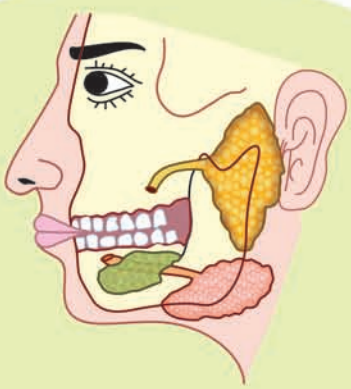
Section

4

Digestive System



Introduction to Digestive System

Chapter 36

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- FUNCTIONAL ANATOMY
- WALL OF GASTROINTESTINAL TRACT
  - MUCUS LAYER
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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.

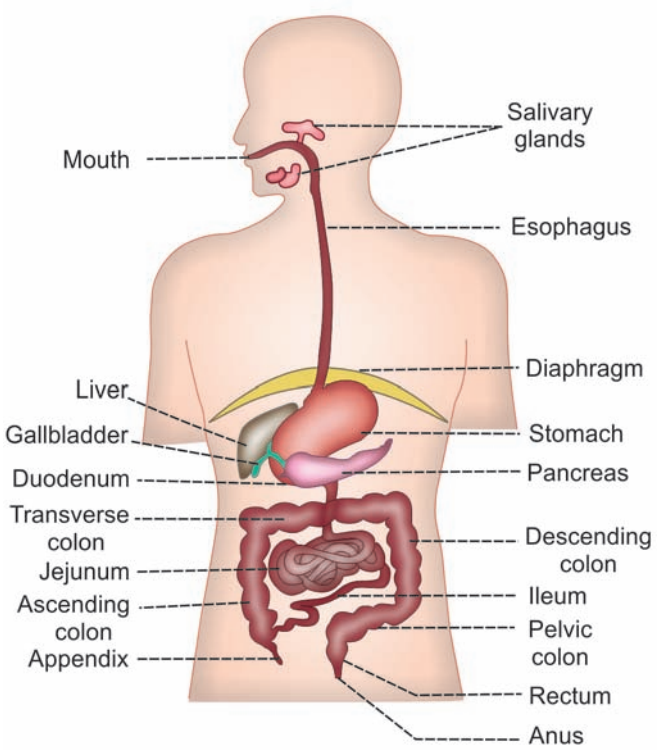

FIGURE 36.1: Gastrointestinal tract

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.

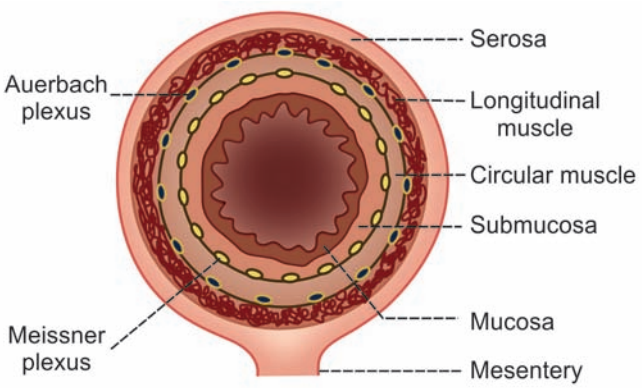

FIGURE 36.2: Structure of intestinal wall with intrinsic nerve plexus

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.

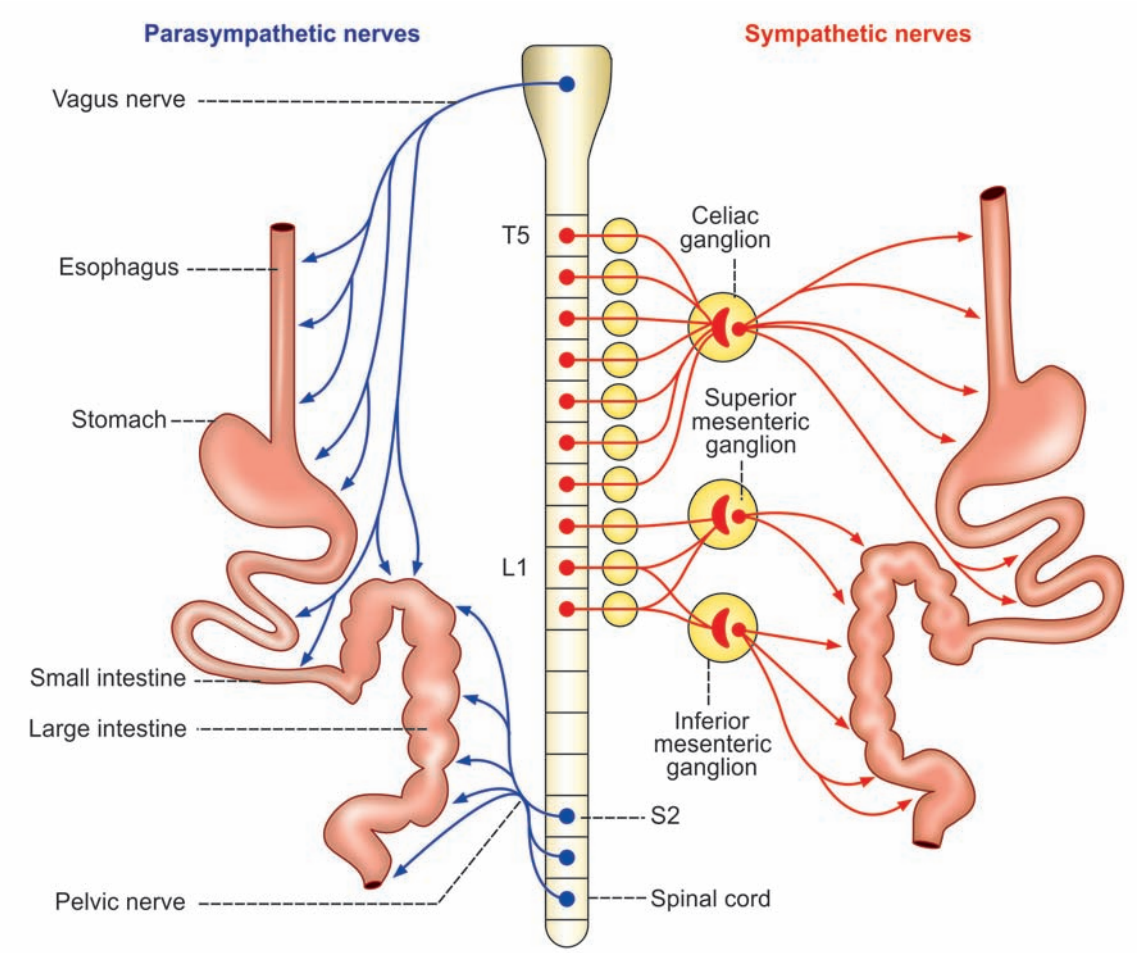

FIGURE 36.3: Extrinsic nerve supply to GI tract.
T5 = 5th thoracic segment of spinal cord
L1 = 1st lumbar segment of spinal cord
S2 = 2nd sacral segment of spinal cord

Preganglionic parasympathetic nerve fibers to esophagus, stomach, small intestine and upper part of large intestine pass through vagus nerve. Preganglionic nerve fibers to lower part of large intestine arise from second, third and fourth sacral segments (S2, S3 and S4) of spinal cord and pass through pelvic nerve. All these preganglionic parasympathetic nerve fibers synapse with the postganglionic nerve cells in the myenteric and submucus plexus.

Functions of parasympathetic nerve fibers

Parasympathetic nerve fibers accelerate the movements and increase the secretions of GI tract. The neurotransmitter secreted by the parasympathetic nerve fibers is acetylcholine (Ach).

Chapter 37

Mouth and Salivary Glands

- 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.**

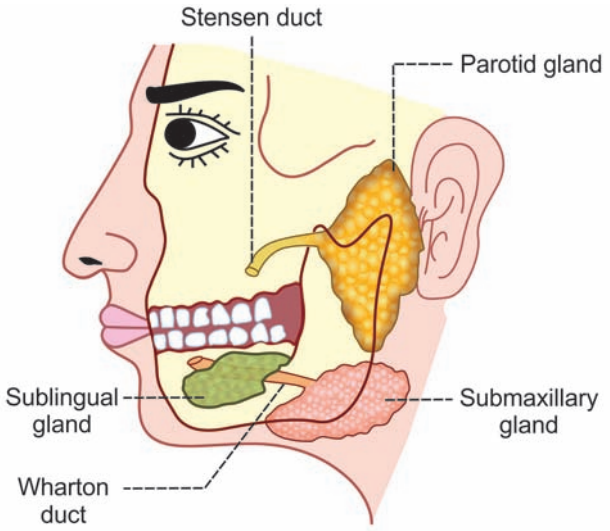

FIGURE 37.1: Major salivary glands

3. *Sublingual Glands*

Sublingual glands are the smallest salivary glands situated in the mucosa at the floor of the mouth. Each gland weighs about 2 to 3 g. Saliva from these glands is poured into 5 to 15 small ducts called **ducts of Rivinus.** These ducts open on small papillae beneath the tongue. One of the ducts is larger and it is called **Bartholin duct** (Table 37.1). It drains the anterior part of the gland and opens on caruncula sublingualis near the opening of submaxillary duct.

■ MINOR SALIVARY GLANDS

1. *Lingual Mucus Glands*

Lingual mucus glands are situated in posterior one third of the tongue, behind **circumvallate papillae** and at the tip and margins of tongue.

2. *Lingual Serous Glands*

Lingual serous glands are located near circumvallate papillae and **filiform papillae.**

3. *Buccal Glands*

Buccal glands or molar glands are present between the mucus membrane and buccinator muscle. Four to five of these are larger and situated outside buccinator, around the terminal part of parotid duct.

4. *Labial Glands*

Labial glands are situated beneath the mucus membrane around the orifice of mouth.

TABLE 37.1: Ducts of major salivary glands

Gland	Duct
Parotid gland	Stensen duct
Submaxillary gland	Wharton duct
Sublingual gland	Ducts of Rivinus/Bartholin duct

5. *Palatal Glands*

Palatal glands are found beneath the mucus membrane of the soft palate.

■ CLASSIFICATION OF SALIVARY GLANDS

Salivary glands are classified into three types, based on the type of secretion:

1. *Serous Glands*

Serous glands are mainly made up of serous cells. These glands secrete thin and watery saliva. Parotid glands and lingual serous glands are the serous glands.

2. *Mucus Glands*

Mucus glands are mainly made up of mucus cells. These glands secrete thick, viscous saliva with high mucin content. Lingual mucus glands, buccal glands and palatal glands belong to this type.

3. *Mixed Glands*

Mixed glands are made up of both serous and mucus cells. Submandibular, sublingual and labial glands are the mixed glands.

■ STRUCTURE AND DUCT SYSTEM OF SALIVARY GLANDS

Salivary glands are formed by **acini** or **alveoli.** Each acinus is formed by a small group of cells which surround a central globular cavity. Central cavity of each acinus is continuous with the lumen of the duct. The fine duct draining each acinus is called **intercalated duct.** Many intercalated ducts join together to form **intralobular duct.** Few intralobular ducts join to form **interlobular ducts,** which unite to form the main duct of the gland (Fig. 37.2). A gland with this type of structure and duct system is called **racemose type** (racemose = bunch of grapes).

■ PROPERTIES AND COMPOSITION OF SALIVA

■ PROPERTIES OF SALIVA

1. *Volume:* 1000 mL to 1500 mL of saliva is secreted per day and it is approximately about 1 mL/minute.

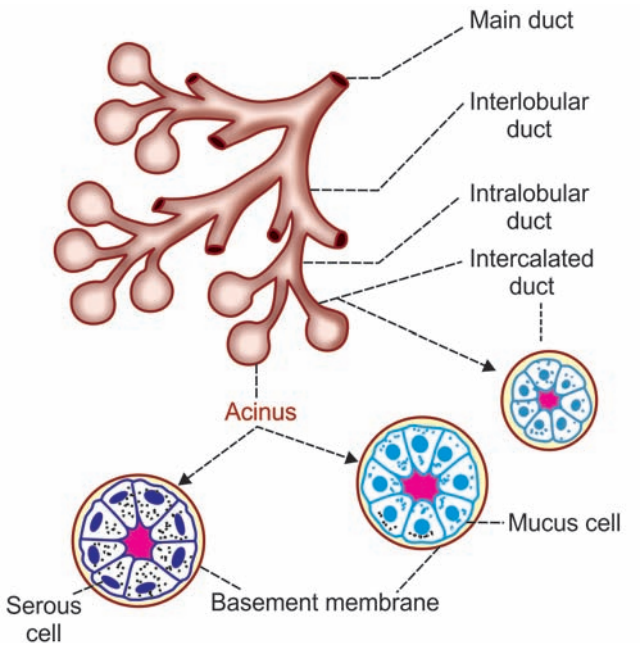

FIGURE 37.2: Diagram showing acini and duct system in salivary glands

Contribution by each major salivary gland is:

i. Parotid glands : 25%
ii. Submaxillary glands : 70%
iii. Sublingual glands : 5%.

2. *Reaction:* Mixed saliva from all the glands is slightly acidic with pH of 6.35 to 6.85
3. *Specific gravity:* It ranges between 1.002 and 1.012
4. *Tonicity:* Saliva is hypotonic to plasma.

■ COMPOSITION OF SALIVA

Mixed saliva contains 99.5% water and 0.5% solids. Composition of saliva is given in Figure 37.3.

■ FUNCTIONS OF SALIVA

Saliva is a very essential digestive juice. Since it has many functions, its absence leads to many inconveniences.

■ 1. PREPARATION OF FOOD FOR SWALLOWING

When food is taken into the mouth, it is moistened and dissolved by saliva. The mucus membrane of mouth is also moistened by saliva. It facilitates chewing. By the movement of tongue, the moistened and masticated food is rolled into a bolus. **Mucin** of saliva lubricates the bolus and facilitates swallowing.

■ 2. APPRECIATION OF TASTE

Taste is a chemical sensation. By its solvent action, saliva dissolves the solid food substances, so that the

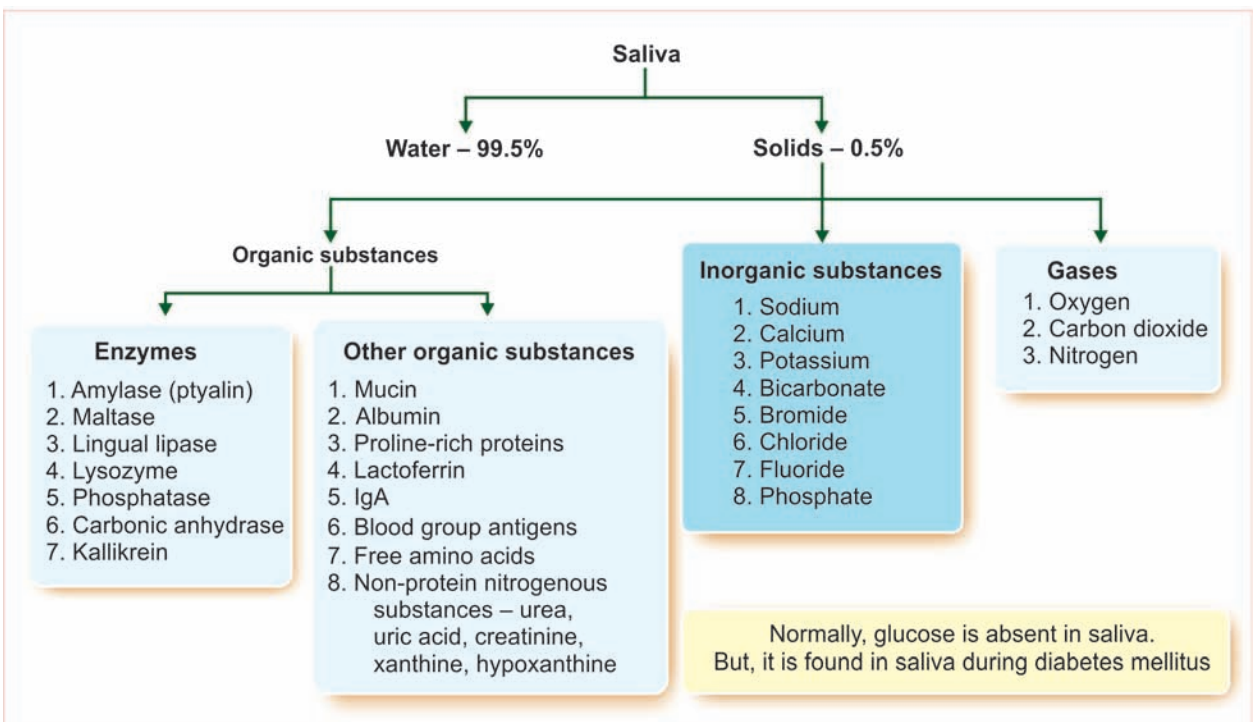

FIGURE 37.3: Composition of saliva

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 antimicrobial property.

