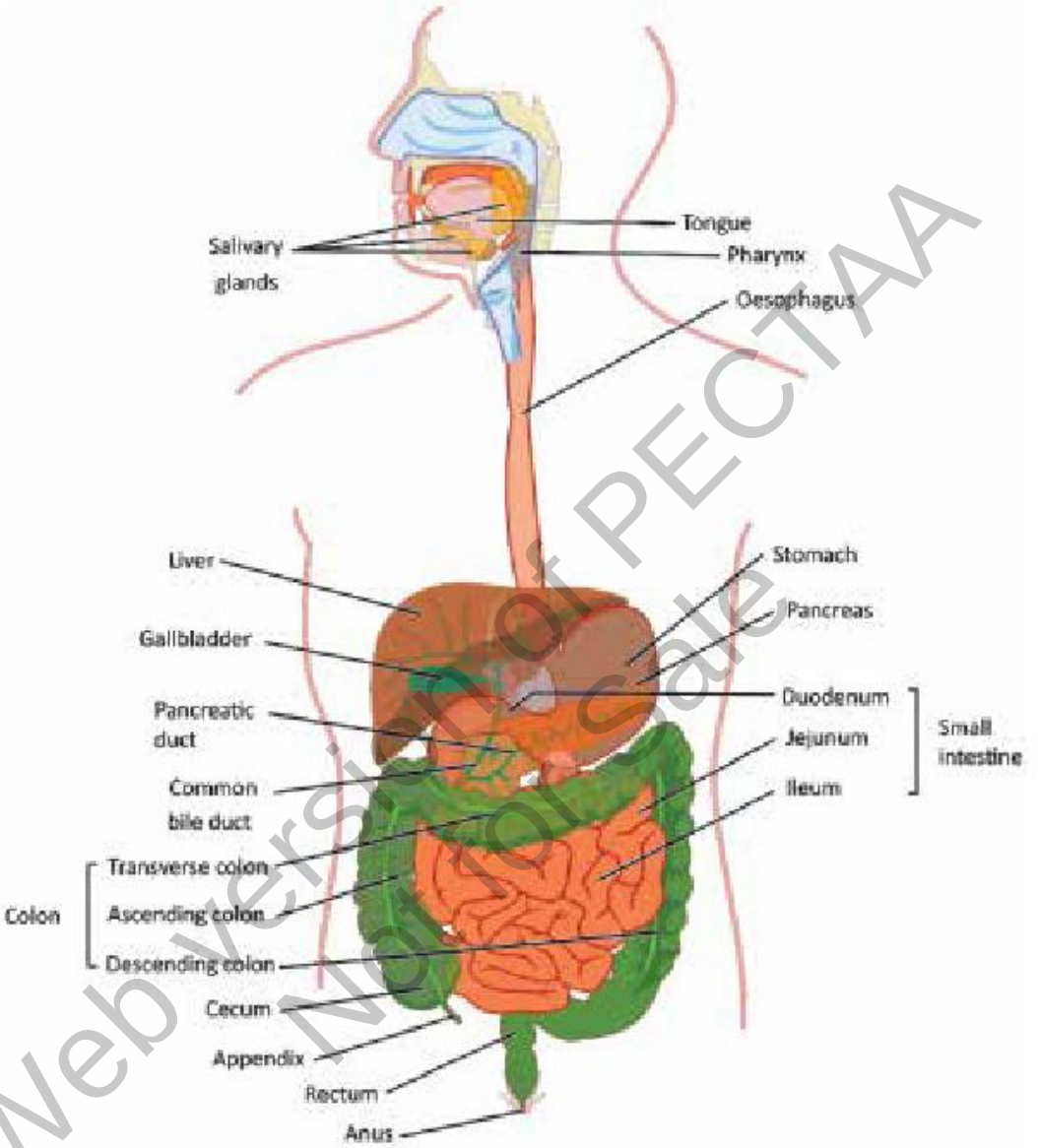

Figure 9.1: Human digestive system

Oral Cavity

It is a cavity immediately after the opening of mouth. **Lips** are made of highly vascularized, skeletal muscle tissue with many sensory nerve endings. Lips help to retain food as it is being chewed. They also play a role in phonation (the modification of sound). The important functions performed by oral cavity are as follows:

Selection of food: The muscular tongue plays role in the selection of food through its taste buds. When food enters the oral cavity, it is tasted and physically felt. If the

taste or smell is unpleasant or if hard objects like bone or dirt are present in the food, it is rejected. The senses of smell and sight also play role in the selection of food.

