Introduction to Digestive System

Chapter 36

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INTRODUCTION

Digestion is defined as the process by which food is broken down into simple chemical substances that can be absorbed and used as nutrients by the body. Most of the substances in the diet cannot be utilized as such. These substances must be broken into smaller particles, so that they can be absorbed into blood and distributed to various parts of the body for utilization. Digestive system is responsible for these functions.

Digestive process is accomplished by mechanical and enzymatic breakdown of food into simpler chemical compounds. A normal young healthy adult consumes about 1 kg of solid diet and about 1 to 2 liter of liquid diet every day. All these food materials are subjected to digestive process, before being absorbed into blood and distributed to the tissues of the body. Digestive system plays the major role in the digestion and absorption of food substances.

Thus, the functions of digestive system include:

1. Ingestion or consumption of food substances
2. Breaking them into small particles
3. Transport of small particles to different areas of the digestive tract
4. Secretion of necessary enzymes and other substances for digestion
5. Digestion of the food particles
6. Absorption of the digestive products (nutrients)
7. Removal of unwanted substances from the body.

FUNCTIONAL ANATOMY OF DIGESTIVE SYSTEM

Digestive system is made up of gastrointestinal tract (GI tract) or alimentary canal and accessory organs, which help in the process of digestion and absorption (Fig. 36.1). GI tract is a tubular structure extending from the mouth up to anus, with a length of about 30 feet. It opens to the external environment on both ends.

GI tract is formed by two types of organs:

1. Primary digestive organs.
2. Accessory digestive organs.

1. Primary Digestive Organs

Primary digestive organs are the organs where actual digestion takes place.

Primary digestive organs are:

i. Mouth
ii. Pharynx
iii. Esophagus
iv. Stomach

v. Small intestine
vi. Large intestine

2. Accessory Digestive Organs

Accessory digestive organs are those which help primary digestive organs in the process of digestion.

Accessory digestive organs are:

i. Teeth
ii. Tongue
iii. Salivary glands
iv. Exocrine part of pancreas
v. Liver
vi. Gallbladder.

WALL OF GASTROINTESTINAL TRACT

In general, wall of the GI tract is formed by four layers which are from inside out:

1. Mucus layer
2. Submucus layer
3. Muscular layer
4. Serous or fibrous layer.

1. MUCUS LAYER

Mucus layer is the innermost layer of the wall of GI tract. It is also called gastrointestinal mucosa or mucus membrane. It faces the cavity of GI tract.

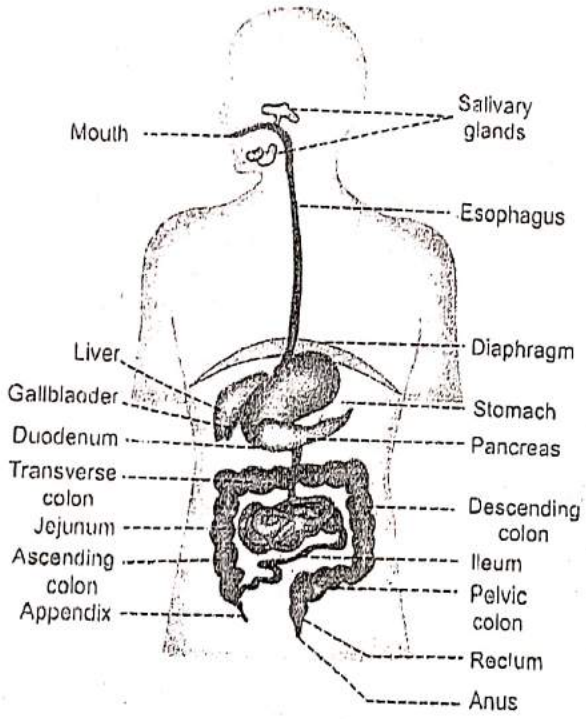

FIGURE 36.1: Gastrointestinal tract

Mucosa has three layer of structures

i. Epithelial lining
ii. Lamina propria
iii. Muscularis mucosa.

Epithelial Lining

Epithelial lining is in contact with the contents of GI tract. The type of cells in this layer varies in different parts of GI tract. The inner surface of mouth, surface of tongue, inner surface of pharynx and esophagus have stratified squamous epithelial cells. However, mucus membrane lining the other parts such as stomach, small intestine and large intestine has columnar epithelial cells.

Lamina Propria

Lamina propria is formed by connective tissues, which contain fibroblasts, macrophages, lymphocytes and eosinophils.

Muscularis Mucosa

Muscularis mucosa layer consists of a thin layer of smooth muscle fibers. It is absent in mouth and pharynx. It is present from esophagus onwards.

2. SUBMUCUS LAYER

Submucus layer is also present in all parts of GI tract, except the mouth and pharynx. It contains loose collagen fibers, elastic fibers, reticular fibers and few cells of connective tissue. Blood vessels, lymphatic vessels and nerve plexus are present in this layer.

3. MUSCULAR LAYER

Muscular layer in lips, cheeks and wall of pharynx contains skeletal muscle fibers. The esophagus has both skeletal and smooth muscle fibers. Wall of the stomach and intestine is formed by smooth muscle fibers.

Smooth muscle fibers in stomach are arranged in three layers:

i. Inner oblique layer
ii. Middle circular layer
iii. Outer longitudinal layer.

Smooth muscle fibers in the intestine are arranged in two layers:

i. Inner circular layer
ii. Outer longitudinal layer.

Auerbach nerve plexus is present in between the circular and longitudinal muscle fibers. The smooth muscle fibers present in inner circular layer of anal canal constitute internal anal sphincter. The external anal sphincter is formed by skeletal muscle fibers.

4. SEROUS OR FIBROUS LAYER

Outermost layer of the wall of GI tract is either serous or fibrous in nature. The serous layer is also called **serosa** or **serous membrane** and it is formed by connective tissue and mesoepithelial cells. It covers stomach, small intestine and large intestine.

The fibrous layer is otherwise called **fibrosa** and it is formed by connective tissue. It covers pharynx and esophagus.

NERVE SUPPLY TO GASTROINTESTINAL TRACT

GI tract has two types of nerve supply:

I. Intrinsic nerve supply
II. Extrinsic nerve supply.

INTRINSIC NERVE SUPPLY – ENTERIC NERVOUS SYSTEM

Intrinsic nerves to GI tract form the enteric nervous system that controls all the secretions and movements of GI tract. Enteric nervous system is present within the wall of GI tract from esophagus to anus. Nerve fibers of this system are interconnected and form two major networks called

1. Auerbach plexus
2. Meissner plexus.

These nerve plexus contain nerve cell bodies, processes of nerve cells and the receptors. The receptors in the GI tract are stretch receptors and chemoreceptors. Enteric nervous system is controlled by extrinsic nerves.

1. *Auerbach Plexus*

Auerbach plexus is also known as **myenteric nerve plexus.** It is present in between the inner circular muscle layer and the outer longitudinal muscle layer (Fig. 36.2).

Functions of Auerbach plexus

Major function of this plexus is to regulate the movements of GI tract. Some nerve fibers of this plexus accelerate the movements by secreting the excitatory neurotransmitter substances like acetylcholine, serotonin and substance P. Other fibers of this plexus inhibit the GI motility by secreting the inhibitory neurotransmitters such as vasoactive intestinal polypeptide (VIP), neurotensin and enkephalin.

2. *Meissner Nerve Plexus*

Meissner plexus is otherwise called submucus nerve plexus. It is situated in between the muscular layer and submucosal layer of GI tract.

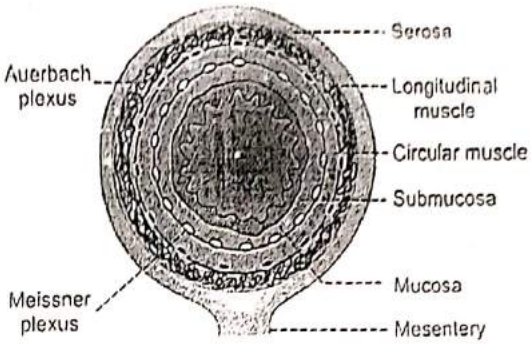

FIGURE 36.2: Structure of intestinal wall with intrinsic nerve plexus

Functions of Meissner plexus

Function of Meissner plexus is the regulation of secretory functions of GI tract. These nerve fibers cause constriction of blood vessels of GI tract.

EXTRINSIC NERVE SUPPLY

Extrinsic nerves that control the enteric nervous system are from autonomic nervous system. Both sympathetic and parasympathetic divisions of autonomic nervous system innervate the GI tract (Fig. 36.3).

Sympathetic Nerve Fibers

Preganglionic sympathetic nerve fibers to GI tract arise from lateral horns of spinal cord between fifth thoracic and second lumbar segments (T5 to L2). From here, the fibers leave the spinal cord, pass through the ganglia of sympathetic chain without having any synapse and then terminate in the **celiac** and **mesenteric ganglia.** The postganglionic fibers from these ganglia are distributed throughout the GI tract.

Functions of sympathetic nerve fibers

Sympathetic nerve fibers inhibit the movements and decrease the secretions of GI tract by secreting the neurotransmitter noradrenaline. It also causes constriction of sphincters.

Parasympathetic Nerve Fibers

Parasympathetic nerve fibers to GI tract pass through some of the **cranial nerves** and **sacral nerves.** The preganglionic and postganglionic parasympathetic nerve fibers to mouth and salivary glands pass through facial and glossopharyngeal nerves.

Chapter

Mouth and Salivary Glands

37

- FUNCTIONAL ANATOMY OF MOUTH
- FUNCTIONS OF MOUTH
- SALIVARY GLANDS
- PROPERTIES AND COMPOSITION OF SALIVA
- FUNCTIONS OF SALIVA
- REGULATION OF SALIVARY SECRETION
- EFFECT OF DRUGS AND CHEMICALS ON SALIVARY SECRETION
- APPLIED PHYSIOLOGY

FUNCTIONAL ANATOMY OF MOUTH

Mouth is otherwise known as oral cavity or **buccal cavity.** It is formed by cheeks, lips and palate. It encloses the teeth, tongue and salivary glands. Mouth opens anteriorly to the exterior through lips and posteriorly through fauces into the pharynx.

Digestive juice present in the mouth is saliva, which is secreted by the salivary glands.

FUNCTIONS OF MOUTH

Primary function of mouth is eating and it has few other important functions also.

Functions of mouth include:

1. Ingestion of food materials
2. Chewing the food and mixing it with saliva
3. Appreciation of taste of the food
4. Transfer of food (bolus) to the esophagus by swallowing
5. Role in speech
6. Social functions such as smiling and other expressions.

SALIVARY GLANDS

In humans, the saliva is secreted by three pairs of major (larger) salivary glands and some minor (small) salivary glands.

MAJOR SALIVARY GLANDS

Major glands are:

1. Parotid glands
2. Submaxillary or submandibular glands
3. Sublingual glands.

1. *Parotid Glands*

Parotid glands are the largest of all salivary glands, situated at the side of the face just below and in front of the ear. Each gland weighs about 20 to 30 g in adults. Secretions from these glands are emptied into the oral cavity by **Stensen duct.** This duct is about 35 mm to 40 mm long and opens inside the cheek against the upper second molar tooth (Fig. 37.1).

2. *Submaxillary Glands*

Submaxillary glands or submandibular glands are located in submaxillary triangle, medial to mandible. Each gland weighs about 8 to 10 g. Saliva from these glands is emptied into the oral cavity by **Wharton duct,** which is about 40 mm long. The duct opens at the side of **frenulum** of tongue, by means of a small opening on the summit of papilla called **caruncula sublingualis.**

dissolved substances can stimulate the taste buds. The stimulated taste buds recognize the taste.

3. DIGESTIVE FUNCTION

Saliva has three digestive enzymes, namely salivary amylase, maltase and lingual lipase (Table 37.1).

Salivary Amylase

Salivary amylase is a carbohydrate-digesting (amylolytic) enzyme. It acts on cooked or boiled starch and converts it into **dextrin** and **maltose**. Though starch digestion starts in the mouth, major part of it occurs in stomach because, food stays only for a short time in the mouth.

Optimum pH necessary for the activation of salivary amylase is 6. Salivary amylase cannot act on **cellulose**.

Maltase

Maltase is present only in traces in human saliva and it converts maltose into glucose.

Lingual Lipase

Lingual lipase is a lipid-digesting (lipolytic) enzyme. It is secreted from serous glands situated on the posterior aspect of tongue. It digests milk fats (**pre-emulsified fats**). It hydrolyzes triglycerides into fatty acids and diacylglycerol (Table 37.2).

4. CLEANSING AND PROTECTIVE FUNCTIONS

i. Due to the constant secretion of saliva, the mouth and teeth are rinsed and kept free off food debris, shed epithelial cells and foreign particles. In this way, saliva prevents bacterial growth by removing materials, which may serve as culture media for the bacterial growth.

ii. Enzyme lysozyme of saliva kills some bacteria such as *staphylococcus, streptococcus* and *brucella*.

iii. **Proline-rich proteins** present in saliva posses antimicrobial property and neutralize the toxic substances such as tannins. Tannins are present in many food substances including fruits.

iv. Lactoferrin of saliva also has anti... property.

v. Proline-rich proteins and lactoferrin prot... teeth by stimulating enamel formation.

vi. Immunoglobulin IgA in saliva also ... antibacterial and antiviral actions.

vii. Mucin present in the saliva protects the mo... by lubricating the mucus membrane of mouth.

ROLE IN SPEECH

By moistening and lubricating soft parts of mouth and lips, saliva helps in speech. If the mouth becomes dry, articulation and pronunciation becomes difficult.

EXCRETORY FUNCTION

Many substances, both organic and inorganic, are excreted in saliva. It excretes substances like mercury, potassium iodide, lead, and thiocyanate. Saliva also excretes some viruses such as those causing rabies and mumps.

In some pathological conditions, saliva excretes certain substances, which are not found in saliva under normal conditions. Example is glucose in diabetes mellitus. In certain conditions, some of the normal constituents of saliva are excreted in large quantities. For example, excess urea is excreted in saliva during nephritis and excess calcium is excreted during hyperparathyroidism.

REGULATION OF BODY TEMPERATURE

In dogs and cattle, excessive dripping of saliva during panting helps in the loss of heat and regulation of body temperature. However, in human beings, sweat glands play a major role in temperature regulation and saliva does not play any role in this function.

REGULATION OF WATER BALANCE

When the body water content decreases, salivary secretion also decreases. This causes dryness of the mouth and induces thirst. When water is taken, it quenches the thirst and restores the body water content.

TABLE 37.2: Digestive enzymes of saliva

Enzyme	Source of secretion	Activator	Action
Salivary amylase	All salivary glands	Acid medium	Converts starch into maltose
Maltase	Major salivary glands	Acid medium	Converts maltose into glucose
Lingual lipase	Lingual glands	Acid medium	Converts triglycerides of milk fat into fatty acids and diacylglycerol

REGULATION OF SALIVARY SECRETION

Salivary secretion is regulated only by nervous mechanism. Autonomic nervous system is involved in the regulation of salivary secretion.

NERVE SUPPLY TO SALIVARY GLANDS

Salivary glands are supplied by both parasympathetic and sympathetic divisions of autonomic nervous system.

PARASYMPATHETIC FIBERS

Parasympathetic Fibers to Submandibular and Sublingual Glands

Parasympathetic preganglionic fibers to submandibular and sublingual glands arise from the superior salivatory nucleus, situated in pons. After taking origin from this nucleus, the preganglionic fibers run through nervus intermedius of Wrisberg, geniculate ganglion, the motor fibers of facial nerve, chorda tympani branch of facial nerve and lingual branch of trigeminal nerve and finally reach the submaxillary ganglion (Fig. 37.4).

Postganglionic fibers arising from this ganglion supply the submaxillary and sublingual glands.

Parasympathetic Fibers to Parotid Gland

Parasympathetic preganglionic fibers to parotid gland arise from inferior salivatory nucleus situated in the upper part of medulla oblongata. From here, the fibers pass through tympanic branch of glossopharyngeal nerve, tympanic plexus and lesser petrosal nerve and end in otic ganglion (Fig. 37.5).

Postganglionic fibers arise from this ganglion and supply the parotid gland by passing through auriculotemporal branch in mandibular division of trigeminal nerve.

Function of Parasympathetic Fibers

Stimulation of parasympathetic fibers of salivary glands causes secretion of saliva with large quantity of water. It is because the parasympathetic fibers activate the acinar cells and dilate the blood vessels of salivary glands. However, the amount of organic constituents in saliva is less. The neurotransmitter is acetylcholine.

SYMPATHETIC FIBERS

Sympathetic preganglionic fibers to salivary glands arise from the lateral horns of first and second thoracic segments of spinal cord. The fibers leave the cord through the anterior nerve roots and end in superior cervical ganglion of the sympathetic chain.

Postganglionic fibers arise from this ganglion and are distributed to the salivary glands along the nerve plexus, around the arteries supplying the glands.

Function of Sympathetic Fibers

Stimulation of sympathetic fibers causes secretion of saliva, which is thick and rich in organic constituents such

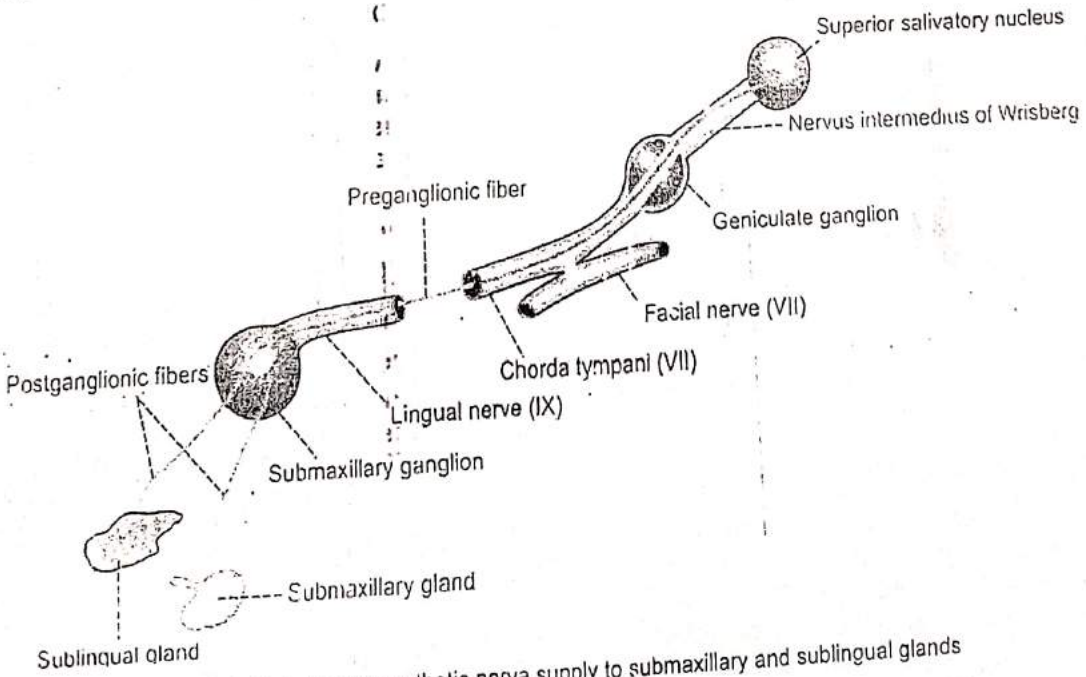

FIGURE 37.4: Parasympathetic nerve supply to submaxillary and sublingual glands

Chapter

38

Stomach

- FUNCTIONAL ANATOMY OF STOMACH
- GLANDS OF STOMACH – GASTRIC GLANDS
- FUNCTIONS OF STOMACH
- PROPERTIES AND COMPOSITION OF GASTRIC JUICE
- FUNCTIONS OF GASTRIC JUICE
- SECRETION OF GASTRIC JUICE
- REGULATION OF GASTRIC SECRETION
- COLLECTION OF GASTRIC JUICE
- GASTRIC ANALYSIS
- APPLIED PHYSIOLOGY

FUNCTIONAL ANATOMY OF STOMACH

Stomach is a hollow organ situated just below the diaphragm on the left side in the abdominal cavity. Volume of empty stomach is 50 mL. Under normal conditions, it can expand to accommodate 1 L to 1.5 L of solids and liquids. However, it is capable of expanding still further up to 4 L.

PARTS OF STOMACH

In humans, stomach has four parts:

1. Cardiac region
2. Fundus
3. Body or corpus
4. Pyloric region.

1. *Cardiac Region*

Cardiac region is the upper part of the stomach where esophagus opens. The opening is guarded by a sphincter called cardiac sphincter, which opens only towards stomach. This portion is also known as cardiac end.

2. *Fundus*

Fundus is a small dome-shaped structure. It is elevated above the level of esophageal opening.

3. *Body or Corpus*

Body is the largest part of stomach forming about 75% to 80% of the whole stomach. It extends from just below the fundus up to the pyloric region (Fig. 38.1).

4. *Pyloric Region*

Pyloric region has two parts, antrum and pyloric canal. The body of stomach ends in **antrum.** Junction between body and antrum is marked by an angular notch called **incisura angularis.** Antrum is continued as the narrow canal, which is called pyloric canal or pyloric end. Pyloric canal opens into first part of small intestine called duodenum. The opening of pyloric canal is guarded by a sphincter called pyloric sphincter. It opens towards duodenum.

Stomach has two curvatures. One on the right side is **lesser curvature** and the other on left side is **greater curvature.**

STRUCTURE OF STOMACH WALL

Stomach wall is formed by four layers of structures:

1. *Outer serous layer:* Formed by peritoneum
2. *Muscular layer:* Made up of three layers of smooth muscle fibers, namely inner oblique, middle circular and outer longitudinal layers

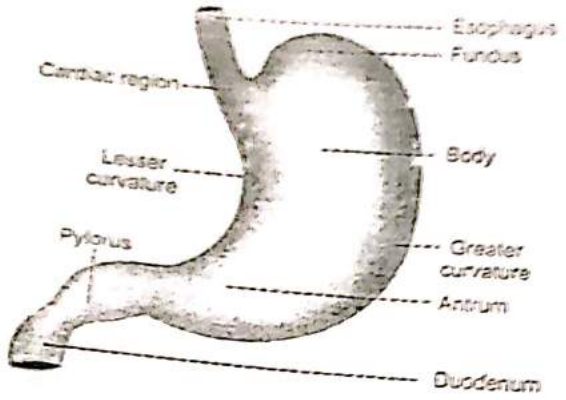

FIGURE 38.1: Parts of stomach

3. *Submucus layer:* Formed by areolar tissue, blood vessels, lymph vessels and Meissner nerve plexus.
4. *Inner mucus layer:* Lined by mucus-secreting columnar epithelial cells. The gastric glands are situated in this layer. Under resting conditions, the mucosa of the stomach is thrown into many folds. These folds are called rugae. The rugae disappear when the stomach is distended after meals. Throughout the inner mucus layer, small depressions called gastric pits are present. Glands of the stomach open into these pits. Inner surface of mucus layer is covered by 2 mm thick mucus.

GLANDS OF STOMACH – GASTRIC GLANDS

Glands of the stomach or gastric glands are tubular structures made up of different types of cells. These glands open into the stomach cavity via gastric pits.

CLASSIFICATION OF GLANDS OF THE STOMACH

Gastric glands are classified into three types, on the basis of their location in the stomach:

1. *Fundic glands or main gastric glands or oxyntic glands:* Situated in body and fundus of stomach
2. *Pyloric glands:* Present in the pyloric part of the stomach
3. *Cardiac glands:* Located in the cardiac region of the stomach.

STRUCTURE OF GASTRIC GLANDS

1. Fundic Glands

Fundic glands are considered as the typical gastric glands (Fig. 38.2). These glands are long and tubular. Each gland has three parts, viz body, neck and isthmus.

Cells of fundic glands

1. Chief cells or pepsinogen cells
2. Parietal cells or oxyntic cells
3. Mucus neck cells
4. Enterochromaffin (EC) cells or Kulchitsky cells
5. Enterochromaffin-like (ECL) cells.

Parietal cells are different from other cells of the gland because of the presence of canaliculi (singular = canaliculus). Parietal cells empty their secretions into the lumen of the gland through the canaliculi. But other cells empty their secretions directly into lumen of the gland.

2. Pyloric Glands

Pyloric glands are short and tortuous in nature. These glands are formed by G cells, mucus cells, EC cells and ECL cells.

3. Cardiac Glands

Cardiac glands are also short and tortuous in structure, with many mucus cells. EC cells, ECL cells and chief cells are also present in the cardiac glands

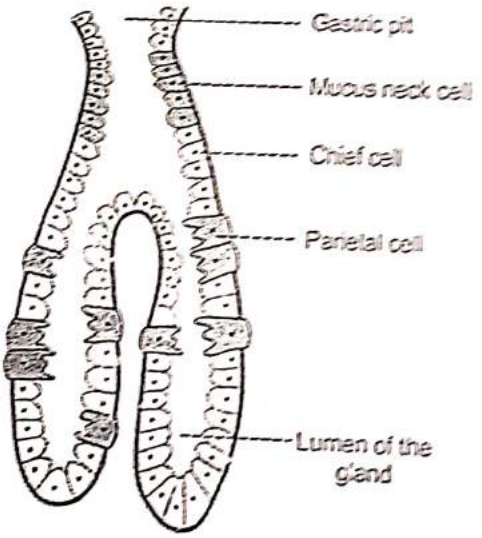

FIGURE 38.2: Gastric glands

Enteroendocrine Cells

Enteroendocrine cells are the hormone-secreting cells present in the glands or mucosa of gastrointestinal tract, particularly stomach and intestine. The enteroendocrine cells present in gastric glands are G cells, EC cells and ECL cells (Table 38.1).