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

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

vii. Mucin present in the saliva protects the mouth 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 the 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

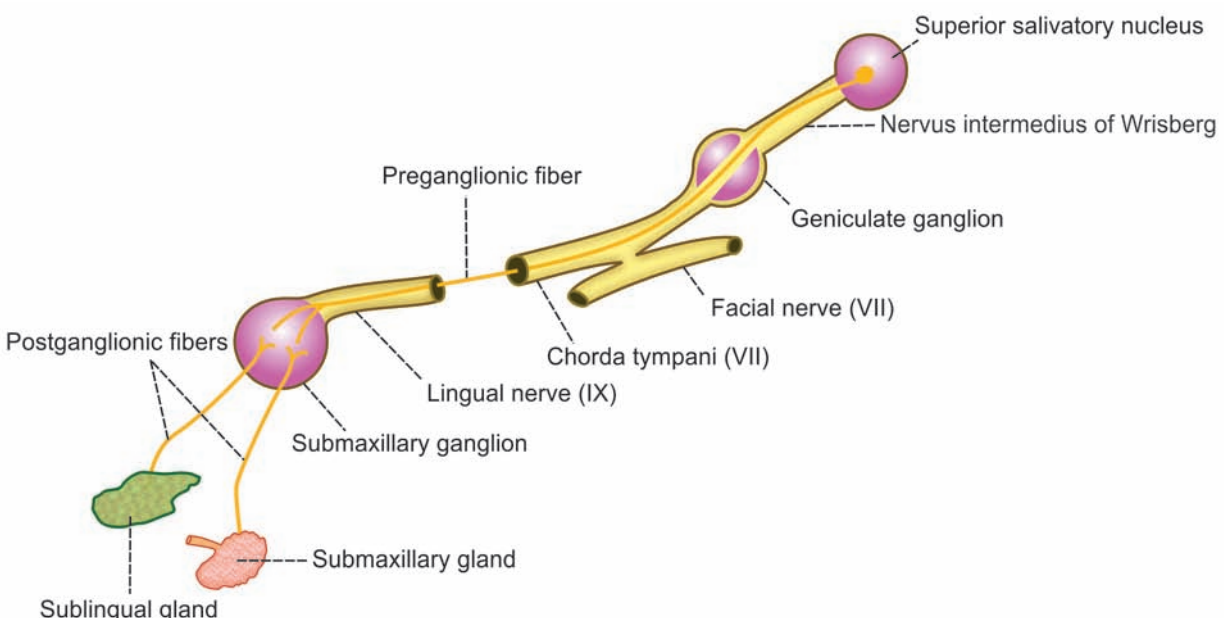

FIGURE 37.4: Parasympathetic nerve supply to submaxillary and sublingual glands

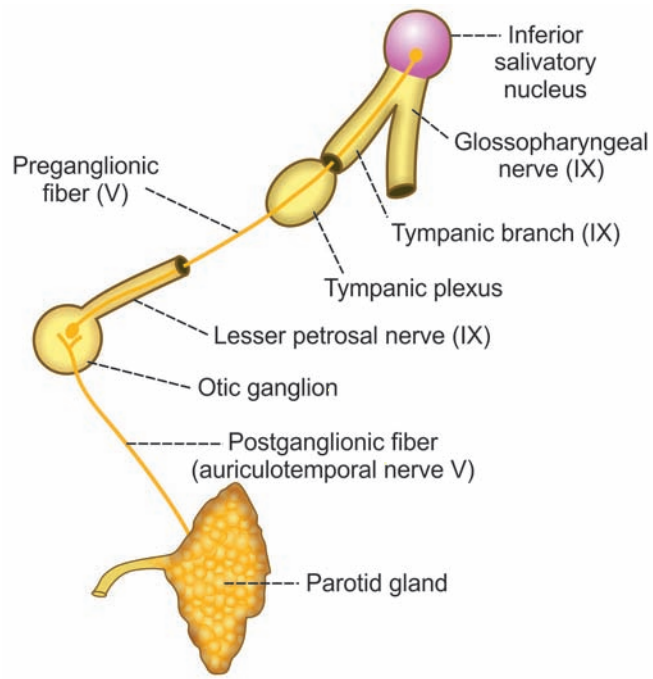

FIGURE 37.5: Parasympathetic nerve supply to parotid gland

as mucus. It is because, these fibers activate the acinar cells and cause vasoconstriction. The neurotransmitter is noradrenaline.

■ REFLEX REGULATION OF SALIVARY SECRETION

Salivary secretion is regulated by nervous mechanism through reflex action.

Salivary reflexes are of two types:

1. Unconditioned reflex.
2. Conditioned reflex.

1. *Unconditioned Reflex*

Unconditioned reflex is the inborn reflex that is present since birth. It does not need any previous experience (Chapter 162). This reflex induces salivary secretion when any substance is placed in the mouth. It is due to the stimulation of nerve endings in the mucus membrane of the oral cavity.

2. *Conditioned Reflex*

Conditioned reflex is the one that is acquired by experience and it needs previous experience (Chapter 162). Presence of food in the mouth is not necessary to elicit this reflex. The stimuli for this reflex are the sight, smell, hearing or thought of food.

■ EFFECT OF DRUGS AND CHEMICALS ON SALIVARY SECRETION

Substances which increase salivary secretion

1. Sympathomimetic drugs like adrenaline and ephedrine.
2. Parasympathomimetic drugs like acetylcholine, pilocarpine, muscarine and physostigmine.
3. Histamine.

Substances which decrease salivary secretion

1. Sympathetic depressants like ergotamine and dibenamine.
2. Parasympathetic depressants like atropine and scopolamine.
3. Anesthetics such as chloroform and ether stimulate the secretion of saliva. However, deep anesthesia decreases the secretion due to central inhibition.

■ APPLIED PHYSIOLOGY

■ HYPOSALIVATION

Reduction in the secretion of saliva is called hyposalivation. It is of two types, namely temporary hyposalivation and permanent hyposalivation.

1. Temporary hyposalivation occurs in:
   i. Emotional conditions like fear.
   ii. Fever.
   iii. Dehydration.
2. Permanent hyposalivation occurs in:
   i. Sialolithiasis (obstruction of salivary duct).
   ii. Congenital absence or hypoplasia of salivary glands.
   iii. Bell palsy (paralysis of facial nerve).

■ HYPERSALIVATION

Excess secretion of saliva is known as hypersalivation. Physiological condition when hypersalivation occurs is pregnancy. Hypersalivation in pathological conditions is called ptyalism, sialorrhea, sialism or sialosis.

Hypersalivation occurs in the following pathological conditions:

1. Decay of tooth or neoplasm (abnormal new growth or tumor) in mouth or tongue due to continuous irritation of nerve endings in the mouth.
2. Disease of esophagus, stomach and intestine.
3. Neurological disorders such as cerebral palsy, mental retardation, cerebral stroke and parkinsonism.
4. Some psychological and psychiatric conditions.
5. Nausea and vomiting.

■ OTHER DISORDERS

In addition to hyposalivation and hypersalivation, salivary secretion is affected by other disorders also, which include:

1. Xerostomia
2. Drooling
3. Chorda tympani syndrome
4. Paralytic secretion of saliva
5. Augmented secretion of saliva
6. Mumps
7. Sjögren syndrome.

1. *Xerostomia*

Xerostomia means dry mouth. It is also called pasties or cottonmouth. It is due to hyposalivation or absence of salivary secretion (aptyalism).

Causes

i. Dehydration or renal failure.
ii. Sjögren syndrome (see below).
iii. Radiotherapy.
iv. Trauma to salivary gland or their ducts.
v. Side effect of some drugs like antihistamines, antidepressants, monoamine oxidase inhibitors, antiparkinsonian drugs and antimuscarinic drugs.
vi. Shock.
vii. After smoking marijuana (psychoactive compound from the plant *Cannabis*).

Xerostomia causes difficulties in mastication, swallowing and speech. It also causes halitosis (bad breath; exhalation of unpleasant odors).

2. *Drooling*

Uncontrolled flow of saliva outside the mouth is called drooling. It is often called ptyalism.

Causes

Drooling occurs because of excess production of saliva, in association with inability to retain saliva within the mouth.

Drooling occurs in the following conditions:

i. During teeth eruption in children.
ii. Upper respiratory tract infection or nasal allergies in children.
iii. Difficulty in swallowing.
iv. Tonsillitis.
v. Peritonsillar abscess.

3. *Chorda Tympani Syndrome*

Chorda tympani syndrome is the condition characterized by sweating while eating. During trauma or surgical procedure, some of the parasympathetic nerve fibers to salivary glands may be severed. During the regeneration, some of these nerve fibers, which run along with chorda tympani branch of facial nerve may deviate and join with the nerve fibers supplying sweat glands. When the food is placed in the mouth, salivary secretion is associated with sweat secretion.

4. *Paralytic Secretion of Saliva*

When the parasympathetic nerve to salivary gland is cut in experimental animals, salivary secretion increases for first three weeks and later diminishes; finally it stops at about sixth week. The increased secretion of saliva after cutting the parasympathetic nerve fibers is called paralytic secretion. It is because of hyperactivity of sympathetic nerve fibers to salivary glands after cutting the parasympathetic fibers. These hyperactive sympathetic fibers release large amount of catecholamines, which induce paralytic secretion. Moreover, the acinar cells of the salivary glands become hypersensitive to catecholamines after denervation. The paralytic secretion does not occur after the sympathetic nerve fibers to salivary glands are cut.

5. *Augmented Secretion of Saliva*

If the nerves supplying salivary glands are stimulated twice, the amount of saliva secreted by the second stimulus is more than the amount secreted by the first stimulus. It is because, the first stimulus increases excitability of acinar cells, so that when the second stimulus is applied, the salivary secretion is augmented.

6. *Mumps*

Mumps is the acute viral infection affecting the parotid glands. The virus causing this disease is paramyxovirus. It is common in children who are not immunized. It occurs in adults also. Features of mumps are puffiness of cheeks (due to swelling of parotid glands), fever, sore throat and weakness. Mumps affects meninges, gonads and pancreas also.

7. *Sjögren Syndrome*

Sjögren syndrome is an autoimmune disorder in which the immune cells destroy exocrine glands such as lacrimal glands and salivary glands. It is named after Henrik Sjögren who discovered it. Common symptoms of this syndrome are dryness of the mouth due to lack of saliva (xerostomia), persistent cough and dryness of eyes. In some cases, it causes dryness of skin, nose and vagina. In severe conditions, the organs like kidneys, lungs, liver, pancreas, thyroid, blood vessels and brain are affected.

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

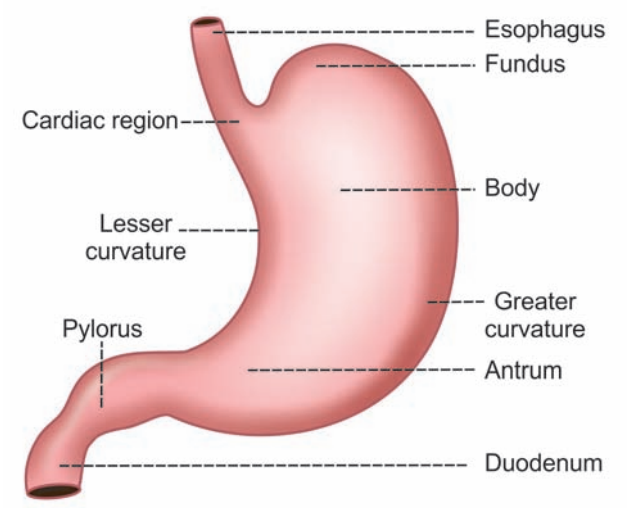

FIGURE 38.1: Parts of stomach

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

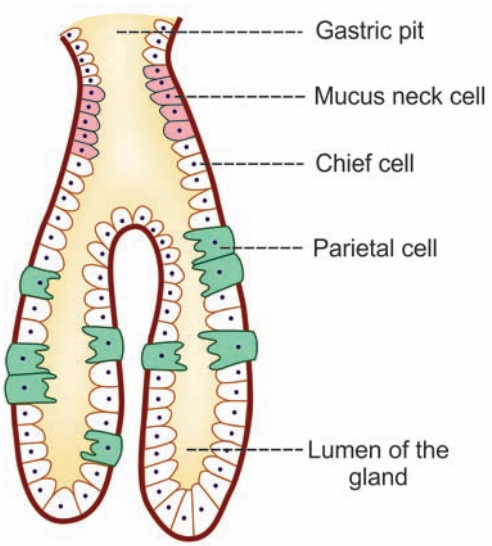

FIGURE 38.2: Gastric glands

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 during 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.

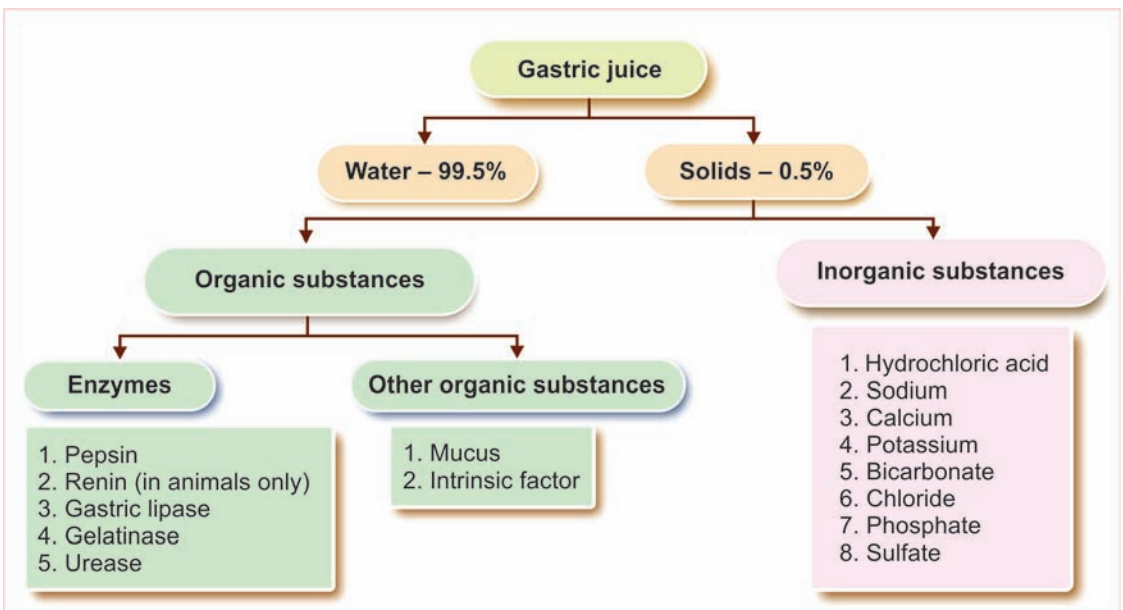

FIGURE 38.3: Composition of gastric juice

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

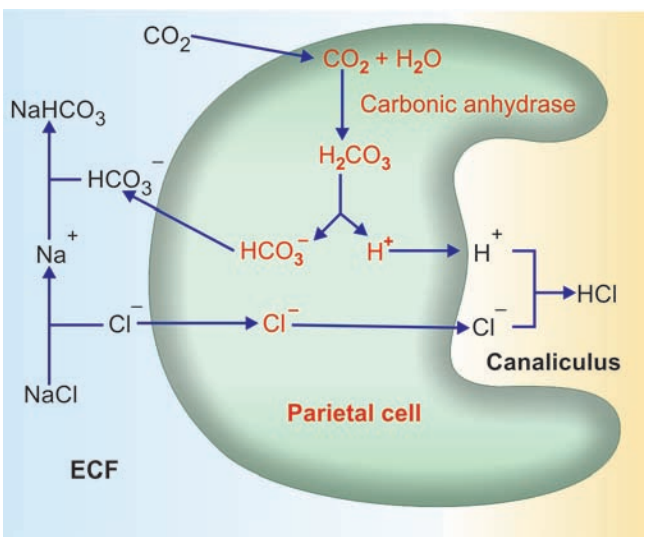

FIGURE 38.4: Secretion of hydrochloric acid in the parietal cell of gastric gland

is completely divided. A small part of muscular coat called **isthmus** is retained. Isthmus connects the two parts.

The cut edges of major portions are stitched. Smaller part is also stitched, leaving a small outlet. This outlet is brought out through the abdominal wall and used to drain the pouch.

Nerve supply of Pavlov pouch

Pavlov pouch receives parasympathetic (vagus) nerve fibers through isthmus and sympathetic fibers through blood vessels.

Use of Pavlov pouch

Pavlov pouch is used to demonstrate the different phases of gastric secretion, particularly the cephalic phase and used to demonstrate the role of vagus in cephalic phase.

2. *Heidenhain Pouch*

Heidenhain pouch is the modified Pavlov pouch. It is completely separated from main portion of stomach by cutting the isthmus without damaging blood vessels. So, the blood vessels are intact. Thus, Heidenhain pouch does not have parasympathetic supply, but the sympathetic fibers remain intact through the blood vessels.

Uses of Heidenhain pouch

Heidenhain pouch is useful to demonstrate the role of sympathetic nerve and the hormonal regulation of gastric secretion after vagotomy (cutting the vagus nerve).

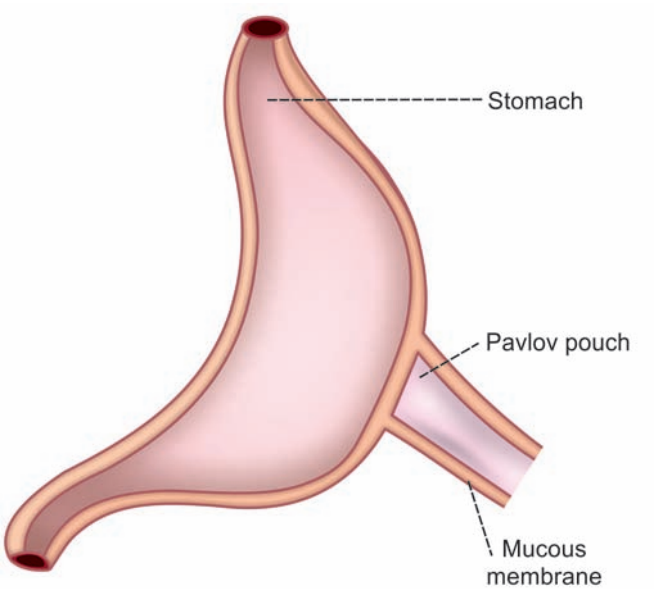

FIGURE 38.5: Pavlov pouch

3. *Bickel Pouch*

In this, even the sympathetic nerve fibers are cut by removing the blood vessels. So, Bickel pouch is a totally denervated pouch.

Uses of Bickel pouch

Bickel pouch is used to demonstrate the role of hormones in gastric secretion.

4. *Farrel and Ivy Pouch*

Farrel and Ivy pouch is prepared by completely removing the Bickel pouch from the stomach and transplanting it in the subcutaneous tissue of abdominal wall or thoracic wall in the same animal. New blood vessels develop after some days. It is used for experimental purpose, when the new blood vessels are developed.

Uses of Farrel and Ivy pouch

This pouch is useful to study the role of hormones during gastric and intestinal phases of gastric secretion.

5. *Sham Feeding*

Sham feeding means the false feeding. It is another experimental procedure devised by Pavlov to demonstrate the regulation of gastric secretion.

Procedure

i. A hole is made in the neck of an anesthetized dog
ii. Esophagus is transversely cut and the cut ends are drawn out through the hole in the neck
iii. When the dog eats food, it comes out through the cut end of the esophagus
iv. But the dog has the satisfaction of eating the food. Hence it is called sham feeding.

This experimental procedure is supported by the preparation of Pavlov pouch with a **fistula** from the stomach. The fistula opens to exterior and it is used to observe the gastric secretion. The animal is used for experimental purpose after a week, when healing is completed.

Advantage of sham feeding

Sham feeding is useful to demonstrate the secretion of gastric juice during cephalic phase. In the same animal after **vagotomy,** sham feeding does not induce gastric secretion. It proves the role of vagus nerve during cephalic phase.

■ PHASES OF GASTRIC SECRETION

Secretion of gastric juice is a continuous process. But the quantity varies, depending upon time and stimulus.

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.