Mechanical digestion of food: The ingested food is physically broken down by the teeth through a process called **mastication** (chewing). Chewing breaks down food into smaller and more manageable pieces, increasing the surface area for enzymatic action.

Chemical digestion of food: As the chewing of food goes on, the salivary glands pour their secretion, **saliva**, into oral cavity. Palate, tongue and cheeks help in the mixing of chewed food with saliva. There are three pairs of salivary glands which pour saliva into oral cavity. These three pairs are; **sublingual** glands situated below tongue, **submaxillary** glands located behind jaws, and **parotid** glands located in front of ears.

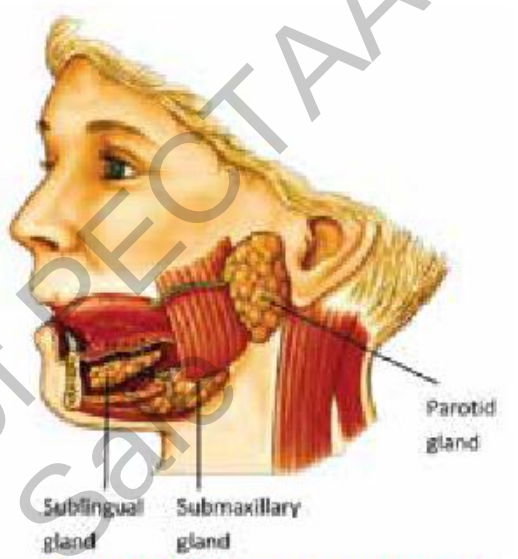

Figure 9.2: Location of salivary glands

Saliva contains water and mucus that moisten and lubricate the food. Saliva also contains bicarbonate ions, which buffer chemicals in the oral cavity, and thiocyanate ions, which kill microorganisms. Fresh saliva is alkaline (pH: 8) but it quickly loses CO_2 and gets pH 6. Saliva also contains an enzyme, **salivary amylase**. It partially digests the polysaccharides (starch and glycogen) to disaccharides (maltose). After the mechanical and chemical digestive processes in the oral cavity, food mass is in the form of a small moist mass called a **bolus**.

Pharynx

The pharynx is a cavity behind the mouth. It is the common passageway for both the digestive and respiratory tracts. The bolus is pushed to the back of the mouth and is swallowed through the pharynx.

Swallowing of food: During swallowing, the tongue moves upwards and backwards against the roof of the mouth. Due to it, the bolus is forced to the back of oral cavity. The soft palate is also raised against the back wall of pharynx. These movements close the passage between nasal cavity and pharynx. At the same time, the larynx moves upward and it lowers the **epiglottis** (a flap of cartilage) and closes the opening of trachea. In this way, the bolus passes over the trachea and enters oesophagus.

The beginning of the swallowing action is voluntary, but once the food reaches the back of the mouth, swallowing becomes automatic.