FUNCTIONS OF GASTRIC GLANDS

Function of the gastric gland is to secrete gastric juice. Secretory activities of different cells of gastric glands and enteroendocrine cells are listed in Table 38.1.

FUNCTIONS OF STOMACH

1. MECHANICAL FUNCTION

i. Storage Function

Food is stored in the stomach for a long period, i.e. for 3 to 4 hours and emptied into the intestine slowly. The maximum capacity of stomach is up to 1.5 L. Slow emptying of stomach provides enough time for proper digestion and absorption of food substances in the small intestine.

ii. Formation of Chyme

Peristaltic movements of stomach mix the bolus with gastric juice and convert it into the semisolid material known as chyme.

2. DIGESTIVE FUNCTION

Refer functions of gastric juice.

3. PROTECTIVE FUNCTION

Refer functions of gastric juice.

TABLE 38.1: Secretory function of cells in gastric glands

Cell	Secretory products
Chief cells	Pepsinogen Rennin Lipase Gelatinase Urase
Parietal cells	Hydrochloric acid Intrinsic factor of Castle
Mucus neck cells	Mucin
G cells	Gastrin
Enterochromaffin (EC) cells	Serotonin
Enterochromaffin-like (ECL) cells	Histamine

4. HEMOPOIETIC FUNCTION

Refer functions of gastric juice.

5. EXCRETORY FUNCTION

Many substances like toxins, alkaloids and metals are excreted through gastric juice.

PROPERTIES AND COMPOSITION OF GASTRIC JUICE

Gastric juice is a mixture of secretions from different gastric glands.

PROPERTIES OF GASTRIC JUICE

Volume : 1200 mL/day to 1500 mL/day.
Reaction : Gastric juice is highly acidic with a pH of 0.9 to 1.2. Acidity of gastric juice is due to the presence of hydrochloric acid.
Specific gravity : 1.002 to 1.004

COMPOSITION OF GASTRIC JUICE

Gastric juice contains 99.5% of water and 0.5% solids. Solids are organic and inorganic substances. Refer Fig. 38.3 for composition of gastric juice.

FUNCTIONS OF GASTRIC JUICE

1. DIGESTIVE FUNCTION

Gastric juice acts mainly on proteins. Proteolytic enzymes of the gastric juice are pepsin and rennin (Table 38.2). Gastric juice also contains some other enzymes like gastric lipase, gelatinase, urase and gastric amylase.

Pepsin

Pepsin is secreted as inactive pepsinogen. Pepsinogen is converted into pepsin by hydrochloric acid. Optimum pH for activation of pepsinogen is below 6.

Action of pepsin

Pepsin converts proteins into proteoses, peptones and polypeptides. Pepsin also causes curdling and digestion of milk (casein).

Gastric Lipase

Gastric lipase is a weak lipolytic enzyme when compared to pancreatic lipase. It is active only when the pH is between 4 and 5 and becomes inactive at a pH below

2.5. Gastric lipase is a tributyrase and it hydrolyzes tributyrin (butter fat) into fatty acids and glycerols.

Actions of Other Enzymes of Gastric Juice

i. Gelatinase: Degrades type I and type V gelatin and type IV and V collagen (which are proteoglycans in meat) into peptides
ii. Urase: Acts on urea and produces ammonia
iii. Gastric amylase: Degrades starch (but its action is insignificant)
iv. Rennin: Curdles milk (present in animals only).

2. HEMOPOIETIC FUNCTION

Intrinsic factor of Castle, secreted by parietal cells of gastric glands plays an important role in erythropoiesis. It is necessary for the absorption of vitamin B12 (which is called extrinsic factor) from GI tract into the blood.

Vitamin B12 is an important maturation factor for erythropoiesis. Absence of intrinsic factor in gastric juice causes deficiency of vitamin B12, leading to **pernicious anemia** (Chapter 14).

PROTECTIVE FUNCTION – FUNCTION OF MUCUS

Mucus is a mucoprotein, secreted by mucus neck cells of the gastric glands and surface mucus cells in fundus, body and other parts of stomach. It protects the gastric wall by the following ways:

Mucus:

i. Protects the stomach wall from irritation or mechanical injury, by virtue of its high viscosity.
ii. Prevents the digestive action of pepsin on the wall of the stomach, particularly gastric mucosa.

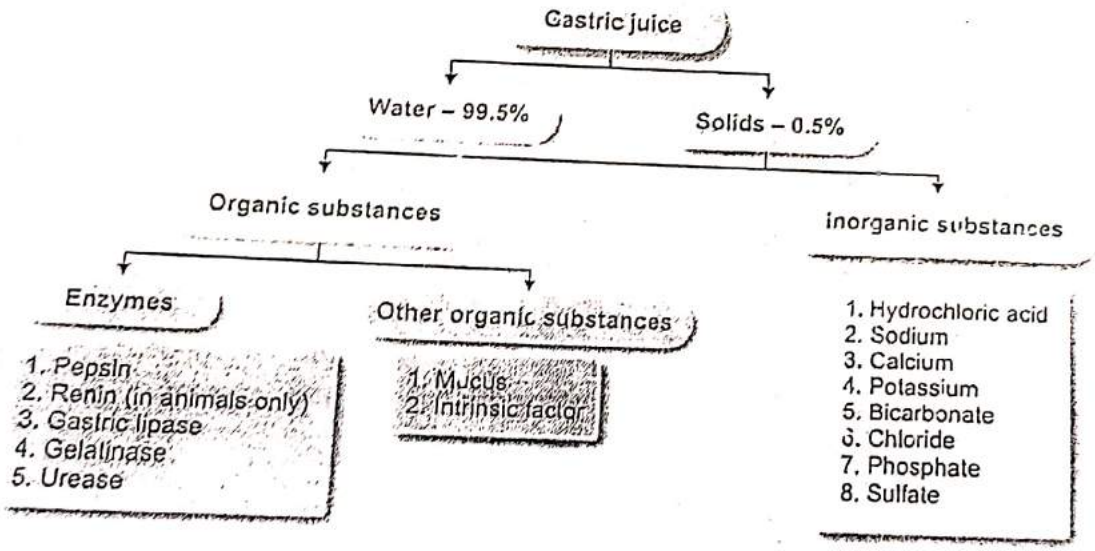

FIGURE 38.3: Composition of gastric juice

TABLE 38.2: Digestive enzymes of gastric juice

Enzyme	Activator	Substrate	End products
Pepsin	Hydrochloric acid	Proteins	Proteoses peptones and polypeptides
Gastric lipase	Acid medium	Triglycerides of butter	Fatty acids and glycerols
Gastric amylase	Acid medium	Starch	Dextrin and maltose (negligible action)
Gelatinase	Acid medium	Gelatin and collagen of meat	Peptides
Urase	Acid medium	Urea	Ammonia

iii. Protects the gastric mucosa from hydrochloric acid of gastric juice because of its alkaline nature and its acid-combining power.

4. FUNCTIONS OF HYDROCHLORIC ACID

Hydrochloric acid is present in the gastric juice:

i. Activates pepsinogen into pepsin
ii. Kills some of the bacteria entering the stomach along with food substances. This action is called bacteriolytic action
iii. Provides acid medium, which is necessary for the action of hormones.

SECRETION OF GASTRIC JUICE

SECRETION OF PEPSINOGEN

Pepsinogen is synthesized from amino acids in the ribosomes attached to endoplasmic reticulum in chief cells. Pepsinogen molecules are packed into **zymogen granules** by Golgi apparatus.

When zymogen granule is secreted into stomach from chief cells, the granule is dissolved and pepsinogen is released into gastric juice. Pepsinogen is activated into pepsin by hydrochloric acid.

SECRETION OF HYDROCHLORIC ACID

According to Davenport theory, hydrochloric acid secretion is an active process that takes place in the canaliculi of parietal cells in gastric glands. The energy for this process is derived from oxidation of glucose.

Carbon dioxide is derived from metabolic activities of parietal cell. Some amount of carbon dioxide is obtained from blood also. It combines with water to form carbonic acid in the presence of **carbonic anhydrase.** This enzyme is present in high concentration in parietal cells. Carbonic acid is the most unstable compound and immediately splits into hydrogen ion and bicarbonate ion. The hydrogen ion is actively pumped into the canaliculus of parietal cell.

Simultaneously, the chloride ion is also pumped into canaliculus actively. The chloride is derived from sodium chloride in the blood. Now, the hydrogen ion combines with chloride ion to form hydrochloric acid. To compensate the loss of chloride ion, the bicarbonate ion from parietal cell enters the blood and combines with sodium to form sodium bicarbonate. Thus, the entire process is summarized as (Fig. 38.4):

$$CO_2 + H_2O + NaCl \rightarrow HCl + NaHCO_3$$

Factors Stimulating the Secretion of Hydrochloric Acid

1. Gastrin
2. Histamine
3. Vagal stimulation.

Factors Inhibiting the Secretion of Hydrochloric Acid

1. Secretin
2. Gastric inhibitory polypeptide
3. Peptide YY.

REGULATION OF GASTRIC SECRETION

Regulation of gastric secretion and intestinal secretion is studied by some experimental procedures.

METHODS OF STUDY

1. *Pavlov Pouch*

Pavlov pouch is a small part of the stomach that is incompletely separated from the main portion and made into a small bag-like pouch (Fig. 38.5). Pavlov pouch was designed by the Russian scientist Pavlov, in a dog during his studies on conditioned reflexes.

Procedure

To prepare a Pavlov pouch, stomach of an anesthetized dog is divided into a larger part and a smaller part by making an incomplete incision. The mucus membrane

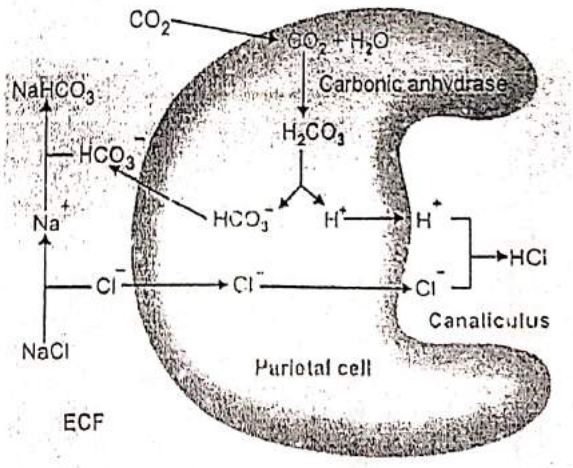

FIGURE 38.4: Secretion of hydrochloric acid in the parietal cell of gastric gland

Phases of Gastric Secretion.

Accordingly, gastric secretion occurs in three different phases

I. Cephalic phase
II. Gastric phase
III. Intestinal phase.

In human beings, a fourth phase called **Interdigestive phase** exists. Each phase is regulated by neural mechanism or hormonal mechanism or both.

CEPHALIC PHASE

Secretion of gastric juice by the stimuli arising from head region (cephalus) is called cephalic phase (Fig. 38.6). This phase of gastric secretion is regulated by nervous mechanism. The gastric juice secreted during this phase is called appetite juice.

During this phase, gastric secretion occurs even without the presence of food in stomach. The quantity of the juice is less but it is rich in enzymes and hydrochloric acid.

Nervous mechanism regulates cephalic phase through reflex action. Two types of reflexes occur.

1. Unconditioned reflex
2. Conditioned reflex.

Unconditioned Reflex

Unconditioned reflex is the inborn reflex. When food is placed in the mouth, salivary secretion is induced (Chapter 37). Simultaneously, gastric secretion also occurs.

Stages of reflex action:

I. Presence of food in the mouth stimulates the taste buds and other receptors in the mouth
II. Sensory (afferent) impulses from mouth pass via afferent nerve fibers of glossopharyngeal and facial nerves to amygdala and appetite center present in hypothalamus

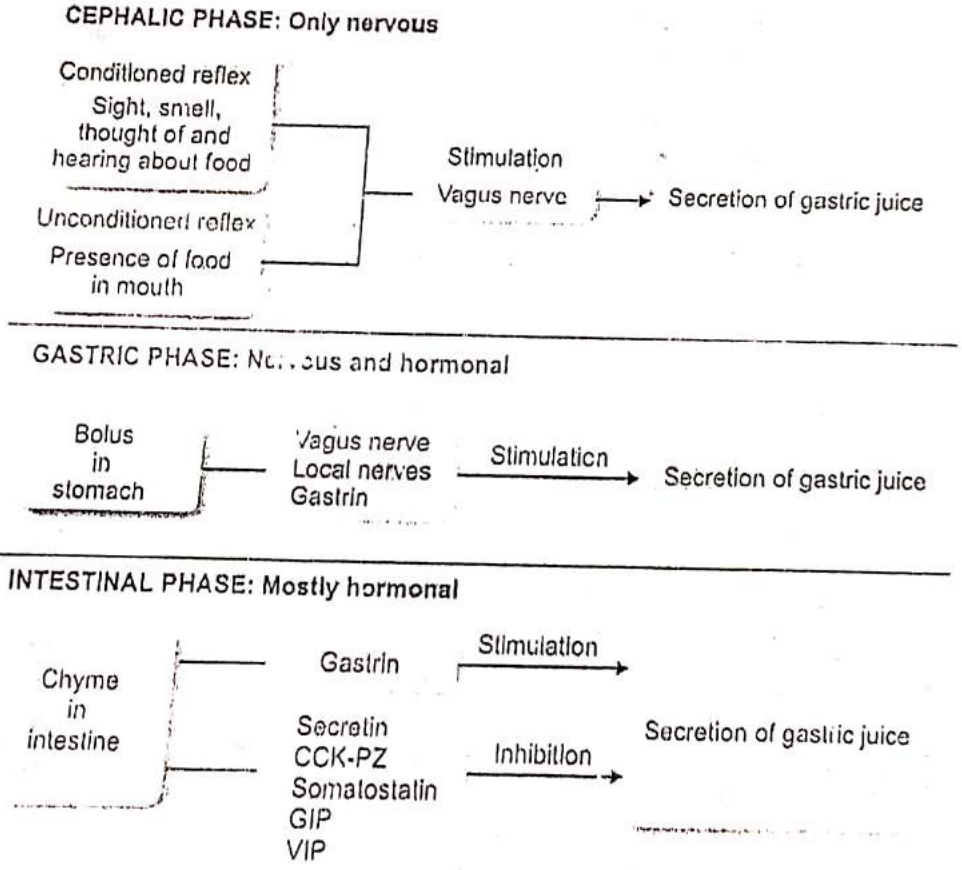

FIGURE 38.6: Schematic diagram showing the regulation of gastric secretion
CCK-PZ = Cholecystokinin-pancreozymin, GIP = Gastric Inhibitory peptide, VIP = Vasoactive intestinal peptide.

iii. From here, the efferent impulses pass through dorsal nucleus of vagus and vagal efferent nerve fibers to the wall of the stomach
iv. Vagal efferent nerve endings secrete acetylcholine, which stimulates gastric secretion.

Conditioned Reflex

Conditioned reflex is the reflex response acquired by previous experience (Chapter 162). Presence of food in the mouth is not necessary to elicit this reflex. The sight, smell, hearing or thought of food, which induce salivary secretion induce gastric secretion also.

Stages of reflex action:

i. Impulses from the special sensory organs (eye, ear and nose) pass through afferent fibers of neural circuits to the cerebral cortex. Thinking of food stimulates the cerebral cortex directly
ii. From cerebral cortex, the impulses pass through dorsal nucleus of vagus and vagal efferents and reach the stomach wall
iii. Vagal nerve endings secrete acetylcholine, which stimulates the gastric secretion.

Experimental evidences to prove cephalic phase

i. Unconditioned reflex of gastric secretion is proved by sham feeding along with Pavlov pouch (see above). After vagotomy, sham feeding does not cause gastric secretion. It proves the importance of vagus nerve in this phase.
ii. Conditioned reflex of gastric secretion is proved by Pavlov pouch and **belldog experiment** (Chapter 162).

GASTRIC PHASE

Secretion of gastric juice when food enters the stomach is called gastric phase. This phase is regulated by both nervous and hormonal control. Gastric juice secreted during this phase is rich in pepsinogen and hydrochloric acid.

Mechanisms involved in gastric phase are:

1. Nervous mechanism through local myenteric reflex and vagovagal reflex
2. Hormonal mechanism through gastrin

Stimuli, which initiate these two mechanisms are:

1. Distention of stomach
2. Mechanical stimulation of gastric mucosa by bulk of food
3. Chemical stimulation of gastric mucosa by the food contents.

1. Nervous Mechanism

Local myenteric reflex

Local myenteric reflex is the reflex elicited by stimulation of myenteric nerve plexus in stomach wall. After entering stomach, the food particles stimulate the local nerve plexus (Chapter 36) present in the wall of the stomach. These nerve fibers release acetylcholine, which stimulates the gastric glands to secrete a large quantity of gastric juice. Simultaneously, acetylcholine stimulates G cells to secrete gastrin (see below).

Vagovagal reflex

Vagovagal reflex is the reflex which involves both afferent and efferent vagal fibers. Entrance of bolus into the stomach stimulates the sensory (afferent) nerve endings of vagus and generates sensory impulses. These sensory impulses are transmitted by sensory fibers of vagus to dorsal nucleus of vagus, located in medulla of brainstem. This nucleus in turn, sends efferent impulses through the motor (efferent) fibers of vagus, back to stomach and cause secretion of gastric juice. Since, both afferent and efferent impulses pass through vagus, this reflex is called vagovagal reflex (Fig. 38.7).

Hormonal Mechanism – Gastrin

Gastrin is a gastrointestinal hormone secreted by the G cells which are present in the pyloric glands of stomach. Small amount of gastrin is also secreted in mucosa of upper small intestine. In fetus, it is also secreted by islets of Langerhans in pancreas. Gastrin is a polypeptide containing G14, G17 or G34 amino acids.

Gastrin is released when food enters stomach. Mechanism involved in the release of gastrin may be the local nervous reflex or vagovagal reflex. Nerve endings release the neurotransmitter called gastrin-releasing peptide, which stimulates the G cells to secrete gastrin.

Actions of gastrin on gastric secretion

Gastrin stimulates the secretion of pepsinogen and hydrochloric acid by the gastric glands. Refer Chapter 44 for other actions of gastrin.

Experimental evidences of gastric phase

Nervous mechanism of gastric secretion during gastric phase is proved by Pavlov pouch. Hormonal mechanism of gastric secretion is proved by Heidenhain pouch, Bickel pouch and Farrel and Ivy pouch.

INTESTINAL PHASE

Intestinal phase is the secretion of gastric juice when chyme enters the intestine. When chyme enters the

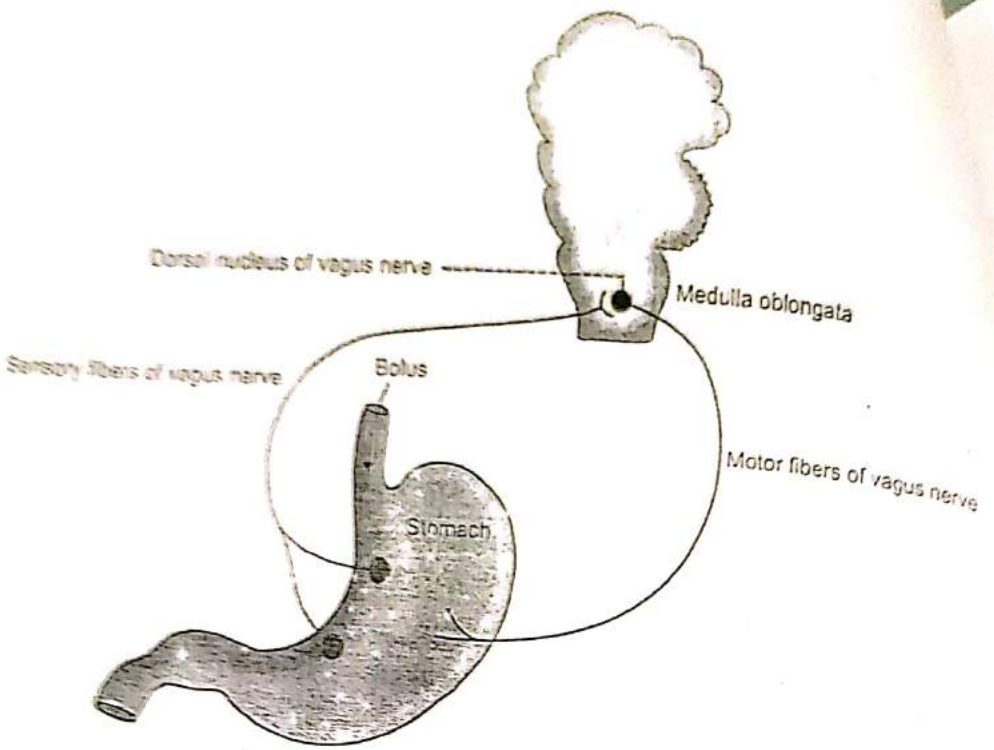

FIGURE 38.7: Vagovagal reflex

intestine. Initially, the gastric secretion increases but later it stops. Intestinal phase of gastric secretion is regulated by nervous and hormonal control.

Initial Stage of Intestinal Phase

Chyme that enters the intestine stimulates the duodenal mucosa to release gastrin, which is transported to stomach by blood. There it increases gastric secretion.

Later Stage of Intestinal Phase

After the initial increase, there is a decrease or complete stoppage of gastric secretion. Gastric secretion is inhibited by two factors:

1. Enterogastric reflex
2. Gastrointestinal (GI) hormones.

1. Enterogastric reflex

Enterogastric reflex inhibits the gastric secretion and motility. It is due to the distention of intestinal mucosa by chyme or chemical or osmotic irritation of intestinal mucosa by chemical substances in the chyme. It is mediated by myenteric nerve (Auerbach) plexus and vagus.

2. Gastrointestinal hormones

Presence of chyme in the intestine stimulates the secretion of many GI hormones from intestinal mucosa and other structures. All these hormones inhibit the gastric secretion. Some of these hormones inhibit the gastric motility also.

GI hormones which inhibit gastric secretion:

i. *Secretin:* Secreted by the presence of acid chyme in the intestine
ii. *Cholecystokinin:* Secreted by the presence of chyme containing fats and amino acids in intestine
iii. *Gastric inhibitory peptide (GIP):* Secreted by the presence of chyme containing glucose and fats in the intestine
iv. *Vasoactive intestinal polypeptide (VIP):* Secreted by the presence of acidic chyme in intestine
v. *Peptide YY:* Secreted by the presence of fatty chyme in intestine.

In addition to these hormones, pancreas also secretes a hormone called somatostatin during

intestinal phase. It also inhibits gastric secretion. Refer Chapter 44 for details of GI hormones.

Thus, enterogastric reflex and intestinal hormones collectively apply a strong brake on the secretion and motility of stomach during intestinal phase.

Experimental evidences for intestinal phase

Intestinal phase of gastric secretion is demonstrated by Bickel pouch and Farrel and Ivy pouch.

INTERDIGESTIVE PHASE

Secretion of small amount of gastric juice in between meals (or during period of fasting) is called interdigestive phase. Gastric secretion during this phase is mainly due to the hormones like gastrin. This phase of gastric secretion is demonstrated by Farrel and Ivy pouch.

FACTORS INFLUENCING GASTRIC SECRETION

Gastric secretion is also influenced by some factors which increase the gastric secretion by stimulating gastric mucosa such as:

1. Alcohol
2. Caffeine.

COLLECTION OF GASTRIC JUICE

In human beings, the gastric juice is collected by using Ryle tube. The tube is made out of rubber or plastic. It is passed through nostril or mouth and through esophagus into the stomach. A line is marked in the tube. The entrance of the tip of the tube into stomach is indicated when this line comes near the mouth. Then, the contents of stomach are collected by means of aspiration.

GASTRIC ANALYSIS

For analysis, the gastric juice is collected from patient only in the morning. Analysis of the gastric juice is done for the diagnosis of ulcer and other disorders of stomach.

Gastric juice is analyzed for the following:

1. Measurement of peptic activity
2. Measurement of gastric acidity: Total acid, free acid (hydrochloric acid) and combined acid.

METHODS OF GASTRIC ANALYSIS

1. *Fractional Test Meal (FTM)*

After overnight fasting, the gastric juice is collected. Then, the patient takes a small test meal called fractional test meal (FTM).

Typical test meals are:

i. A piece of bread and a cup of tea
ii. Wheat biscuit and 400 mL of water
iii. 300 mL of oatmeal gruel.

Fractional gastric analysis

After the ingestion of a test meal, gastric juice is collected at every 15th minute for a period of two and a half hours. All these samples are analyzed for peptic activity and acidity.

2. *Nocturnal Gastric Analysis*

Patient is given a clear liquid diet at noon and at 5 pm. At 7.30 pm, the tube is introduced into the patient's stomach. Then from 8 pm to 8 am, hourly samples of gastric juice are collected and analyzed.

3. *Histamine Test*

After overnight fasting, the stomach is emptied in the morning by aspiration. Then histamine is injected subcutaneously (0.01 mg/kg). Histamine stimulates secretion of hydrochloric acid in the stomach. After 30 minutes, 4 samples of gastric juice are collected over a period of 1 hour at 15 minutes interval and analyzed.

APPLIED PHYSIOLOGY

Gastric secretion is affected by the following disorders:

1. GASTRITIS

Inflammation of gastric mucosa is called gastritis. It may be acute or chronic. Acute gastritis is characterized by inflammation of superficial layers of mucus membrane and infiltration with leukocytes, mostly neutrophils. Chronic gastritis involves inflammation of even the deeper layers and infiltration with more lymphocytes. It results in the atrophy of the gastric mucosa, with loss of chief cells and parietal cells of glands. Therefore, the secretion of gastric juice decreases.