1. *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

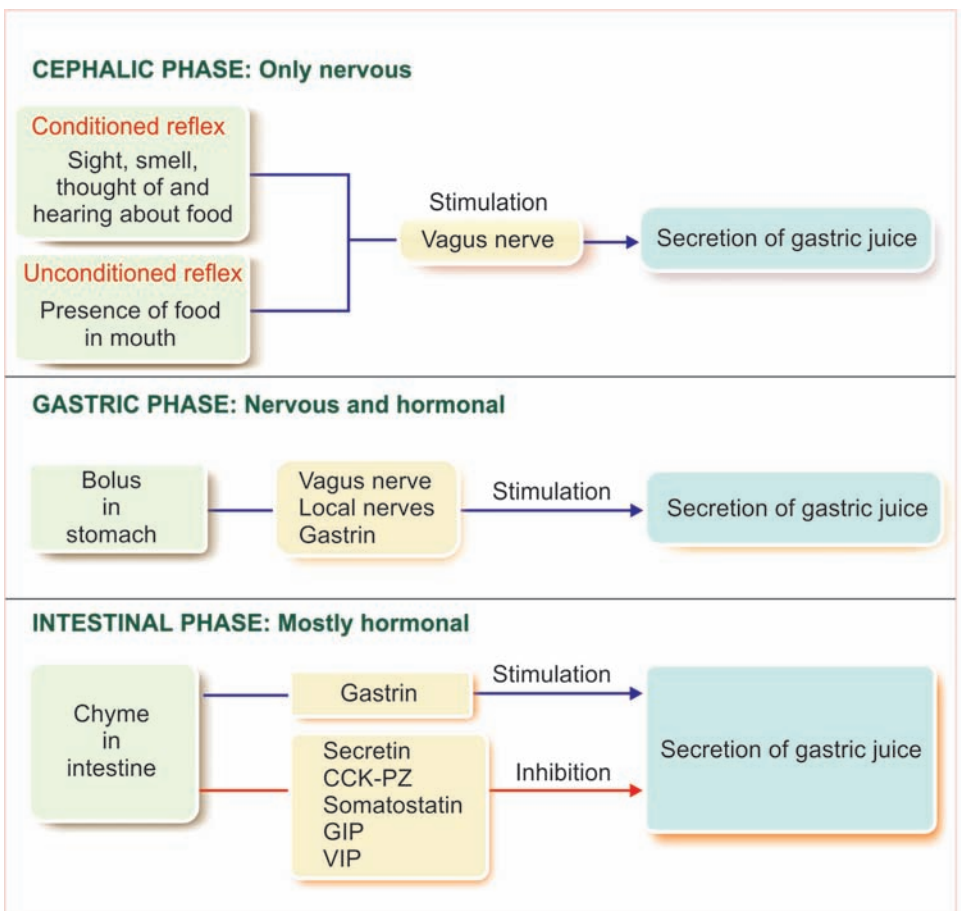

FIGURE 38.6: Schematic diagram showing the regulation of gastric secretion
CCK-PZ = Cholecystokinin-pancreozymin, GIP = Gastric inhibitory peptide, VIP = Vasoactive intestinal peptide.

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.

2. *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).

2. *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

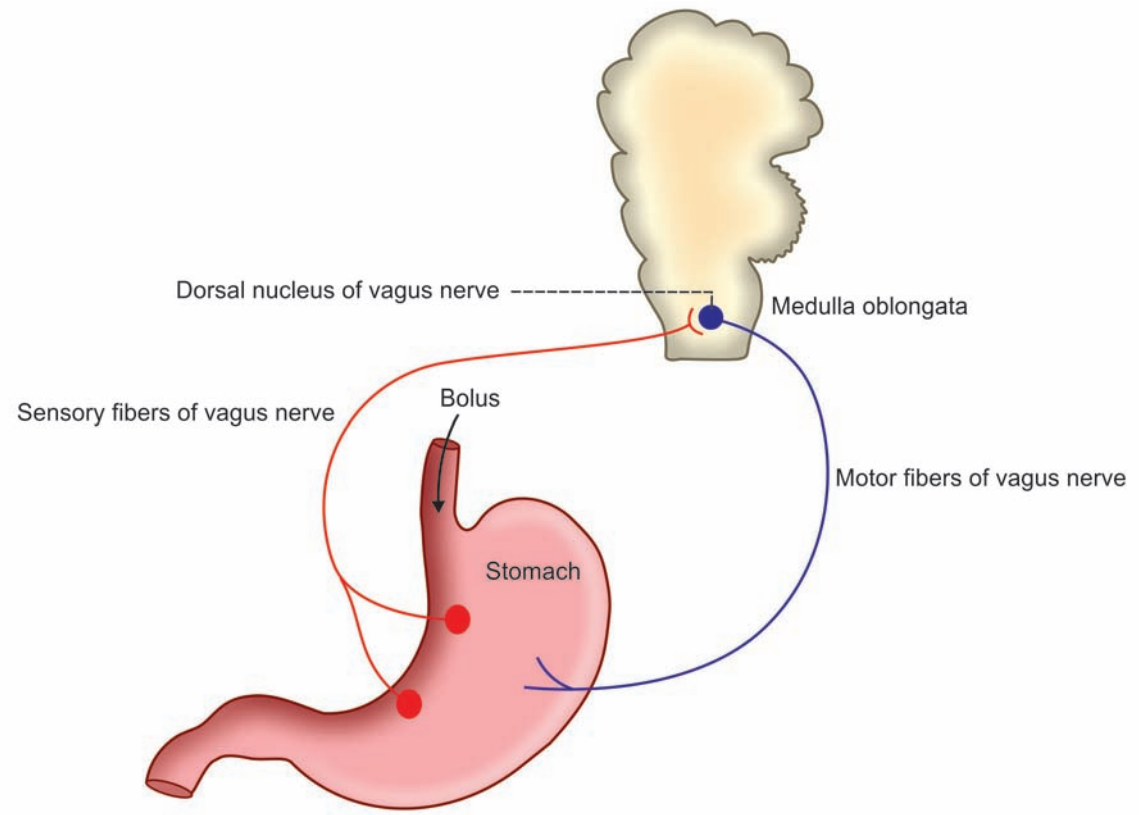

FIGURE 38.7: Vagovagal reflex

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 patients'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*

ii. Long-term intake of excess alcohol
iii. Long-term use of NSAIDs
iv. Autoimmune disease.

Features

Features of gastritis are nonspecific. Common feature is abdominal upset or pain felt as a diffused burning sensation. It is often referred to **epigastric pain.** Other features are:

i. Nausea
ii. Vomiting
iii. **Anorexia** (loss of appetite)
iv. Indigestion
v. Discomfort or feeling of fullness in the epigastric region
vi. **Belching** (process to relieve swallowed air that is accumulated in stomach).

■ 2. GASTRIC ATROPHY

Gastric atrophy is the condition in which the muscles of the stomach shrink and become weak. Gastric glands also shrink, resulting in the deficiency of gastric juice.

Cause

Gastric atrophy is caused by chronic gastritis called chronic atrophic gastritis. There is atrophy of gastric mucosa including loss of gastric glands. **Autoimmune atrophic gastritis** also causes gastric atrophy.

Features

Generally, gastric atrophy does not cause any noticeable symptom. However, it may lead to **achlorhydria** (absence of hydrochloric acid in gastric juice) and pernicious anemia. Some patients develop gastric cancer.

■ 3. PEPTIC ULCER

Ulcer means the erosion of the surface of any organ due to shedding or sloughing of inflamed **necrotic tissue** that lines the organ. Peptic ulcer means an ulcer in the wall of stomach or duodenum, caused by digestive action of gastric juice. If peptic ulcer is found in stomach, it is called **gastric ulcer** and if found in duodenum, it is called **duodenal ulcer.**

Causes

i. Increased peptic activity due to excessive secretion of pepsin in gastric juice
ii. Hyperacidity of gastric juice
iii. Reduced alkalinity of duodenal content
iv. Decreased mucin content in gastric juice or decreased protective activity in stomach or duodenum
v. Constant physical or emotional stress
vi. Food with excess spices or smoking (classical causes of ulcers)
vii. Long-term use of NSAIDs (see above) such as Aspirin, Ibuprofen and Naproxen
viii. Chronic inflammation due to *Helicobacter pylori*.

Features

Most common feature of peptic ulcer is severe burning pain in epigastric region. In gastric ulcer, pain occurs while eating or drinking. In duodenal ulcer, pain is felt 1 or 2 hours after food intake and during night.

Other symptoms accompanying pain are:

i. Nausea
ii. Vomiting
iii. **Hematemesis** (vomiting blood)
iv. **Heartburn** (burning pain in chest due to regurgitation of acid from stomach into esophagus)
v. Anorexia (loss of appetite)
vi. Loss of weight.

■ 4. ZOLLINGER-ELLISON SYNDROME

Zollinger-Ellison syndrome is characterized by secretion of excess hydrochloric acid in the stomach.

Cause

This disorder is caused by tumor of pancreas. Pancreatic tumor produces a large quantity of gastrin. Gastrin increases the hydrochloric acid secretion in stomach by stimulating the parietal cells of gastric glands.

Features

i. Abdominal pain
ii. Diarrhea (frequent and watery, loose bowel movements)
iii. Difficulty in eating
iv. Occasional hematemesis (see above).

Chapter 39

Pancreas

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 (7 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.

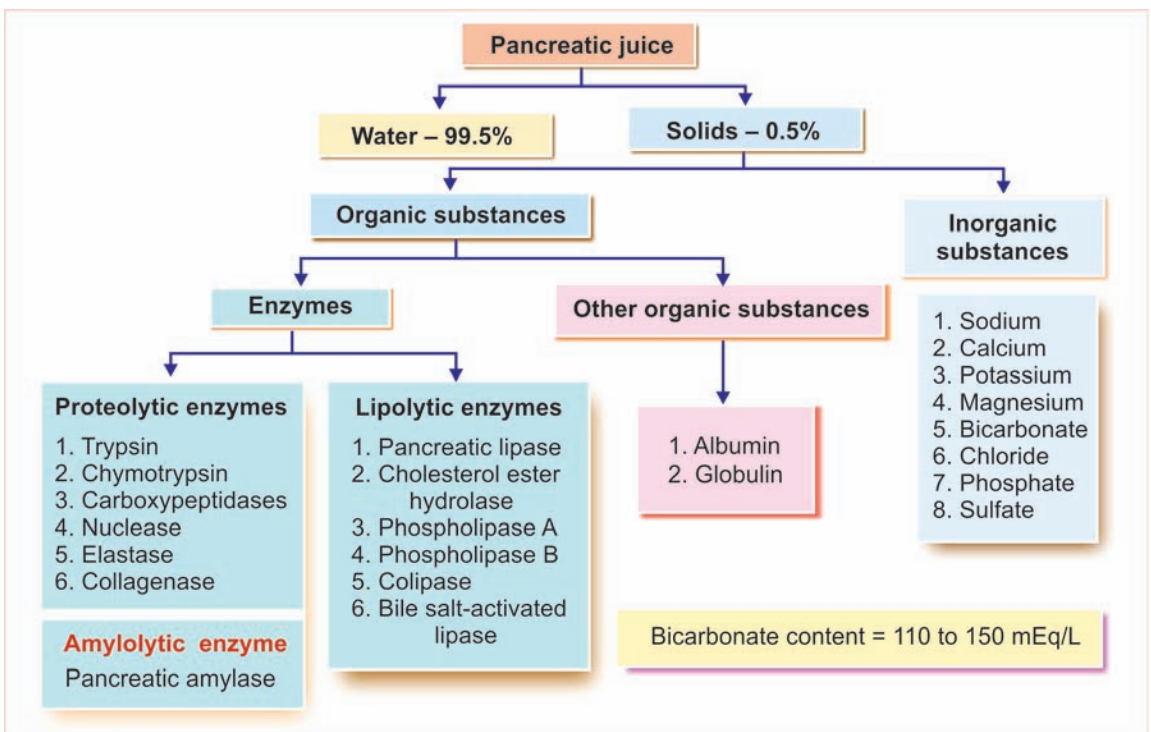

FIGURE 39.1: Composition of pancreatic juice

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	Lysophospholipids
		Cholesterol esters	Cholesterol and fatty acids
		Triglycerides	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

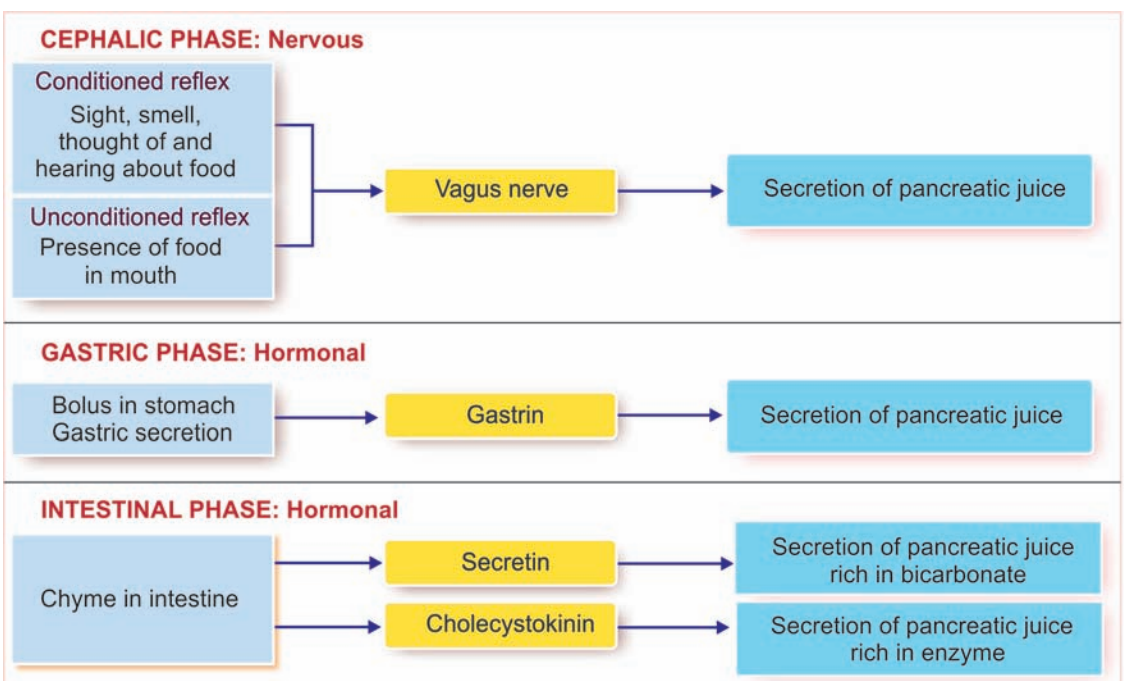

FIGURE 39.2: Schematic diagram showing the regulation of pancreatic secretion

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

is fat digestion that results in steatorrhea (see below)

iii. Severe pain in upper abdominal region, which radiates to the back
iv. Fever, nausea and vomiting
v. Tender and swollen abdomen
vi. Weight loss.

■ STEATORRHEA

Steatorrhea is the formation of bulky, foul-smelling, frothy and clay-colored stools with large quantity of undigested fat because of impaired digestion and absorption of fat.

Causes of Steatorrhea

Any condition that causes indigestion or malabsorption of fat leads to steatorrhea. Various causes of steatorrhea are:

1. *Lack of pancreatic lipase:* Since most of the fat is digested only by pancreatic lipase, its deficiency leads to steatorrhea
2. *Liver disease affecting secretion of bile:* Bile salts are essential for the digestion of fat by lipase and absorption of fat from intestine. Absence of bile salts results in excretion of fatty stool
3. *Celiac disease:* Atrophy of intestinal villi leads to malabsorption, resulting in steatorrhea
4. Cystic fibrosis (see above).

Liver and Gallbladder

Chapter 40

- FUNCTIONAL ANATOMY OF LIVER AND BILIARY SYSTEM
- BLOOD SUPPLY TO LIVER
- PROPERTIES AND COMPOSITION OF BILE
- SECRETION OF BILE
- STORAGE OF BILE
- BILE SALTS
- BILE PIGMENTS
- FUNCTIONS OF BILE
- FUNCTIONS OF LIVER
- GALLBLADDER
- REGULATION OF BILE SECRETION
- APPLIED PHYSIOLOGY

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

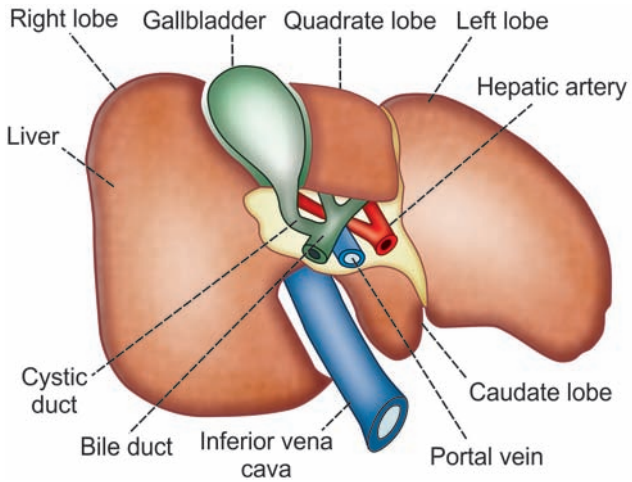

FIGURE 40.1: Posterior surface of liver

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 branch enters a portal triad.