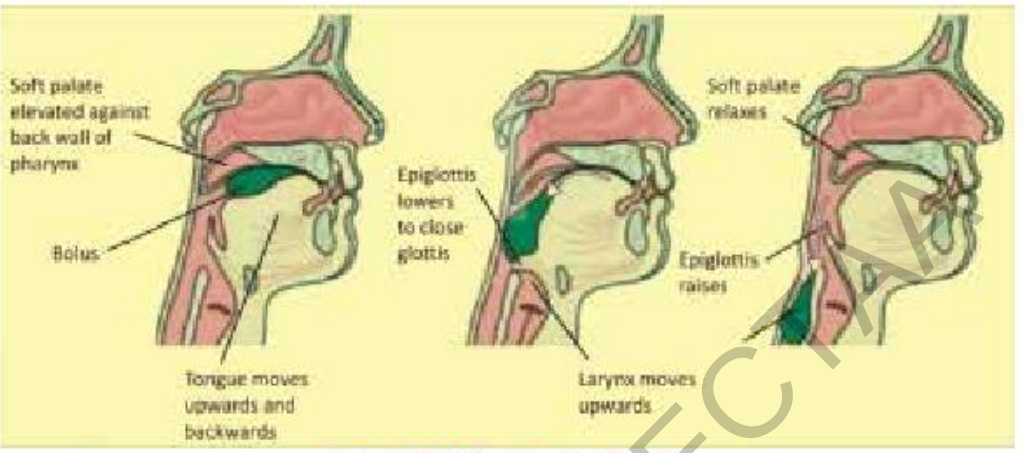

Figure 9.3: Swallowing of food

Oesophagus

After being swallowed, the food enters the tube called oesophagus. It connects the pharynx to the stomach. The previous digestive actions of saliva continue in oesophagus. In adult human, the oesophagus is about 25 cm long and its lower end opens in stomach. Food moves down through the oesophagus to the stomach by **peristalsis**. The exit of food from the oesophagus to the stomach is controlled by the **lower oesophageal sphincter** or **cardiac sphincter**, which opens in response to the pressure exerted by food. It also prevents the backflow of stomach contents into the oesophagus.

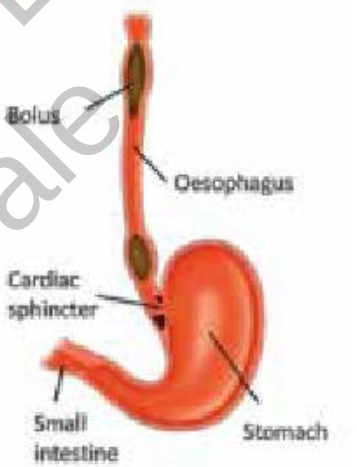

Figure 9.4: Oesophagusand its connections

Motility of Alimentary Canal

The following two types of movements occur in alimentary canal.

Peristalsis: It is the rhythmic sequence of waves of contraction in the smooth-muscles of the walls of alimentary canal. Peristalsis squeezes the food down along oesophagus and other parts of the alimentary canal.

Segmentation: The small and large intestines also have rings of smooth-muscles, which contract and relax repeatedly. These contractions and relaxations create a back-and-forth movement in the same place, called segmentation. This movement mixes the food with digestive secretions and increases the efficiency of absorption.

Antiperistalsis

Occasionally, the peristaltic movements may reverse in a process called **antiperistalsis**, pushing food from the intestines back into the stomach and oral cavity, leading to **vomiting**. In contrast, **hunger contractions** are peristaltic movements triggered by low blood glucose levels, creating the uncomfortable sensation known as **hunger pangs**.

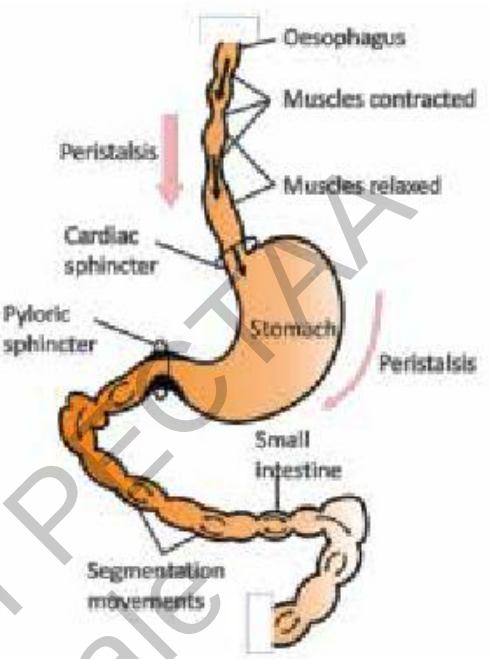

Figure 9.5: Peristalsis and Segmentation

The Stomach

The stomach is an elastic muscular bag (J-shaped) situated after oesophagus and before duodenum. It is located in the left side in abdominal cavity, right below the diaphragm. Its has three portions. The **cardiac portion** is present immediately after oesophagus. **Fundus portion** is present on a side of the cardiac portion. **Pyloric portion** is located beneath the cardiac portion. The cardiac sphincter opens when a wave of peristaltic contractions coming down the oesophagus reaches it and allows food to enter the stomach.

Mechanical digestion of food: The stomach wall is made of the four layers which are:

Mucosa: It is the inner layer of stomach which contain glands. These glands secrete digestive enzymes, HCl and mucus.