Causes of Acute Gastritis

i. Infection with bacterium *Helicobacter pylori*
ii. Excess consumption of alcohol
iii. Excess administration of Aspirin and other non-steroidal antiinflammatory drugs (NSAIDs)
iv. Trauma by nasogastric tubes
v. Repeated exposure to radiation (rare).

Causes of Chronic Gastritis

i. Chronic infection with *Helicobacter pylori*

Pancreas

Chapter 39

- FUNCTIONAL ANATOMY AND NERVE SUPPLY OF PANCREAS
- PROPERTIES AND COMPOSITION OF PANCREATIC JUICE
- FUNCTIONS OF PANCREATIC JUICE
  - DIGESTIVE FUNCTIONS
  - DIGESTION OF PROTEINS
  - DIGESTION OF LIPIDS
  - DIGESTION OF CARBOHYDRATES
  - NEUTRALIZING ACTION
- MECHANISM OF PANCREATIC SECRETION
  - SECRETION OF PANCREATIC ENZYMES
  - SECRETION OF BICARBONATE IONS
- REGULATION OF PANCREATIC SECRETION
  - STAGES OF PANCREATIC SECRETION
  - CEPHALIC PHASE
  - GASTRIC PHASE
  - INTESTINAL PHASE
- COLLECTION OF PANCREATIC JUICE
  - IN ANIMALS
  - IN HUMAN
- APPLIED PHYSIOLOGY
  - PANCREATITIS
  - STEATORRHEA

FUNCTIONAL ANATOMY AND NERVE SUPPLY OF PANCREAS

Pancreas is a dual organ having two functions, namely **endocrine function** and **exocrine function.** Endocrine function is concerned with the production of hormones (Chapter 69). The exocrine function is concerned with the secretion of digestive juice called pancreatic juice.

FUNCTIONAL ANATOMY OF EXOCRINE PART OF PANCREAS

Exocrine part of pancreas resembles salivary gland in structure. It is made up of acini or alveoli. Each acinus has a single layer of acinar cells with a lumen in the center. Acinar cells contain zymogen granules, which possess digestive enzymes.

A small duct arises from lumen of each alveolus. Some of these ducts from neighboring alveoli unite to form **intralobular duct.** All the intralobular ducts unite to form the main duct of pancreas called **Wirsung duct.** Wirsung duct joins common bile duct to form **ampulla of Vater,** which opens into duodenum (see Fig. 40.3).

In some persons, an accessory duct called **duct of Santorini** exists. It also opens into duodenum, proximal to the opening of ampulla of Vater.

NERVE SUPPLY TO PANCREAS

Pancreas is supplied by both sympathetic and parasympathetic fibers. Sympathetic fibers are supplied through splanchnic nerve and parasympathetic fibers are supplied through vagus nerve.

PROPERTIES AND COMPOSITION OF PANCREATIC JUICE

PROPERTIES OF PANCREATIC JUICE

Volume : 500 to 800 mL/day
Reaction : Highly alkaline with a pH of 8 to 8.3
Specific gravity : 1.010 to 1.018

COMPOSITION OF PANCREATIC JUICE

Pancreatic juice contains 99.5% of water and 0.5% of solids. The solids are the organic and inorganic substances. Composition of pancreatic juice is given in Fig. 39.1.

Bicarbonate content is very high in pancreatic juice. It is about 110 to 150 mEq/ L, against the plasma level of 24 mEq/L. High bicarbonate content of pancreatic juice is important because of two reasons:

i. High bicarbonate content makes the pancreatic juice highly alkaline, so that it protects the intestinal mucosa from acid chyme by neutralizing it.
ii. Bicarbonate ions provide the required pH (8 to 9) for the activation of pancreatic enzymes.

FUNCTIONS OF PANCREATIC JUICE

Pancreatic juice has digestive functions and neutralizing action.

DIGESTIVE FUNCTIONS OF PANCREATIC JUICE

Pancreatic juice plays an important role in the digestion of proteins and lipids. It also has mild digestive action on carbohydrates.

DIGESTION OF PROTEINS

Major proteolytic enzymes of pancreatic juice are trypsin and chymotrypsin. Other proteolytic enzymes are carboxypeptidases, nuclease, elastase and collagenase.

1. *Trypsin*

Trypsin is a single polypeptide with a molecular weight of 25,000. It contains 229 amino acids.

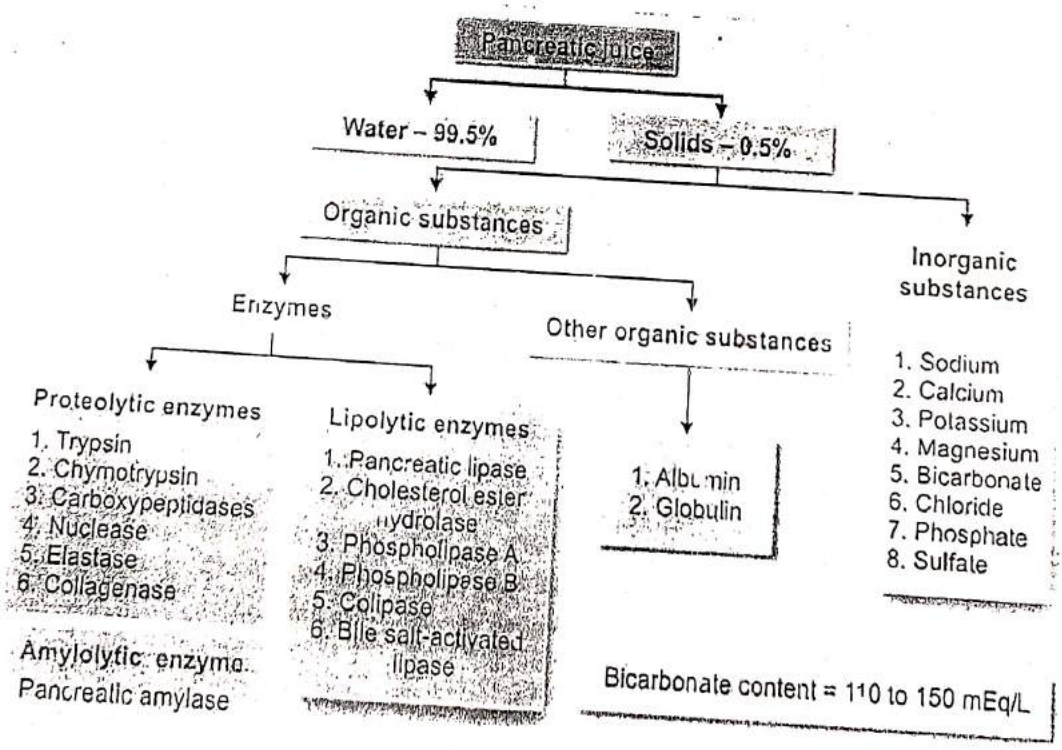

FIGURE 39.1: Composition of pancreatic juice

It is secreted as inactive trypsinogen, which is converted into active trypsin by **enterokinase.** Enterokinase is also called **enteropeptidase** and it is secreted by the brush-bordered cells of duodenal mucus membrane. Once formed, trypsin itself activates trypsinogen by means of **autocatalytic** or **autoactive** action.

Trypsin inhibitor

Trypsinogen is activated only when it reaches the small intestine. If trypsin is activated when it is in pancreas, it may hydrolyze the pancreatic tissue proteins, resulting in pancreatic damage. But its activation in the secretory cells, acini and ducts of pancreas is prevented by an inhibitor protein called trypsin inhibitor. Any abnormality or deficiency of the trypsin inhibitor will result in unopposed trypsin activity, which damages the pancreas.

Actions of trypsin

i. Digestion of proteins: Trypsin is the most powerful proteolytic enzyme. It is an **endopeptidase** and breaks the interior bonds of the protein molecules and converts proteins into proteoses and polypeptides
ii. Curdling of milk: It converts **caseinogen** in the milk into **casein**
iii. Blood clotting: It accelerates blood clotting
iv. It activates the other enzymes of pancreatic juice, viz.
   a. Chymotrypsinogen into chymotrypsin
   b. Procarboxypeptidases into carboxypeptidases
   c. Proelastase into elastase
   d. Procolipase into colipase
v. Trypsin also activates collagenase, phospholipase A and phospholipase B
vi. Autocatalytic action: Once formed, trypsin itself converts trypsinogen into trypsin.

2. *Chymotrypsin*

Chymotrypsin is a polypeptide with a molecular weight of 25,700 and 246 amino acids. It is secreted as inactive chymotrypsinogen, which is activated into chymotrypsin by trypsin.

Actions of chymotrypsin

i. *Digestion of proteins:* Chymotrypsin is also an endopeptidase and it converts proteins into polypeptides
ii. *Digestion of milk:* Chymotrypsin digests caseinogen faster than trypsin. Combination of both enzymes causes rapid digestion of milk
iii. *On blood clotting:* No action.

3. *Carboxypeptidases*

Carboxypeptidases are carboxypeptidase A and carboxypeptidase B. Carboxypeptidase A is derived from the precursor procarboxypeptidase A. Carboxypeptidase B is derived from procarboxypeptidase B. Procarboxypeptidases are activated into carboxypeptidases by trypsin.

Actions of carboxypeptidases

Carboxypeptidases are **exopeptidases** and break the terminal bond of protein molecules. Exopeptidases split the polypeptides and other proteins into amino acids.

Carboxypeptidase A splits the proteins into amino acids having aromatic or aliphatic side chains. Carboxypeptidase B converts the proteins into amino acids having basic side chains.

4. *Nucleases*

Nucleases of pancreatic juice are ribonuclease and deoxyribonuclease, which are responsible for the digestion of nucleic acids. These enzymes convert the ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) into mononucleotides.

5. *Elastase*

Elastase is secreted as inactive proelastase, which is activated into elastase by trypsin. Elastase digests the elastic fibers.

6. *Collagenase*

Collagenase is secreted as inactive procollagenase, which is activated into collagenase by trypsin. It digests collagen.

■ DIGESTION OF LIPIDS

Lipolytic enzymes present in pancreatic juice are pancreatic lipase, cholesterol ester hydrolase, phospholipase A, phospholipase B, colipase and bile-salt-activated lipase.

1. *Pancreatic lipase*

Pancreatic lipase is a powerful lipolytic enzyme. It digests triglycerides into monoglycerides and fatty

acids. Activity of pancreatic lipase is accelerated in the presence of bile. Optimum pH required for activity of this enzyme is 7 to 9.

Digestion of fat by pancreatic lipase requires two more factors:

i. Bile salts, which are responsible for the emulsification of fat, prior to their digestion
ii. Colipase, which is a coenzyme necessary for the pancreatic lipase to digest the dietary lipids.

About 80% of the fat is digested by pancreatic lipase. Deficiency or absence of this enzyme leads to excretion of undigested fat in feces (steatorrhea; see below).

2. *Cholesterol ester hydrolase*

Cholesterol ester hydrolase or cholesterol esterase converts cholesterol ester into free cholesterol and fatty acid by hydrolysis.

3. *Phospholipase A*

Phospholipase A is activated by trypsin. Phospholipase A digests phospholipids, namely lecithin and cephalin and converts them into lysophospholipids. It converts lecithin into lysolecithin and cephalin into lysocephalin.

4. *Phospholipase B*

Phospholipase B is also activated by trypsin. It converts lysophospholipids (lysolecithin and lysocephalin) to **phosphoryl choline** and free fatty acids.

5. *Colipase*

Colipase is a small coenzyme, secreted as inactive procolipase. Procolipase is activated into colipase by trypsin. Colipase facilitates digestive action of pancreatic lipase on fats.

6. *Bile-salt-activated lipase*

Bile-salt-activated lipase is the lipolytic enzyme activated by bile salt. It is also called **carboxyl ester lipase** or **cholesterol esterase.** This enzyme has a weak lipolytic action than pancreatic lipase. But it hydrolyses a variety of lipids such as phospholipids, cholesterol esters and triglycerides. **Human milk** contains an enzyme similar to bile-salt-activated lipase (Table 39.1).

■ DIGESTION OF CARBOHYDRATES

Pancreatic amylase is the amylolytic enzyme present in pancreatic juice. Like salivary amylase, the pancreatic amylase also converts starch into dextrin and maltose.

■ NEUTRALIZING ACTION OF PANCREATIC JUICE

When acid chyme enters intestine from stomach, pancreatic juice with large quantity of bicarbonate is released into intestine. Presence of large quantity of bicarbonate ions makes the pancreatic juice highly alkaline. This alkaline pancreatic juice neutralizes acidity of chyme in the intestine.

Neutralizing action is an important function of pancreatic juice because it protects the intestine from the destructive action of acid in the chyme.

■ MECHANISM OF PANCREATIC SECRETION

■ SECRETION OF PANCREATIC ENZYMES

Pancreatic enzymes are synthesized in ribosomes, which are attached to the endoplasmic reticulum of acinar cells in pancreas. The raw materials for the synthesis of pancreatic enzymes are the amino acids, which are derived from the blood. After synthesis, the enzymes are packed into different zymogen granules by Golgi apparatus and stored in cytoplasm. When stimulated, the acinar cells release zymogen granules into the pancreatic duct. From the granules, the enzymes are liberated into intestine.

■ SECRETION OF BICARBONATE IONS

Bicarbonate ions of pancreatic juice are secreted from the cells of pancreatic ductules and released into the pancreatic duct.

Mechanism of bicarbonate secretion

1. Carbon dioxide derived from blood or metabolic process combines with water inside the cell to form carbonic acid in the presence of carbonic anhydrase
2. Carbonic acid dissociates into hydrogen and bicarbonate ions
3. Bicarbonate ions are actively transported out of the cell into the lumen
4. Hydrogen ion is actively transported into blood in exchange for sodium ion
5. Sodium ion from the cell is transported into the lumen, where it combines with bicarbonate to form sodium bicarbonate
6. Because of the loss of sodium and bicarbonate ions from the blood, there is some disturbance in the **osmotic equilibrium** of the blood. To maintain

TABLE 39.1: Digestive enzymes of pancreatic juice

Enzyme	Activator	Acts on (substrate)	End products
Trypsin	Enterokinase Trypsin	Proteins	Proteoses and polypeptides
Chymotrypsin	Trypsin	Proteins	Polypeptides
Carboxypeptidases	Trypsin	Polypeptides	Amino acids
Nucleases	Trypsin	RNA and DNA	Mononucleotides
Elastase	Trypsin	Elastin	Amino acids
Collagenase	Trypsin	Collagen	Amino acids
Pancreatic lipase	Alkaline medium	Triglycerides	Monoglycerides and fatty acids
Cholesterol ester hydrolase	Alkaline medium	Cholesterol ester	Cholesterol and fatty acids
Phospholipase A	Trypsin	Phospholipids	Lysophospholipids
Phospholipase B	Trypsin	Lysophospholipids	Phosphoryl choline and free fatty acids
Colipase	Trypsin	Facilitates action of pancreatic lipase	–
Bile-salt-activated lipase	Trypsin	Phospholipids Cholesterol esters Triglycerides	Lysophospholipids Cholesterol and fatty acids Monoglycerides and fatty acids
Pancreatic amylase	–	Starch	Dextrin and maltose

the osmotic equilibrium, water leaves the blood and enters the lumen of pancreatic duct by osmosis

7. In the lumen, bicarbonate combines with water forming the solution of bicarbonate.

REGULATION OF PANCREATIC SECRETION

Secretion of pancreatic juice is regulated by both nervous and hormonal factors.

STAGES OF PANCREATIC SECRETION

Pancreatic juice is secreted in three stages (Fig. 39.2) like the gastric juice:

1. Cephalic phase
2. Gastric phase
3. Intestinal phase.

These three phases of pancreatic secretion correspond with the three phases of gastric secretion.

1. CEPHALIC PHASE

As in case of gastric secretion, cephalic phase is regulated by nervous mechanism through reflex action.

Two types of reflexes occur:

1. Unconditioned reflex
2. Conditioned reflex.

Unconditioned Reflex

Unconditioned reflex is the inborn reflex. When food is placed in the mouth, salivary secretion (Chapter 37) and gastric secretion (Chapter 38) are induced. Simultaneously, pancreatic secretion also occurs.

Stages of reflex action:

i. Presence of food in the mouth stimulates the taste buds and other receptors in the mouth
ii. Sensory (afferent) impulses from mouth reach dorsal nucleus of vagus and efferent impulses reach pancreatic acini via vagal efferent nerve fibers
iii. Vagal efferent nerve endings secrete acetylcholine, which stimulates pancreatic secretion.

Conditioned Reflex

Conditioned reflex is the reflex response acquired by previous experience (Chapter 162). Presence of food in the mouth is not necessary to elicit this reflex. The sight, smell, hearing or thought of food, which induce salivary secretion and gastric secretion induce pancreatic secretion also.

Stages of reflex action:

i. Impulses from the special sensory organs (eye, ear and nose) pass through afferent fibers of

neural circuits to the cerebral cortex. Thinking of food stimulates the cerebral cortex directly

ii. From cerebral cortex, the impulses pass through dorsal nucleus of vagus and vagal efferents and reach pancreatic acini

iii. Vagal nerve endings secrete acetylcholine, which stimulates pancreatic secretion.

■ 2. GASTRIC PHASE

Secretion of pancreatic juice when food enters the stomach is known as gastric phase. This phase of pancreatic secretion is under hormonal control. The hormone involved is gastrin.

When food enters the stomach, gastrin is secreted from stomach (Chapter 39). When gastrin is transported to pancreas through blood, it stimulates the pancreatic secretion. The pancreatic juice secreted during gastric phase is rich in enzymes.

■ 3. INTESTINAL PHASE

Intestinal phase is the secretion of pancreatic juice when the chyme enters the intestine. This phase is also under hormonal control.

When chyme enters the intestine, many hormones are released. Some hormones stimulate the pancreatic secretion and some hormones inhibit the pancreatic secretion.

Hormones Stimulating Pancreatic Secretion

i. Secretin

ii. Cholecystokinin.

Secretin

Secretin is produced by S cells of mucous membrane in duodenum and jejunum. It is secreted as inactive prosecretin, which is activated into secretin by acid chyme.

The stimulant for the release and activation of prosecretin is the acid chyme entering intestine. Products of protein digestion also stimulate the hormonal secretion.

Action of secretin

Secretin stimulates the secretion of watery juice which is rich in of bicarbonate ion and high in volume. It increases the pancreactic secretion by acting on pancreatic ductules via cyclic AMP (messenger). Other actions of secretin are explained in Chapter 44.

Cholecystokinin

Cholecystokinin (CCK) is also called cholecystokinin-pancreozymin (CCK-PZ). It is secreted by I cells in duodenal and jejunal mucosa. The stimulant for the

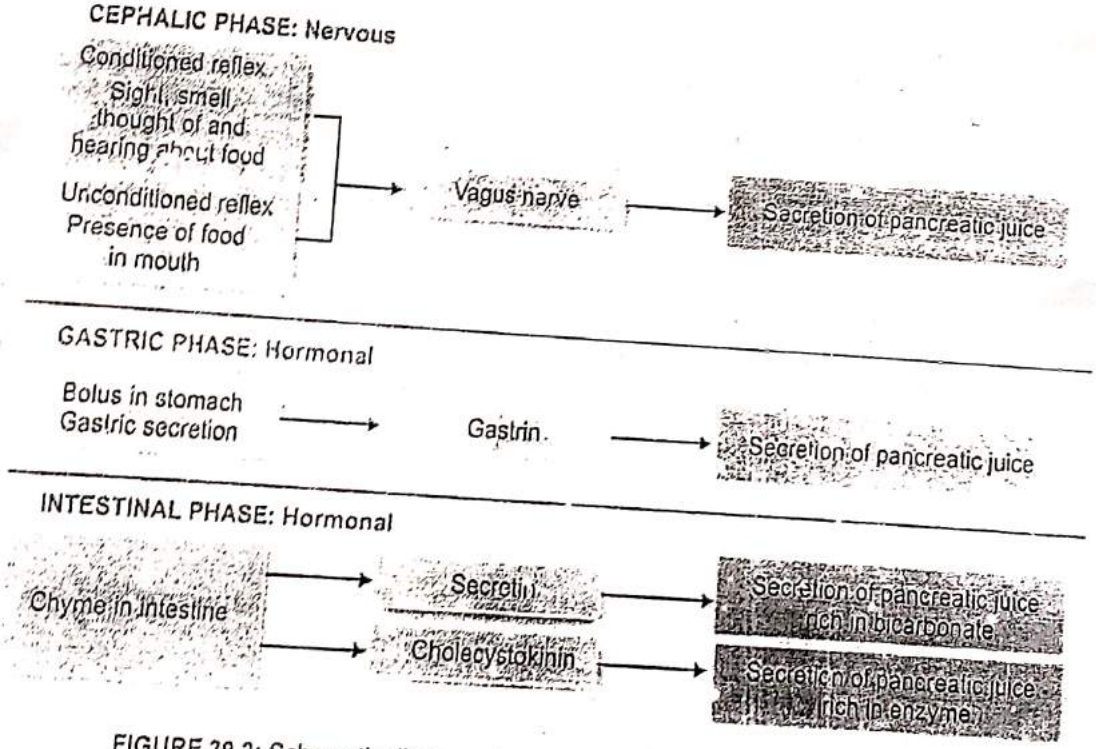

FIGURE 39.2: Schematic diagram showing the regulation of pancreatic secretion

release of this hormone is the chyme containing digestive products such as fatty acids, peptides and amino acids.

Action of cholecystokinin

Cholecystokinin stimulates the secretion of pancreatic juice which is rich in enzyme and low in volume, by acting on pancreatic acinar cells via inosine triphosphate (second messenger). The other actions of cholecystokinin are described in Chapter 44.

Hormones Inhibiting Pancreatic Secretion

i. Pancreatic polypeptide (PP) secreted by PP cells in islets of Langerhans of pancreas
ii. Somatostatin secreted by D cells in islets of Langerhans of pancreas
iii. Peptide YY secreted by intestinal mucosa
iv. Peptides like ghrelin and leptin

Refer Chapter 44 for details of these hormones.

COLLECTION OF PANCREATIC JUICE

IN ANIMALS

In animals, the pancreatic juice is collected by connecting a fistula between the pancreatic duct and the opening in the abdominal wall.

IN HUMAN

In human beings, a multilumen tube is inserted through nose or mouth, till the tip of this tube reaches the intestine near the ampulla of Vater. The tube has a marking. The entrance of the tip of the tube into the intestine near the ampulla is indicated when this line comes near the mouth. The tube has three lumens. Small balloons are attached to the two outer lumens. When balloons are inflated by air, the intestine near the ampulla is enlarged. Now, the pancreatic juice is collected through the middle lumen by means of aspiration.

APPLIED PHYSIOLOGY

PANCREATITIS

Pancreatitis is the inflammation of pancreatic acini. It is a rare but dangerous disease.

Pancreatitis is of two types:

1. Acute pancreatitis
2. Chronic pancreatitis.

1. *Acute Pancreatitis*

Acute pancreatitis is more severe and it occurs because of heavy alcohol intake or gallstones.

Features of acute pancreatitis:

i. Severe upper abdominal pain
ii. Nausea and vomiting
iii. Loss of appetite and weight
iv. Fever
v. Shock.

2. *Chronic Pancreatitis*

Chronic pancreatitis develops due to repeated acute inflammation or chronic damage to pancreas.

Causes of chronic pancreatitis

i. Long-time consumption of alcohol
ii. Chronic obstruction of ampulla of Vater by gallstone
iii. Hereditary cause (passed on genetically from one generation to another)
iv. Congenital abnormalities of pancreatic duct
v. **Cystic fibrosis,** a generalized disorder affecting the functions of many organs such as lungs (due to excessive mucus), exocrine glands like pancreas, biliary system and immune system
vi. Malnutrition (poor nutrition; mal = bad)
vii. Idiopathic pancreatitis (due to unknown cause).

Features of chronic pancreatitis

i. *Complete destruction of pancreas:* During the obstruction of biliary ducts, more amount of trypsinogen and other enzymes are accumulated. In spite of the presence of trypsin inhibitor in acini, some trypsinogen is activated. Trypsin in turn activates other proteolytic enzymes. All these enzymes destroy the pancreatic tissues completely
ii. *Absence of pancreatic enzymes:* Pancreatitis is more dangerous because the destruction of acinar cells in pancreas leads to deficiency or total absence of pancreatic enzymes. So the digestive processes are affected; worst affected

Chapter

Liver and Gallbladder

40

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FUNCTIONAL ANATOMY OF LIVER AND BILIARY SYSTEM

Liver is a dual organ having both secretory and excretory functions. It is the largest gland in the body, weighing about 1.5 kg in man. It is located in the upper and right side of the abdominal cavity, immediately beneath diaphragm.

LIVER

Hepatic Lobes

Liver is made up of many lobes called hepatic lobes (Fig. 40.1). Each lobe consists of many lobules called hepatic lobules.

Hepatic Lobules

Hepatic lobule is the structural and functional unit of liver. There are about 50,000 to 100,000 lobules in the liver. The lobule is a honeycomb-like structure and it is made up of liver cells called hepatocytes.

Hepatocytes and Hepatic Plates

Hepatocytes are arranged in columns, which form the hepatic plates. Each plate is made up of two columns of cells. In between the two columns of each plate lies a bile canaliculus (Fig. 40.2).

In between the neighboring plates, a blood space called **sinusoid** is present. Sinusoid is lined by the endothelial cells. In between the endothelial cells some special macrophages called **Kupffer cells** are present.