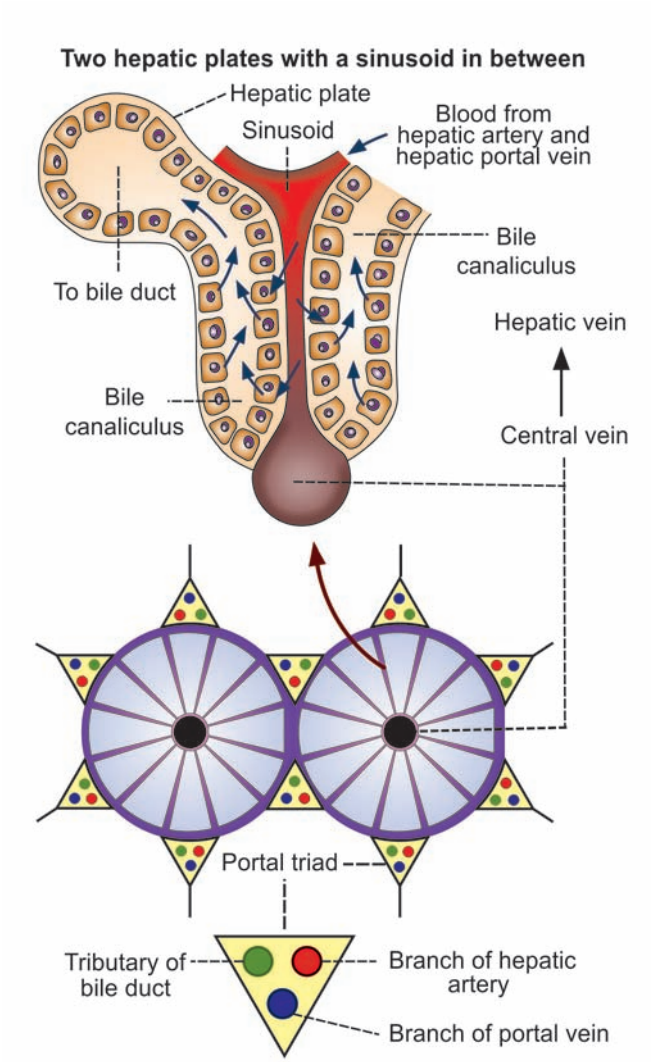

FIGURE 40.2: Hepatic lobule

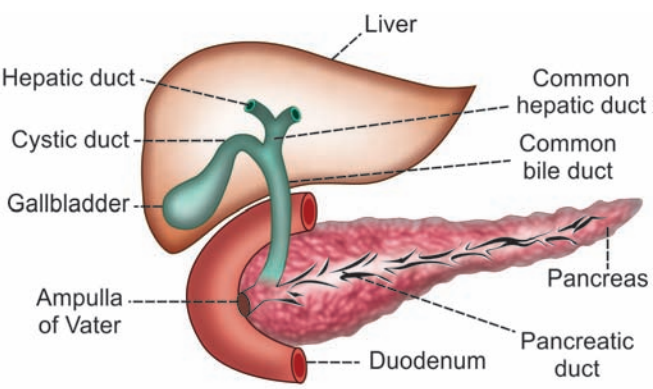

FIGURE 40.3: Biliary system

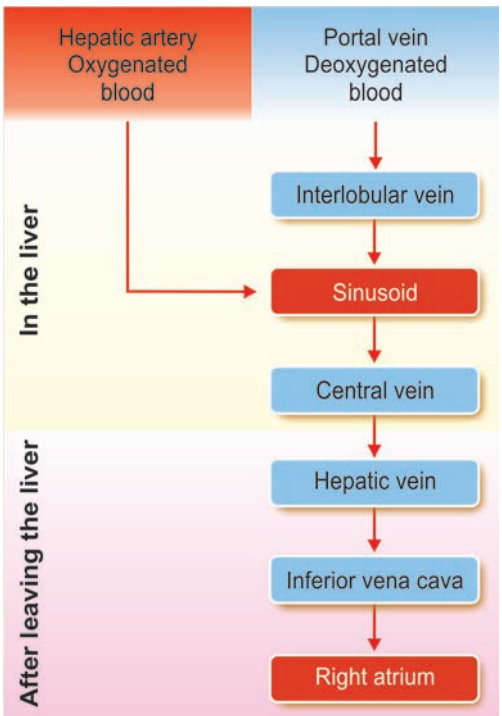

FIGURE 40.4: Schematic diagram of blood flow through liver

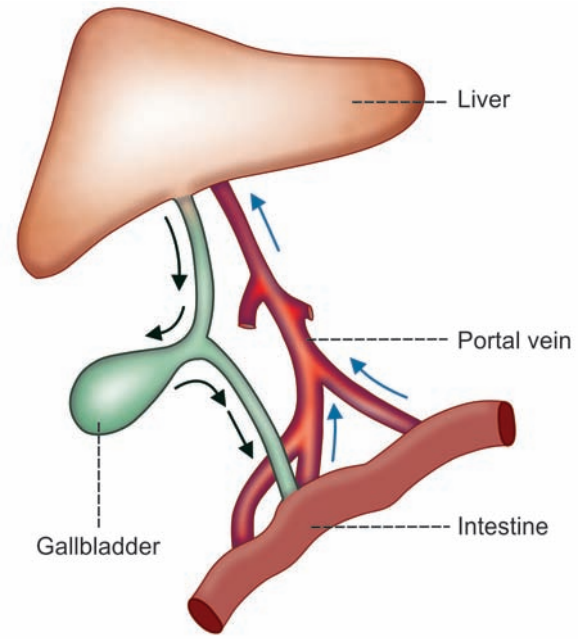

FIGURE 40.5: Enterohepatic circulation

■ 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 gallbladder, where it is stored. It is released from gallbladder into the intestine whenever it is required. When bile is stored in gallbladder,

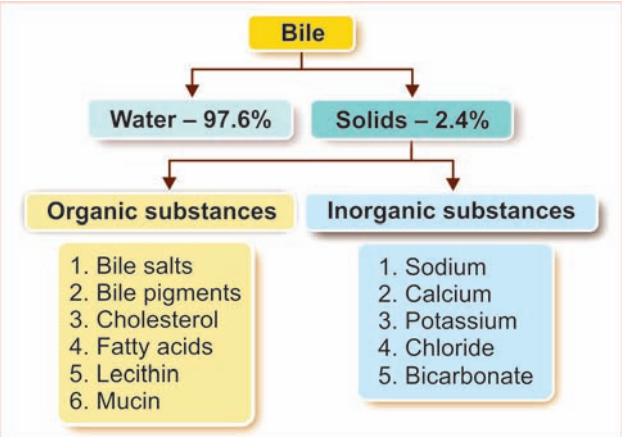

FIGURE 40.6: Composition of bile

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).

■ 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).

TABLE 40.1: Differences between liver bile and gallbladder bile

Types of entities	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

■ 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.

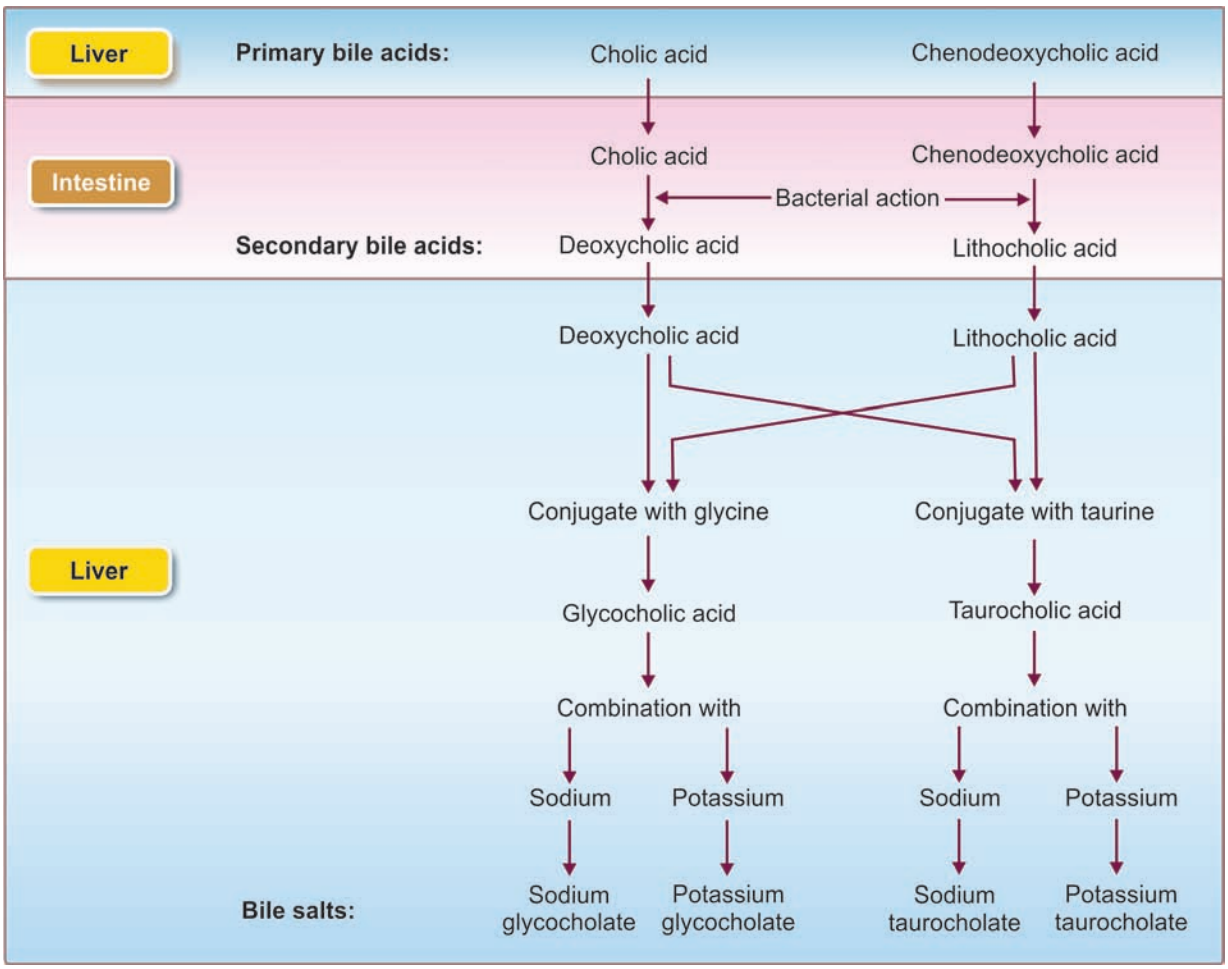

FIGURE 40.7: Formation of bile salts

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 is converted into **urobilinogen** by intestinal bacteria. First the conjugated bilirubin is deconjugated into **free 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.

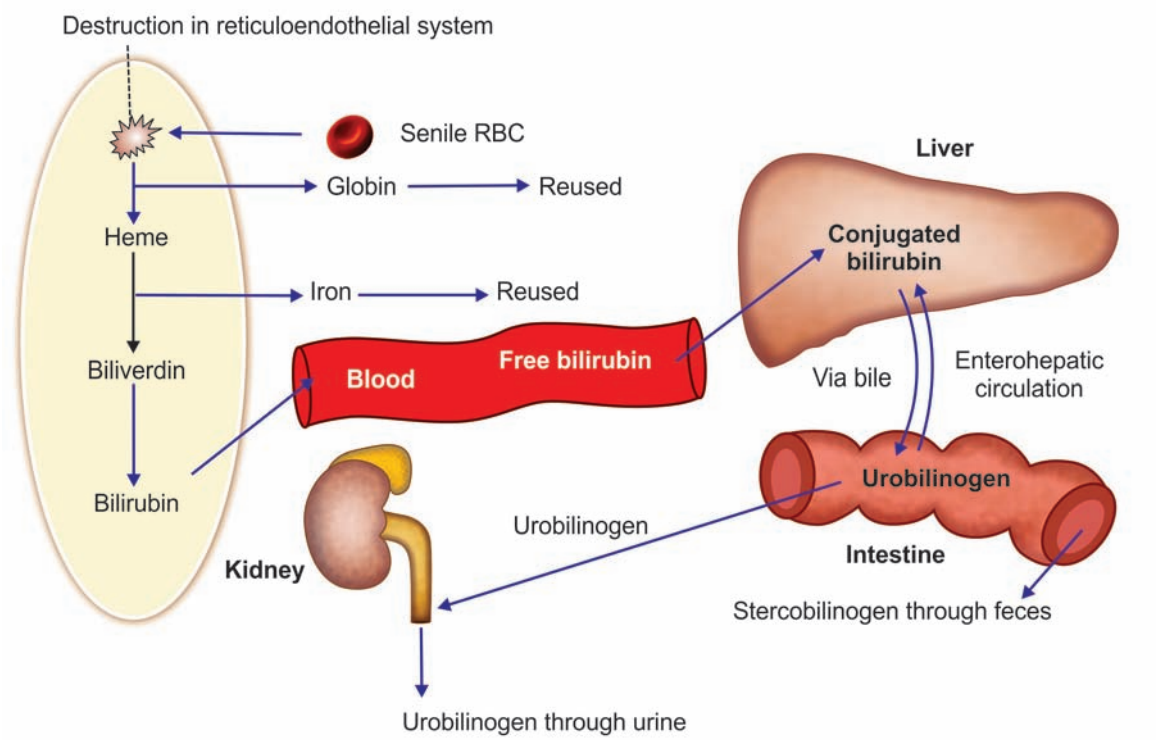

FIGURE 40.8: Formation and circulation of bile pigments

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*

Gallbladder 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.

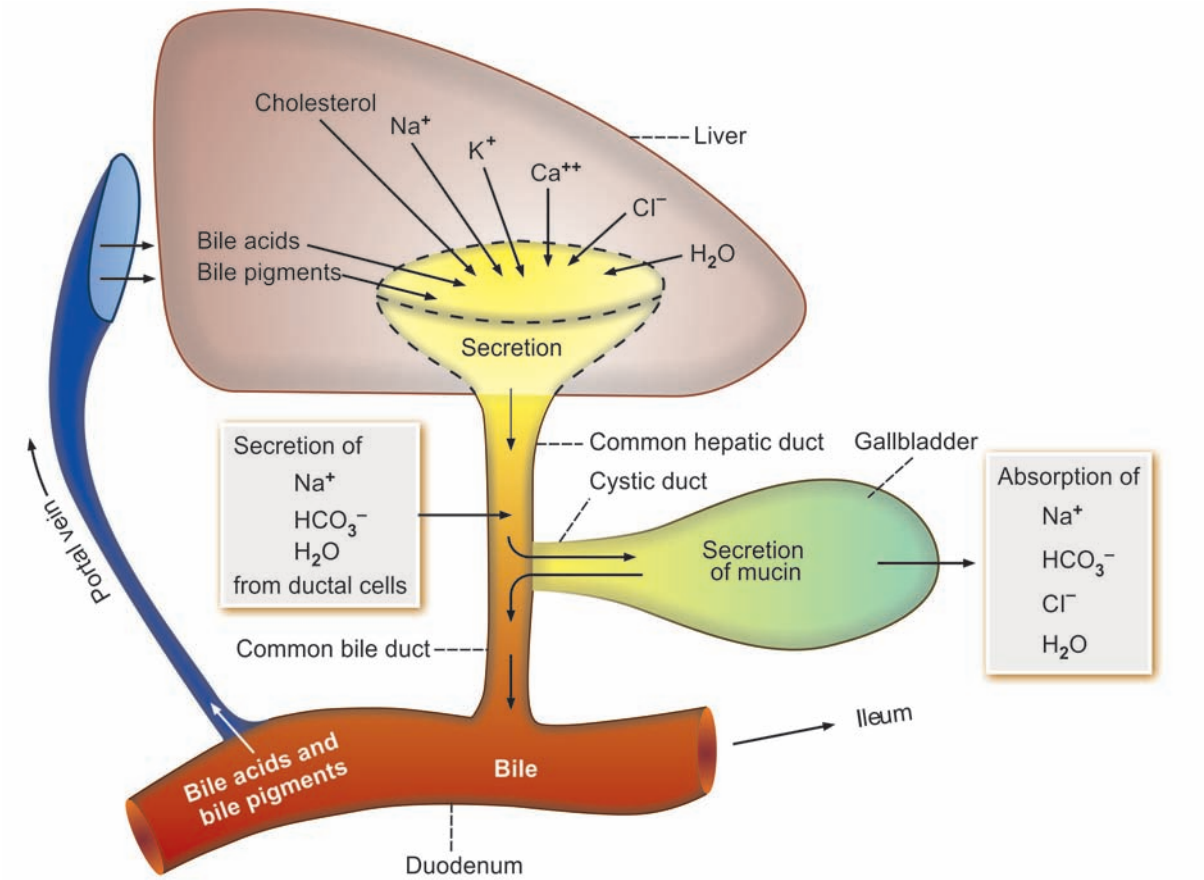

FIGURE 40.9: Diagram showing the formation of bile from liver and changes taking place in the composition of gallbladder bile

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.

Common cholagogues are:

i. Bile salts
ii. Calcium
iii. Fatty acids
iv. Amino acids
v. Inorganic acids

All these substances stimulate the secretion of cholecystokinin, which in turn causes contraction of gallbladder and flow of bile into intestine.

3. *Hydrocholeretic Agents*

Hydrocholeretic agent is a substance which causes the secretion of bile from liver, with large amount of water and less amount of solids. Hydrochloric acid is a hydrocholeretic agent.

APPLIED PHYSIOLOGY

JAUNDICE OR ICTERUS

Jaundice or icterus is the condition characterized by yellow coloration of the skin, mucous membrane and deeper tissues due to increased bilirubin level in blood. The word jaundice is derived from the French word **'jaune'** meaning yellow.

The normal serum bilirubin level is 0.5 to 1.5 mg/dL. Jaundice occurs when bilirubin level exceeds 2 mg/dL.

Types of Jaundice

Jaundice is classified into three types:

1. Prehepatic or hemolytic jaundice
2. Hepatic or hepatocellular jaundice
3. Posthepatic or obstructive jaundice.

1. *Prehepatic or Hemolytic Jaundice*

Hemolytic jaundice is the type of jaundice that occurs because of excessive destruction of RBCs resulting in increased blood level of free (unconjugated) bilirubin. In this condition, the excretory function of liver is normal. But the quantity of bilirubin increases enormously. The liver cells cannot excrete that much excess bilirubin rapidly. Unconjugated bilirubin is insoluble in water and is not excreted in urine. So, it accumulates in the blood resulting in jaundice.

Formation of urobilinogen also increases resulting in the excretion of more amount of urobilinogen in urine.

Causes

Any condition that causes hemolytic anemia can lead to hemolytic jaundice.

Common causes of hemolytic jaundice are:

i. Renal disorder
ii. Hypersplenism
iii. Burns
iv. Infections such as malaria
v. Hemoglobin abnormalities such as sickle cell anemia or thalassemia
vi. Drugs or chemical substances causing red cell damage
vii. Autoimmune diseases.

2. *Hepatic or Hepatocellular or Cholestatic Jaundice*

Hepatic jaundice is the type of jaundice that occurs due to the damage of hepatic cells. Because of the damage, the conjugated bilirubin from liver cannot be excreted and it returns to blood.

Causes

i. Infection (infective jaundice) by virus, resulting in hepatitis (viral hepatitis)
ii. Alcoholic hepatitis
iii. Cirrhosis of liver
iv. Exposure to toxic materials.

3. *Posthepatic or Obstructive or Extrahepatic Jaundice*

Posthepatic type of jaundice occurs because of the obstruction of bile flow at any level of the biliary system. The bile cannot be excreted into small intestine. So, bile salts and bile pigments enter the circulation. The blood contains more amount of conjugated bilirubin (Table 40.2).

Causes

i. Gallstones
ii. Cancer of biliary system or pancreas.

HEPATITIS

Hepatitis is the liver damage caused by many agents. It is characterized by swelling and inadequate functioning of liver. Hepatitis may be acute or chronic. In severe conditions, it may lead to liver failure and death.

Causes and Types

1. Viral infection (viral hepatitis: see below)
2. Bacterial infection like leptospirosis and Q fever
3. Excess consumption of alcohol

TABLE 40.2: Features of different types of jaundice

Features	Prehepatic jaundice (Hemolytic)	Hepatic jaundice (hepatocellular)	Posthepatic jaundice (Obstructive)
Cause	Excess breakdown of RBCs	Liver damage	Obstruction of bile ducts
Type of bilirubin in blood	Unconjucated	Conjugated and unconjugated	Conjugated
Urinary excretion of urobilinogen	Increases	Decreases	Decreases Absent in severe obstruction
Fecal excretion of stercobilinogen	Increases	Decreases (pale feces)	Absent (clay-colored feces)
van den Bergh reaction	Indirect – positive	Biphasic	Direct – positive
Liver functions	Normal	Abnormal	Exaggerated
Blood picture	Anemia Reticulocytosis Abnormal RBC	Normal	Normal
Plasma albumin and globulin	Normal	Albumin – increases Globulin – increases A : G ratio – decreases	Normal
Hemorrhagic tendency	Absent	Present due to lack of vitamin K	Present due to lack of vitamin K

4. Excess administration of drugs like paracetamol
5. Poisons like carbon tetrachloride and aflatoxin
6. Wilson disease (Chapter 151)
7. Circulatory insufficiency
8. Inheritance from mother during parturition.

Viral Hepatitis

Viral hepatitis is the type of hepatitis caused by viruses. It is caused by two types of viruses, hepatitis A and hepatitis B.