Submucosa: It is a layer of connective tissue which contain blood vessels, lymphatic and nerve.

Muscularis externa: It is a layer of muscle i.e., outer longitudinal muscles, middle circular muscles and the inner oblique muscles.

Serosa: It is an outermost thin layer that forms part of peritoneum and provides protection.

The muscular walls of stomach contract and vigorously and help in churning of food (mechanical digestion) and mixing the food with stomach secretions. These contractions also generate enough heat that melts the solid fats.

Chemical digestion of food: The mucosa of stomach possesses numerous tubular **gastric glands**. These glands open in the mucosa wall through deep depressions,

Sometimes there is a back flush of acidic chyme from stomach into the oesophagus. It causes a painful burning sensation in the chest and this condition is known as **pyrosis** or **heartburn**.

thick secretion that covers the inside of the stomach and protects it from HCl and digestive enzymes.

ii. The **parietal (oxyntic) cells** which secrete hydrochloric acid. It adjusts the pH of stomach contents to about 2-3. HCl also softens the food, activates the pepsinogen and kills microorganisms.

iii. The **chief cells** which secrete enzyme, pepsinogen.

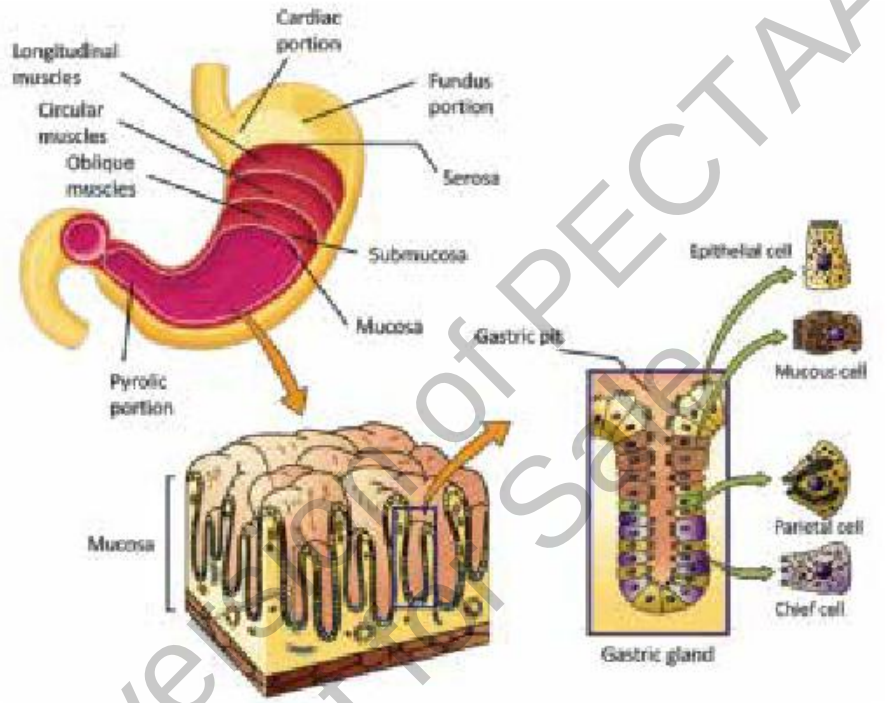

Figure 9.6: Stomach; external and internal structure

All the secretions of gastric glands are collectively called **gastric juice.** When the bolus enters the stomach, the gastric glands secrete gastric juice. The H^+ ions of the HCl activate pepsinogen into pepsin. Pepsin catalyses the breakdown of proteins to yield polypeptides and peptides. About three to four hours after a meal, the stomach contents have been sufficiently mixed and are semi-liquid acidic mass called **chyme.** The **pyloric sphincter** regulates the release of the chyme into the small intestine.

Regulation of Secretion of Gastric Juice

The secretion of gastric juice is regulated by both the nervous system and hormonal mechanisms. In reaction to the smell, sight, or thought of food, the medulla of brain sends message to the gastric glands

The mucosa of stomach is susceptible to damage from acid and pepsin if it had no protection. Protection of the mucosa is provided in two ways; viscous mucous and bicarbonate, which neutralizes acid.

to secrete small amounts of gastric juice. When food arrives in stomach, the distension of stomach and decrease in the pH of the gastric contents stimulate more secretion and powerful contractions.