Portal Triads

Each lobule is surrounded by many portal triads. Each portal triad consists of three vessels:

1. A branch of hepatic artery
2. A branch of portal vein
3. A tributary of bile duct.

Branches of hepatic artery and portal vein open into the sinusoid. Sinusoid opens into the central vein. Central vein empties into hepatic vein.

Bile is secreted by hepatic cells and emptied into bile canaliculus. From canaliculus, the bile enters the

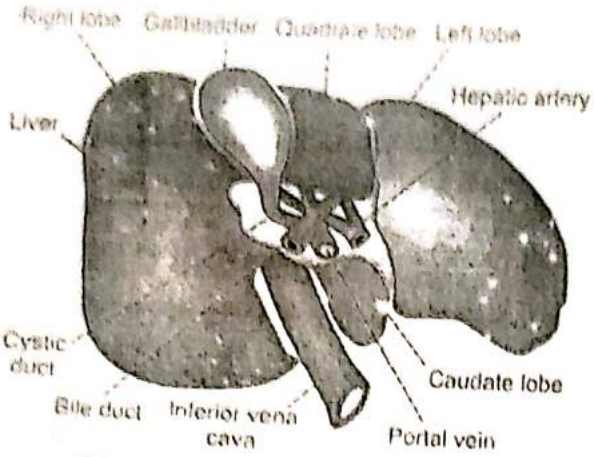

FIGURE 40.1: Posterior surface of liver

tributary of bile duct. Tributaries of bile duct from canaliculi of neighboring lobules unite to form small bile ducts. These small bile ducts join together and finally form left and right hepatic ducts, which emerge out of liver.

BILIARY SYSTEM

Biliary system or **extrahepatic biliary apparatus** is formed by gallbladder and **extrahepatic bile ducts** (bile ducts outside the liver). Right and left hepatic bile ducts which come out of liver join to form common hepatic duct. It unites with the cystic duct from gallbladder to form **common bile duct** (Fig. 40.3). All these ducts have similar structures.

Common bile duct unites with pancreatic duct to form the **common hepatopancreatic duct** or **ampulla of Vater**, which opens into the duodenum.

There is a sphincter called **sphincter of Oddi** at the lower part of common bile duct, before it joins the pancreatic duct. It is formed by smooth muscle fibers of common bile duct. It is normally kept closed; so the bile secreted from liver enters gallbladder where it is stored. Upon appropriate stimulation, the sphincter opens and allows flow of bile from gallbladder into the intestine.

BLOOD SUPPLY TO LIVER

Liver receives maximum blood supply of about 1,500 mL/minute. It receives blood from two sources, namely the hepatic artery and portal vein (Fig. 40.4).

HEPATIC ARTERY

Hepatic artery arises directly from aorta and supplies oxygenated blood to liver. After entering the liver, the

hepatic artery divides into many branches. Each one enters a portal triad

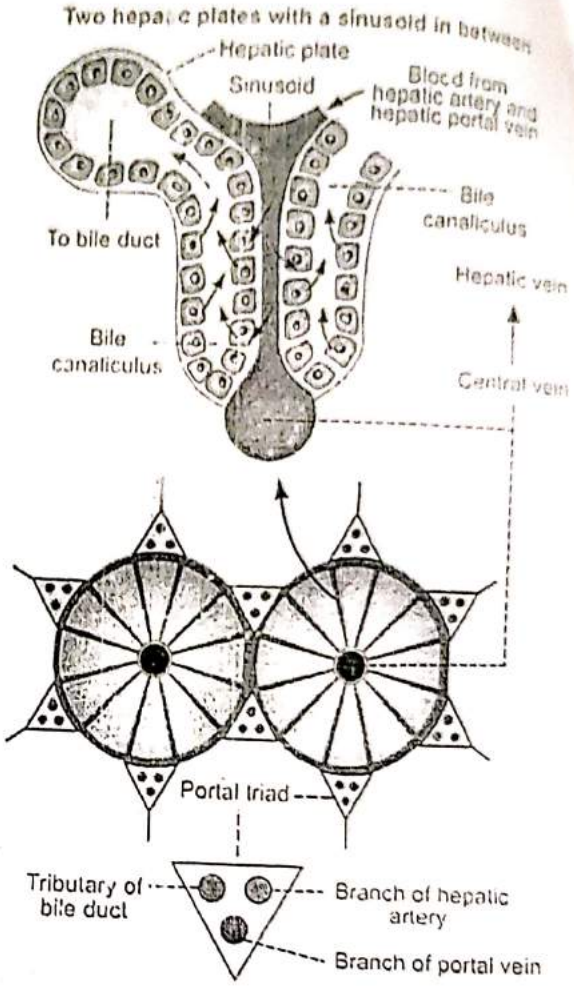

FIGURE 40.2: Hepatic lobule

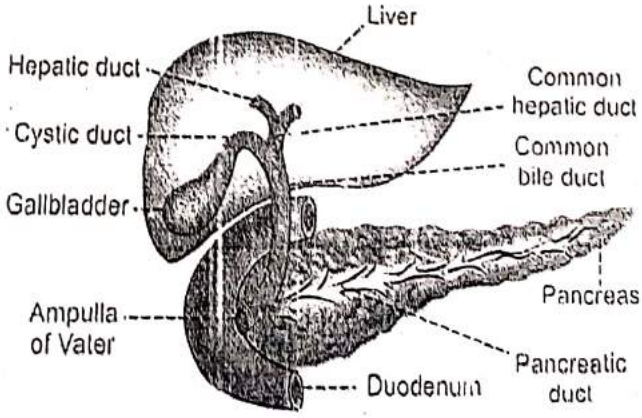

FIGURE 40.3: Biliary system

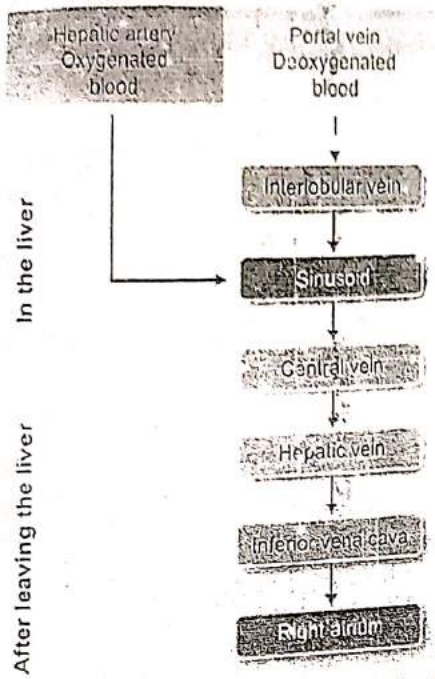

FIGURE 40.4: Schematic diagram of blood flow through liver

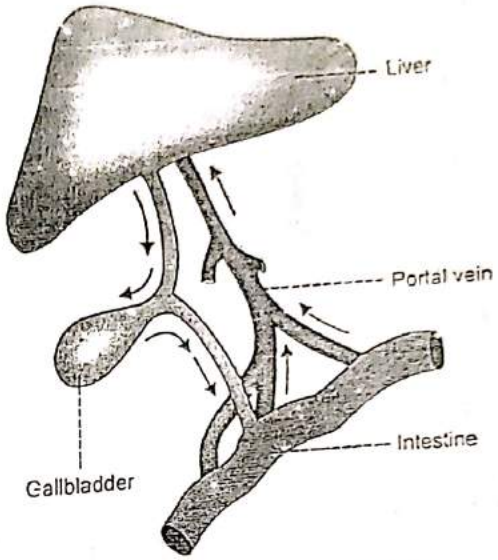

FIGURE 40.5: Enterohepatic circulation

PORTAL VEIN

Portal vein is formed by superior mesenteric vein and splenic vein. It brings **deoxygenated** blood from stomach, intestine, spleen and pancreas. Portal blood is rich in monosaccharides and amino acids. It also contains bile salts, bilirubin, urobilinogen and GI hormones. However, the oxygen content is less in portal blood.

Flow of blood from intestine to liver through portal vein is known as **enterohepatic circulation** (Fig. 40.5).

The blood from hepatic artery mixes with blood from portal vein in **hepatic sinusoids.** Hepatic cells obtain oxygen and nutrients from the sinusoid.

HEPATIC VEIN

Substances synthesized by hepatic cells, waste products and carbon dioxide are discharged into **sinusoids.** Sinusoids drain them into **central vein** of the lobule. Central veins from many lobules unite to form bigger veins, which ultimately form hepatic veins (right and left) which open into inferior vena cava.

PROPERTIES AND COMPOSITION OF BILE

PROPERTIES OF BILE

Volume	:	800 to 1,200 mL/day
Reaction	:	Alkaline
pH	:	8 to 8.6
Specific gravity	:	1.010 to 1.011
Color	:	Golden yellow or green.

COMPOSITION OF BILE

Bile contains 97.6% of water and 2.4% of solids. Solids include organic and inorganic substances. Refer Fig. 40.6 for details.

SECRETION OF BILE

Bile is secreted by hepatocytes. The initial bile secreted by hepatocytes contains large quantity of bile acids, bile pigments, cholesterol, lecithin and fatty acids. From hepatocytes, bile is released into canaliculi. From here, it passes through small ducts and hepatic ducts and reaches the common hepatic duct. From common hepatic duct, bile is diverted either directly into the intestine or into the gallbladder.

Sodium, bicarbonate and water are added to bile when it passes through the ducts. These substances are secreted by the epithelial cells of the ducts. Addition of sodium, bicarbonate and water increases the total quantity of bile.

STORAGE OF BILE

Most of the bile from liver enters the galibladder, where it is stored. It is released from gallbladder into the intestine whenever it is required. When bile is stored in gallbladder,

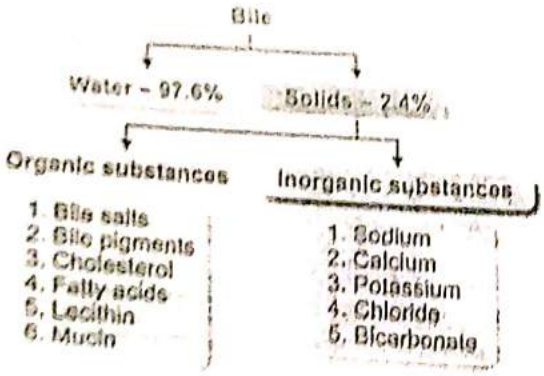

FIGURE 40.6: Composition of bile

It undergoes many changes both in quality and quantity such as

1. Volume is decreased because of absorption of a large amount of water and electrolytes (except calcium and potassium)
2. Concentration of bile salts, bile pigments, cholesterol, fatty acids and lecithin is increased because of absorption of water and electrolytes
3. The pH is decreased slightly
4. Specific gravity is increased
5. Mucin is added to bile (Table 40.1).

TABLE 40.1 Differences between liver bile and gallbladder bile

Types of bile	Liver bile	Gallbladder bile
pH	8 to 8.6	7 to 7.6
Specific gravity	1010 to 1011	1026 to 1032
Water content	97.6%	89%
Solids	2.4%	11%
Organic substances		
Bile Salts	0.5 g/dL	6.0 g/dL
Bile Pigments	0.05 g/dL	0.3 g/dL
Cholesterol	0.1 g/dL	0.5 g/dL
Fatty Acids	0.2 g/dL	1.2 g/dL
Lecithin	0.05 g/dL	0.4 g/dL
Mucin	Absent	Present
Inorganic substances		
Sodium	150 mEq/L	135 mEq/L
Calcium	4 mEq/L	22 mEq/L
Potassium	5 mEq/L	12 mEq/L
Chloride	100 mEq/L	10 mEq/L
Bicarbonate	30 mEq/L	10 mEq/L

BILE SALTS

Bile salts are the sodium and potassium salts of bile acids, which are conjugated with glycine or taurine.

FORMATION OF BILE SALTS

Bile salts are formed from bile acids. There are two primary bile acids in human, namely cholic acid and chenodeoxycholic acid, which are formed in liver and enter the intestine through bile. Due to the bacterial action in the intestine, the primary bile acids are converted into secondary bile acids:

Cholic acid → deoxycholic acid
Chenodeoxycholic acid → lithocholic acid

Secondary bile acids from intestine are transported back to liver through enterohepatic circulation. In liver, the secondary bile acids are conjugated with glycine (amino acid) or taurin (derivative of an amino acid) and form conjugated bile acids, namely glycocholic acid and taurocholic acids. These bile acids combine with sodium or potassium ions to form the salts, sodium or potassium glycocholate and sodium or potassium taurocholate (Fig. 40.7).

ENTEROHEPATIC CIRCULATION OF BILE SALTS

Enterohepatic circulation is the transport of substances from small intestine to liver through portal vein. About 90% to 95% of bile salts from intestine are transported to liver through enterohepatic circulation. Remaining 5% to 10% of the bile salts enter large intestine. Here, the bile salts are converted into deoxycholate and lithocholate, which are excreted in feces.

FUNCTIONS OF BILE SALTS

Bile salts are required for digestion and absorption of fats in the intestine. The functions of bile salts are:

1. *Emulsification of Fats*

Emulsification is the process by which the fat globules are broken down into minute droplets and made in the form of a milky fluid called emulsion in small intestine, by the action of bile salts.

Lipolytic enzymes of GI tract cannot digest the fats directly because the fats are insoluble in water due to the surface tension. Bile salts emulsify the fats by reducing the surface tension due to their detergent action. Now the fats can be easily digested by lipolytic enzymes.

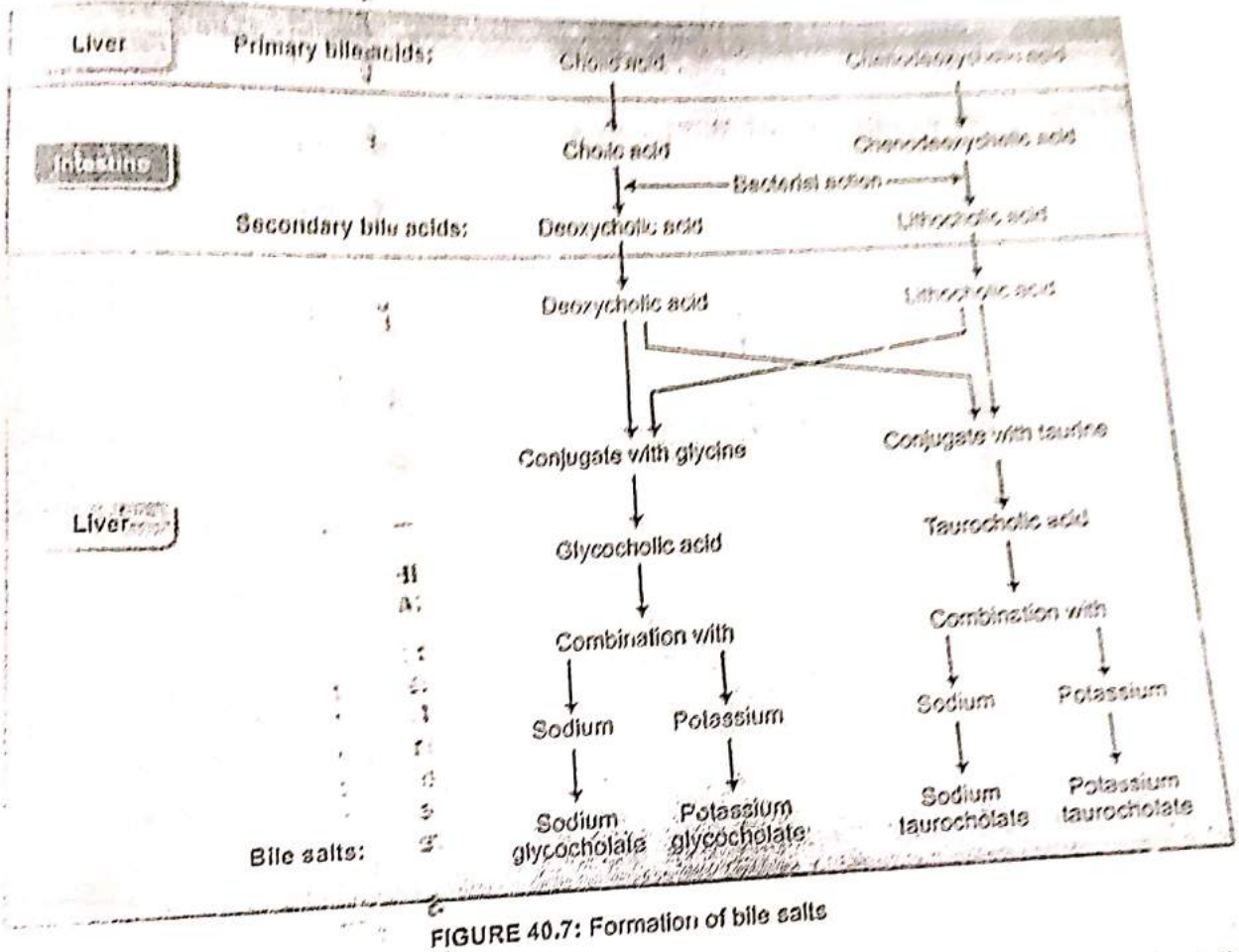

FIGURE 40.7: Formation of bile salts

Unemulsified fat usually passes through the intestine and then it is eliminated in feces.

Emulsification of fats by bile salts needs the presence of lecithin from bile.

2. *Absorption of Fats*

Bile salts help in the absorption of digested fats from intestine into blood. Bile salts combine with fats and make complexes of fats called micelles. The fats in the form of micelles can be absorbed easily.

3. *Choleretic Action*

Bile salts stimulate the secretion of bile from liver. This action is called choleretic action.

4. *Cholagogue Action*

Cholagogue is an agent which causes contraction of gallbladder and release of bile into the intestine. Bile salts act as cholagogues indirectly by stimulating the secretion of hormone cholecystokinin. This hormone causes contraction of gallbladder, resulting in release of bile.

5. *Laxative Action*

Laxative is an agent which induces defecation. Bile salts act as laxatives by stimulating peristaltic movements of the intestine.

6. *Prevention of Gallstone Formation*

Bile salts prevent the formation of gallstone by keeping the cholesterol and lecithin in solution. In the absence of bile salts, cholesterol precipitates along with lecithin and forms gallstone.

BILE PIGMENTS

Bile pigments are the excretory products in bile. Bilirubin and biliverdin are the two bile pigments and bilirubin is the major bile pigment in human beings.

Bile pigments are formed during the breakdown of hemoglobin, which is released from the destroyed RBCs in the reticuloendothelial system (Fig. 40.8).

FORMATION AND EXCRETION OF BILE PIGMENTS

Stages of formation and circulation of bile pigments:

1. Senile erythrocytes are destroyed in reticuloendothelial system and hemoglobin is released from them
2. Hemoglobin is broken into globin and heme
3. Heme is split into iron and the pigment biliverdin
4. Iron goes to iron pool and is reused
5. First formed pigment biliverdin is reduced to bilirubin.
6. Bilirubin is released into blood from the reticuloendothelial cells
7. In blood, the bilirubin is transported by the plasma protein, albumin. Bilirubin circulating in the blood is called free bilirubin or unconjugated bilirubin
8. Within few hours after entering the circulation, the free bilirubin is taken up by the liver cells
9. In the liver, it is conjugated with glucuronic acid to form **conjugated bilirubin**
10. Conjugated bilirubin is then excreted into intestine through bile.

FATE OF CONJUGATED BILIRUBIN

Stages of excretion of conjugated bilirubin

1. In intestine, 50% of the conjugated bilirubin converted into urobilinogen by intestinal bacter First the conjugated bilirubin is deconjugated into fr **bilirubin**, which is later reduced into urobilinogen
2. Remaining 50% of conjugated bilirubin from intestine is absorbed into blood and enters the liver through portal vein (enterohepatic circulation). From liver, it is re-excreted in bile
3. Most of the urobilinogen from intestine enters liver via enterohepatic circulation. Later, it is re-excreted through bile
4. About 5% of urobilinogen is excreted by kidney through urine. In urine, due to exposure to air, the urobilinogen is converted into urobilin by oxidation
5. Some of the urobilinogen is excreted in feces as stercobilinogen. In feces, stercobilinogen is oxidized to stercobilin.

NORMAL PLASMA LEVELS OF BILIRUBIN

Normal bilirubin (Total bilirubin) content in plasma is 0.5 to 1.5 mg/dL. When it exceeds 1mg/dL, the condition is called **hyperbilirubinemia**. When it exceeds 2 mg/dL, **jaundice** occurs.

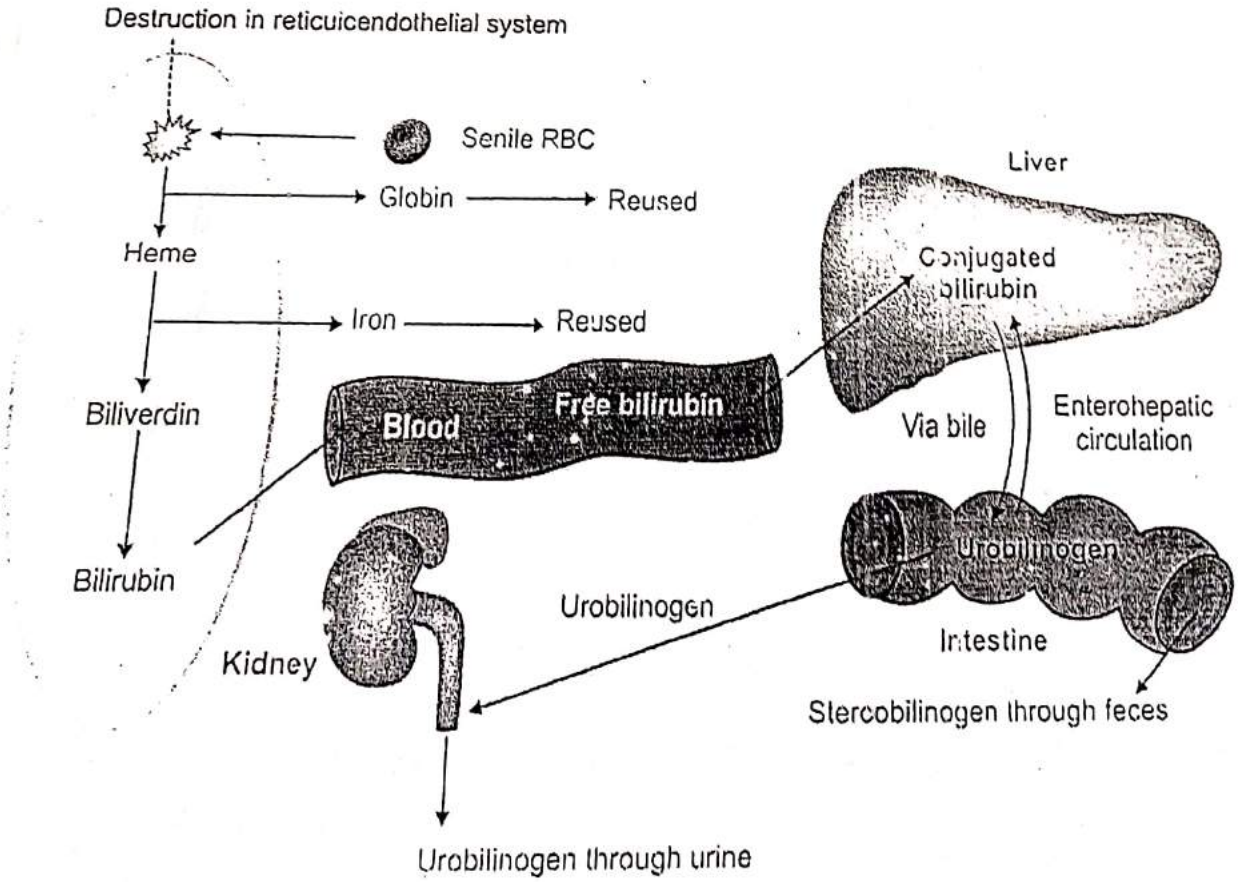

FIGURE 40.8: Formation and circulation of bile pigments

FUNCTIONS OF BILE

Most of the functions of bile are due to the bile salts.

1. DIGESTIVE FUNCTION

Refer functions of bile salts.

2. ABSORPTIVE FUNCTIONS

Refer functions of bile salts.

3. EXCRETORY FUNCTIONS

Bile pigments are the major excretory products of the bile. Other substances excreted in bile are:

i. Heavy metals like copper and iron
ii. Some bacteria like typhoid bacteria
iii. Some toxins
iv. Cholesterol
v. Lecithin
vi. Alkaline phosphatase.

4. LAXATIVE ACTION

Bile salts act as laxatives (see above).

5. ANTISEPTIC ACTION

Bile inhibits the growth of certain bacteria in the lumen of intestine by its natural detergent action.

6. CHOLERETIC ACTION

Bile salts have the choleretic action (see above).

7. MAINTENANCE OF pH IN GASTROINTESTINAL TRACT

As bile is highly alkaline, it neutralizes the acid chyme which enters the intestine from stomach. Thus, an optimum pH is maintained for the action of digestive enzymes.

8. PREVENTION OF GALLSTONE FORMATION

Refer function of bile salts.

9. LUBRICATION FUNCTION

The mucin in bile acts as a lubricant for the chyme in intestine.

10. CHOLAGOGUE ACTION

Bile salts act as cholagogues (see above).

FUNCTIONS OF LIVER

Liver is the largest gland and one of the vital organs of the body. It performs many vital metabolic and homeostatic functions, which are summarized below:

1. METABOLIC FUNCTION

Liver is the organ where maximum metabolic reactions such as metabolism of carbohydrates, proteins, fats, vitamins and many hormones are carried out.

2. STORAGE FUNCTION

Many substances like glycogen, amino acids, iron, folic acid and vitamins A, B12 and D are stored in liver.