Causes of viral hepatitis

i. Mainly by intake of water and food contaminated with hepatitis virus
ii. Sharing needles with infected persons
iii. Accidental prick by infected needle
iv. Having unprotected sex with infected persons
v. Inheritance from mother during parturition
vi. Blood transfusion from infected donors.

Hepatitis caused by hepatitis B virus is more common and considered more serious because it may lead to cirrhosis and cancer of liver.

Features of Hepatitis

1. Fever
2. Nausea
3. Vomiting, diarrhea and loss of appetite
4. Headache and weakness
5. In addition, chronic hepatitis is characterized by
   i. Stomach pain
   ii. Paleness of skin
   iii. Dark-colored urine and pale stool
   iv. Jaundice
   v. Personality changes.

■ CIRRHOSIS OF LIVER

Cirrhosis of liver refers to inflammation and damage of parenchyma of liver. It results in degeneration of hepatic cells and dysfunction of liver.

Causes

1. Infection
2. Retention of bile in liver due to obstruction of ducts of biliary system
3. Enlargement of liver due to intoxication
4. Inflammation around liver (perihepatitis)
5. Infiltration of fat in hepatic cells.

Features

1. Fever, nausea and vomiting
2. Jaundice
3. Increased heart rate and cardiac output
4. Portal hypertension
5. Muscular weakness and wasting of muscles
6. Drowsiness
7. Lack of concentration and confused state of mind
8. Coma in advanced stages.

■ GALLSTONES

Definitions

Gallstone is a solid crystal deposit that is formed by cholesterol, calcium ions and bile pigments in the gallbladder or bile duct. **Cholelithiasis** is the presence of gallstones in gallbladder. **Choledocholithiasis** is the presence of gallstones in the bile ducts.

Formation of Gallstones

Normally, cholesterol present in the bile combines with bile salts and lecithin, which make the cholesterol soluble in water. Under some abnormal conditions, this water-soluble cholesterol precipitates resulting in the formation of gallstone.

Initially, small quantity of cholesterol begins to precipitate forming many small crystals of cholesterol in the mucosa of gallbladder. This stimulates further formation of crystals and the crystals grow larger and larger. Later, bile pigments and calcium are attached to these crystals, resulting in formation of gallstones.

Causes for Gallstone Formation

1. Reduction in bile salts and/or lecithin
2. Excess of cholesterol
3. Disturbed cholesterol metabolism
4. Excess of calcium ions due to increased concentration of bile
5. Damage or infection of gallbladder epithelium. It alters the absorptive function of the mucous membrane of the gallbladder. Sometimes, there is excessive absorption of water or even bile salts, leading to increased concentration of cholesterol, bile pigments and calcium ions
6. Obstruction of bile flow from the gallbladder.

Diagnosis of Gallstone

Presence of gallstone is diagnosed by ultrasound scanning and **cholangiography.** Cholangiography is the radiological study of biliary ducts after the administration of a contrast medium.

Features

Common feature of gallstone is the pain in stomach area or in upper right part of the belly under the ribs. Other features include nausea, vomiting, abdominal bloating and indigestion.

Treatment for Gallstone

Simple cholesterol gallstones can be dissolved over a period of one or two years by giving 1 to 1.5 gm of chemodeoxycholic acid daily. This increases the concentration of bile acids. So, excessive concentration of bile does not occur.

In severe conditions, the gallbladder has to be removed **(cholecystectomy).** Laparoscopic surgery is the common method.

Chapter 41

Small Intestine

- 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.**

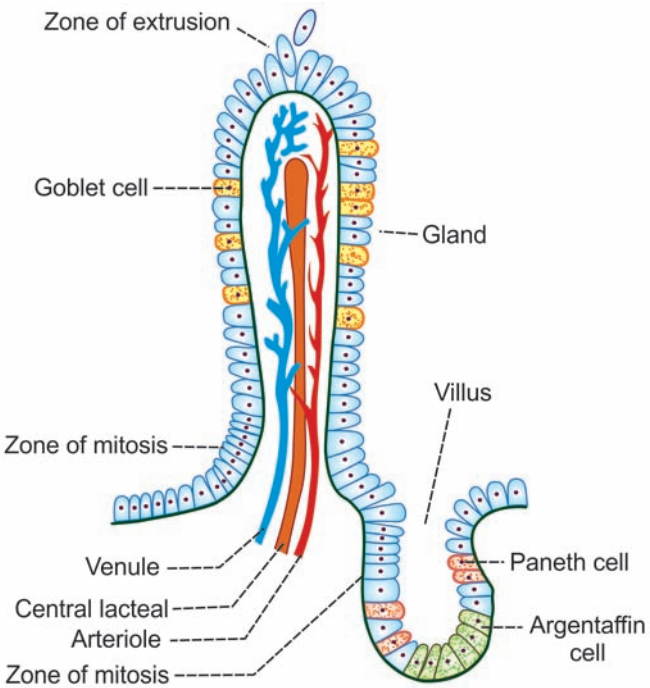

FIGURE 41.1: Intestinal gland and villus

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 partially digested food and convert them into final digestive products. Enzymes are produced and released into 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.

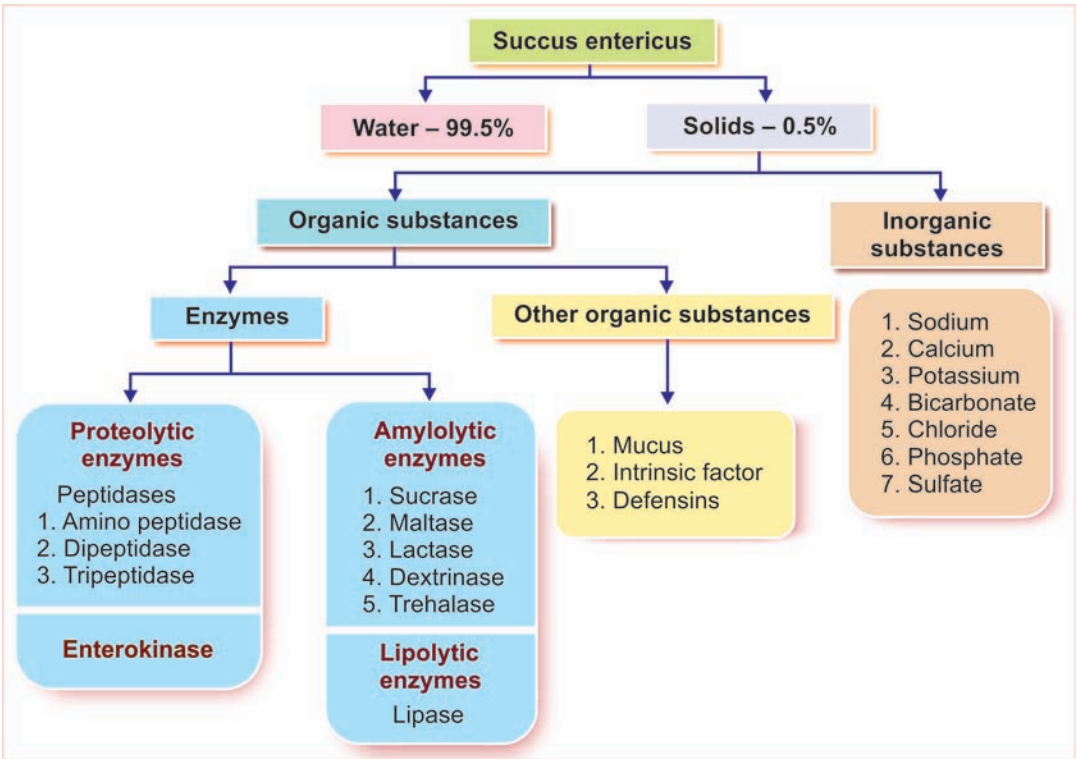

FIGURE 41.2: Composition of succus entericus

■ 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.

APPLIED PHYSIOLOGY

1. MALABSORPTION

Malabsorption is the failure to absorb nutrients such as proteins, carbohydrates, fats and vitamins.

Malabsorption affects growth and development of the body. It also causes specific diseases (see below).

2. MALABSORPTION SYNDROME

Malabsorption syndrome is the condition characterized by the failure of digestion and absorption in small intestine. Malabsorption syndrome is generally caused by **Crohn's disease, tropical sprue, steatorrhea** and **celiac disease.**

3. CROHN'S DISEASE OR ENTERITIS

Enteritis is an inflammatory bowel disease (IBD), characterized by inflammation of small intestine. Usually, it affects the lower part of small intestine, the ileum. The inflammation causes malabsorption and diarrhea.

Causes

Crohn's disease develops because of abnormalities of the immune system. The immune system reacts to a virus or a bacterium, resulting in inflammation of the intestine.

Features

i. Malabsorption of vitamin
ii. Weight loss
iii. Abdominal pain
iv. Diarrhea
v. Rectal bleeding, anemia and fever
vi. Delayed or stunted growth in children.

4. TROPICAL SPRUE

Tropical sprue is a malabsorption syndrome, affecting the residents of or the visitors to tropical areas where the disease is epidemic.

Cause

The cause of this disease is not known and it may be related to infectious organisms.

Features

i. Indigestion
ii. Diarrhea
iii. Anorexia and weight loss
iv. Abdominal and muscle cramps.

5. STEATORRHEA

Steatorrhea is the condition caused by deficiency of pancreatic lipase, resulting in malabsorption of fat. Refer Chapter 39 for details.

6. CELIAC DISEASE

Celiac disease is an autoimmune disorder characterized by the damage of mucosa and atrophy of villi in small intestine, resulting in impaired digestion and absorption. It is also known as **gluten-sensitive enteropathy,** celiac sprue and non-tropical sprue.

Cause

Celiac disease is caused by gluten. It is a protein present in wheat, oats, rye, barley and other grains. **Gluten** is like a poison to individuals with celiac disease, because it damages the intestine severely.

Features

i. Diarrhea
ii. Steatorrhea
iii. Abdominal pain
iv. Weight loss
v. Irritability
vi. Depression.

Large Intestine

Chapter 42

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.

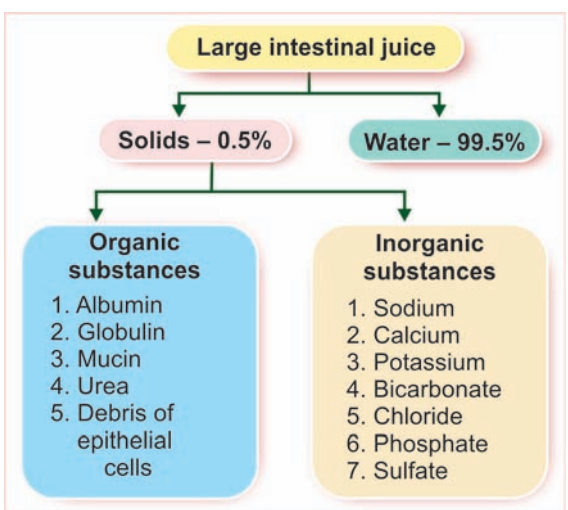

FIGURE 42.1: Composition of large intestinal juice

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.

Components of Dietary Fiber

Major components of dietary fiber are cellulose, hemicelluloses, D-glucans, pectin, lignin and gums. Cellulose, hemicelluloses and pectin are partially degradable, while other components are indigestible. Dietary fiber also contains minerals, antioxidants and other chemicals that are useful for health.

Sources of Dietary Fiber

Sources of dietary fiber are fruits, vegetables, cereals, bread and wheat grain (particularly its outer layer).

Significance of Dietary Fiber

Diet with high dietary fiber has health benefits since dietary fiber:

1. Delays emptying of stomach
2. Increases formation of bulk and soft feces and eases defecation
3. Contains substances such as antioxidants and other useful substances.

When high dietary fiber food is taken, other foods, which may cause some diseases may be decreased in quantity or completely excluded from diet. Diet with high fiber content tends to be low in energy and it may be useful in reducing the body weight. Some components of dietary fiber also reduce blood cholesterol level and thereby decrease the risk for **coronary heart disease** and **gallstones.**

Dietary fiber is suggested for treating or to prevent **constipation** and **bowel syndrome.** It is also useful in treatment of some disorders such as diabetics, cancer, ulcer, etc.

■ APPLIED PHYSIOLOGY

■ DIARRHEA

Diarrhea is the frequent and profuse discharge of intestinal contents in loose and fluid form. It occurs due to the increased movement of intestine. It may be acute or chronic.

Causes

Normally, when digested food passes through colon, large portion of fluid is absorbed and only a semisolid stool remains. In diarrhea, the fluid is not absorbed sufficiently, resulting in watery bowel discharge. Acute diarrhea may be caused by temporary problems like infection and chronic diarrhea may be due to disorders of intestinal mucosa. Thus, the general causes of diarrhea are:

1. *Dietary abuse:* Diarrhea is caused by intake of contaminated water or food, artificial sweeteners found in food, spicy food, etc.
2. *Food intolerance:* Acute diarrhea is caused mainly by indigestion of food substances, particularly lactose, a sugar present in milk and milk products may not be digested easily
3. *Infections by:*
   i. Bacteria such as *Escherichia coli, Salmonella, Shigella,* etc.
   ii. Viruses like rotavirus, hepatitis virus, etc.
   iii. Parasites like *Entamoeba histolytica, Giardia lamblia,* etc.
4. *Reaction to medicines such as:*
   i. Antibiotics
   ii. Antihypertensive drugs
   iii. Antacids containing magnesium
   iv. Laxatives
5. *Intestinal diseases:* Chronic diarrhea occurs during inflammation of intestine, irritable bowel syndrome and abnormal motility of the intestine.

Features

Severe diarrhea results in loss of excess water and electrolytes. This leads to **dehydration** and electrolyte imbalance. Chronic diarrhea results in **hypokalemia** and **metabolic acidosis.** Other features of diarrhea are abdominal pain, nausea and **bloating** (a condition in which the subject feels the abdomen full and tight due to excess intestinal gas).

■ CONSTIPATION

Failure of voiding of feces, which produces discomfort is known as constipation. It is due to the lack of movements necessary for defecation (Chapter 43). Due to the absence of mass movement in colon, feces remain in the large intestine for a long time, resulting in absorption of fluid. So the feces become hard and dry.

Causes

1. *Dietary causes*

Lack of fiber or lack of liquids in diet causes constipation.

2. *Irregular bowel habit*

Irregular bowel habit is most common cause for constipation. It causes constipation by inhibiting the normal defecation reflexes.

3. *Spasm of sigmoid colon*

Spasm in the sigmoid colon **(spastic colon)** prevents its motility, resulting in constipation.

4. *Diseases*

Constipation is common in many types of diseases.

5. *Dysfunction of myenteric plexus in large intestine – megacolon*

Megacolon is the condition characterized by distension and hypertrophy of colon, associated with constipation. It is caused by the absence or damage of ganglionic cells in myenteric plexus, which causes dysfunction of myenteric plexus. It leads to accumulation of large quantity of feces in colon. The colon is distended to a diameter of 4 to 5 inch. It also results in hypertrophy of colon. Congenital development of megacolon is called **Hirschsprung disease.**

6. *Drugs*

The drugs like diuretics, pain relievers (narcotics), antihypertensive drugs (calcium channel blockers), antiparkinson drugs, antidepressants and the anticonvulsants cause constipation.

■ APPENDICITIS

Inflammation of appendix is known as appendicitis. Appendix is a small, worm-like appendage, projecting from cecum of ascending colon. It is situated on the lower right side of the abdomen.

Appendix does not have any function in human beings. But, it can create major problems when diseased. Appendicitis can develop at any age. However, it is very common between 10 and 30 years of age.

Causes

The cause for appendicitis is not known. It may occur by bacterial or viral infection. It also occurs during blockage of connection between appendix and large intestine by feces, foreign body or tumor.

Features

1. Main symptom of appendicitis is the pain, which starts around the umbilicus and then spreads to the lower right side of the abdomen. It becomes severe within 6 to 12 hours
2. Nausea
3. Vomiting
4. Constipation or diarrhea
5. Difficulty in passing gas
6. Low fever
7. Abdominal swelling
8. Loss of appetite.

If not treated immediately, the appendix may rupture and the inflammation will spread to the whole body, leading to severe complications, sometimes even death. Therefore, the treatment of appendicitis is considered as an emergency.

Usual standard treatment for appendicitis is **appendectomy** (surgical removal of appendix).

■ ULCERATIVE COLITIS

Ulcerative colitis is an inflammatory bowel disease (IBD), characterized by the inflammation and ulcerative aberrations in the wall of the large intestine. It is also known as **colitis** or **proctitis.** Rectum and lower part of the colon are commonly affected. Sometimes, the entire colon is affected.

Ulcerative colitis can occur at any age. More commonly, it affects people in the age group of 15 to 30 years. Rarely it affects 50 to 70 years old people.

Cause

Exact cause for ulcerative colitis is not known. However, it is believed that the interaction between the immune system and viral or bacterial infection causes this disease.

Features

1. Abdominal pain
2. Diarrhea with blood in the stools
3. Early fatigue
4. Loss of appetite and weight
5. Arthritis and osteoporosis
6. Eye inflammation
7. Liver diseases like hepatitis, cirrhosis, etc.
8. Skin rashes
9. Anemia.

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.

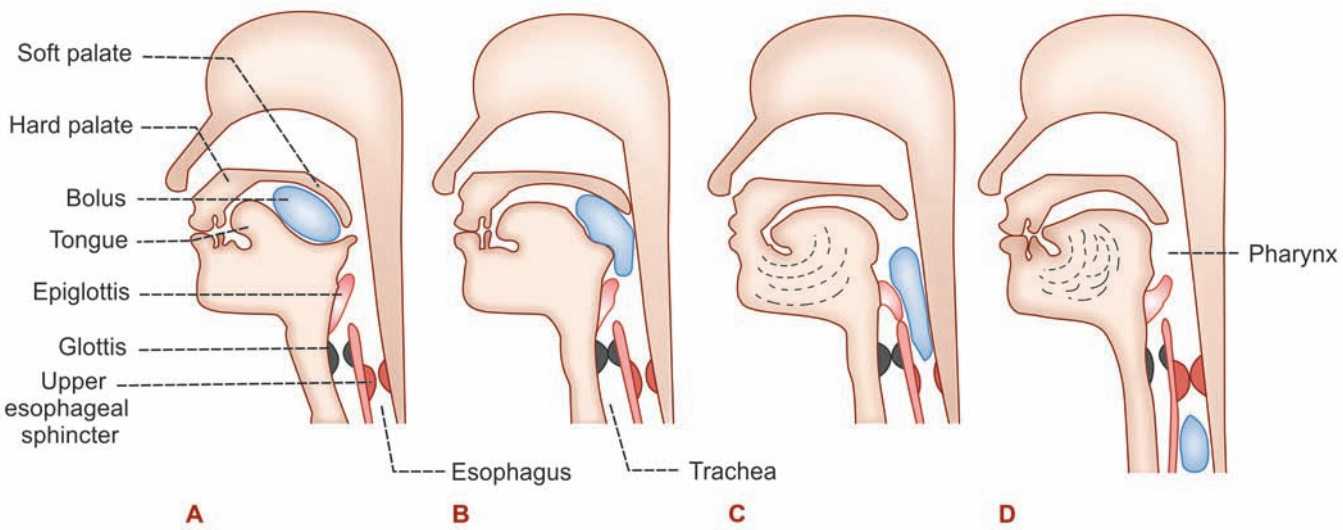

FIGURE 43.1: Stages of deglutition. **A.** Preparatory stage; **B.** Oral stage; **C.** Pharyngeal stage; **D.** Esophageal stage.