The presence of proteins in food stimulate special endocrine cells present in the mucosa of stomach to release a hormone called **gastrin**. Gastrin is carried by blood to the gastric glands where it stimulates them to produce and secrete more gastric juice. When food moves from stomach to small intestine, a hormone called **somatostatin** stops the release of hydrochloric acid.

The Small Intestine

It is the longest part of alimentary canal. It starts after the stomach and ends at the large intestine. In adult man it is about 2-3 cm in diameter and 6 m in length. Small intestine is responsible not only for the final digestion of all kinds of food but also for the absorption of digested food into blood and lymph. Small intestine consists of three parts i.e., duodenum, jejunum and ileum.

Duodenum

The first 20 – 25 cm long portion is the duodenum. It is concerned with the digestion of food. It also contains glands, which produce an alkaline secretion containing bicarbonate. Two main secretions are poured into duodenum.

a- Pancreatic juice: It is the secretion of pancreas and is poured into duodenum. It is slightly alkaline (pH: 8) due to the presence of bicarbonate. It neutralizes the acidity of chyme. The important enzymes in pancreatic juice are:

i. **Pancreatic amylase,** which digests polysaccharides into maltose and even glucose)
ii. **Trypsinogen,** which is in inactive form. Another enzyme **enterokinase** (secreted by the walls of duodenum) activates trypsinogen into trypsin, which digests proteins into polypeptides.
iii. **Chymotrypsin and carboxypeptidase,** which digest proteins into smaller peptides and then into amino acids.
iv. **Pancreatic lipase,** which digests lipids to glycerol and fatty acids.
v. **Pancreatic nucleases,** which digest DNA and RNA into nucleotides.

Fats are insoluble in water. So, they cannot be attacked readily by lipase enzymes of pancreatic juice. Bile salts act as detergent molecules. They break fats into droplets and keep them separate from one another.

b- Bile: It is the secretion of liver. Before its release, it is stored in gallbladder. It contains salts which emulsify fats and break them into small droplets (emulsion). These droplets provide large surface areas for effective action of lipids-digesting enzymes.

If bile pigments are prevented from leaving digestive tract, they may accumulate in blood, causing a condition known as jaundice.

Jejunum and Ileum

Jejunum is 2.4 meters long part, next to duodenum. Ileum is the last three fifth i.e., about 3.5 metres long part of small intestine. These parts carry out the rest of digestion and absorption of food. The walls of jejunum and ileum contain glands which secrete intestinal juice. It contains various enzymes; for example, aminopeptidase digests polypeptides into dipeptides, erypsin digests dipeptides into amino acids, lipase digests fats into fatty acids and glycerol, maltase digests maltose into glucose, sucrase digests sucrose into glucose and fructose, and lactase digests lactose into glucose and galactose. After the action of enzymes of intestinal juice, the chyme is converted into an alkaline emulsion, called **chyle**.

Absorption of Digested Food and Water

The absorption of digested food, water, and dissolved minerals occurs in jejunum and ileum. The inner wall of jejunum and ileum contains large circular folds. These folds have numerous finger-like projections called **villi**.

Each villus is richly supplied with blood capillaries and a vessel of lymphatic system, called **lacteal**. The blood capillaries and lacteal are covered by a single-cell thick epithelium. The epithelial cells of villi have countless cytoplasmic projections, called **microvilli**. The total surface area of absorption becomes extraordinarily large due to villi and microvilli.

Due to the presence of folds and numerous villi, the internal surface of Jejunum and Ileum appears velvety.