3. SYNTHETIC FUNCTION

Liver produces glucose by gluconeogenesis. It synthesizes all the plasma proteins and other proteins (except immunoglobulins) such as clotting factors, complement factors and hormone-binding proteins. It also synthesizes steroids, somatomedin and heparin.

4. SECRETION OF BILE

Liver secretes bile which contains bile salts, bile pigments, cholesterol, fatty acids and lecithin.

The functions of bile are mainly due to bile salts. Bile salts are required for digestion and absorption of fats in the intestine. Bile helps to carry away waste products and breakdown fats, which are excreted through feces or urine.

5. EXCRETORY FUNCTION

Liver excretes cholesterol, bile pigments, heavy metals (like lead, arsenic and bismuth), toxins, bacteria and virus (like that of yellow fever) through bile.

6. HEAT PRODUCTION

Enormous amount of heat is produced in the liver because of metabolic reactions. Liver is the organ where maximum heat is produced.

7. HEMOPOIETIC FUNCTION

In fetus (hepatic stage), liver produces the blood cells (Chapter 10). It stores vitamin B12 necessary for erythropoiesis and iron necessary for synthesis

of hemoglobin. Liver produces thrombopoietin that promotes production of thrombocytes.

8. HEMOLYTIC FUNCTION

The senile RBCs after a lifespan of 120 days are destroyed by reticuloendothelial cells (Kupffer cells) of liver.

9. INACTIVATION OF HORMONES AND DRUGS

Liver catabolizes the hormones such as growth hormone, parathormone, cortisol, insulin, glucagon and estrogen. It also inactivates the drugs, particularly the fat-soluble drugs. The fat-soluble drugs are converted into water-soluble substances, which are excreted through bile or urine.

10. DEFENSIVE AND DETOXIFICATION FUNCTIONS

Reticuloendothelial cells (Kupffer cells) of the liver play an important role in the defense of the body. Liver is also involved in the detoxification of the foreign bodies.

i. Foreign bodies such as bacteria or antigens are swallowed and digested by reticuloendothelial cells of liver by means of **phagocytosis.**
ii. Reticuloendothelial cells of liver also produce substances like interleukins and tumor necrosis factors, which activate the immune system of the body (Chapter 17).
iii. Liver cells are involved in the removal of toxic property of various harmful substances. Removal of toxic property of the harmful agent is known as detoxification.

Detoxification in liver occurs in two ways:

a. Total destruction of the substances by means of metabolic degradation.
b. Conversion of toxic substances into non-toxic materials by means of conjugation with glucuronic acid or sulfates.

GALLBLADDER

Bile secreted from liver is stored in gallbladder. The capacity of gallbladder is approximately 50 mL. Gallbladder is not essential for life and it is removed (**cholecystectomy**) in patients suffering from gallbladder dysfunction. After cholecystectomy, patients do not suffer from any major disadvantage. In some species, gallbladder is absent.

FUNCTIONS OF GALLBLADDER

Major functions of gallbladder are the storage and concentration of bile.

1. *Storage of Bile*

Bile is continuously secreted from liver. But it is released into intestine only intermittently and most of the bile is stored in gallbladder till it is required.

2. *Concentration of Bile*

Bile is concentrated while it is stored in gallbladder. The mucosa of gallbladder rapidly reabsorbs water and electrolytes, except calcium and potassium. But the bile salts, bile pigments, cholesterol and lecithin are not reabsorbed. So, the concentration of these substances in bile increases 5 to 10 times (Fig. 40.9).

3. *Alteration of pH of Bile*

The pH of bile decreases from 8 – 8.6 to 7 – 7.6 and it becomes less alkaline when it is stored in gallbladder.

4. *Secretion of Mucin*

Galibladder secretes mucin and adds it to bile. When bile is released into the intestine, mucin acts as a lubricant for movement of chyme in the intestine.

5. *Maintenance of Pressure in Biliary System*

Due to the concentrating capacity, gallbladder maintains a pressure of about 7 cm H_2O in biliary system. This pressure in the biliary system is essential for the release of bile into the intestine.

FILLING AND EMPTYING OF GALLBLADDER

Usually, the sphincter of Oddi is closed during fasting and the pressure in the biliary system is only 7 cm H_2O. Because of this pressure, the bile from liver enters the gallbladder.

While taking food or when chyme enters the intestine, gallbladder contracts along with relaxation of sphincter of Oddi. Now, the pressure increases to about 20 cm H_2O. Because of the increase in pressure, the bile from gallbladder enters the intestine. Contraction of gallbladder is influenced by neural and hormonal factors.

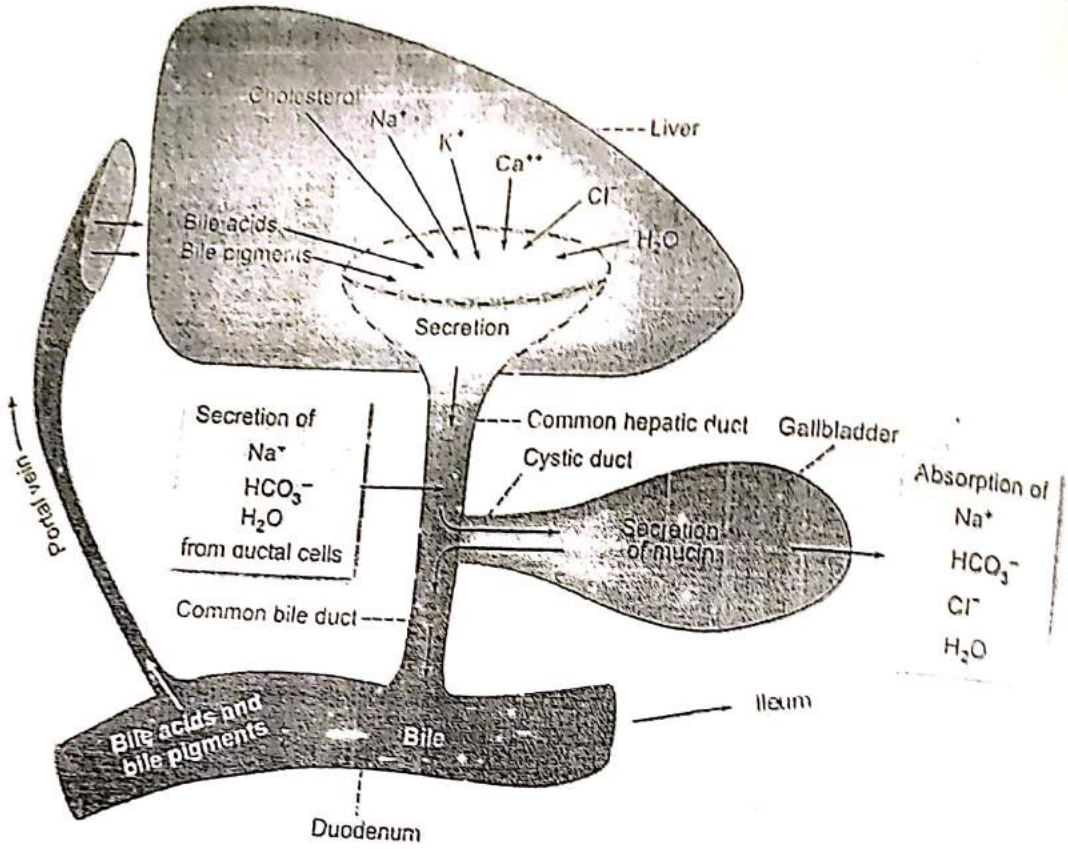

FIGURE 40.9: Diagram showing the formation of bile from liver and changes taking place in the composition of gallbladder bile

1. *Neural Factor*

Stimulation of parasympathetic nerve (vagus) causes contraction of gallbladder by releasing acetylcholine. The vagal stimulation occurs during the cephalic phase and gastric phase of gastric secretion.

2. *Hormonal Factor*

When a fatty chyme enters the intestine from stomach, the intestine secretes the cholecystokinin, which causes contraction of the gallbladder.

REGULATION OF BILE SECRETION

Bile secretion is a continuous process though the amount is less during fasting. It starts increasing after meals and continues for three hours. Secretion of bile from liver and release of bile from the gallbladder are influenced by some chemical factors, which are categorized into three groups:

1. Choleretics
2. Cholagogue
3. Hydrocholeretic agents.

1. *Choleretics*

Substances which increase the secretion of bile from liver are known as choleretics.

Effective choleretic agents are:

i. Acetylcholine
ii. Secretin
iii. Cholecystokinin
iv. Acid chyme in intestine
v. Bile salts.

2. *Cholagogues*

Cholagogue is an agent which increases the release of bile into the intestine by contracting gallbladder

Small Intestine

Chapter 41

- FUNCTIONAL ANATOMY
- INTESTINAL VILLI AND GLANDS
- PROPERTIES AND COMPOSITION OF SUCCUS ENTERICUS
- FUNCTIONS OF SUCCUS ENTERICUS
- FUNCTIONS OF SMALL INTESTINE
- REGULATION OF SECRETION OF SUCCUS ENTERICUS
- METHODS OF COLLECTION OF SUCCUS ENTERICUS
- APPLIED PHYSIOLOGY

FUNCTIONAL ANATOMY

Small intestine is the part of gastrointestinal (GI) tract, extending between the **pyloric sphincter** of stomach and **ileocecal valve**, which opens into large intestine. It is called small intestine because of its small diameter, compared to that of the large intestine. But it is longer than large intestine. Its length is about 6 meter.

Important function of small intestine is absorption. Maximum absorption of digested food products takes place in small intestine.

Small intestine consists of three portions.

1. Proximal part known as duodenum
2. Middle part known as jejunum
3. Distal part known as ileum.

Wall of the small intestine has all the four layers as in stomach (Chapter 36).

INTESTINAL VILLI AND GLANDS OF SMALL INTESTINE

INTESTINAL VILLI

Mucous membrane of small intestine is covered by minute projections called villi. The height of villi is about 1 mm and the diameter is less than 1 mm.

Villi are lined by columnar cells, which are called **enterocytes**. Each enterocyte gives rise to hair-like projections called **microvilli**. Villi and microvilli increase the surface area of mucous membrane by many folds. Within each villus, there is a central channel called lacteal, which opens into lymphatic vessels. It contains blood vessels also.

CRYPTS OF LIEBERKÜHN OR INTESTINAL GLANDS

Crypts of Lieberkühn or intestinal glands are simple tubular glands of intestine. Intestinal glands do not penetrate the muscularis mucosa of the intestinal wall, but open into the lumen of intestine between the villi. Intestinal glands are lined by columnar cells. Lining of each gland is continuous with epithelial lining of the villi (Fig. 41.1).

Epithelial cells lining the intestinal glands undergo division by mitosis at a faster rate. Newly formed cells push the older cells upward over the lining of villi. These cells which move to villi are called enterocytes. Enterocytes secrete the enzymes. Old enterocytes are continuously shed into lumen along with enzymes.

Types of cells interposed between columnar cells of intestinal glands:

1. **Argentaffin cells** or **enterochromaffin cells**, which secrete **intrinsic factor of Castle**
2. **Goblet cells**, which secrete mucus
3. **Paneth cells**, which secrete the cytokines called **defensins.**

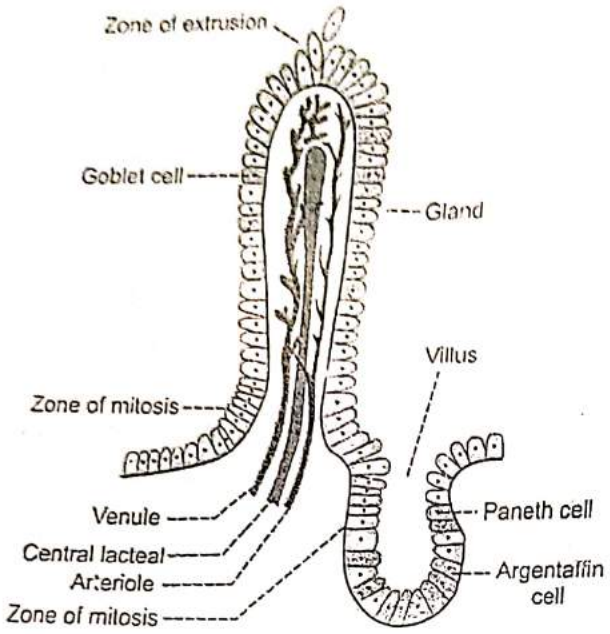

FIGURE 41.1: Intestinal gland and villus

BRUNNER GLANDS

In addition to intestinal glands, the first part of duodenum contains some mucus glands, which are called Brunner glands. These glands penetrate muscularis mucosa and extend up to the submucus coat of the intestinal wall. Brunner glands open into the lumen of intestine directly. Brunner gland secretes mucus and traces of enzymes.

PROPERTIES AND COMPOSITION OF SUCCUS ENTERICUS

Secretion from small intestine is called succus entericus.

PROPERTIES OF SUCCUS ENTERICUS

Volume : 1800 mL/day
Reaction : Alkaline
pH : 8.3

COMPOSITION OF SUCCUS ENTERICUS

Succus entericus contains water (99.5%) and solids (0.5%). Solids include organic and inorganic substances (Fig. 41.2). Bicarbonate concentration is slightly high in succus entericus.

FUNCTIONS OF SUCCUS ENTERICUS

1. DIGESTIVE FUNCTION

Enzymes of succus entericus act on the partly digested food and convert them into final digested products. Enzymes are produced and released in succus entericus by enterocytes of the villi.

Proteolytic Enzymes

Proteolytic enzymes present in succus entericus are the peptidases, which are given in Fig. 41.2. These peptidases convert peptides into amino acids.

Amylolytic Enzymes

Amylolytic enzymes of succus entericus are listed in Fig. 41.2.

Lactase, sucrase and maltase convert the disaccharides (lactose, sucrose and maltose) into two molecules of monosaccharides (Table 41.1).

Dextrinase converts dextrin, maltose and maltriose into glucose. Trehalase or trehalose glucohydrolase causes hydrolysis of trehalose (carbohydrate present in mushrooms and yeast) and converts it into glucose.

Lipolytic Enzyme

Intestinal lipase acts on triglycerides and converts them into fatty acids.

2. PROTECTIVE FUNCTION

i. Mucus present in the succus entericus protects the intestinal wall from the acid chyme, which enters the intestine from stomach; thereby it prevents the intestinal ulcer.
ii. **Defensins** secreted by paneth cells of intestinal glands are the **antimicrobial peptides.**

These peptides are called natural peptide antibiotics because of their role in killing the phagocytosed bacteria.

3. ACTIVATOR FUNCTION

Enterokinase present in intestinal juice activates trypsinogen into trypsin. Trypsin, in turn activates other enzymes (Chapter 39).

4. HEMOPOIETIC FUNCTION

Intrinsic factor of Castle present in the intestine plays an important role in erythropoiesis (Chapter 10). It is necessary for the absorption of vitamin B12.

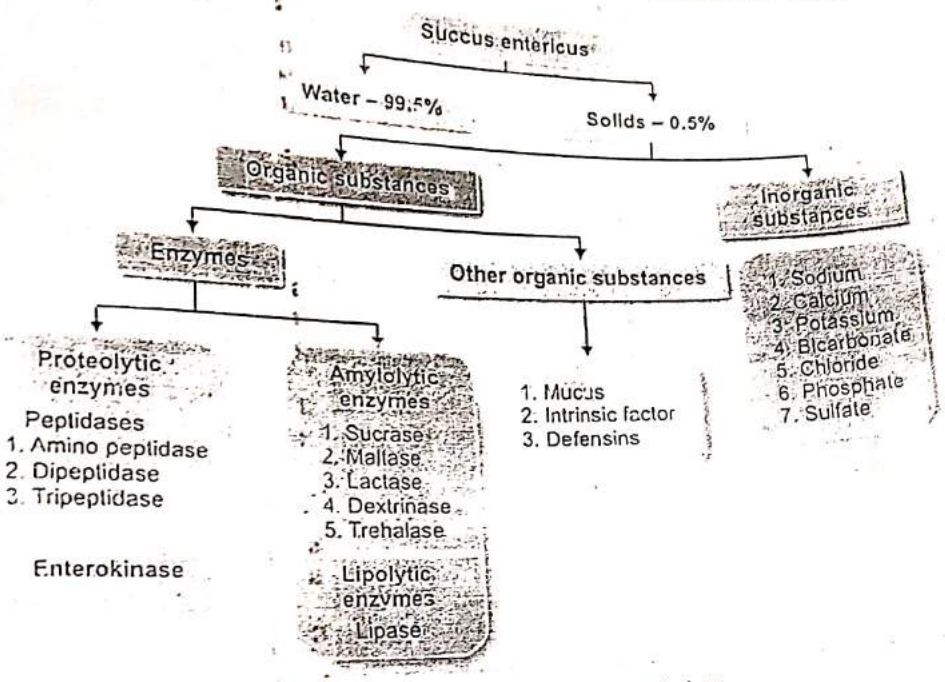

FIGURE 41.2: Composition of succus entericus

5. HYDROLYTIC PROCESS

Intestinal juice helps in all the enzymatic reactions of digestion.

FUNCTIONS OF SMALL INTESTINE

1. MECHANICAL FUNCTION

Mixing movements of small intestine help in the thorough mixing of chyme with the digestive juices like succus entericus, pancreatic juice and bile.

2. SECRETORY FUNCTION

Small intestine secretes succus entericus, enterokinase and the GI hormones.

3. HORMONAL FUNCTION

Small intestine secretes many GI hormones such as secretin, cholecystokinin, etc. These hormones regulate the movement of GI tract and secretory activities of small intestine and pancreas (Chapter 44).

4. DIGESTIVE FUNCTION

Refer functions of succus entericus.

5. ACTIVATOR FUNCTION

Refer functions of succus entericus.

6. HEMOPOIETIC FUNCTION

Refer functions of succus entericus.

7. HYDROLYTIC FUNCTION

Refer functions of succus entericus.

TABLE 41.1: Digestive enzymes of succus entericus

Enzyme	Substrate	End products
Peptidases	Peptides	Amino acids
Sucrase	Sucrose	Fructose and glucose
Maltase	Maltose and maltriose	Glucose
Lactase	Lactose	Galactose and glucose
Dextrinase	Dextrin, maltose and maltriose	Glucose
Trehalase	Trehalose	Glucose
Intestinal lipase	Triglycerides	Fatty acids

8. ABSORPTIVE FUNCTIONS

Presence of villi and microvilli in small intestinal mucosa increases the surface area of mucosa. This facilitates the absorptive function of intestine.

Digested products of foodstuffs, proteins, carbohydrates, fats and other nutritive substances such as vitamins, minerals and water are absorbed mostly in small intestine. From the lumen of intestine, these substances pass through lacteal of villi, cross the mucosa and enter the blood directly or through lymphatics.

Absorption of Carbohydrates

Refer Chapter 45.

Absorption of Proteins

Refer Chapter 46.

Absorption of Fats

Refer Chapter 47.

Absorption of Water and Minerals

i. In small intestine, sodium is absorbed actively. It is responsible for absorption of glucose, amino acids and other substances by means of sodium cotransport.
ii. Water moves in or out of the intestinal lumen until the osmotic pressure of intestinal contents becomes equal to that of plasma.
iii. In ileum, chloride ion is actively absorbed in exchange for bicarbonate. The significance of this exchange is not known.
iv. Calcium is actively absorbed mostly in upper part of small intestine.

Absorption of Vitamins

Most of the vitamins are absorbed in upper part of small intestine and vitamin B_{12} is absorbed in ileum. Absorption of water-soluble vitamins is faster than fat-soluble vitamins.

REGULATION OF SECRETION OF SUCCUS ENTERICUS

Secretion of succus entericus is regulated by both nervous and hormonal mechanisms.

NERVOUS REGULATION

Stimulation of parasympathetic nerves causes vasodilatation and increases the secretion of succus entericus. Stimulation of sympathetic nerves causes vasoconstriction and decreases the secretion of succus entericus. But, the role of these nerves in the regulation of intestinal secretion in physiological conditions is uncertain.

However, the local nervous reflexes play an important role in increasing the secretion of intestinal juice. When chyme enters the small intestine, the mucosa is stimulated by tactile stimuli or irritation. It causes the development of local nervous reflexes, which stimulate the glands of intestine.

HORMONAL REGULATION

When chyme enters the small intestine, intestinal mucosa secretes enterocrinin, secretin and cholecystokinin, which promote the secretion of succus entericus by stimulating the intestinal glands.

METHODS OF COLLECTION OF SUCCUS ENTERICUS

IN HUMAN

In human beings, the intestinal juice is collected by using multilumen tube. The multilumen tube is inserted through nose or mouth, until the tip of this tube reaches the intestine. A line is marked on the tube. Entrance of tip of the tube into small intestine is indicated when this line comes near the mouth. This tube has three lumens. To the outer two lumens, small balloons are attached. When these balloons are inflated, the intestine is enlarged. Now, the intestinal juice is collected through the middle lumen, by means of aspiration.

IN ANIMALS

Thiry Loop

A portion of intestine is separated from the gut by incising at both ends. The cut ends of the main gut are connected and the continuity is re-established. One end of isolated segment is closed and the other end is brought out through abdominal wall. It is called Thiry loop or Thiry fistula.

Thiry-Vella Loop

Thiry-Vella loop is the modified Thiry loop. In this, a long segment of intestine is cut and separated from the main gut. Both the ends of this segment are brought out through the abdominal wall. The cut ends of the main gut are joined.

Large Intestine

Chapter 42

- FUNCTIONAL ANATOMY
  - PARTS OF LARGE INTESTINE
  - STRUCTURE OF WALL OF LARGE INTESTINE
- SECRETIONS OF LARGE INTESTINE
  - COMPOSITION OF LARGE INTESTINAL JUICE
  - FUNCTIONS OF LARGE INTESTINAL JUICE
- FUNCTIONS OF LARGE INTESTINE
  - ABSORPTIVE FUNCTION
  - FORMATION OF FECES
  - EXCRETORY FUNCTION
  - SECRETORY FUNCTION
  - SYNTHETIC FUNCTION
- DIETARY FIBER
- APPLIED PHYSIOLOGY
  - DIARRHEA
  - CONSTIPATION
  - APPENDICITIS
  - ULCERATIVE COLITIS

FUNCTIONAL ANATOMY OF LARGE INTESTINE

Large intestine or colon extends from ileocecal valve up to anus (Fig. 36.1).

PARTS OF LARGE INTESTINE

Large intestine is made up of the following parts:

1. Cecum with appendix
2. Ascending colon
3. Transverse colon
4. Descending colon
5. Sigmoid colon or pelvic colon
6. Rectum
7. Anal canal.

STRUCTURE OF WALL OF LARGE INTESTINE

Wall of large intestine is formed by four layers of structures like any other part of the gut.

1. *Serous layer:* It is formed by peritoneum
2. *Muscular layer:* Smooth muscles of large intestine are distributed in two layers, namely the outer longitudinal layer and inner circular layer. The longitudinal muscle fibers of large intestine are arranged in the form of three long bands called **tenia coli.** The length of the tenia coli is less when compared to the length of large intestine. Because of this, the large intestine is made into series of pouches called **haustra**

3. *Submucus layer*: It is not well developed in large intestine
4. *Mucus layer*: The crypts of Leiberkühn are present in mucosa of large intestine. But the villi, which are present in mucus membrane of small intestine, are absent in the large intestine. Only mucus-secreting glands are present in the mucosa of large intestine.

SECRETIONS OF LARGE INTESTINE

Large intestinal juice is a watery fluid with pH of 8.0.

COMPOSITION OF LARGE INTESTINAL JUICE

Large intestinal juice contains 99.5% of water and 0.5% of solids (Fig. 42.1). Digestive enzymes are absent and concentration of bicarbonate is high in large intestinal juice.

FUNCTIONS OF LARGE INTESTINAL JUICE

Neutralization of Acids

Strong acids formed by bacterial action in large intestine are neutralized by the alkaline nature of large intestinal juice. The alkalinity of this juice is mainly due to the presence of large quantity of bicarbonate.

Lubrication Activity

Mucin present in the secretion of large intestine lubricates the mucosa of large intestine and the bowel contents, so that, the movement of bowel is facilitated.

Mucin also protects the mucus membrane of large intestine by preventing the damage caused by mechanical injury or chemical substances.

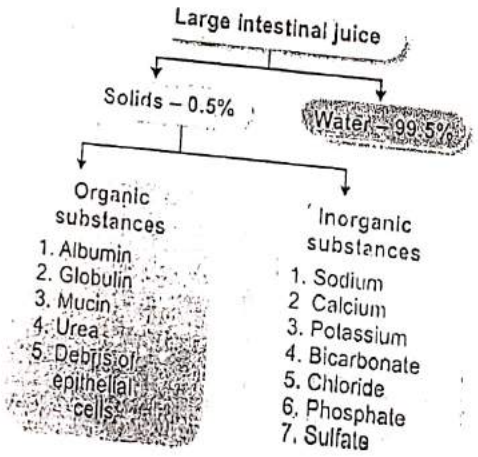

FIGURE 42.1: Composition of large intestinal juice

FUNCTIONS OF LARGE INTESTINE

1. ABSORPTIVE FUNCTION

Large intestine plays an important role in the absorption of various substances such as:

i. Water
ii. Electrolytes
iii. Organic substances like glucose
iv. Alcohol
v. Drugs like anesthetic agents, sedatives and steroids.

2. FORMATION OF FECES

After the absorption of nutrients, water and other substances, the unwanted substances in the large intestine form feces. This is excreted out.

3. EXCRETORY FUNCTION

Large intestine excretes heavy metals like mercury, lead, bismuth and arsenic through feces.

4. SECRETORY FUNCTION

Large intestine secretes mucin and inorganic substances like chlorides and bicarbonates.