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.

Nervous Factor

Nervous factor which regulates the emptying of stomach is the enterogastric reflex.

Enterogastric Reflex

Enterogastric reflex is the reflex that inhibits gastric emptying. It is elicited by the presence of chyme in the duodenum, which prevents further emptying of stomach.

Mechanism of enterogastric reflex

1. Presence of chyme in duodenum causes generation of nerve impulses which are transmitted to stomach by the intrinsic nerve fibers of GI tract. After reaching the stomach, these impulses inhibit emptying.
2. Impulses from duodenum pass via extrinsic sympathetic fibers to stomach and inhibit emptying.
3. Some impulses from duodenum travel through afferent vagal fibers to the brainstem. Normally, brainstem neurons send excitatory impulses to stomach through efferent vagal fibers and stimulate gastric emptying. However, the impulses from duodenum inhibit these brainstem neurons and thereby inhibit gastric emptying.

Factors which initiate enterogastric reflex

1. Duodenal distension
2. Irritation of the duodenal mucosa
3. Acidity of the chyme
4. Osmolality of the chyme
5. Breakdown products of proteins and fats.

Hormonal Factors

When an acid chyme enters the duodenum, the duodenal mucosa releases some hormones which enter the stomach through blood and inhibit the motility of stomach.

Hormones inhibiting gastric motility and emptying

1. Vasoactive intestinal peptide (VIP)
2. Gastric inhibitory peptide (GIP)
3. Secretin
4. Cholecystokinin
5. Somatostatin
6. Peptide YY.

■ APPLIED PHYSIOLOGY – ABNORMAL GASTRIC EMPTYING

1. Gastric Dumping Syndrome

Gastric dumping syndrome or rapid gastric emptying is the condition characterized by series of upper abdominal symptoms. It is due to the rapid or quick dumping of undigested food from stomach into the jejunum. It occurs in patients following partial **gastrectomy** (removal of stomach) or **gastroenterostomy** (gastric bypass surgery). The rapid gastric emptying may begin immediately after taking meals **(early dumping)** or about few hours after taking meals **(late dumping).**

Causes

i. Gastric surgery.
ii. Zollinger-Ellison syndrome (rare disorder due to severe peptic ulcer and gastrin-secreting tumor in pancreas).

Symptoms of early dumping

i. Nausea and vomiting
ii. Bloating (increase in abdominal volume with feeling of abdominal fullness and tightness)
iii. Diarrhea
iv. Sweating and weakness
v. Fatigue and dizziness
vi. Fainting and palpitations (sensation of heart beat).

Symptoms of late dumping

i. Hypoglycemia
ii. Sweating and weakness
iii. Dizziness.

2. Gastroparesis

Gastroparesis is a chronic disorder characterized by delayed gastric emptying. It usually occurs as a secondary disorder, precipitated by a primary cause.

Causes

i. Diabetes mellitus
ii. Postsurgical complications
iii. Motility disorder
iv. Gastric infection
v. Metabolic and endocrine disorder
vi. Decrease in myenteric ganglia (rare).

Symptoms

i. Early satiety (feeling full with small quantity of food)
ii. Nausea
iii. Vomiting
iv. Bloating
v. Upper abdominal discomfort.

■ VOMITING

Vomiting or **emesis** is the abnormal emptying of stomach and upper part of intestine through esophagus and mouth.

■ CAUSES OF VOMITING

1. Presence of irritating contents in GI tract
2. Mechanical stimulation of pharynx
3. Pregnancy
4. Excess intake of alcohol
5. Nauseating sight, odor or taste
6. Unusual stimulation of labyrinthine apparatus, as in the case of sea sickness, air sickness, car sickness or swinging
7. Abnormal stimulation of sensory receptors in other organs like kidney, heart, semicircular canals or uterus
8. Drugs like antibiotics, opiates, etc.
9. Any GI disorder
10. Acute infection like urinary tract infection, influenza, etc.
11. Metabolic disturbances like carbohydrate starvation and ketosis (pregnancy), uremia, ketoacidosis (diabetes) and hypercalcemia.

■ MECHANISM OF VOMITING

Nausea

Vomiting is always preceded by nausea. Nausea is unpleasant sensation which induces the desire for vomiting. It is characterized by secretion of large amount of saliva containing more amount of mucus.

Retching

Strong involuntary movements in the GI tract which start even before actual vomiting. These movements intensify the feeling of vomiting. This condition is called retching **(try to vomit)** and vomiting occurs few minutes after this.

Act of Vomiting

Act of vomiting involves series of movements that takes place in GI tract.

Sequence of events:

1. Beginning of **antiperistalsis,** which runs from ileum towards the mouth through the intestine, pushing the intestinal contents into the stomach within few minutes. Velocity of the antiperistalsis is about 2 to 3 cm/second
2. Deep inspiration followed by temporary cessation of breathing
3. Closure of glottis
4. Upward and forward movement of larynx and hyoid bone
5. Elevation of soft palate
6. Contraction of diaphragm and abdominal muscles with a characteristic jerk, resulting in elevation of intra-abdominal pressure
7. Compression of the stomach between diaphragm and abdominal wall leading to rise in intragastric pressure
8. Simultaneous relaxation of lower esophageal sphincter, esophagus and upper esophageal sphincter
9. Forceful expulsion of gastric contents **(vomitus)** through esophagus, pharynx and mouth.

Movements during act of vomiting throw the vomitus (materials ejected during vomiting) to the exterior through mouth. Some of the movements play important roles by preventing the entry of vomitus through other routes and thereby prevent the adverse effect of the vomitus on many structures.

Such movements are:

1. Closure of glottis and cessation of breathing prevents entry of vomitus into the lungs
2. Elevation of soft palate prevents entry of vomitus into the nasopharynx
3. Larynx and hyoid bone move upward and forward and are placed in this position rigidly. This causes the dilatation of throat, which allows free exit of vomitus.

■ VOMITING REFLEX

Vomiting is a reflex act. Sensory impulses for vomiting arise from the irritated or distended part of GI tract or other organs and are transmitted to the vomiting center through vagus and sympathetic afferent fibers.

Vomiting center is situated bilaterally in medulla oblongata near the nucleus tractus solitarius.

Motor impulses from the vomiting center are transmitted through V, VII, IX, X and XII cranial nerves to the upper part of GI tract; and through spinal nerves to diaphragm and abdominal muscles.

Center for Vomiting during Motion Sickness and Vomiting Induced by Drugs

Center for vomiting during motion sickness and vomiting induced by drugs such as morphine, apomorphine, etc. is on the floor of fourth ventricle. This area is called **chemoreceptor trigger zone.** During motion sickness, the afferent impulses from vestibular apparatus reach vomiting center through this zone.

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

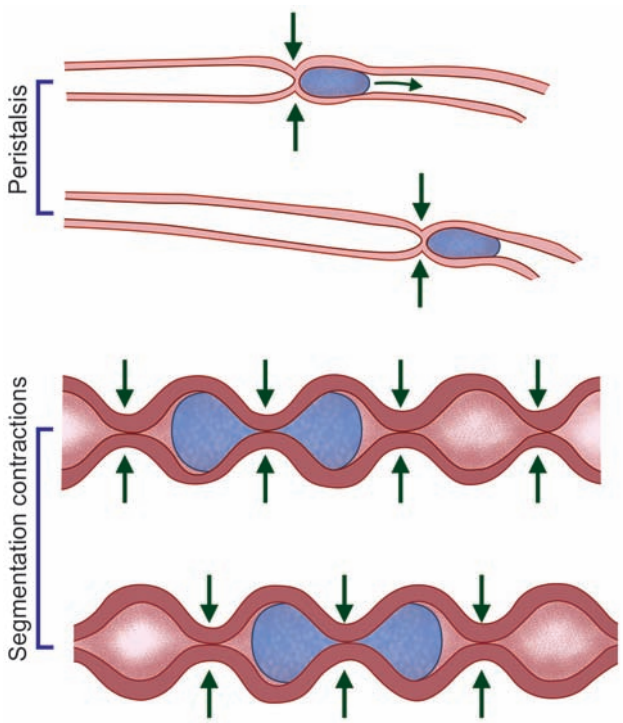

FIGURE 43.2: Movements of small intestine

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.

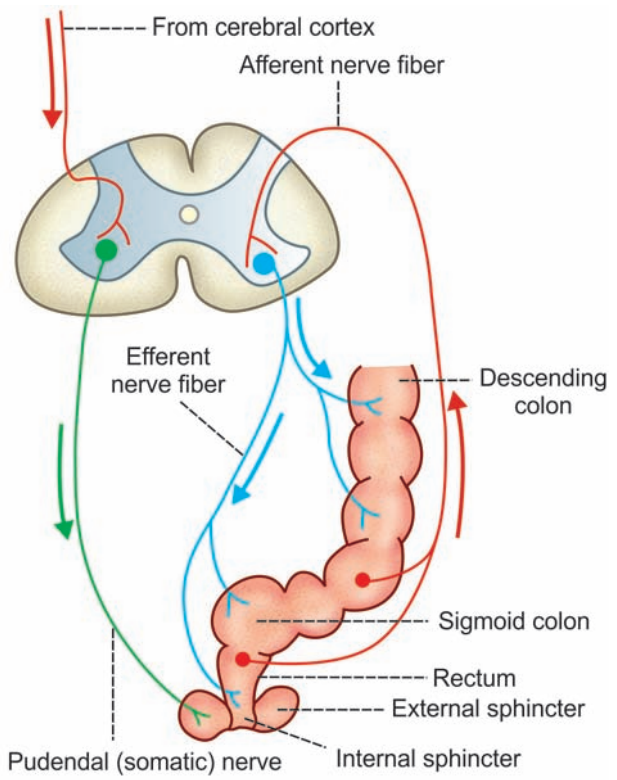

FIGURE 43.3: Defecation reflex. Afferent and efferent fibers of the reflex pass through pelvic (parasympathetic) nerve. Voluntary control of defecation is by pudendal (somatic) nerve. Defecation center is in the sacral segments of spinal cord

1. *Exogenous Gases*

Exogenous gases form about 90% of accumulated gases. These gases enter the GI tract either by swallowing through mouth or drinking carbonated beverages.

2. *Endogenous Gases*

Endogenous gases form about 10% of accumulated gases. These gases are produced by digestion of food stuffs and interaction between bacteria and food stuffs in the intestine.

■ EVACUATION OF ACCUMULATED GASES

Evacuation of accumulated gases usually occurs by two processes:

1. Belching
2. Flatulence.

■ BELCHING

Belching is the process by which the gas accumulated in stomach is expelled through mouth. It is also called **burping.** It occurs because of inflation (distention) of stomach by swallowed air. The distention of the stomach causes abdominal discomfort and the belching expels the air and relieves the discomfort.

Most of the gas accumulated in stomach is expelled through mouth. Only a small amount enters the intestine.

Causes for Accumulation of Gases in Stomach

1. Aerophagia: Swallowing large amounts of air due to gulping the food or drink too rapidly
2. Drinking carbonated beverages
3. During some emotional conditions like anxiety lot of air enters the stomach through mouth.

Act of Belching

Belching is not a simple act and it requires the coordination of several activities such as:

1. Closure of larynx, which prevents entry of liquid or food with the air from stomach into the lungs.
2. Elevation of larynx and relaxation of upper esophageal sphincter. It allows exit of air through esophagus more easily.
3. Opening of lower esophageal sphincter.
4. Descent of diaphragm, which increases abdominal pressure and decreases intrathoracic pressure.

All these activities are responsible for the expulsion of air from stomach to the exterior via esophagus.

■ FLATULENCE

Flatulence is the production of a mixture of intestinal gases. The mixture of gases is known as **flatus** (in Latin, flatus = wind). Expulsion of flatus through anus under pressure is called farting or passing gas. Farting is associated with disagreeable odor (due to odorous gases) and sound (due to vibration of anal sphincter).

Quantity of Flatus

Average flatus released by human is about 500 to 1500 mL per day, with 10 to 25 episodes throughout the day.

Source of Gases in Intestine

Flatulence is the mixture of gases present in the intestine. Flatulence by swallowed air is rare.

Common sources of gases in flatulence are:

1. Bacterial action on undigested sugars and polysaccharides (e.g. starch, cellulose)
2. Digestion of some flatulence producing food stuffs such as cheese, yeast in bread, oats, onion, beans, cabbage, milk, etc.

Constituents of Flatus

Major constituents of flatus:

1. Swallowed non-odorous gases
   i. Nitrogen (major constituent)
   ii. Oxygen
2. Non-odorous gases produced by microbes
   i. Methane
   ii. Carbon dioxide
   iii. Hydrogen
3. Odorous materials such as
   i. Low molecular weight fatty acids like butyric acid
   ii. Reduced sulfur compounds (hydrogen sulfide and carbonyl sulfide).

Gastrointestinal Hormones

Chapter 44

INTRODUCTION

Gastrointestinal (GI) hormones are the hormones secreted in GI tract. These hormones are polypeptides in nature and belong to the family of **local hormones** (Chapter 73). Major function of these hormones is to regulate the secretory activities and motility of the GI tract.

CELLS SECRETING THE HORMONES

Enteroendocrine Cells

Enteroendocrine cells are the **hormone-secreting cells** in GI tract. These are the nerve cells and glandular cells which are present in the gastric mucosa, intestinal mucosa and the pancreatic cells.

Neuroendocrine Cells or APUD Cells

Enteroendocrine cells which secrete hormones from amines are known as **amine precursor uptake and decarboxylation cells** (APUD cells) or neuroendocrine cells. For the synthesis of a GI hormone, first a precursor substance of an amine is taken up by these cells. Later, this precursor substance is decarboxylated to form the amine. From this amine, the hormone is synthesized. Because of the uptake of the amine precursor and decarboxylation of this precursor substance, these cells are called APUD cells. This type of cells is also present in other parts of the body, particularly the brain, lungs and the endocrine glands.

Enterochromaffin Cells

Enteroendocrine cells which secrete serotonin are called enterochromaffin cells.

■ DESCRIPTION OF GASTROINTESTINAL HORMONES

■ 1. GASTRIN

Gastrin is a peptide with 34 amino acid residues. It is secreted mainly by the **G cells** of pyloric glands of stomach. It is also secreted by **TG cells** in **stomach, duodenum** and **jejunum.** In fetus, the islets of Langerhans also secrete this hormone (Table 44.1).

Gastrin is secreted from stomach during the gastric (second) phase of gastric secretion and from small intestine during the intestinal (third) phase of gastric secretion.

Stimulant for Secretion

Stimulants for secretion of gastrin are:

i. Presence of food in the stomach.
ii. Stimulation of local nervous plexus in stomach and small intestine.
iii. **Vagovagal reflex** during the gastric phase of gastric secretion: **Gastrin-releasing polypeptide** is released at the vagal nerve ending. It causes the secretion of gastrin by stimulating the G cells or TG cells.

TABLE 44.1: Gastrointestinal hormones

Hormone	Source of secretion	Actions
Gastrin	G cells in stomach TG cells in GI tract Islets in fetal pancreas Anterior pituitary Brain	Stimulates gastric secretion and motility Promotes growth of gastric mucosa Stimulates release of pancreatic hormones Stimulates secretion of pancreatic juice Stimulates secretion of pancreatic hormones
Secretin	S cells of small intestine	Stimulates secretion of watery and alkaline pancreatic secretion Inhibits gastric secretion and motility Constricts pyloric sphincter Increases potency of cholecystokinin action
Cholecystokinin	I cells of small intestine	Contracts gallbladder Stimulates pancreatic secretion with enzymes Accelerates secretin activity Increases enterokinase secretion Inhibits gastric motility Increases intestinal motility Augments contraction of pyloric sphincter Suppresses hunger Induces drug tolerance to opioids
Gastric inhibitory peptide (GIP)	K cells in duodenum and jejunum Antrum of stomach	Stimulates insulin secretion Inhibits gastric secretion and motility
Vasoactive intestinal polypeptide (VIP)	Stomach Small and large intestines	Dilates splanchnic (peripheral) blood vessels Inhibits Hcl secretion in gastric juice Stimulates secretion of succus entericus Relaxes smooth muscles of intestine Augments acetylcholine action on salivary glands Stimulates insulin secretion
Glucagon	α-cells in pancreas A cells in stomach L cells in intestine	Increases blood sugar level
Glicentin	L cells in duodenum and jejunum	Increases blood sugar level
Glucagon-like polypeptide-1 (GLP-1)	α-cells in pancreas Brain	Stimulates insulin secretion Inhibits gastric motility
GLP-2	L cells in ileum and colon	Suppresses appetite

Contd...

Contd...

Hormone	Source of secretion	Actions
Somatostatin	Hypothalamus D cells in pancreas D cells in stomach and small intestine	Inhibits secretion of growth hormone Inhibits gastric secretion and motility Inhibits secretion of pancreatic juice Inhibits secretion of GI hormones
Pancreatic polypeptide	PP cells in pancreas Small intestine	Increases secretion of glucagons Decreases pancreatic secretion
Peptide YY	L cells of ileum and colon	Inhibits gastric secretion and motility Reduces secretion of pancreatic juice Inhibits intestinal motility and bowel passage Suppresses appetite and food intake
Neuropeptide Y	Ileum and colon Brain and autonomic nervous system (ANS)	Increases blood flow in enteric blood vessels
Motilin	Mo cells in stomach and intestine Enterochromoffin cells in intestine	Accelerates gastric emptying Increases movements of small intestine Increases peristalsis in colon
Substance P	Brain Small intestine	Increases movements of small intestine
Ghrelin	Stomach Hypothalamus Pituitary Kidney Placenta	Promotes growth hormone (GH) release Induces appetite and food intake Stimulates gastric emptying

Actions

Gastrin:

i. Stimulates gastric glands to secrete gastric juice with more pepsin and hydrochloric acid.
ii. Accelerates gastric motility.
iii. Promotes growth of gastric mucosa.
iv. Stimulates secretion of pancreatic juice, which is rich in enzymes.
v. Stimulates islets of Langerhans in pancreas to release pancreatic hormones.

■ 2. SECRETIN

Secretin is a peptide hormone with 27 amino acid residues. Historical importance of secretin is that, it was the first ever hormone discovered. It was discovered in 1902 by Bayliss and Starling. It is secreted by the **S cells** of **duodenum, jejunum** and **ileum.**

Secretin is first produced in an inactive form called **prosecretin.** It is converted into secretin by the acidity of chyme.

Stimulant for Secretion

Stimulant for the release and activation of prosecretin is the **acid chyme** entering the duodenum from stomach. Products of protein digestion also stimulate secretin secretion.