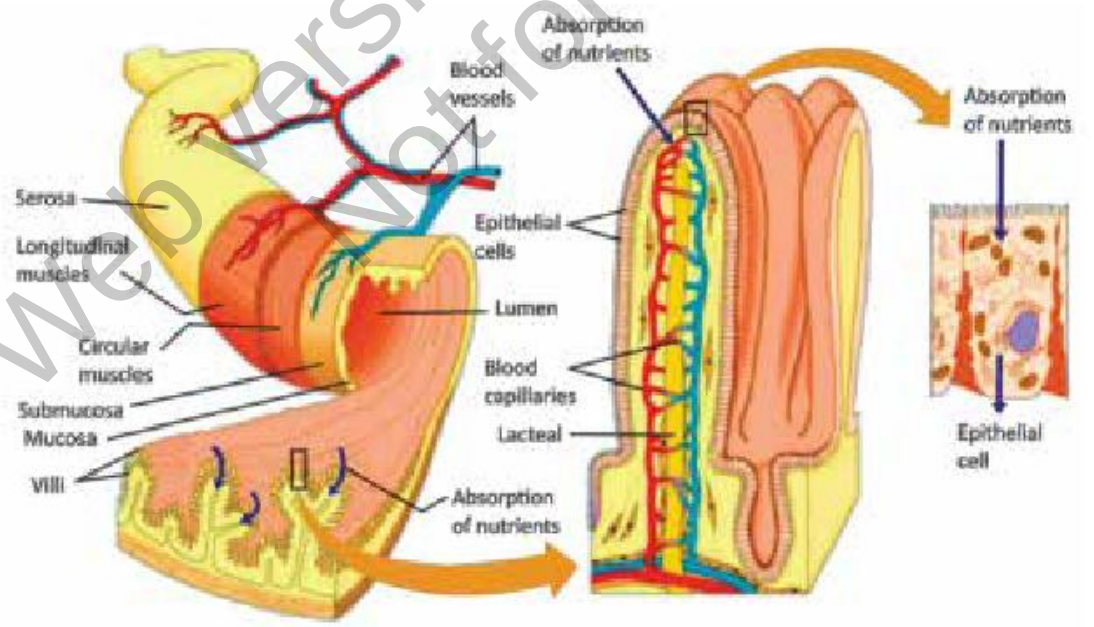

Figure 9.7: Intestinal wall and detailed structure of villi

Absorption of simple sugars and amino acids: Simple sugars (e.g., glucose) and amino acids are absorbed by diffusion or active transport into the epithelial cells of villi. From here, these molecules enter the blood capillaries of villi. Blood capillaries of villi join to form **hepatic portal vein** which carries sugars and amino acids to liver. Liver stores extra glucose and amino acids in the form glycogen and proteins respectively. From liver, the required amounts of these products pass to heart via hepatic vein.

Absorption of Fatty acids and glycerol: The products of fat digestion i.e., fatty acids and glycerol are absorbed by passive transport into the epithelial cells of villi. Inside villi, they combine to form triglycerides. The triglycerides are coated with proteins. In this way small droplets, called **chylomicrons**, are formed. The chylomicrons enter the lacteals of villi. From the lacteals, the chylomicrons move into thoracic lymphatic duct, from where they enter in bloodstream. Blood plasma has enzymes which hydrolyse chylomicrons back into fats and proteins. Fats are ultimately hydrolysed into fatty acids and glycerol and enter body cells.

The Large Intestine

It is the last part of the alimentary canal. It is much shorter than small intestine, occupying about the last metre of the intestinal tract. It is involved in the absorption of water and salts and vitamin 'K' from the lumen of intestine into the blood. The large intestine is not convoluted and its inner surface area does not possess villi. It consists of three parts.

Caecum

It is a blind sac that projects from the area of large intestine between ileum and colon. From the blind end of caecum there arises a finger-like process called vermiform appendix. In human digestive system, appendix performs no function so is vestigial.

Appendicitis is the inflammation of the appendix. It is usually due to bacterial infection. The infected appendix must be removed surgically otherwise it may burst and the inflammation may spread in the entire lining of the abdomen. The surgical removal of appendix is called **appendicectomy.**

Colon

Next to caecum is the colon. It has an ascending, a transverse and a descending limb. Its main function is to absorb water from the alimentary canal. As the water is absorbed, the remaining material becomes more solid. These wastes products, called faeces, consist of a large number of bacteria, indigestible plant fibres (e.g., cellulose), other undigested food stuff, sloughed off mucosal cells, bile pigments and water.

Rectum

It is the last part of large intestine where faeces are temporarily stored. At its distal end, the rectum opens out through anus. Anus is surrounded by two sphincters; the internal sphincter is made of smooth muscles and the outer is made of striated

muscles. Under normal conditions when the rectum is filled up with faeces, it gives rise to a defecation reflex. The defecation reflex is consciously inhibited in adults but in infants it is controlled involuntarily. During growth, the child learns to bring this reflex under voluntary control.