5. SYNTHETIC FUNCTION

Bacterial flora of large intestine synthesizes folic acid, vitamin B12 and vitamin K. By this function, large intestine contributes in erythropoietic activity and blood clotting mechanism.

DIETARY FIBER

Dietary fiber or roughage is a group of food particles which pass through stomach and small intestine without being digested and reach the large intestine unchanged. Other nutritive substances of food are digested and absorbed before reaching large intestine.

Characteristic feature of dietary fiber is that it is not hydrolyzed by digestive enzymes. So, it escapes digestion in small intestine and passes to large intestine. It provides substrate for microflora of large intestine and increases the bacterial mass. The anaerobic bacteria, in turn, degrade the fermentable components of the fiber. Thus, in large intestine, some of the components of fiber are broken down and absorbed and remaining components are excreted through feces.

Movements of Gastrointestinal Tract

Chapter 43

- MASTICATION
- DEGLUTITION
- MOVEMENTS OF STOMACH
- FILLING AND EMPTYING OF STOMACH
- VOMITING
- MOVEMENTS OF SMALL INTESTINE
- MOVEMENTS OF LARGE INTESTINE
- DEFECATION
- EVACUATION OF GASES FROM GASTROINTESTINAL TRACT

MASTICATION

Mastication or chewing is the first mechanical process in the gastrointestinal (GI) tract, by which the food substances are torn or cut into small particles and crushed or ground into a soft bolus.

Significances of mastication

1. Breakdown of foodstuffs into smaller particles
2. Mixing of saliva with food substances thoroughly
3. Lubrication and moistening of dry food by saliva, so that the bolus can be easily swallowed
4. Appreciation of taste of the food.

MUSCLES AND THE MOVEMENTS OF MASTICATION

Muscles of Mastication

1. Masseter muscle
2. Temporal muscle
3. Pterygoid muscles
4. Buccinator muscle.

Movements of Mastication

1. Opening and closure of mouth
2. Rotational movements of jaw
3. Protraction and retraction of jaw.

CONTROL OF MASTICATION

Action of mastication is mostly a reflex process. It is carried out voluntarily also. The center for mastication is situated in medulla and cerebral cortex. Muscles of mastication are supplied by mandibular division of 5th cranial (trigeminal) nerve.

DEGLUTITION

Definition

Deglutition or swallowing is the process by which food moves from mouth into stomach.

Stages of Deglutition

Deglutition occurs in three stages:

I. Oral stage, when food moves from mouth to pharynx
II. Pharyngeal stage, when food moves from pharynx to esophagus
III. Esophageal stage, when food moves from esophagus to stomach.

ORAL STAGE OR FIRST STAGE

Oral stage of deglutition is a voluntary stage. In this stage, the bolus from mouth passes into pharynx by means of series of actions.

Sequence of Events during Oral Stage

1. Bolus is placed over postero-dorsal surface of the tongue. It is called the preparatory position.
2. Anterior part of tongue is retracted and depressed.
3. Posterior part of tongue is elevated and retracted against the hard palate. This pushes the bolus backwards into the pharynx.
4. Forceful contraction of tongue against the palate produces a positive pressure in the posterior part of oral cavity. This also pushes the food into pharynx (Fig. 43.1).

■ PHARYNGEAL STAGE OR SECOND STAGE

Pharyngeal stage is an involuntary stage. In this stage, the bolus is pushed from pharynx into the esophagus.

Pharynx is a common passage for food and air. It divides into larynx and esophagus. Larynx lies anteriorly and continues as respiratory passage. Esophagus lies behind the larynx and continues as GI tract. Since pharynx communicates with mouth, nose, larynx and esophagus, during this stage of deglutition, bolus from the pharynx can enter into four paths:

1. Back into mouth
2. Upward into nasopharynx
3. Forward into larynx
4. Downward into esophagus.

However, due to various coordinated movements, bolus is made to enter only the esophagus. Entrance of bolus through other paths is prevented as follows:

1. *Back into Mouth*

Return of bolus back into the mouth is prevented by:

i. Position of tongue against the soft palate (roof of the mouth)
ii. High intraoral pressure, developed by the movement of tongue.

2. *Upward into Nasopharynx*

Movement of bolus into the nasopharynx from pharynx is prevented by elevation of soft palate along with its extension called uvula.

3. *Forward into Larynx*

Movement of bolus into the larynx is prevented by the following actions:

i. Approximation of the vocal cords
ii. Forward and upward movement of larynx
iii. Backward movement of epiglottis to seal the opening of the larynx (glottis)
iv. All these movements arrest respiration for a few seconds. It is called deglutition apnea.

Deglutition apnea

Apnea refers to temporary arrest of breathing. Deglutition apnea or swallowing apnea is the arrest of breathing during pharyngeal stage of deglutition.

4. *Entrance of Bolus into Esophagus*

As the other three paths are closed, the bolus has to pass only through the esophagus. This occurs by the combined effects of various factors:

i. Upward movement of larynx stretches the opening of esophagus
ii. Simultaneously, upper 3 to 4 cm of esophagus relaxes. This part of esophagus is formed by the cricopharyngeal muscle and it is called upper esophageal sphincter or pharyngoesophageal sphincter
iii. At the same time, peristaltic contractions start in the pharynx due to the contraction of pharyngeal muscles
iv. Elevation of larynx also lifts the glottis away from the food passage.

All the factors mentioned above act together so that, bolus moves easily into the esophagus. The whole process takes place within 1 to 2 seconds and this process is purely involuntary.

■ ESOPHAGEAL STAGE OR THIRD STAGE

Esophageal stage is also an involuntary stage. In this stage, food from esophagus enters the stomach. Esophagus forms the passage for movement of bolus from pharynx to the stomach. Movements of esophagus are specifically organized for this function and the movements are called peristaltic waves. Peristalsis means a wave of contraction, followed by the wave of relaxation of muscle fibers of GI tract, which travel in aboral direction (away from mouth). By this type of movement, the contents are propelled down along the GI tract.

When bolus reaches the esophagus, the peristaltic waves are initiated. Usually, two types of peristaltic contractions are produced in esophagus.

1. Primary peristaltic contractions
2. Secondary peristaltic contractions.

1. *Primary Peristaltic Contractions*

When bolus reaches the upper part of esophagus, the peristalsis starts. This is known as primary peristalsis.

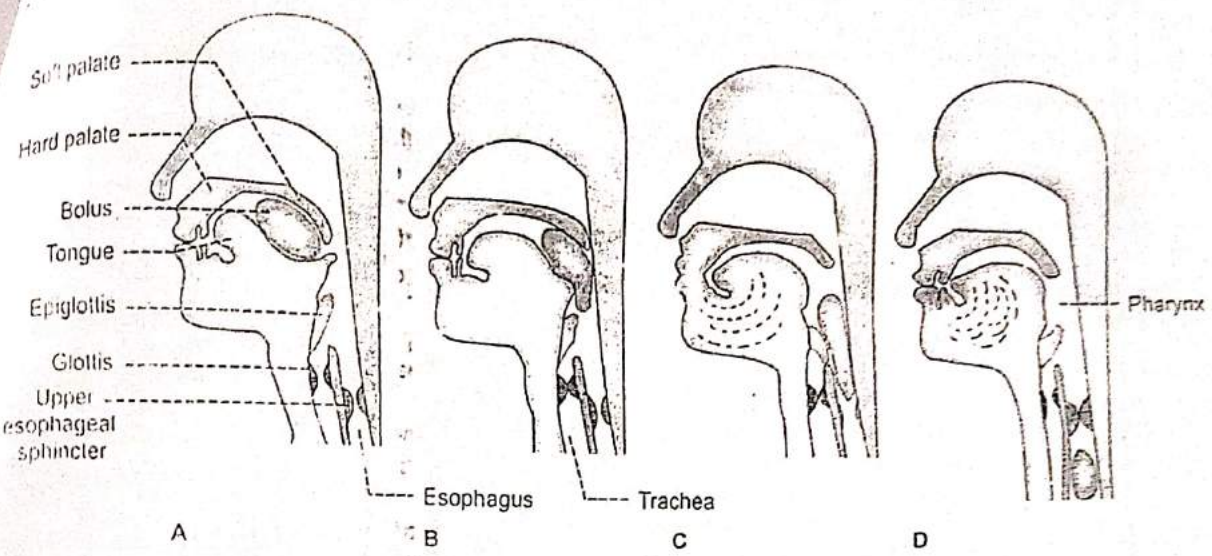

FIGURE 43.1: Stages of deglutition. A. Preparatory stage; B. Oral stage; C. Pharyngeal stage; D. Esophageal stage.

After origin, the peristaltic contractions pass down through the rest of the esophagus, propelling the bolus towards stomach.

Pressure developed during the primary peristaltic contractions is important to propel the bolus. Initially, the pressure becomes negative in the upper part of esophagus. This is due to the stretching of the closed esophagus by the elevation of larynx. But immediately, the pressure becomes positive and increases up to 10 to 15 cm of H_2O.

2. *Secondary Peristaltic Contractions*

If the primary peristaltic contractions are unable to propel the bolus into the stomach, the secondary peristaltic contractions appear and push the bolus into stomach.

Secondary peristaltic contractions are induced by the distention of upper esophagus by the bolus. After origin, these contractions pass down like the primary contractions, producing a positive pressure.

Role of Lower Esophageal Sphincter

Distal 2 to 5 cm of esophagus acts like a sphincter and it is called lower esophageal sphincter. It is constricted always. When bolus enters this part of the esophagus, this sphincter relaxes so that the contents enter the stomach. After the entry of bolus into the stomach, the sphincter constricts and closes the lower end of esophagus. The relaxation and constriction of sphincter occur in sequence with the arrival of peristaltic contractions of esophagus.

DEGLUTITION REFLEX

Though the beginning of swallowing is a voluntary act, later it becomes involuntary and is carried out by a reflex action called deglutition reflex. It occurs during the pharyngeal and esophageal stages.

Stimulus

When the bolus enters the oropharyngeal region, the receptors present in this region are stimulated.

Afferent Fibers

Afferent impulses from the **oropharyngeal receptors** pass via the glossopharyngeal nerve fibers to the deglutition center.

Center

Deglutition center is at the floor of the fourth ventricle in medulla oblongata of brain.

Efferent Fibers

Impulses from deglutition center travel through glossopharyngeal and vagus nerves (parasympathetic motor fibers) and reach soft palate, pharynx and esophagus. The glossopharyngeal nerve is concerned with pharyngeal stage of swallowing. The vagus nerve is concerned with esophageal stage.

Response

The reflex causes upward movement of soft palate, to close nasopharynx and upward movement of larynx,

to close respiratory passage so that bolus enters the esophagus. Now the peristalsis occurs in esophagus, pushing the bolus into stomach.

APPLIED PHYSIOLOGY

1. Dysphagia

Dysphagia means difficulty in swallowing.

Causes of dysphagia

i. Mechanical obstruction of esophagus due to tumor, strictures, diverticular hernia (out pouching of the wall), etc.
ii. Decreased movement of esophagus due to neurological disorders such as parkinsonism
iii. Muscular disorders leading to difficulty in swallowing during oral stage or esophageal stage.

2. Esophageal Achalasia or Achalasia Cardia

Esophageal achalasia or achalasia cardia is a neuromuscular disease, characterized by accumulation of food substances in the esophagus preventing normal swallowing. It is due to the failure of lower esophageal (cardiac) sphincter to relax during swallowing. The accumulated food substances cause dilatation of esophagus.

Features of esophageal achalasia

i. Dysphagia
ii. Chest pain
iii. Weight loss
iv. Cough.

3. Gastroesophageal Reflux Disease (GERD)

GERD is a disorder characterized by regurgitation of acidic gastric content through esophagus. The regurgitated gastric content flows into pharynx or mouth. Regurgitation is due to the weakness or incompetence (failure to constrict) of lower esophageal sphincter.

Features of GERD

i. Heart burn or pyrosis (painful burning sensation in chest due to regurgitation of acidic gastric content into esophagus)
ii. Esophagitis (inflammation of esophagus)
iii. Dysphagia
iv. Cough and change of voice
v. Esophageal ulcers or cancer (in chronic cases).

MOVEMENTS OF STOMACH

Activities of smooth muscles of stomach increase during gastric digestion (when stomach is filled with food) and when the stomach is empty.

Types of movements in stomach

1. Hunger contractions
2. Receptive relaxation
3. Peristalsis.

1. HUNGER CONTRACTIONS

Hunger contractions are the movements of empty stomach. These contractions are related to the sensations of hunger.

Hunger contractions are the peristaltic waves superimposed over the contractions of gastric smooth muscle as a whole. This type of peristaltic waves is different from the digestive peristaltic contractions. The digestive peristaltic contractions usually occur in body and pyloric parts of the stomach. But peristaltic contractions of empty stomach involve the entire stomach. Hunger contractions are of three types:

Type I Hunger Contractions

Type I hunger contractions are the first contractions to appear in the empty stomach, when the tone of the gastric muscles is low. Each contraction lasts for about 20 seconds. The interval between contractions is about 3 to 4 seconds. Tone of the muscles does not increase between contractions. Pressure produced by these contractions is about 5 cm of H_2O.

Type II Hunger Contractions

Type II hunger contractions appear when the tone of stomach is stronger. Tone increases in stomach if food intake is postponed, even after the appearance of the type I contractions. Each of the type II contractions lasts for 20 seconds like type I contractions. But the pause between the contractions is decreased. Pressure produced by these contractions is 10 to 15 cm of H_2O.

Type III Hunger Contractions

Type III hunger contractions are like incomplete tetanus. These contractions appear when the hunger becomes severe and the tone increases to a great extent. Type III hunger contractions are rare in man as the food is taken usually before the appearance of these contractions. These contractions last for 1 to 5 minutes. The pressure produced by these contractions increases to 10 to 20 cm of H_2O.

When the stomach is empty, the type I contractions occur first, followed by type II contractions. If food intake is still postponed, then type III contractions appear and as soon as food is consumed, hunger contractions disappear.

2. RECEPTIVE RELAXATION

Receptive relaxation is the relaxation of the upper portion of the stomach when bolus enters the stomach from esophagus. It involves the fundus and upper part of the body of stomach. Its significance is to accommodate the food easily, without much increase in pressure inside the stomach. This process is called accommodation of stomach.

3. PERISTALSIS

When food enters the stomach, the peristaltic contraction or peristaltic wave appears with a frequency of 3 per minute. It starts from the lower part of the body of stomach, passes through the pylorus till the pyloric sphincter.

Initially, the contraction appears as a slight indentation on the greater and lesser curvatures and travels towards pylorus. The contraction becomes deeper while traveling. Finally, it ends with the constriction of pyloric sphincter. Some of the waves disappear before reaching the sphincter. Each peristaltic wave takes about one minute to travel from the point of origin to the point of ending.

This type of peristaltic contraction is called digestive peristalsis because it is responsible for the grinding of food particles and mixing them with gastric juice for digestive activities.

FILLING AND EMPTYING OF STOMACH

FILLING OF STOMACH

While taking food, it arranges itself in the stomach in different layers. The first eaten food is placed against the greater curvature in the fundus and body of the stomach. The successive layers of food particles lie nearer, the lesser curvature, until the last portion of food eaten lies near the upper end of lesser curvature, adjacent to cardiac sphincter.

The liquid remains near the lesser curvature and flows towards the pyloric end of the stomach along a V-shaped groove. This groove is formed by the smooth muscle and it is called magenstrasse. But, if a large quantity of fluid is taken, it flows around the entire food mass and is distributed over the interior part of stomach, between wall of the stomach and food mass.

EMPTYING OF STOMACH

Gastric emptying is the process by which the chyme from stomach is emptied into intestine. Food that is swallowed enters the stomach and remains there for about 3 hours. During this period, digestion takes place. Partly digested food in stomach becomes the chyme.

Chyme

Chyme is the semisolid mass of partially digested food that is formed in the stomach. It is acidic in nature. Acid chyme is emptied from stomach into the intestine slowly, with the help of peristaltic contractions. It takes about 3 to 4 hours for emptying of the chyme. This slow emptying is necessary to facilitate the final digestion and maximum (about 80%) absorption of the digested food materials from small intestine. Gastric emptying occurs due to the peristaltic waves in the body and pyloric part of the stomach and simultaneous relaxation of pyloric sphincter.

Gastric emptying is influenced by various factors of the gastric content and food.

Factors Affecting Gastric Emptying

1. *Volume of gastric content*

For any type of meal, gastric emptying is directly proportional to the volume. If the content of stomach is more, a large amount is emptied into the intestine rapidly.

2. *Consistency of gastric content*

Emptying of the stomach depends upon consistency (degree of density) of the contents. Liquids, particularly the inert liquids like water leave the stomach rapidly. Solids leave the stomach only after being converted into fluid or semifluid. Undigested solid particles are not easily emptied.

3. *Chemical composition*

Chemical composition of the food also plays an important role in the emptying of the stomach. Carbohydrates are emptied faster than the proteins. Proteins are emptied faster than the fats. Thus, the fats are emptied very slowly.

4. *pH of the gastric content*

Gastric emptying is directly proportional to pH of the chyme.

5. *Osmolar concentration of gastric content*

Gastric content which is isotonic to blood, leaves the stomach rapidly than the hypotonic or hypertonic content.

REGULATION OF GASTRIC EMPTYING

Gastric emptying is regulated by nervous and hormonal factors.

Center for Psychic-stimuli-induced Vomiting

Center for vomiting due to psychic stimuli such as nauseating odor, sight or noise is in cerebral cortex.

MOVEMENTS OF SMALL INTESTINE

Movements of small intestine are essential for mixing the chyme with digestive juices, propulsion of food and absorption.

Types of Movements of Small Intestine

Movements of small intestine are of four types:

1. Mixing movements:
   i. Segmentation movements
   ii. Pendular movements.
2. Propulsive movements:
   i. Peristaltic movements
   ii. Peristaltic rush.
3. Peristalsis in fasting – migrating motor complex
4. Movements of villi.

1. MIXING MOVEMENTS

Mixing movements of small intestine are responsible for proper mixing of chyme with digestive juices such as pancreatic juice, bile and intestinal juice. The mixing movements of small intestine are segmentation contractions and pendular movements.

i. Segmentation Contractions

Segmentation contractions are the common type of movements of small intestine, which occur regularly or irregularly, but in a rhythmic fashion. So, these movements are also called rhythmic segmentation contractions.

The contractions occur at regularly spaced intervals along a section of intestine. The segment of the intestine involved in each contraction is about 1 to 5 cm long. The segments of intestine in between the contracted segments are relaxed. The length of the relaxed segments is same as that of the contracted segments. These alternate segments of contraction and relaxation give appearance of rings, resembling the chain of sausages.

After sometime, the contracted segments are relaxed and the relaxed segments are contracted (Fig. 43.2). Therefore, the segmentation contractions chop the chyme many times. This helps in mixing of chyme with digestive juices.

ii. Pendular Movement

Pendular movement is the sweeping movement of small intestine, resembling the movements of pendulum of clock. Small portions of intestine (loops) sweep forward and backward or upward and downward. It is a type of mixing movement, noticed only by close observation.

It helps in mixing of chyme with digestive juices.

2. PROPULSIVE MOVEMENTS

Propulsive movements are the movements of small intestine which push the chyme in the aboral direction through intestine. The propulsive movements are peristaltic movements and peristaltic rush.

i. Peristaltic Movements

Peristalsis is defined as the wave of contraction followed by wave of relaxation of muscle fibers. In GI tract, it always travels in aboral direction. Stimulation of smooth muscles of intestine initiates the peristalsis. It travels from point of stimulation in both directions. But under normal conditions, the progress of contraction in an oral direction is inhibited quickly and the contractions disappear. Only the contraction that travels in an aboral direction persists.

Starling's law of intestine

Depending upon the direction of the peristalsis, 'Law of intestine' was put forth by Starling.

According to the law of intestine, the response of the intestine for a local stimulus consists of a contraction

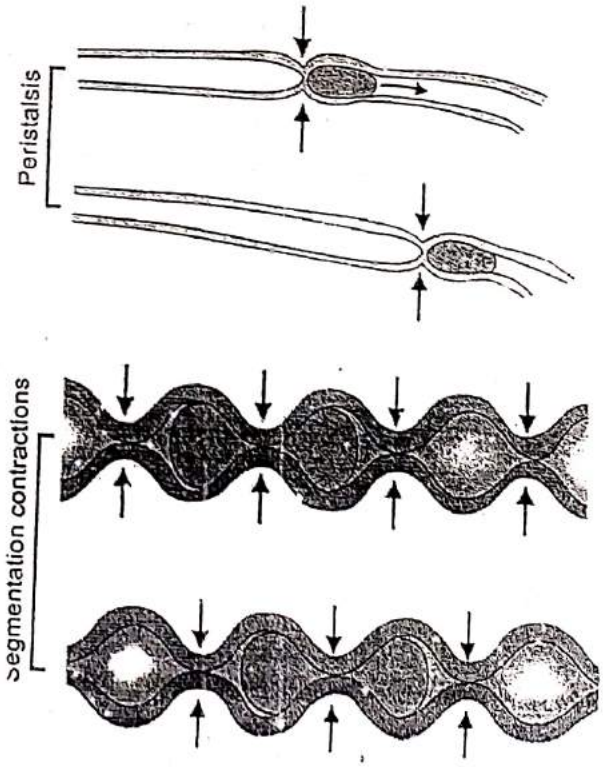

FIGURE 43.2: Movements of small intestine

of smooth muscle above and relaxation below the stimulated area.

Peristaltic contractions start at any part of the intestine and travel towards anal end, at a velocity of 1 to 2 cm/sec. The contractions are always weak and usually disappear after traveling for few centimeter. Because of this, the average movement of chyme through small intestine is very slow and the average velocity of movement of the chyme is less than 1 cm/sec. So, the chyme requires several hours to travel from duodenum to the end of small intestine.

Peristaltic waves in small intestine increase to a great extent immediately after a meal. This is because of **gastroenteric reflex**, which is initiated by the distention of stomach. Impulses for this reflex are transmitted from stomach along the wall of the intestine via myenteric plexus.

ii. Peristaltic Rush

Sometimes, the small intestine shows a powerful peristaltic contraction. It is caused by excessive irritation of intestinal mucosa or extreme distention of the intestine. This type of powerful contraction begins in duodenum and passes through entire length of small intestine and reaches the ileocecal valve within few minutes. This is called peristaltic rush or rush waves.

Peristaltic rush sweeps the contents of intestine into the colon. Thus, it relieves the small intestine off either irritants or excessive distention.

3. PERISTALSIS IN FASTING – MIGRATING MOTOR COMPLEX

Migrating motor complex is a type of peristaltic contraction, which occurs in stomach and small intestine during the periods of fasting for several hours. It is also called **migrating myoelectric complex**. It is different from the regular peristalsis because, a large portion of stomach or intestine is involved in the contraction. The contraction extends to about 20 to 30 cm of stomach or intestine. This type of movement occurs once in every 1½ to 2 hours.

It starts as a moderately active peristalsis in the body of stomach and runs through the entire length of small intestine. It travels at a velocity of 6 to 12 cm/min. Thus, it takes about 10 minutes to reach the colon after taking origin from the stomach.

Significance of Peristalsis in Fasting

Migrating motor complex sweeps the excess digestive secretions into the colon and prevents the accumulation of the secretions in stomach and intestine. It also sweeps the residual indigested materials into colon.

4. MOVEMENTS OF VILLI

Intestinal villi also show movements simultaneously along with intestinal movements. It is because of the extension of smooth muscle fibers of the intestinal wall into the villi.

Movements of villi are shortening and elongation, which occur alternatively and help in emptying lymph from the central lacteal into the lymphatic system. The surface area of villi is increased during elongation. This helps absorption of digested food particles from the lumen of intestine.

Movements of villi are caused by local nervous reflexes, which are initiated by the presence of chyme in small intestine. Hormone secreted from the small intestinal mucosa called **villikinin** is also believed to play an important role in increasing the movements of villi.

MOVEMENTS OF LARGE INTESTINE

Usually, the large intestine shows sluggish movements. Still, these movements are important for mixing, propulsive and absorptive functions.

Types of Movements of Large Intestine

Movements of large intestine are of two types:

1. Mixing movements: Segmentation contractions
2. Propulsive movements: Mass peristalsis.

1. MIXING MOVEMENTS – SEGMENTATION CONTRACTIONS

Large circular constrictions, which appear in the colon, are called mixing segmentation contractions. These contractions occur at regular distance in colon. Length of the portion of colon involved in each contraction is nearly about 2.5 cm.

2. PROPULSIVE MOVEMENTS – MASS PERISTALSIS

Mass peristalsis or mass movement propels the feces from colon towards anus. Usually, this movement occurs only a few times every day. Duration of mass movement is about 10 minutes in the morning before or after breakfast. This is because of the neurogenic factors like **gastrocolic reflex** (see below) and parasympathetic stimulation.

DEFECATION

Voiding of feces is known as defecation. Feces is formed in the large intestine and stored in sigmoid colon. By the influence of an appropriate stimulus, it is expelled out

through the anus. This is prevented by tonic constriction of anal sphincters, in the absence of the stimulus.

DEFECATION REFLEX

Mass movement drives the feces into sigmoid or pelvic colon. In the sigmoid colon, the feces is stored. The desire for defecation occurs when some feces enters rectum due to the mass movement. Usually, the desire for defecation is elicited by an increase in the intrarectal pressure to about 20 to 25 cm H_2O.

Usual stimulus for defecation is intake of liquid like coffee or tea or water. But it differs from person to person.

Act of Defecation

Act of defecation is preceded by voluntary efforts like assuming an appropriate posture, voluntary relaxation of external sphincter and the compression of abdominal contents by voluntary contraction of abdominal muscles.