Actions

Major actions

Secretin stimulates exocrine pancreatic secretion. It acts on the cells of pancreatic ductule via cyclic AMP and causes secretion of large amount of watery juice with high content of bicarbonate ion. Bicarbonate content of pancreatic juice (released by secretin) has functional significance (Chapter 39).

Other actions

Secretin:

i. Inhibits secretion of gastric juice
ii. Inhibits motility of stomach
iii. Causes constriction of pyloric sphincter
iv. Increases the potency of action of cholecystokinin on pancreatic secretion.

■ 3. CHOLECYSTOKININ

Cholecystokinin is made up of 39 amino acid residues. Previously it was thought that there were two separate hormones, namely pancreozymin and cholecystokinin. It

was thought that pancreozymin stimulated the secretion of pancreatic juice with large amount of enzymes and the cholecystokinin stimulated the contraction of gallbladder. But now it is established that the same hormone has actions on both pancreas and gallbladder. So, it is named as **cholecystokinin-pancreozymin** (CCK-PZ) or cholecystokinin (CCK).

Cholecystokinin is secreted by **I cells** in mucosa of **duodenum** and **jejunum.** A small quantity of the hormone is secreted in the **ileum** also.

Stimulant for Secretion

Stimulant for the release of this hormone is the presence of chyme-containing digestive products of fats and proteins, viz. fatty acids, peptides and amino acids in the upper part of small intestine.

Actions

Major actions

Cholecystokinin:

i. Contracts gallbladder.
ii. Stimulates exocrine pancreatic secretion: It activates the pancreatic acinar cells via the second messenger inositol triphosphate. Cholecystokinin causes secretion of pancreatic juice with large amount of enzymes.

Other actions

Cholecystokinin:

i. Accelerates the activity of secretin to produce alkaline pancreatic juice, with large amount of bicarbonate ions.
ii. Increases the secretion of enterokinase.
iii. Inhibits the gastric motility.
iv. Increases the motility of intestine.
v. Augments contraction of pyloric sphincter.
vi. Plays an important role in satiety by suppressing hunger.
vii. Induces drug tolerance to opioids.

■ 4. GLUCOSE-DEPENDENT INSULINOTROPIC HORMONE

Earlier it was called **gastric inhibitory peptide** (GIP). It is a peptide hormone, formed by 42 amino acid residues. It is secreted by **K cells** in **duodenum** and in **jejunum.** It is also secreted in antrum of **stomach.**

Stimulant for Secretion

GIP is secreted when chyme containing **glucose** and **fat** enters the duodenum.

Actions

Gastric inhibitory peptide (GIP):

i. Stimulates the beta cells in the islets of Langerhans in pancreas to release insulin. It causes insulin secretion, whenever chyme with glucose enters the small intestine. Hence it is called glucose-dependent insulinotropic hormone.
ii. Inhibits the secretion of gastric juice.
iii. Inhibits gastric motility.

Recent studies reveal that GIP does not show significant action on gastric secretion.

■ 5. VASOACTIVE INTESTINAL POLYPEPTIDE

Vasoactive intestinal polypeptide (VIP) contains 28 amino acid residues. This polypeptide is secreted in the **stomach** and **small intestine.** A small amount of this hormone is also secreted in large intestine.

Stimulant for Secretion

Presence of **acid chyme** in the stomach and intestine causes secretion of VIP.

Actions

Vasoactive intestinal polypeptide (VIP):

i. Dilates splanchnic (peripheral) blood vessels.
ii. Inhibits hydrochloric acid secretion in gastric juice.
iii. Stimulates secretion of succus entericus with large amounts of electrolytes and water.
iv. Relaxes smooth muscles of intestine.
v. Augments action of acetylcholine on salivary glands.
vi. Stimulates insulin secretion.

■ 6. GLUCAGON

Glucagon has 29 amino acid residues. It is secreted mainly by **alpha cells** of islets of Langerhans in pancreas. It is also secreted by **A cells** in the **stomach** and **L cells** in the **intestine.** In intestine, it is secreted as **preproglucagon.**

Stimulant for Secretion

Presence of food with more **fat** and **protein** in the stomach is the stimulant for glucagon secretion in stomach and duodenum. **Hypoglycemia** is the stimulant for secretion of pancreatic glucagon.

Action

Glucagon increases blood sugar level (Chapter 69).

■ 7. GLICENTIN

Glicentin polypeptide is secreted by L cells in duodenum and jejunum and **α-cells** of pancreatic islets. It is also secreted in **brain.**

Precursor of this hormone is the **preproglucagon.** In intestine, the preproglucagon is converted into glicentin and glucagon-like polypeptide-2 (GLP-2). In pancreas, it is converted into glucagon, glucagon-like polypeptide-1 (GLP-1) and major proglucagon fragment.

Stimulant for Secretion

Glicentin is secreted when chyme with **fat** and **protein** enters the intestine.

Action

Like glucagon, glicentin also increases the blood sugar level.

■ 8. GLUCAGON-LIKE POLYPEPTIDE-1

Glucagon-like polypeptide-1 (GLP-1) is secreted in **α-cells** of pancreatic islets (see above). Structurally, it is similar to GLP-2 and glucagon. It is found in brain also.

Stimulant for Secretion

Presence of food with **glucose** in the small intestine stimulates the release of GLP-1.

Actions

Glucagon-like polypeptide-1 (GLP-1):

i. Stimulates the insulin secretion from β-cells of islets in pancreas
ii. Inhibits gastric motility.

■ 9. GLUCAGON-LIKE POLYPEPTIDE-2

Glucagon-like polypeptide-2 (GLP-2) is secreted by **L cells** in **ileum** and **colon** (see above). Structurally, it is similar to GLP-1 and glucagons. Like GLP-1, it is also found in brain.

Stimulant for Secretion

Presence of food with **glucose** in the small intestine stimulates the release of GLP-2 also.

Action

GLP-2 is believed to suppress appetite.

■ 10. SOMATOSTATIN

Somatostatin was first found in **hypothalamus** and named as **growth hormone-inhibiting hormone.** Now it is found in **D cells** of **stomach** and upper part of **small intestine** and **D cells** of **pancreatic** islets also. Somatostatin is secreted in two forms, one with 14 amino acids and the other one with 28 amino acids.

Stimulant for Secretion

Presence of chyme with **glucose** and **proteins** in stomach and small intestine causes release of somatostatin.

Actions

Somatostatin:

i. Inhibits the secretion of growth hormone (GH) and thyroid-stimulating hormone (TSH) from anterior pituitary
ii. Inhibits gastric secretion and motility
iii. Inhibits secretion of pancreatic juice
iv. Inhibits secretion of GI hormones such as:
    a. Gastrin
    b. Cholecystokinin (CCK)
    c. Vasoactive intestinal polypeptide (VIP)
    d. Gastric inhibitory peptide (GIP).

■ 11. PANCREATIC POLYPEPTIDE

Source of Secretion

Pancreatic polypeptide is a polypeptide with 36 amino acid residues. It is secreted mainly by the **PP cells** of the islets of Langerhans in **pancreas.** It is also found in **small intestine** (Table 44.1).

Stimulant for Secretion

Pancreatic polypeptide is secreted by the presence of chyme with **proteins** in the small intestine. It is also secreted in conditions like **hypoglycemia, fasting** and **exercise.**

Actions

Pancreatic polypeptide:

i. Increases the secretion of glucagon from α-cells of islets of Langerhans in pancreas.
ii. Decreases the secretion of pancreatic juice from exocrine part of pancreas.

■ 12. PEPTIDE YY

Polypeptide YY with 36 amino acid residues, is structurally related to pancreatic polypeptide and neuropeptide Y. It is secreted in **L cells** of **ileum** and **colon.**

Stimulant for Secretion

Presence of **fat**-containing chyme stimulates the release of peptide YY.

Actions

Peptide YY:

i. Inhibits gastric secretion and motility
ii. Reduces secretion of pancreatic juice
iii. Inhibits the intestinal motility and stops passage of bowel beyond ileum (ileal brake)
iv. Suppresses appetite and food intake.

■ 13. NEUROPEPTIDE Y

Neuropeptide Y contains 36 amino acid residues. It is structurally related to pancreatic polypeptide and peptide YY. It is secreted by **enteric nerve endings** particularly in **ileum** and **colon.** It is also secreted in medulla, hypothalamus and neurons of autonomic nervous system (ANS).

Stimulant for Secretion

Secretion of neuropeptide Y is stimulated by **fat**-containing chyme.

Action

Neuropeptide Y increases the blood flow in enteric blood vessels and stimulates food intake (Chapter 141).

■ 14. MOTILIN

Motilin is built by 22 amino acid residues. It is secreted by **Mo cells,** which are present in **stomach** and **intestine.** It is also believed to be secreted by enterochromoffin cells of intestine.

Stimulant for Secretion

Motilin is secreted when the **chyme** from stomach enters the duodenum.

Actions

Motilin:

i. Accelerates gastric emptying
ii. Increases the mixing and propulsive movements of small intestine
iii. Increases the peristalsis in colon.

■ 15. SUBSTANCE P

Source of Secretion

Substance P is a neurotransmitter with 11 amino acid residues. It is secreted at the **pain nerve endings** in **brain** and **enteric nerve endings** in **small intestine.**

Stimulant for Secretion

Secretion of substance P in intestine is caused by the presence of **chyme.**

Actions

In GI tract, substance P increases the mixing and propulsive movements of small intestine (refer Chapter 141 for its actions in brain).

■ 16. GHRELIN

Ghrelin is a recently discovered hormone. This 28 amino acid polypeptide is synthesized by **epithelial cells** in the fundus of **stomach.** It is also produced in smaller amounts in hypothalamus, pituitary, kidney and placenta.

Stimulant for Secretion

Secretion of ghrelin increases during **fasting** and decreases when stomach is full.

Actions

Ghrelin:

i. Promotes the secretion of growth hormone (GH) by stimulating somatotropes (growth hormone synthesizing cells) in anterior pituitary. Receptors for this hormone called growth hormone secretogogues receptor (GHS-R) were identified in the somatotropes before the discovery of the hormone itself. These receptors are also found in adipose tissue, heart and hypothalamus.
ii. Induces appetite and food intake by acting via feeding center in hypothalamus (Chapter 149).
iii. Stimulates gastric emptying.

■ OTHER GASTROINTESTINAL HORMONES

Mucosa of GI tract secretes many other hormones such as:

1. Enkephalins
2. Dynorphin
3. Neurotensin
4. Serotonin
5. Urogastrone
6. Enterocrinin
7. Villikinin
8. Guanylin
9. Bombesin.

However, the significant biological actions of these hormones on GI tract are not clear.

Digestion, Absorption and Metabolism of Carbohydrates

Chapter 45

- CARBOHYDRATES IN DIET
- DIGESTION
- ABSORPTION
- METABOLISM
- DIETARY FIBER

CARBOHYDRATES IN DIET

Human diet contains three types of carbohydrates:

1. POLYSACCHARIDES

Large polysaccharides are glycogen, amylose and amylopectin, which are in the form of starch (glucose polymers). Glycogen is available in **non-vegetarian diet.** Amylose and amylopectin are available in **vegetarian diet** because of their plant origin.

2. DISACCHARIDES

Two types of disaccharides are available in the diet.

i. Sucrose (Glucose + Fructose), which is called table sugar or cane sugar
ii. Lactose (Glucose + Galactose), which is the sugar available in milk.

3. MONOSACCHARIDES

Monosaccharides consumed in human diet are mostly glucose and fructose.

Other carbohydrates in the diet include

i. Alcohol
ii. Lactic acid
iii. Pyruvic acid
iv. Pectins
v. Dextrins
vi. Carbohydrates in meat.

Diet also contains large amount of **cellulose,** which cannot be digested in the human GI tract so it is not considered as a food for human beings.

DIGESTION OF CARBOHYDRATES

IN THE MOUTH

Enzymes involved in the digestion of carbohydrates are known as **amylolytic enzymes.** The only amylolytic enzyme present in saliva is the salivary amylase or ptyalin (Chapter 37).

IN THE STOMACH

Gastric juice contains a **weak amylase,** which plays a minor role in digestion of carbohydrates.

IN THE INTESTINE

Amylolytic enzymes present in the small intestine are derived from pancreatic juice and succus entericus (Table 45.1).

Amylolytic Enzyme in Pancreatic Juice

Pancreatic juice contains **pancreatic amylase** (Chapter 39).

Amylolytic Enzymes in Succus Entericus

Amylolytic enzymes present in succus entericus are **maltase, sucrase, lactase, dextrinase** and **trehalase** (Chapter 41).

FINAL PRODUCTS OF CARBOHYDRATE DIGESTION

Final products of carbohydrate digestion are monosaccharides, which are glucose, fructose and galactose.

TABLE 45.1: Digestion of carbohydrates

Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	Salivary amylase	Polysaccharides – cooked starch	Disaccharides – dextrin and maltose
Stomach	Gastric juice	Gastric amylase	Weak amylase	The action is negligible
Small intestine	Pancreatic juice	Pancreatic amylase	Polysaccharides	Disaccharides – Dextrin, maltose and maltriose
	Succus entericus	Sucrase	Sucrose	Glucose and fructose
		Maltase	Maltose and maltriose	Glucose
		Lactase	Lactose	Glucose and galactose
		Dextrinase	Dextrin, maltose and maltriose	Glucose
		Trehalase	Trehalose	Glucose

Glucose represents 80% of the final product of carbohydrate digestion. Galactose and fructose represent the remaining 20%.

■ ABSORPTION OF CARBOHYDRATES

Carbohydrates are absorbed from the small intestine mainly as monosaccharides, viz. glucose, galactose and fructose.

■ ABSORPTION OF GLUCOSE

Glucose is transported from the lumen of small intestine into the epithelial cells in the mucus membrane of small intestine, by means of sodium cotransport. Energy for this is obtained by the binding process of sodium ion and glucose molecule to carrier protein.

From the epithelial cell, glucose is absorbed into the portal vein by **facilitated diffusion.** However, sodium ion moves laterally into the intercellular space. From here, it is transported into blood by active transport, utilizing the energy liberated by breakdown of ATP.

■ ABSORPTION OF GALACTOSE

Galactose is also absorbed from the small intestine in the same mechanism as that of glucose.

■ ABSORPTION OF FRUCTOSE

Fructose is absorbed into blood by means of **facilitated diffusion.** Some molecules of fructose are converted into glucose. Glucose is absorbed as described above.

■ METABOLISM OF CARBOHYDRATES

Metabolism is the process in which food substances undergo chemical and energy transformation. After digestion and absorption, food substances must be utilized by the body. The utilization occurs mainly by oxidative process in which the carbohydrates, proteins and lipids are burnt slowly to release energy. This process is known as catabolism.

Part of the released energy is utilized by tissues for physiological actions and rest of the energy is stored as rich energy phosphate bonds and in the form of proteins, carbohydrates and lipids in the tissues. This process is called anabolism.

Metabolism of carbohydrates is given in the form of schematic diagram (Fig. 45.1).

■ 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 digestible 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.

Components of Dietary Fiber

Major components of dietary fiber are cellulose, hemicelluloses, D-glucans, pectin, lignin and gums. Cellulose, hemicelluloses and pectin are partially degradable, while other components are indigestible. Dietary fiber also contains minerals, antioxidants and other chemicals that are useful for health.

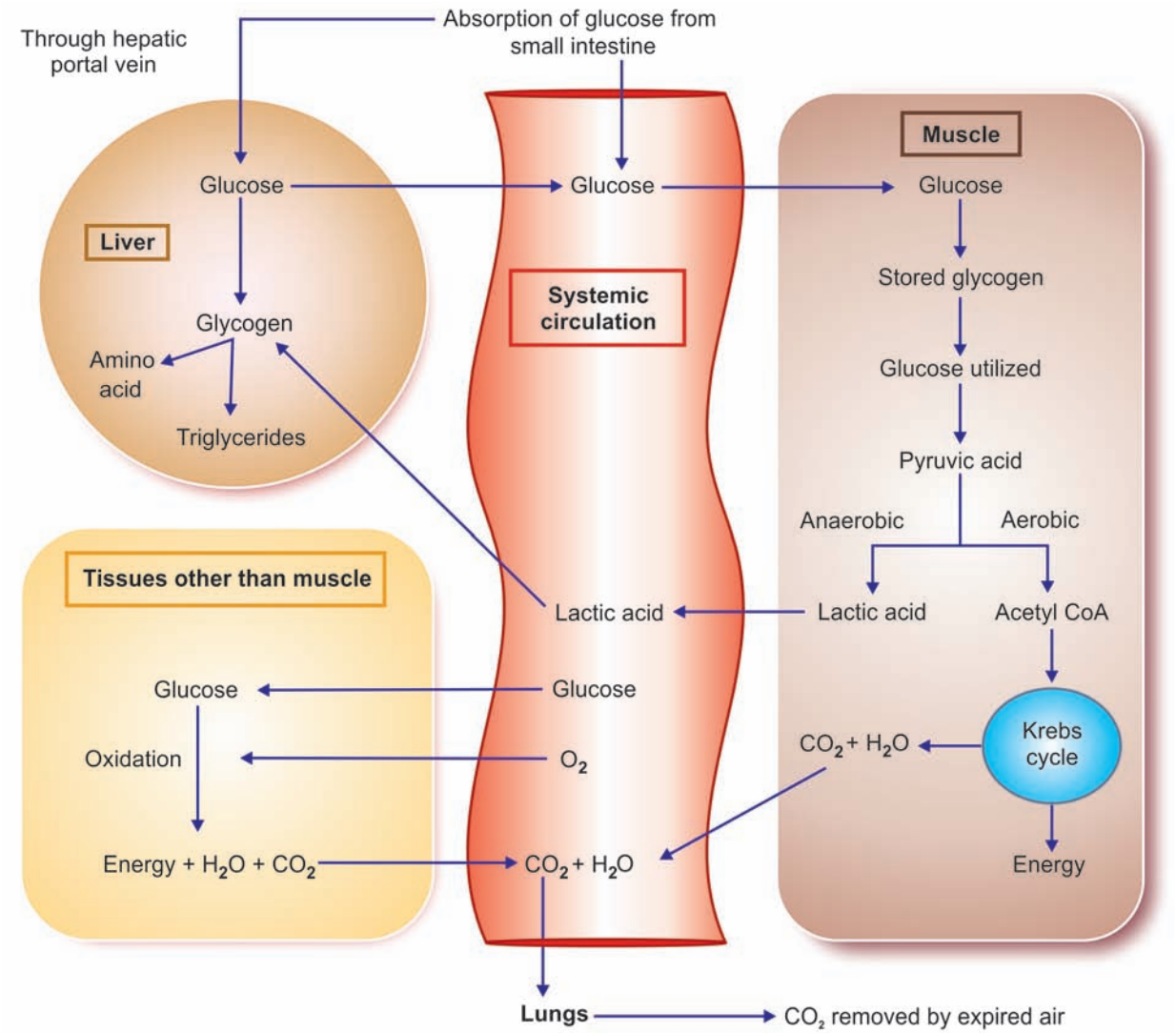

FIGURE 45.1: Schematic diagram of carbohydrate metabolism

Source of Dietary Fiber

Source of dietary fiber are fruits, vegetables, cereals, bread and wheat grain (particularly its outer layer).