Many bacteria, for example E. coli, live and actively divide within colon. During their metabolism, they produce amino acids and vitamin K. Vitamin K is necessary for man for the coagulation of blood. It is absorbed from the large intestine into the blood.

Control of Egestion

The involuntary reflex for **egestion** in infants and the voluntary control in adults represent two stages of neurological and muscular development. In infants, egestion is an involuntary reflex mediated by the spinal cord, where rectal distension triggers automatic relaxation of the internal anal sphincter and expulsion of waste. This occurs because the higher brain centres responsible for voluntary control are not yet fully developed. In adults, egestion becomes voluntary as the **cerebral cortex** matures, allowing conscious regulation of the external anal sphincter to delay or initiate defecation. This transition reflects the integration of reflex pathways with cognitive control, adapting to social and environmental demands.

Accessory Digestive Organs

1. Liver and Gallbladder

The liver plays a vital role in digestion by producing **bile**, which is essential for fat digestion. Bile emulsifies fats, making them easier to digest. Liver also processes nutrients absorbed from the small intestine, detoxifies harmful substances, synthesizes proteins and stores glycogen for energy.

Cholesterol, secreted by the liver, may precipitate in the gall bladder to produce gall stones, which may block release of bile.

The gallbladder stores and concentrates bile produced by the liver. When food enters the small intestine, the gallbladder releases bile through the bile duct.

2. Pancreas

Pancreas is a large gland situated just ventral to the stomach. It has exocrine and endocrine portions. The **exocrine** (ducted) portion secretes its secretion i.e., pancreatic juice into pancreatic duct. The pancreatic duct joins with the common bile duct from the liver and enters the duodenum. Pancreatic juice contains enzymes for the digestion of all groups of food. Its major enzymes include trypsin, chymotrypsin, lipases, amylases, nucleases etc. The **endocrine** (ductless) portion of pancreas secretes its secretion i.e., insulin and glucagon hormones into extracellular fluid from where they diffuse into nearby capillaries.

Hormonal Control of the Secretions of Pancreas and Liver

We have studied the regulation of gastric secretions through nervous system and hormones. The release of secretions from pancreas and liver is also controlled by hormones. When chyme enters duodenum from stomach, its acidity stimulates duodenal walls to release a hormone, **secretin**. Similarly, the partially digested proteins and fats present in chyme stimulate the duodenal walls to secrete another hormone, **cholecystokinin** (CCK). Both these hormones stimulate pancreas to release pancreatic juice, and gallbladder to release bile.