Usually, the rectum is empty. During the development of mass movement, the feces is pushed into rectum and the defecation reflex is initiated. The process of defecation involves the contraction of rectum and relaxation of internal and external anal sphincters.

Internal anal sphincter is made up of smooth muscle and it is innervated by parasympathetic nerve fibers via pelvic nerve. **External anal sphincter** is composed of skeletal muscle and it is controlled by somatic nerve fibers, which pass through **pudendal nerve.** Pudendal nerve always keeps the external sphincter constricted and the sphincter can relax only when the pudendal nerve is inhibited.

Gastrocolic Reflex

Gastrocolic reflex is the contraction of rectum, followed by the desire for defecation caused by distention of stomach by food. It is mediated by intrinsic nerve fibers of GI tract.

This reflex causes only a weak contraction of rectum. But, it initiates defecation reflex.

PATHWAY FOR DEFECATION REFLEX

When rectum is distended due to the entry of feces by mass movement, sensory nerve endings are stimulated. Impulses from the nerve endings are transmitted via afferent fibers of pelvic nerve to the defecation center, situated in sacral segments (center) of spinal cord.

The center in turn, sends motor impulses to the descending colon, sigmoid colon and rectum via efferent nerve fibers of pelvic nerve. Motor impulses cause strong contraction of descending colon, sigmoid colon and rectum and relaxation of internal sphincter.

Simultaneously, voluntary relaxation of external sphincter occurs. It is due to the inhibition of pudendal nerve, by impulses arising from cerebral cortex (Fig. 43.3).

CONSTIPATION

Constipation is the failure of voiding of feces. Refer Chapter 42 for details.

EVACUATION OF GASES FROM GASTROINTESTINAL TRACT

Normally, gas accumulates in the GI tract either because of entrance of outside air or production of gases in the body. Accordingly, the gases accumulated in GI tract are classified into two groups:

1. Exogenous gases
2. Endogenous gases.

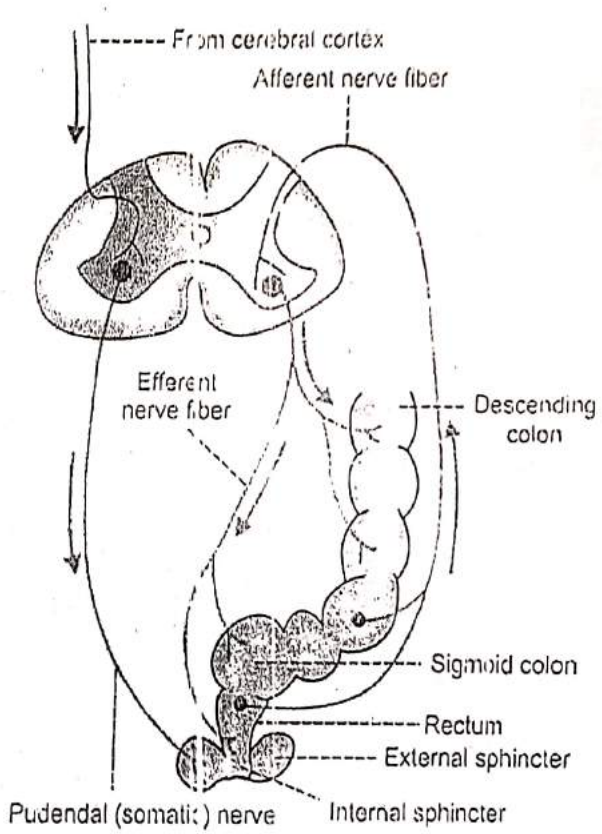

FIGURE 43.3: Defecation reflex. Afferent and efferent fibers of the reflex pass through pelvic (parasympathetic) nerve. Voluntary control of defecation is by pudendal (somatic) nerve. Defecation center is in the sacral segments of spinal cord

(Nataraj Sir)

Physiological Anatomy of Respiratory Tract

Chapter 118

- INTRODUCTION
  - TYPES OF RESPIRATION
  - PHASES OF RESPIRATION
- FUNCTIONAL ANATOMY OF RESPIRATORY TRACT
- RESPIRATORY UNIT
  - STRUCTURE OF RESPIRATORY UNIT
  - RESPIRATORY MEMBRANE
- NON-RESPIRATORY FUNCTIONS OF RESPIRATORY TRACT
  - OLFACTION
  - VOCALIZATION
  - PREVENTION OF DUST PARTICLES
  - DEFENSE MECHANISM
  - MAINTENANCE OF WATER BALANCE
  - REGULATION OF BODY TEMPERATURE
  - REGULATION OF ACID-BASE BALANCE
  - ANTICOAGULANT FUNCTION
  - SECRETION OF ANGIOTENSIN-CONVERTING ENZYME
  - SYNTHESIS OF HORMONAL SUBSTANCES
- RESPIRATORY PROTECTIVE REFLEXES
  - COUGH REFLEX
  - SNEEZING REFLEX
  - SWALLOWING REFLEX

INTRODUCTION

Respiration is the process by which oxygen is taken in and carbon dioxide is given out. The first breath takes place only after birth. Fetal lungs are non-functional. So, during intrauterine life the exchange of gases between fetal blood and mother's blood occurs through placenta.

After the first breath, the respiratory process continues throughout the life. Permanent stoppage of respiration occurs only at death.

Normal Respiratory Rate at Different Age

Newborn	: 30 to 60/minute
Early childhood	: 20 to 40/minute
Late childhood	: 15 to 25/minute
Adult	: 12 to 16/minute.

TYPES OF RESPIRATION

Respiration is classified into two types:

1. External respiration that involves exchange of respiratory gases, i.e. oxygen and carbon dioxide between lungs and blood
2. Internal respiration, which involves exchange of gases between blood and tissues.

PHASES OF RESPIRATION

Respiration occurs in two phases:

1. Inspiration during which air enters the lungs from atmosphere

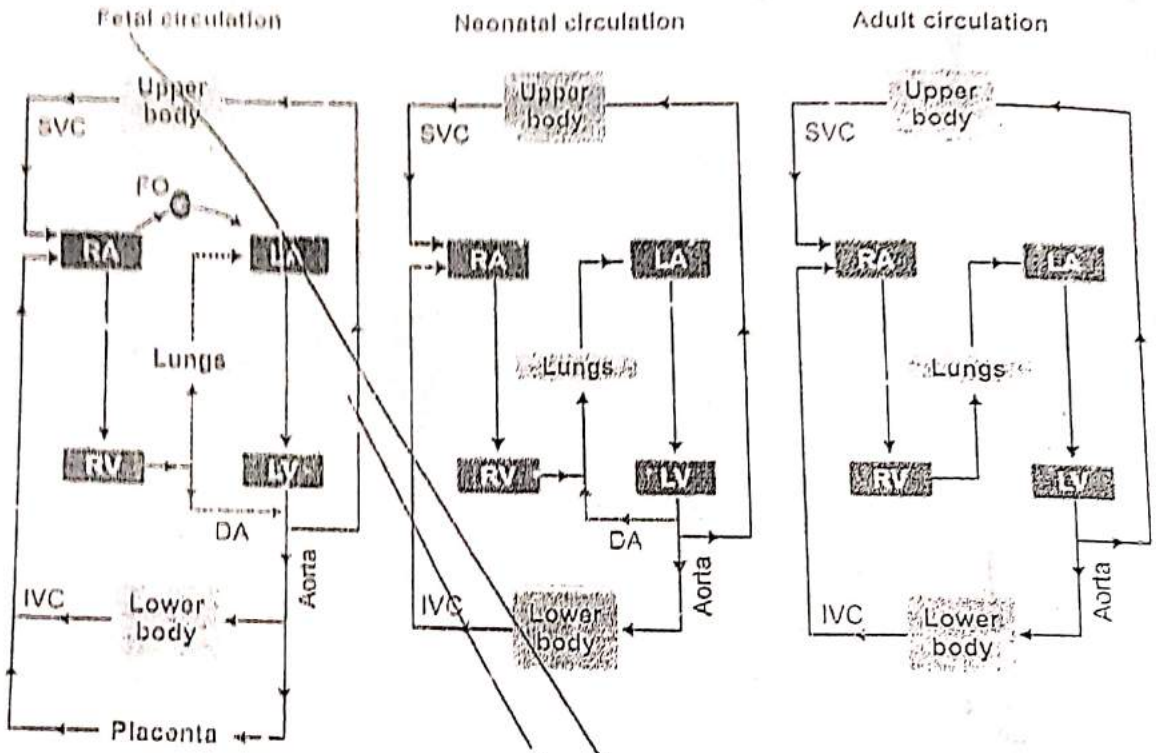

FIGURE 114.2: Fetal, neonatal and adult circulation. RA = Right atrium, LA = Left atrium, RV = Right ventricle, LV = Left ventricle, FO = Foramen ovale, DA = Ductus arteriosus, SVC = Superior vena cava, IVC = Inferior vena cava, Dashed blue line (Fetal circulation) indicates flow of very less quantity of blood.

left atrium. It causes increase in the left atrial pressure. Simultaneously, due to stoppage of blood from placenta, pressure in inferior vena cava is decreased. It leads to fall in right atrial pressure. Thus, the pressure in right atrium is less and the pressure in left atrium is already high. This causes the closure of foramen ovale. Within few days after birth, the foramen ovale closes completely and fuses with the atrial wall.

4. REVERSAL OF BLOOD FLOW IN DUCTUS ARTERIOSUS

In fetus, since pulmonary arterial pressure is very high, the blood passes from pulmonary artery into aorta via ductus arteriosus. However, in neonatal life, since the systemic arterial pressure is more than pulmonary arterial pressure, the blood passes in opposite direction in ductus arteriosus, i.e. from systemic aorta into pulmonary aorta (Fig. 114.2). The reversed flow in ductus arteriosus is heard as continuous murmur in infants.

5. CLOSURE OF DUCTUS VENOSUS

Due to the contraction of smooth muscle near junction between umbilical vein and ductus venosus, the constriction and closure of ductus venosus occurs. Later, the ductus venosus becomes fibrous band.

6. CLOSURE OF DUCTUS ARTERIOSUS

Ductus arteriosus starts closing due to narrowing. It closes completely after 2 days and the adult type of circulation starts. In some rare cases, the ductus arteriosus does not close. It remains intact producing a continuous murmur. This condition with intact ductus arteriosus is known as **patent ductus arteriosus** (Refer to Chapter 106).

2. **Expiration** during which air leaves the lungs.

During normal breathing, inspiration is an active process and expiration is a passive process.

FUNCTIONAL ANATOMY OF RESPIRATORY TRACT

Respiratory tract is the anatomical structure through which air moves in and out. It includes nose, pharynx, larynx, trachea, bronchi and lungs (Fig. 118.1).

Pleura

Each lung is enclosed by a bilayered serous membrane called pleura or **pleural sac**. Pleura has two layers namely inner **visceral** and outer **parietal** layers. Visceral layer is attached firmly to the surface of the lungs. At hilum, it is continuous with parietal layer, which is attached to the wall of thoracic cavity.

Intrapleural Space or Pleural Cavity

Intrapleural space or pleural cavity is the narrow space in between the two layers of pleura.

Intrapleural Fluid

Intrapleural space contains a thin film of serous fluid called intrapleural fluid, which is secreted by the visceral layer of the pleura.

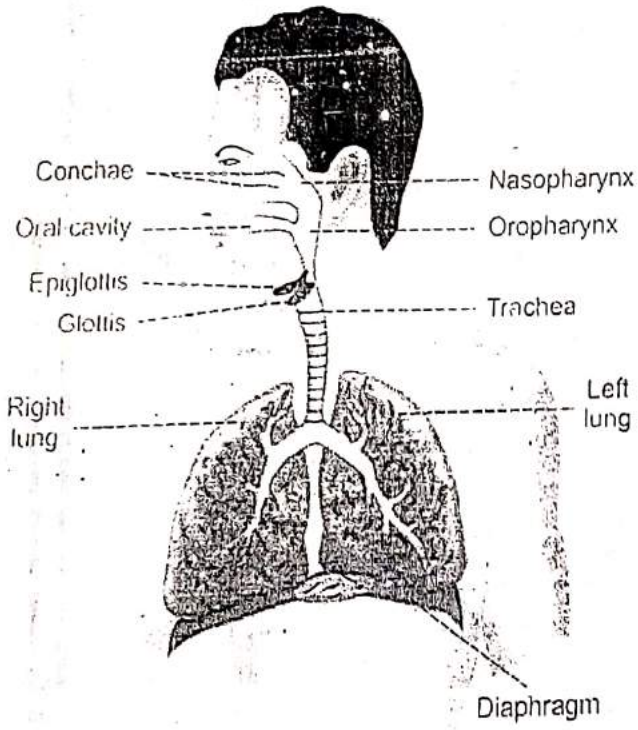

FIGURE 118.1: Respiratory tract

Functions of intrapleural fluid

1. It functions as the **lubricant** to prevent friction between two layers of pleura
2. It is involved in creating the negative pressure called **intrapleural pressure** within intrapleural space.

Pleural Cavity in Abnormal Conditions

In some pathological conditions, the pleural cavity expands with accumulation of air (**pneumothorax**), water (**hydrothorax**), blood (**hemothorax**) or pus (**pyothorax**).

Tracheobronchial Tree

Trachea and bronchi are together called tracheobronchial tree. It forms a part of air passage.

Components of tracheobronchial tree

1. **Trachea** bifurcates into two main or **primary bronchi** called right and left bronchi
2. Each primary bronchus enters the lungs and divides into **secondary bronchi**
3. Secondary bronchi divide into **tertiary bronchi**. In right lung, there are 10 tertiary bronchi and in left lung, there are eight tertiary bronchi
4. Tertiary bronchi divide several times with reduction in length and diameter into many generations of **bronchioles**
5. When the diameter of bronchiole becomes 1 mm or less, it is called **terminal bronchiole**
6. Terminal bronchiole continues or divides into **respiratory bronchioles**, which have a diameter of 0.5 mm.

Upper and Lower Respiratory Tracts

Generally, respiratory tract is divided into two parts:

1. Upper respiratory tract that includes all the structures from nose up to vocal cords; vocal cords are the folds of mucous membrane within larynx that vibrates to produce the voice
2. Lower respiratory tract, which includes trachea, bronchi and lungs.

RESPIRATORY UNIT

Parenchyma of lungs is formed by respiratory unit that forms the terminal portion of respiratory tract. Respiratory unit is defined as the structural and functional unit of lung. Exchange of gases occurs only in this part of the respiratory tract.

STRUCTURE OF RESPIRATORY UNIT

Respiratory unit starts from the respiratory bronchioles (Fig. 118.2). Each respiratory bronchiole divides into

alveolar ducts. Each alveolar duct enters an enlarged structure called the **alveolar sac**. Space inside the alveolar sac is called **antrum**. Alveolar sac consists of a cluster of alveoli. Few alveoli are present in the wall of alveolar duct also.

Thus, respiratory unit includes:

1. Respiratory bronchioles
2. Alveolar ducts
3. Alveolar sacs
4. Antrum
5. Alveoli.

Each alveolus is like a pouch with the diameter of about 0.2 to 0.5 mm. It is lined by epithelial cells.

Alveolar Cells or Pneumocytes

Alveolar epithelium consists of alveolar cells or pneumocytes, which are of two types namely type I alveolar cells and type II alveolar cells.

Type I alveolar cells

Type I alveolar cells are the squamous epithelial cells forming about 95% of the total number of cells. These cells form the site of gaseous exchange between the alveolus and blood.

Type II alveolar cells

Type II alveolar cells are cuboidal in nature and form about 5% of alveolar cells. These cells are also called **granular pneumocytes**. Type II alveolar cells secrete **alveolar fluid** and **surfactant**.

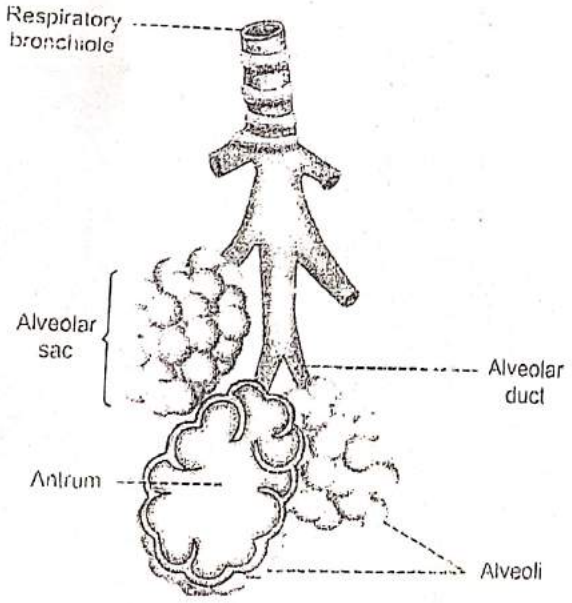

FIGURE 118.2: Respiratory unit

RESPIRATORY MEMBRANE

Respiratory membrane is the membranous structure through which the exchange of gases occurs.

Respiratory membrane separates air in the alveoli from the blood in capillary. It is formed by the alveolar membrane and capillary membrane. Respiratory membrane has a surface area of 70 square meter and thickness of 0.5 micron. Structure of respiratory membrane is explained in Chapter 124 (See Fig. 124.1).

NON-RESPIRATORY FUNCTIONS OF RESPIRATORY TRACT

Besides primary function of gaseous exchange, the respiratory tract is involved in several non-respiratory functions of the body. Particularly, the lungs function as a defense barrier and metabolic organs, which synthesize some important compounds. Non-respiratory functions of the respiratory tract are:

1. OLFACTION

Olfactory receptors present in the mucous membrane of nostril are responsible for olfactory sensation.

2. VOCALIZATION

Along with other structures, larynx forms the speech **apparatus**. However, larynx alone plays major role in the process of vocalization. Therefore, it is called **sound box**.

3. PREVENTION OF DUST PARTICLES

Dust particles, which enter the nostrils from air, are prevented from reaching the lungs by **filtration action** of the hairs in nasal mucous membrane. Small particles, which escape the hairs, are held by the **mucus** secreted by nasal mucous membrane. Those dust particles, which escape nasal hairs and nasal mucous membrane, are removed by the phagocytic action of macrophages in the alveoli.

Particles, which escape the protective mechanisms in nose and alveoli are thrown out by **cough reflex** and **sneezing reflex** (Chapter 126).

4. DEFENSE MECHANISM

Lungs play important role in the **immunological** defense system of the body. Defense functions of the lungs are performed by their own defenses and by the presence of various types of cells in mucous membrane lining the alveoli of lungs. These cells are leukocytes, macrophages, mast cells, natural killer cells and dendritic cells.

i. Lung's Own Defenses

Epithelial cells lining the air passage secrete some innate immune factors called **defensins** and **cathelicidins.** These substances are the antimicrobial peptides, which play an important role in lung's natural defenses. Refer Chapter 17 for detail.

ii. Defense through Leukocytes

Leukocytes, particularly the neutrophils and lymphocytes present in the alveoli of lungs provide defense mechanism against bacteria and virus. **Neutrophils** kill the bacteria by phagocytosis. **Lymphocytes** develop immunity against bacteria.

iii. Defense through Macrophages

Macrophages engulf the dust particles and the pathogens, which enter the alveoli and thereby act as **scavengers** in lungs. Macrophages are also involved in the development of immunity by functioning as **antigen presenting cells.** When foreign organisms invade the body, the macrophages and other antigen presenting cells kill them. Later, the antigen from the organisms is digested into polypeptides. Polypeptide products are presented to T lymphocytes and B lymphocytes by the macrophages.

Macrophages secrete interleukins, tumor necrosis factors (TNF) and chemokines (Chapter 24). Interleukins and TNF activate the general immune system of the body (Chapter 17). Chemokines attract the white blood cells towards the site of any inflammation.

iv. Defense through Mast Cell

Mast cell is a large cell resembling the basophil. Mast cell produces the **hypersensitivity reactions** like allergy and anaphylaxis (Chapter 17). It secretes heparin, histamine, serotonin and hydrolytic enzymes.

v. Defense through Natural Killer Cell

Natural killer (NK) cell is a large granular cell, considered as the third type of lymphocyte. Usually NK cell is present in lungs and other lymphoid organs. Its granules contain hydrolytic enzymes, which destroy the microorganisms.

NK cell is said to be the first line of defense in specific immunity particularly **against viruses.**

It destroys the viruses and viral infected or damaged cells, which may form the tumors. It also destroys the malignant cells and prevents development of cancerous tumors. NK cells secrete interferons and the tumor necrosis factors (Chapter 17).

vi. Defense through Dendritic Cells

Dendritic cells in the lungs play important role in immunity. Along with macrophages, these cells function as antigen presenting cells.

5. MAINTENANCE OF WATER BALANCE

Respiratory tract plays a role in water loss mechanism. During expiration, water evaporates through the expired air and some amount of body water is lost by this process.

6. REGULATION OF BODY TEMPERATURE

During expiration, along with water, heat is also lost from the body. Thus, respiratory tract plays a role in heat loss mechanism.

7. REGULATION OF ACID-BASE BALANCE

Lungs play a role in maintenance of acid-base balance of the body by regulating the carbon dioxide content in blood. Carbon dioxide is produced during various metabolic reactions in the tissues of the body. When it enters the blood, carbon dioxide combines with water to form carbonic acid. Since carbonic acid is unstable, it splits into hydrogen and bicarbonate ions.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

Entire reaction is reversed in lungs when carbon dioxide is removed from blood into the alveoli of lungs (Chapter 125).

$$H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow CO_2 + H_2O$$

As carbon dioxide is a volatile gas, it is practically blown out by ventilation.

When metabolic activities are accelerated, more amount of carbon dioxide is produced in the tissues. Concentration of hydrogen ion is also increased. This leads to reduction in pH. Increased hydrogen ion concentration causes increased pulmonary ventilation (hyperventilation) by acting through various mechanisms like chemoreceptors in aortic and carotid bodies and in medulla of the brain (Chapter 126). Due to hyperventilation, excess of carbon dioxide is removed from body fluids and the pH is brought back to normal.

8. ANTICOAGULANT FUNCTION

Mast cells in lungs secrete **heparin.** Heparin is an anticoagulant and it prevents the intravascular clotting.

9. SECRETION OF ANGIOTENSIN-CONVERTING ENZYME

Endothelial cells of the pulmonary capillaries secrete the angiotensin-converting enzyme (ACE). It converts

the angiotensin I into active angiotensin II, which plays an important role in the regulation of ECF volume and blood pressure (Chapter 50).

10. SYNTHESIS OF HORMONAL SUBSTANCES

Lung tissues are also known to synthesize the hormonal substances, prostaglandins, acetylcholine and serotonin, which have many physiological actions in the body including regulation of blood pressure (Chapter 73).

RESPIRATORY PROTECTIVE REFLEXES

Respiratory protective reflexes are the reflexes that protect lungs and air passage from foreign particles. Respiratory process is modified by these reflexes in order to eliminate the foreign particles or to prevent the entry of these particles into the respiratory tract. Following are the respiratory protective reflexes:

COUGH REFLEX

Cough is a modified respiratory process characterized by forced expiration. It is a protective reflex and it is caused by irritation of respiratory tract and some other areas such as external auditory canal (see below).

Causes

Cough is produced mainly by irritant agents. It is also produced by several disorders such as cardiac disorders (congestive heart failure), pulmonary disorders (chronic obstructive pulmonary disease – COPD) and tumor in thorax, which may exert pressure on larynx, trachea, bronchi or lungs.

Mechanism

Cough begins with deep inspiration followed by forced expiration with closed glottis. This increases the intrapleural pressure above 100 mm Hg. Then, glottis opens suddenly with explosive outflow of air at a high velocity. Velocity of the airflow may reach 960 km/hour. It causes expulsion of irritant substances out of the respiratory tract.

Reflex Pathway

Receptors that initiate the cough are situated in several locations such as nose, paranasal sinuses, larynx, pharynx, trachea, bronchi, pleura, diaphragm, pericardium, stomach, external auditory canal and tympanic membrane.

Afferent nerve fibers pass via vagus, trigeminal, glossopharyngeal and phrenic nerves. The center for cough reflex is in the medulla oblongata.

Efferent nerve fibers arising from the medullary center pass through the vagus, phrenic and spinal motor nerves. These nerve fibers activate the primary and accessory respiratory muscles.

SNEEZING REFLEX

Sneezing is also a modified respiratory process characterized by forced expiration. It is a protective reflex caused by irritation of nasal mucous membrane.

Causes

Irritation of the nasal mucous membrane occurs because of dust particles, debris, mechanical obstruction of the airway and excess fluid accumulation in the nasal passages.

Mechanism

Sneezing starts with deep inspiration, followed by forceful expiratory effort with opened glottis resulting in expulsion of irritant agents out of respiratory tract.

Reflex Pathway

Sneezing is initiated by the irritation of nasal mucous membrane, the olfactory receptors and trigeminal nerve endings present in the nasal mucosa.

Afferent nerve fibers pass through the trigeminal and olfactory nerves. Sneezing center is in medulla oblongata. It is located diffusely in spinal nucleus of trigeminal nerve, nucleus solitarius and the reticular formation of medulla.

Efferent nerve fibers from the medullary center pass via trigeminal, facial, glossopharyngeal, vagus and intercostal nerves. These nerve fibers activate the pharyngeal, tracheal and respiratory muscles.

SWALLOWING (DEGLUTITION) REFLEX

Swallowing reflex is a respiratory protective reflex that prevents entrance of food particles into the air passage during swallowing.

While swallowing of the food, the respiration is arrested for a while. Temporary arrest of respiration is called apnea. Arrest of breathing during swallowing is called swallowing apnea or deglutition apnea. It takes place during pharyngeal stage, i.e. second stage of deglutition and prevents entry of food particles into the respiratory tract. Refer Chapter 43 for details.