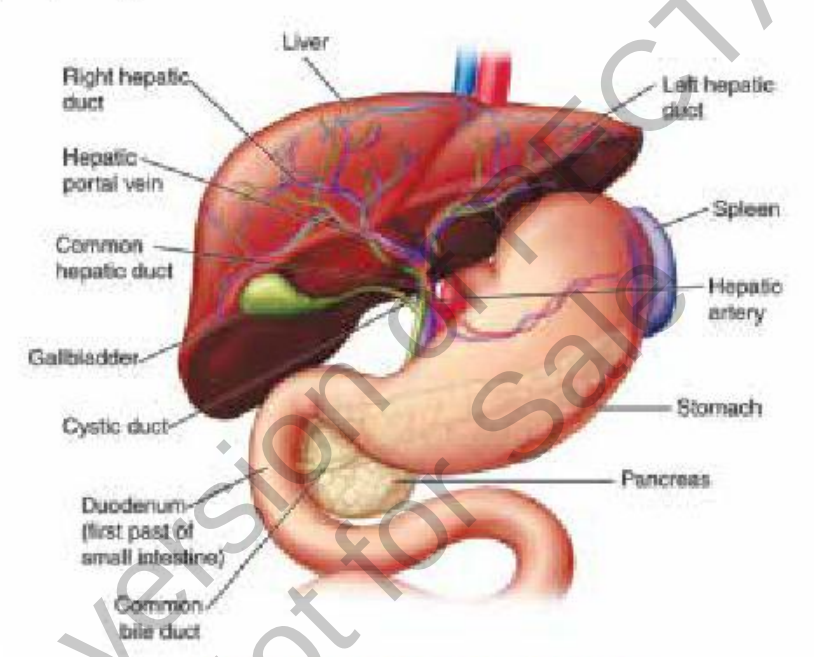

Figure 9.8: Accessory Digestive Organs

Storage and Metabolic Role of the Liver

The liver performs many important functions, especially in storing nutrients and regulating metabolism. It stores excess nutrients from the food and releases them when the body needs energy or building materials. These nutrients stored in the liver include glucose (stored as glycogen), vitamins (like A, D, B12, and K), minerals (e.g., iron and copper), and fats and fat-soluble substances. It also plays a central role in metabolism. It helps in breaking down, building up, and converting substances in the body. For example, it converts excess glucose into glycogen and back when needed. It also breaks down fats to produce energy and forms cholesterol and lipoproteins. It converts amino acids and removes harmful ammonia by turning it into urea, which is excreted in urine. It breaks down and removes toxins, drugs, and alcohol from the blood. The liver also helps in breaking down and regulating hormones

EXERCISE

SECTION 1: MULTIPLE CHOICE QUESTIONS

1. Where does chemical digestion of carbohydrates begin?
   (a) Stomach (b) Oesophagus (c) Small intestine (d) Mouth
2. Which enzyme in saliva starts breaking down starch?
   (a) Lipase (b) Amylase (Ptyalin) (c) Trypsin (d) Pepsin
3. What prevents food from entering the trachea during swallowing?
   (a) Epiglottis (b) Oesophageal sphincter
   (c) Uvula (d) Tongue
4. Why does the enzyme activity drops in the stomach when pH rises?
   (a) Acid blocks food entry (b) Enzymes denature in low pH
   (c) Enzymes need acidic pH to work (d) Saliva dilutes gastric juice
5. Which change would most affect protein digestion?
   (a) Blocking bile release (b) Inhibiting salivary glands
   (c) Inhibiting pepsin production (d) Slowing peristalsis
6. Why is lipase not active in the stomach?
   (a) It is destroyed by acid (b) It needs alkaline pH to work
   (c) It is secreted by the liver (d) It digests only proteins
7. Which stomach secretion activates pepsin and kills bacteria?
   (a) Bile (b) Hydrochloric acid (HCl)
   (c) Sodium bicarbonate (d) Mucus
8. Why is segmentation important in the small intestine?
   (a) It absorbs bile (b) It breaks down enzymes
   (c) It mixes food with digestive juices (d) It pushes food to the rectum
9. What is the function of villi and microvilli in the small intestine?
   (a) Produce enzymes (b) Increase surface area for absorption
   (c) Store bile (d) Neutralize stomach acid
10. Which best explains the liver's role in digestion?
    (a) It produces insulin (b) It stores undigested food
    (c) It produces bile for fat digestion (d) It secretes enzymes into the colon

SECTION 2: SHORT QUESTIONS

1. What is the main function of the digestive system?
2. What is the mode of action of saliva in mouth?
3. What is role of tongue in the mouth?
4. What role does the epiglottis play during swallowing?
5. What is the composition of gastric juice?
6. Why is hydrochloric acid (HCl) important in the stomach?
7. What is the difference between bolus and chyme?

8. Which organ produces bile, and what is its function?
9. Differentiate between physical and chemical digestion.
10. What do you understand by emulsification of fats?
11. What is role of the role of the pyloric sphincter in digestion?
12. How do villi and microvilli help in nutrient absorption?
13. What are the main functions of the large intestine?
14. What causes jaundice in the digestive system?
15. How does stress negatively impact digestion?

SECTION 3: LONG QUESTIONS

1. Explain the complete process of digestion, starting from ingestion in the mouth to egestion in the large intestine. Include the roles of mechanical and chemical digestion at each stage.
2. Describe the structure and function of the stomach in digestion.
3. Compare and contrast the roles of the small intestine and large intestine in digestion.
4. Explain the absorption of food from the small intestine?
5. Discuss accessory organs (liver, gallbladder and pancreas) and their contributions in digestion.
6. Describe the hormonal and nervous regulation of gastric acid secretion.

INQUISITIVE QUESTIONS

1. Why does the small intestine need both peristalsis and segmentation?
2. How does the liver help digestion without using enzymes?
3. Why do we need bile if we already have enzymes for fat digestion?
4. How does the pancreas "know" when to release its enzymes?
5. Why are pancreatic secretions alkaline, not acidic?