Chapter 121

Pulmonary Function Tests

- INTRODUCTION
- LUNG VOLUMES
- LUNG CAPACITIES
- MEASUREMENT OF LUNG VOLUMES AND CAPACITIES
- MEASUREMENT OF FUNCTIONAL RESIDUAL CAPACITY AND RESIDUAL VOLUME
- VITAL CAPACITY
- FORCED EXPIRATORY VOLUME OR TIMED VITAL CAPACITY
- RESPIRATORY MINUTE VOLUME
- MAXIMUM BREATHING CAPACITY OR MAXIMUM VENTILATION VOLUME
- PEAK EXPIRATORY FLOW RATE
- RESTRICTIVE AND OBSTRUCTIVE RESPIRATORY DISEASES

INTRODUCTION

Pulmonary function tests or lung function tests are useful in assessing the functional status of the respiratory system both in physiological and pathological conditions. Lung function tests are based on the measurement of volume of air breathed in and out in quiet breathing and forced breathing. These tests are carried out mostly by using spirometer.

TYPES OF LUNG FUNCTION TESTS

Lung function tests are of two types:

1. Static lung function tests
2. Dynamic lung function tests.

Static Lung Function Tests

Static lung function tests are based on volume of air that flows into or out of lungs. These tests do not depend upon the rate at which air flows.

Static lung function tests include static lung volumes and static lung capacities.

Dynamic Lung Function Tests

Dynamic lung function tests are based on time, i.e. the rate at which air flows into or out of lungs. These tests include forced vital capacity, forced expiratory volume, maximum ventilation volume and peak expiratory flow.

Dynamic lung function tests are useful in determining the severity of obstructive and restrictive lung diseases.

LUNG VOLUMES

Static lung volumes are the volumes of air breathed by an individual. Each of these volumes represents the volume of air present in the lung under a specified static condition (specific position of thorax).

Static lung volumes are of four types:

1. Tidal volume
2. Inspiratory reserve volume
3. Expiratory reserve volume
4. Residual volume.

TIDAL VOLUME

Tidal volume (TV) is the volume of air breathed in and out of lungs in a single normal quiet respiration. Tidal volume signifies the normal depth of breathing.

Normal Value

500 mL (0.5 L).

INSPIRATORY RESERVE VOLUME

Inspiratory reserve volume (IRV) is an additional volume of air that can be inspired forcefully after the end of normal inspiration.

Normal Value

3,300 mL (3.3 L).

EXPIRATORY RESERVE VOLUME

Expiratory reserve volume (EVR) is the additional volume of air that can be expired out forcefully, after normal expiration.

Normal Value

1,000 mL (1 L).

RESIDUAL VOLUME

Residual volume (RV) is the volume of air remaining in lungs even after forced expiration. Normally, lungs cannot be emptied completely even by forceful expiration. Some quantity of air always remains in the lungs even after the forced expiration.

Residual volume is significant because of two reasons:

1. It helps to aerate the blood in between breathing and during expiration
2. It maintains the contour of the lungs.

Normal Value

1,200 mL (1.2 L)

LUNG CAPACITIES

Static lung capacities are the combination of two or more lung volumes.

Static lung capacities are of four types:

1. Inspiratory capacity
2. Vital capacity
3. Functional residual capacity
4. Total lung capacity.

INSPIRATORY CAPACITY TV + IRV

Inspiratory capacity (IC) is the maximum volume of air that is inspired after normal expiration (end expiratory position). It includes tidal volume and inspiratory reserve volume (Fig. 121.1).

IC = TV + IRV
= 500 + 3,300 = 3,800 mL

VITAL CAPACITY (VC) IRV + TV + ERV

Vital capacity (VC) is the maximum volume of air that can be expelled out forcefully after a deep (maximal) inspiration. VC includes inspiratory reserve volume, tidal volume and expiratory reserve volume.

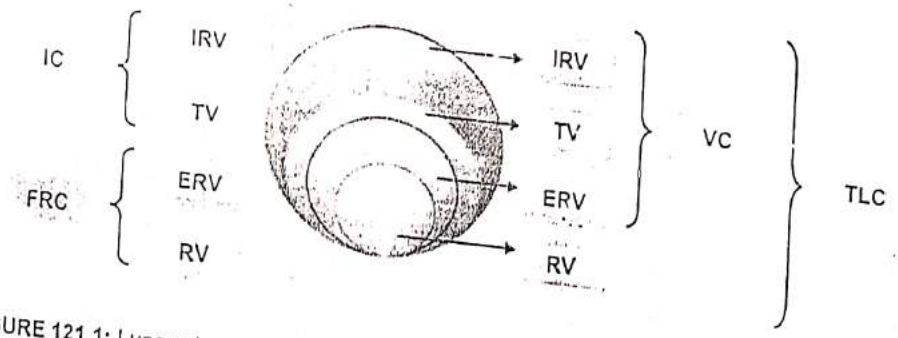

FIGURE 121.1: Lung volumes and capacities. TV = Tidal volume, IRV = Inspiratory reserve volume, ERV = Expiratory reserve volume, RV = Residual volume, IC = Inspiratory capacity, FRC = Functional residual capacity, VC = Vital capacity, TLC = Total lung capacity.

VC = IRV + TV + ERV
= 3,300 + 500 + 1,000 = 4,800 mL

Vital capacity is significant physiologically and its determination is useful in clinical diagnosis as explained later in this chapter.

FUNCTIONAL RESIDUAL CAPACITY

Functional residual capacity (FRC) is the volume of air remaining in lungs after normal expiration (after normal tidal expiration). Functional residual capacity includes expiratory reserve volume and residual volume.

FRC = ERV + RV
= 1,000 + 1,200 = 2,200 mL

TOTAL LUNG CAPACITY

Total lung capacity (TLC) is the volume of air present in lungs after a deep (maximal) inspiration. It includes all the volumes.

TLC = IRV + TV + ERV + RV
= 3,300 + 500 + 1,000 + 1,200 = 6,000 mL

MEASUREMENT OF LUNG VOLUMES AND CAPACITIES

Spirometry is the method to measure lung volumes and capacities. Simple instrument used for this purpose is called **spirometer**. Modified spirometer is known as **respirometer**. Nowadays **plethysmograph** is also used to measure lung volumes and capacities.

SPIROMETER

Spirometer is made up of metal and it contains two chambers namely outer chamber and inner chamber (Fig. 121.2). Outer chamber is called the **water chamber** because it is filled with water. A **floating drum** is immersed in the water in an inverted position. Drum is counter balanced by a weight. Weight is attached to the top of the inverted drum by means of string or chain. A **pen with ink** is attached to the counter weight. Pen is made to write on a calibrated paper, which is fixed to a recording device.

Inner chamber is inverted and has a small hole at the top. A long metal tube passes through the inner

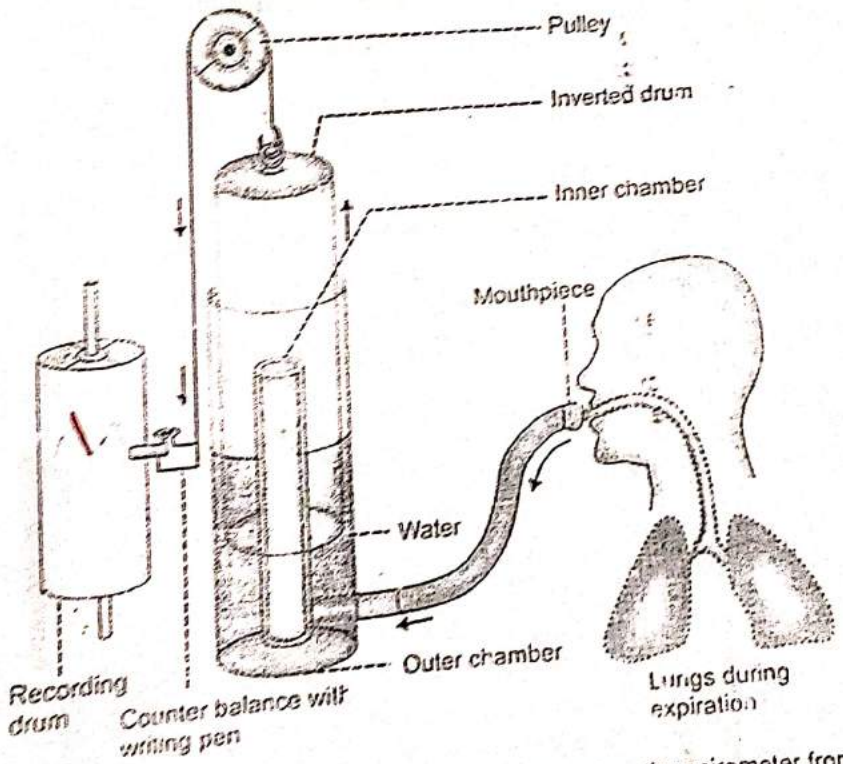

FIGURE 121.2: Spirometer. During expiration, the air enters the spirometer from lungs. Inverted drum moves up and the pen draws a downward curve on the recording drum.

chamber from the bottom towards the top. Upper end of this tube reaches the top portion of the inner chamber. Then the tube passes through a hole at the top of inner chamber and penetrates into outer water chamber above the level of water. A rubber tube is connected to the outer end of the metal tube. At the other end of this rubber tube, a mouthpiece is attached. Subject respires through this mouthpiece by closing the nose with a nose clip.

When the subject breathes with spirometer, during expiration, drum moves up and the counter weight comes down. Reverse of this occurs when the subject breathes the air from the spirometer, i.e. during inspiration. Upward and downward movements of the counter weight are recorded in the form of a graph. (Upward deflection of the curve in the graph shows inspiration) and the downward deflection denotes expiration.

Spirometer is used only for a single breath. Repeated cycles of respiration cannot be recorded by using this instrument because carbon dioxide accumulates in the spirometer and oxygen or fresh air cannot be provided to the subject.

Respirometer

Respirometer is the modified spirometer. It has provision for removal of carbon dioxide and supply of oxygen.

Carbon dioxide is removed by placing soda lime inside the instrument. Oxygen is supplied to the instrument from the oxygen cylinder by a suitable valve system.

Oxygen is filled in the inverted drum above water level and the subject can breathe in and out with instrument for about 6 minutes and recording can be done continuously.

Spirogram

Spirogram is the graphical record of lung volumes and capacities using spirometer. Upward deflection of the spirogram denotes inspiration and the downward curve indicates expiration (Fig. 121.3). In order to determine the lung volumes and capacities, following four levels are to be noted in spirogram:

1. Normal end expiratory level
2. Normal end inspiratory level
3. Maximum expiratory level
4. Maximum inspiratory level.

COMPUTERIZED SPIROMETER

Computerized spirometer is the solid state electronic equipment. It does not contain a drum or water chamber. Subject has to respire into a sophisticated transducer, which is connected to the instrument by means of a cable.

Disadvantages of Spirometry

By using simple spirometer, respirometer or computerized spirometer, not all the lung volumes and lung capacities can be measured.

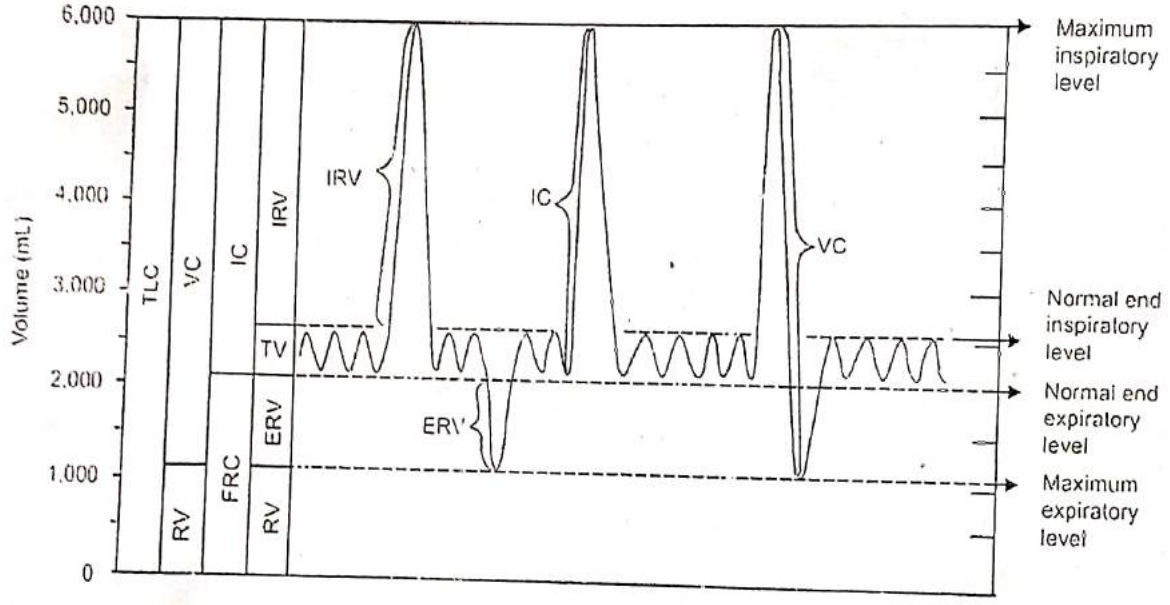

FIGURE 121.3: Spirogram. TV = Tidal volume, IRV = Inspiratory reserve volume, ERV = Expiratory reserve volume, RV = Residual volume, IC = Inspiratory capacity, FRC = Functional residual capacity, VC = Vital capacity, TLC = Total lung capacity.

volume, which cannot be measured by spirometry, is the residual volume. Capacities, which include residual volume also cannot be measured. Capacities that include residual volume are functional residual capacity and total lung capacity.

Volume and capacities, which cannot be measured by spirometry, are measured by nitrogen washout technique or helium dilution technique or by body plethysmograph.

PLETHYSMOGRAPHY

Plethysmography is a technique used to measure all the lung volumes and capacities. It is explained later.

MEASUREMENT OF FUNCTIONAL RESIDUAL CAPACITY AND RESIDUAL VOLUME

Residual volume and the functional residual capacity cannot be measured by spirometer and can be determined by three methods:

1. Helium dilution technique
2. Nitrogen washout method
3. Plethysmography.

1. HELIUM DILUTION TECHNIQUE

Procedure to Measure Functional Residual Capacity

Respirometer is filled with air containing a known quantity of helium. Initially, the subject breathes normally. Then, after the end of expiration, subject breathes from respirometer. Helium from respirometer enters the lungs and starts mixing with air in lungs. After few minutes of breathing, concentration of helium in the respirometer becomes equal to concentration of helium in the lungs of subject. It is called the equilibration of helium. After equilibration of helium between respirometer and lungs, concentration of helium in respirometer is determined (Fig. 121.4).

Functional residual capacity is calculated by the formula:

$$FRC = \frac{V(C_1 - C_2)}{C_2}$$

Where,

C_1 = Initial concentration of helium in the respirometer

C_2 = Final concentration of helium in the respirometer

V = Initial volume of air in the respirometer.

Measured Values

For example, the following data of a subject are obtained from the experiment

1. Initial volume of air in respirometer = 5 L (5,000 mL)
2. Initial concentration of helium in respirometer = 15%
3. Final concentration of helium in respirometer = 10%

Calculation

From the above data, the functional residual capacity of the subject is calculated in the following way:

$$FRC = \frac{V(C_1 - C_2)}{C_2}$$

$$FRC = \frac{5{,}000\ (15/100 - 10/100)}{10/100}\ mL$$

$$= \frac{5{,}000\ (5/100)}{10/100}\ mL$$

$$= \frac{5{,}000 \times 5}{10}\ mL$$

$$= 2{,}500\ mL$$

Thus, the functional residual capacity in this subject is 2,500 mL.

Procedure to Measure Residual Volume

To determine functional residual capacity, the subject starts breathing with respirometer after the end of normal expiration. To measure residual volume, the subject should start breathing from the respirometer after forced expiration.

2. NITROGEN WASHOUT METHOD

Normally, concentration of nitrogen in air is 80%. So, if total quantity of nitrogen in the lungs is measured, the volume of air present in lungs can be calculated.

Procedure to Measure Functional Residual Capacity

Subject is asked to breathe normally. At the end of normal expiration, the subject inspires pure oxygen through a valve and expires into a Douglas bag. This procedure is repeated for 6 to 7 minutes, until the nitrogen in lungs is displaced by oxygen. Nitrogen comes to the Douglas bag. Afterwards, following factors are measured to calculate functional residual capacity.

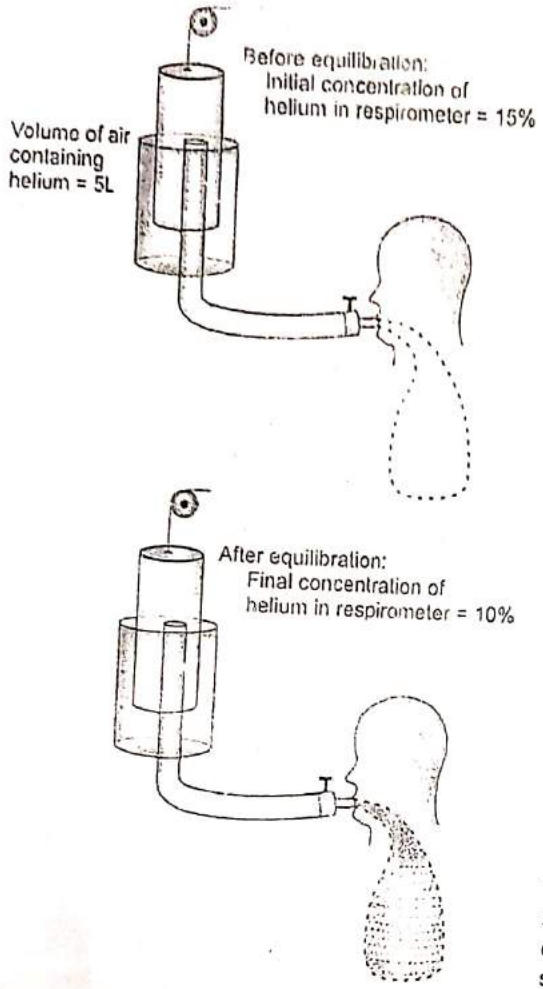

FIGURE 121.4: Measurement of functional residual capacity by using helium

Calculation

i. Volume of air collected in Douglas bag
ii. Concentration of nitrogen in Douglas bag

By using the data, the functional residual capacity is alculated by using the formula:

$$FRC = \frac{C_1 \times V}{C_2}$$

Where,

V = Volume of air collected
C_1 = Concentration of nitrogen in the collected air
C_2 = Normal concentration of nitrogen in the air.

Measured Values

For example, the following data are obtained from the experiment with a subject:

i. Volume of air collected = 40 L (40,000 mL)
ii. Concentration of nitrogen in the collected air = 5%
iii. Normal concentration of nitrogen in the air. = 80%

Calculation

From the above data, the functional residual capacity of the subject is calculated in the following way:

$$FRC = \frac{C_1 \times V}{C_2}$$

$$FRC = \frac{5/100 \times 40{,}000}{80/100} \text{ mL}$$

$$= \frac{5 \times 40{,}000}{80} \text{ mL}$$

$$= 2{,}500 \text{ mL}.$$

Thus, functional residual capacity in this subject is 2,500 mL.

Procedure to Measure Residual Volume

To measure the functional residual capacity, the subject starts inhaling pure oxygen after the end of normal expiration and to determine the residual volume, the subject starts breathing pure oxygen after forceful expiration.

3. PLETHYSMOGRAPHY

Plethysmography is a technique to study the variations in the size or volume of a part of the body such as limb. Plethysmograph is the instrument used for this purpose. Whole body plethysmograph is the instrument used to measure the lung volumes including residual volume.

Plethysmography is based on Boyle's law of gas, which states that the volume of a sample of gas is inversely proportional to the pressure of that gas at constant temperature.

Subject sits in an airtight chamber of the whole body plethysmograph and breathes normally through a mouthpiece connected to a flow transducer called pneumotachograph. It detects the volume changes

during different phases of respiration. After normal breathing for few minutes, the subject breathes rapidly with maximum force. During maximum expiration, the lung volume decreases very much. But volume of gas in the chamber increases with decrease in pressure. By measuring the volume and pressure changes inside the chamber, volume of lungs is calculated by using the formula:

$$P_1 \times V = P_2 (V - \Delta V)$$

Where,

P_1 and P_2 = Pressure changes

V = Functional residual capacity.

1. Asthma
2. Emphysema
3. Weakness or paralysis of respiratory muscle
4. Pulmonary congestion
5. Pneumonia
6. Pneumothorax
7. Hemothorax
8. Pyothorax
9. Hydrothorax
10. Pulmonary edema
11. Pulmonary tuberculosis.

VITAL CAPACITY

DEFINITION

Vital capacity is the maximum volume of air that can be expelled out of lungs forcefully after a maximal or deep inspiration.

LUNG VOLUMES INCLUDED IN VITAL CAPACITY

Vital capacity includes inspiratory reserve volume, tidal volume and expiratory reserve volume.

NORMAL VALUE

VC = IRV + TV + ERV
= 3,300 + 500 + 1,000 = 4,800 mL.

VARIATIONS OF VITAL CAPACITY

Physiological Variations

1. *Sex:* In females, vital capacity is less than in males
2. *Body built:* Vital capacity is slightly more in heavily built persons
3. *Posture:* Vital capacity is more in standing position and less in lying position
4. *Athletes:* Vital capacity is more in athletes
5. *Occupation:* Vital capacity is decreased in people with sedentary jobs. It is increased in persons who play musical wind instruments such as bugle and flute.

Pathological Variations

Vital capacity is decreased in the following respiratory diseases:

Measurement

Vital capacity is measured by spirometry. The subject is asked to take a deep inspiration and expire forcefully.

FORCED VITAL CAPACITY

Forced vital capacity (FVC) is the volume of air that can be exhaled forcefully and rapidly after a maximal or deep inspiration. It is a dynamic lung capacity.

Normally FVC is equal to VC. However in some pulmonary diseases, FVC is decreased.

FORCED EXPIRATORY VOLUME OR TIMED VITAL CAPACITY

DEFINITION

Forced expiratory volume (FEV) is the volume of air, which can be expired forcefully in a given unit of time (after a deep inspiration). It is also called timed vital capacity or forced expiratory vital capacity (FEVC). It is a dynamic lung volume.

FEV_1 = Volume of air expired forcefully in 1 second
FEV_2 = Volume of air expired forcefully in 2 seconds
FEV_3 = Volume of air expired forcefully in 3 seconds.

NORMAL VALUES

Forced expiratory volume in persons with normal respiratory functions is as follows:

FEV_1 = 83% of total vital capacity
FEV_2 = 94% of total vital capacity
FEV_3 = 97% of total vital capacity
After 3rd second = 100% of total vital capacity.

SIGNIFICANCE OF DETERMINING FEV

Vital capacity may be almost normal in some of the respiratory diseases. However, the FEV has great diagnostic value, as it is decreased significantly in some respiratory diseases.

It is very much decreased in obstructive diseases like asthma and emphysema. It is slightly reduced in some restrictive respiratory diseases like fibrosis of lungs (Fig. 121.5).

RESPIRATORY MINUTE VOLUME

DEFINITION

Respiratory minute volume (RMV) is the volume of air breathed in and out of lungs every minute. It is the product of tidal volume (TV) and respiratory rate (RR).

$$RMV = TV \times RR$$
$$= 500 \times 12 = 6{,}000 \text{ mL}$$

NORMAL VALUE

Normal respiratory minute volume is 6 L

VARIATIONS

Respiratory minute volume increases in physiological conditions such as voluntary hyperventilation, exercise and emotional conditions. It is reduced in respiratory diseases.

MAXIMUM BREATHING CAPACITY OR MAXIMUM VENTILATION VOLUME

DEFINITION

Maximum breathing capacity (MEC) is the maximum volume of air, which can be breathed in and out of lungs by forceful respiration (hyperventilation: increase in rate and force of respiration) per minute. It is also called maximum ventilation volume (MVV).

MBC is a dynamic lung capacity and it is reduced in respiratory diseases.

NORMAL VALUE

In healthy adult male, it is 150 to 170 L/minute and in females, it is 80 to 100 L/minute.

MEASUREMENT

Subject is asked to breathe forcefully and rapidly with a respirometer for 15 seconds. Volume of air inspired and expired is measured from the spirogram. From this value, the MBC is calculated for 1 minute.

For example, MBC in 12 seconds = 32 L

$$\text{MBC per minute} = \frac{32}{12} \times 60 \text{ L}$$
$$= 160 \text{ L}$$

PEAK EXPIRATORY FLOW RATE

DEFINITION

Peak expiratory flow rate (PEFR) is the maximum rate at which the air can be expired after a deep inspiration.

NORMAL VALUE

In normal persons, it is 400 L/minute.

MEASUREMENT

Peak expiratory flow rate is measured by using Wright peak flow meter or a mini peak flow meter.

SIGNIFICANCE OF DETERMINING PEFR

Determination of PEFR rate is useful for assessing the respiratory diseases especially to differentiate the obstructive and restrictive diseases. Generally, PEFR is reduced in all type of respiratory disease. However, reduction is more significant in the obstructive diseases than in the restrictive diseases.

Thus, in restrictive diseases, the PEFR is 200 L/minute and in obstructive diseases, it is only 100 L/minute.

RESTRICTIVE AND OBSTRUCTIVE RESPIRATORY DISEASES

Diseases of respiratory tract are classified into two types:

1. Restrictive respiratory disease
2. Obstructive respiratory disease.

These two types of respiratory diseases are determined by lung functions tests, particularly FEV.