Health Benefits of Dietary Fiber

1. By intake of high dietary fiber food, some disease-producing food substances may be decreased in quantity or completely excluded in diet
2. Dietary fiber helps in weight maintenance because it requires more chewing and promotes **hunger satisfaction** by delaying the emptying of stomach and by giving the person a sense of fullness of stomach
3. Diet with high fiber content tends to be low in energy and it is also useful in reducing the body weight
4. Dietary fiber increases the formation of bulk and soft feces and eases defecation
5. It contains some useful substances such as antioxidants
6. Some components of dietary fiber also reduce blood cholesterol level and thereby, decrease the risk of some diseases such as **coronary heart disease** and **gallstones**
7. Dietary fiber is also suggested to prevent or to treat some disorders such as **constipation, bowel syndrome, diabetics, ulcer** and **cancer.**

Digestion, Absorption and Metabolism of Proteins

Chapter 46

- PROTEINS IN DIET
- DIGESTION
- ABSORPTION
- METABOLISM

PROTEINS IN DIET

Foodstuffs containing high protein content are meat, fish, egg and milk. Proteins are also available in wheat, soybeans, oats and various types of pulses.

Proteins present in common foodstuffs are:

1. *Wheat:* Glutenin and gliadin, which constitute gluten
2. *Milk:* Casein, lactalbumin, albumin and myosin
3. *Egg:* Albumin and vitellin
4. *Meat:* Collagen, albumin and myosin.

Dietary proteins are formed by long chains of amino acids, bound together by peptide linkages.

DIGESTION OF PROTEINS

Enzymes responsible for the digestion of proteins are called **proteolytic enzymes.**

IN THE MOUTH

Digestion of proteins does not occur in mouth, since saliva does not contain any proteolytic enzymes. So, the digestion of proteins starts only in stomach (Table 46.1).

TABLE 46.1: Digestion of proteins

Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	No proteolytic enzyme	Polysaccharides – cooked starch	Disaccharides – dextrin and maltose
Stomach	Gastric juice	Pepsin	Proteins	Proteoses, peptones, large polypeptides
Small intestine	Pancreatic juice	Trypsin	Proteoses Peptones	Dipeptides Tripeptides Polypeptides
		Chymotrypsin		
		Carboxypeptidases A and B	Dipeptides Tripeptides Polypeptides	Amino acids
	Succus entericus	Dipeptidases	Dipeptides	Amino acids
		Tripeptidases	Tripeptides	
		Amino peptidases	Large polypeptides	

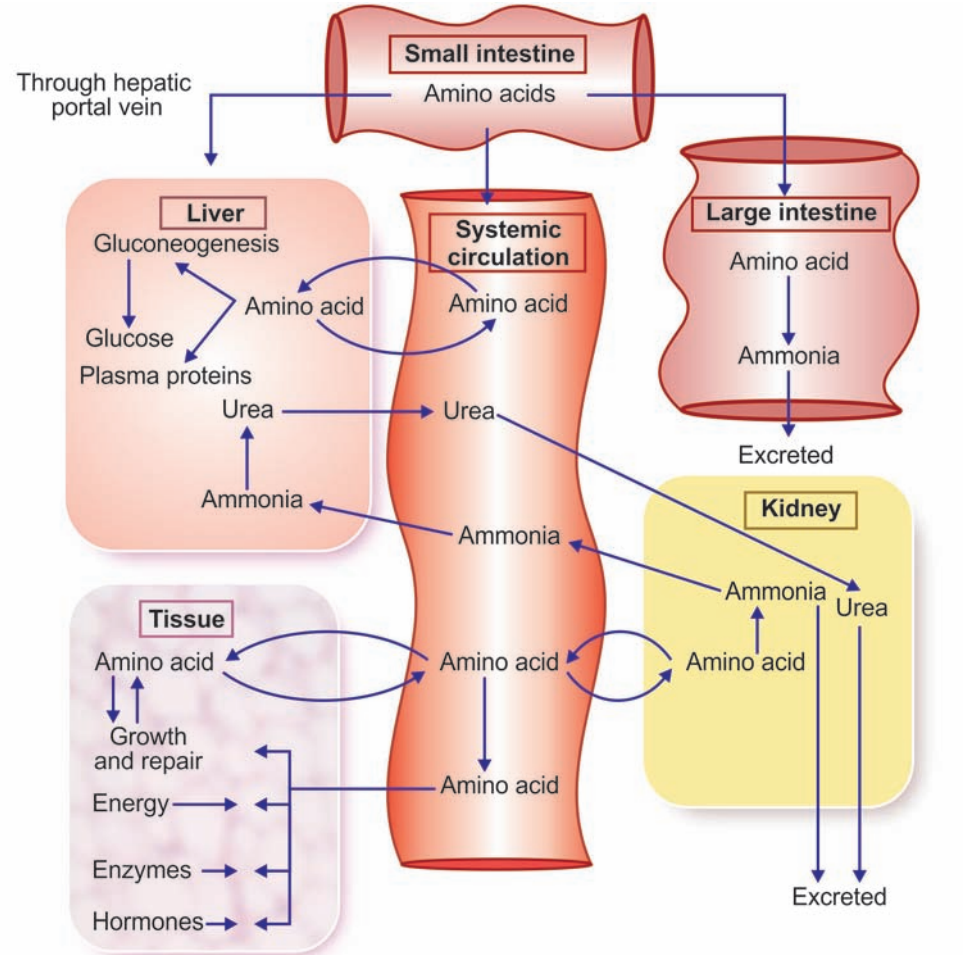

FIGURE 46.1: Schematic diagram of protein metabolism

■ IN THE STOMACH

Pepsin is the only proteolytic enzyme in gastric juice (Chapter 38). **Rennin** is also present in gastric juice. But it is absent in human.

■ IN THE SMALL INTESTINE

Most of the proteins are digested in the duodenum and jejunum by the proteolytic enzymes of the pancreatic juice and succus entericus.

Proteolytic Enzymes in Pancreatic Juice

Pancreatic juice contains **trypsin, chymotrypsin** and **carboxypeptidases.** Trypsin and chymotrypsin are called **endopeptidases,** as these two enzymes break the interior bonds of the protein molecules (Chapter 39).

Proteolytic Enzymes in Succus Entericus

Final digestion of proteins is by the proteolytic enzymes present in the succus entericus. It contains **dipeptidases, tripeptidases** and **aminopeptidases** (Chapter 41).

■ FINAL PRODUCTS OF PROTEIN DIGESTION

Final products of protein digestion are the amino acids, which are absorbed into blood from intestine.

■ ABSORPTION OF PROTEINS

Proteins are absorbed in the form of amino acids from small intestine. The levo amino acids are actively absorbed by means of **sodium cotransport,** whereas, the dextro amino acids are absorbed by means of **facilitated diffusion.**

Absorption of amino acids is faster in duodenum and jejunum and slower in ileum.

■ METABOLISM OF PROTEINS

Metabolism of proteins is given in the form of a schematic diagram (Fig. 46.1).

Digestion, Absorption and Metabolism of Lipids

Chapter 47

- LIPIDS IN DIET
- DIGESTION
- ABSORPTION
- STORAGE
- TRANSPORT IN BLOOD – LIPOPROTEINS
- ADIPOSE TISSUE
- METABOLISM
- LIPID PROFILE

LIPIDS IN DIET

Lipids are mostly consumed in the form of **neutral fats,** which are also known as **triglycerides.** Triglycerides are made up of glycerol nucleus and free fatty acids. Triglycerides form the major constituent in foods of animal origin and much less in foods of plant origin. Apart from triglycerides, usual diet also contains small quantities of **cholesterol** and **cholesterol esters.**

Dietary fats are classified into two types:

1. Saturated fats
2. Unsaturated fats.

SATURATED FATS

Saturated fats are the fats which contain triglycerides formed from only saturated fatty acids. The fatty acids having maximum amount of hydrogen ions without any double bonds between carbon atoms are called saturated fatty acids.

UNSATURATED FATS

Fats containing unsaturated fatty acids are known as unsaturated fats. Unsaturated fatty acids are fatty acids formed by dehydrogenation of saturated fatty acids.

Unsaturated fats are classified into three types:

1. Monounsaturated fats
2. Polyunsaturated fats
3. Trans fats.

1. *Monounsaturated Fats*

Unsaturated fats which contain one double bond between the carbon atoms are called monounsaturated fats.

2. *Polyunsaturated Fats*

Unsaturated fats with more than one double bond between the carbon atoms are called polyunsaturated fats. Polyunsaturated fats belong to the family of essential fatty acids (fatty acids required in diet).

Polyunsaturated fats are of two types:

1. **Omega-3** fats or omega-3 fatty acids having double bond in the third space from the end of the carbon chain
2. **Omega-6** fats or omega-6 fatty acids having double bond in the sixth space from the end of the carbon chain.

Both omega-3 and omega-6 fatty acids are beneficial to the body. However, consuming too much of omega-6 fatty acids results in hazards than benefits. So, the diet containing 3 : 1 ratio of omega-6 to omega-3 fatty acids is often recommended by experts.

3. *Trans Fats*

Trans fats or trans fatty acids are unsaturated fatty acids, with molecules containing trans (across or opposite side) double bonds between carbon atoms.

Sources and the functions of the different types of dietary fats are listed in Table 47.1.

■ DIGESTION OF LIPIDS

Lipids are digested by **lipolytic enzymes.**

■ IN THE MOUTH

Saliva contains **lingual lipase.** This enzyme is secreted by lingual glands of mouth and swallowed along with saliva. So, the lipid digestion does not commence in the mouth (Table 47.2) (Chapter 37).

■ IN THE STOMACH

Gastric lipase or **tributyrase** is the lipolytic enzyme present in gastric juice (Chapter 38).

■ IN THE INTESTINE

Almost all the lipids are digested in the small intestine because of the availability of bile salts, **pancreatic lipolytic enzymes** and **intestinal lipase.**

Role of Bile Salts

Bile salts play an important role in the digestion of lipids (Chapter 40).

Lipolytic Enzymes in Pancreatic Juice

Pancreatic lipase is the most important enzyme for the digestion of fats. Other lipolytic enzymes of pancreatic juice are cholesterol ester hydrolase, phospholipase A and phospholipase B (Chapter 39).

Lipolytic Enzyme in Succus Entericus

Intestinal lipase is the only lipolytic enzyme present in succus entericus (Chapter 41).

■ FINAL PRODUCTS OF FAT DIGESTION

Fatty acids, cholesterol and monoglycerides are the final products of lipid digestion.

■ ABSORPTION OF LIPIDS

Monoglycerides, cholesterol and fatty acids from the micelles enter the cells of intestinal mucosa by simple diffusion.

From here, further transport occurs as follows:

1. In the mucosal cells, most of the monoglycerides are converted into triglycerides. Triglycerides are also formed by **re-esterification** of fatty acids with more than 10 to 12 carbon atoms. Some of the cholesterol is also esterified.

TABLE 47.1: Sources and functions of dietary fats

Type of fat	Sources	Functions
Saturated fats	Full fat milk, cheese, cream, butter. Commercially baked biscuits and pastries Deep-fried fast food Coconut oil and palm oil Fatty meat	Increase blood cholesterol and thereby increase the risk of atherosclerosis and coronary heart diseases
Monounsaturated fats	Oils (canola, olive and peanut oils) Nuts (cashews, almonds, hazelnuts and peanuts) Margarine	Decrease blood cholesterol and thereby decrease the risk of coronary heart diseases
Polyunsaturated fats	*Fruits and vegetables* Vegetable oils (sunflower, safflower, corn or soy oils) Nuts (walnuts) Flax seeds Polyunsaturated margarines Lean meat Fish and sea foods Egg	*Decrease* Blood cholesterol and triglycerides and thereby reduces blood pressure Risk of coronary heart diseases Risk of obesity Platelet aggregation and prevents excess blood clotting Inflammation throughout body *Increase* Disease-countering actions in the body
Trans fats	Milk Cheese and table margarines Lamb and beef	Increase low density lipoproteins and thereby increase the risk of atherosclerosis and coronary heart diseases

TABLE 47.2: Digestion of lipids

Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	Lingual lipase	Triglycerides	Fatty acid 1, 2-diacylglycerol
Stomach	Gastric juice	Gastric lipase (weak lipase)	Triglycerides	Fatty acids Glycerol
Small intestine	Pancreatic juice	Pancreatic lipase	Triglycerides	Monoglycerides Fatty acid
		Cholesterol ester hydrolase	Cholesterol ester	Free cholesterol Fatty acid
		Phospholipase A	Phospholipids	Lysophospholipids
		Phospholipase B	Lysophospholipids	Phosphoryl choline Free fatty acids
		Colipase	Facilitates action of pancreatic lipase	–
		Bile-salt-activated lipase	Phospholipids	Lysophospholipids
			Cholesterol esters	Cholesterol and fatty acids
	Succus entericus	Intestinal lipase	Triglycerides	Fatty acids Glycerol (weak action)

Triglycerides and cholesterol esters are coated with a layer of protein, cholesterol and phospholipids to form the particles called **chylomicrons.**

Chylomicrons cannot pass through the membrane of the blood capillaries because of the larger size. So, these lipid particles enter the lymph vessels and then are transferred into blood from lymph.

2. Fatty acids containing less than 10 to 12 carbon atoms enter the portal blood from mucosal cells and are transported as free fatty acids or unesterified fatty acids. Most of the fats are absorbed in the upper part of small intestine. Presence of bile is essential for fat absorption.

■ STORAGE OF LIPIDS

Lipids are stored in adipose tissue and liver. Fat stored in adipose tissue is called **neutral fat** or **tissue fat.** When chylomicrons are traveling through capillaries of adipose tissue or liver, the enzyme called **lipoprotein lipase** present in the capillary endothelium hydrolyzes triglycerides of chylomicrons into free fatty acids (FFA) and glycerol. FFA and glycerol enter the **fat cells** (adipocytes or lipocytes) of the adipose tissue or liver cells. Then, the FFA and glycerol are again converted into triglycerides and stored in these cells. Other contents of chylomicrons such as cholesterol and phospholipids, which are released into the blood combine with proteins to form lipoproteins.

When other tissues of the body need energy, triglycerides stored in adipose tissue is hydrolyzed into FFA and glycerol. FFA is transported to the body tissues through blood.

■ TRANSPORT OF LIPIDS IN BLOOD – LIPOPROTEINS

Free fatty acids are transported in the blood in combination with albumin. Other lipids are transported in the blood, in the form of lipoproteins.

■ LIPOPROTEINS

Lipoproteins are the small particles in the blood which contain cholesterol, phospholipids, triglycerides and proteins. Proteins are beta-globulins called **apoproteins.**

Classification of Lipoproteins

Lipoproteins are classified into four types on the basis of their density:

1. *Very-low-density lipoproteins (VLDL):* Contain high concentration of triglycerides (formed from FFA and glycerol) and moderate concentration of cholesterol and phospholipids
2. *Intermediate-density lipoproteins (IDL):* Formed by the removal of large portion of triglycerides from VLDL by lipoprotein lipase. Concentration of

cholesterol and phospholipids increases because of removal of triglycerides

3. *Low-density lipoproteins (LDL):* Formed from IDL by the complete removal of triglycerides. These lipoproteins contain only cholesterol and phospholipids
4. *High-density lipoproteins (HDL):* Contain high concentrations of proteins with low concentration of cholesterol and phospholipids.

All the lipoproteins are synthesized in liver. HDL is synthesized in intestine also.

Functions of Lipoproteins

Primary function of lipoproteins is to transport the lipids via blood to and from the tissues. Functions of each type of lipoproteins are given in Table 47.3.

Importance of Lipoproteins

High-density lipoprotein

High-denisty lipoprotein (HDL) is referred as the **'good cholesterol'** because it carries cholesterol and phospholipids from tissues and organs back to the liver for degradation and elimination. It prevents the deposition of cholesterol on the walls of arteries, by carrying cholesterol away from arteries to the liver.

High level of HDL is a good indicator of a healthy heart, because it reduces the blood cholesterol level. HDL also helps in the normal functioning of some hormones and certain tissues of the body. It is also used for the formation of bile in liver.

Low-density lipoprotein

Low-density lipoprotein (LDL) is considered as the **'bad cholesterol'** because it carries cholesterol and phospholipids from the liver to different areas of the body, viz. muscles, other tissues and organs such as heart. It is responsible for deposition of cholesterol on walls of arteries causing **atherosclerosis** (blockage and hardening of the arteries). High level of LDL increases the **risk of heart disease.**

TABLE 47.3: Functions of lipoproteins

Lipoproteins	Functions
VLDL	Transports triglycerides from liver to adipose tissue
IDL	Transports triglycerides, cholesterol and phospholipids from liver to peripheral tissues
LDL	Transports cholesterol and phospholipids from liver to tissues and organs like heart
HDL	Transports cholesterol and phospholipids from tissues and organs like heart back to liver

Very-low-density lipoprotein

Very-low-density lipoprotein (VLDL) carries cholesterol from liver to organs and tissues in the body. It is also associated with **atherosclerosis** and **heart disease.**

■ ADIPOSE TISSUE

Adipose tissue or fat is a loose connective tissue that forms the storage site of fat in the form of triglycerides. It is composed of **adipocytes,** which are also called **fat cells** or **lipocytes.** Obesity does not depend on the body weight, but on the amount of body fat, specifically adipose tissue.

Adipose tissue is of two types, white adipose tissue and brown adipose tissue.

■ WHITE ADIPOSE TISSUE OR WHITE FAT

White adipose tissue is distributed through the body beneath the skin, forming **subcutaneous fat.** It also surrounds the internal organs. This adipose tissue is formed by fat cells which are **unilocular,** i.e. these cells contain one large vacuole filled with fat.

Functions of White Adipose Tissue

White adipose tissue has three functions:

1. Storage of energy: Main function of white adipose tissue is the storage of lipids. Utilization or storage of fat is regulated by hormones, particularly insulin, depending upon the blood glucose level. If the blood glucose level increases, insulin stimulates synthesis and storage of fat in white adipose tissue (Chapter 69). On the other hand, if blood glucose level decreases insulin causes release of fat from adipose tissue. Released fat is utilized for energy
2. Heat insulation: **Insulation function** is due to the presence of adipose tissue beneath the skin (subcutaneous adipose tissue)
3. Protection of internal organs: White adipose tissue protects the body and internal organs by surrounding them and by acting like a **mechanical cushion.**

■ BROWN ADIPOSE TISSUE OR BROWN FAT

Brown adipose tissue is a specialized form of adipose tissue, having the function opposite to that of white adipose tissue. It is present only in certain areas of the body such as back of neck and intrascapular region. It is abundant in infants forming about 5% of total adipose tissue. After infancy, brown adipose tissue disappears gradually and forms only about 1% of total adipose tissue in adults. It is formed by fat cells which are **multilocular,** i.e. these cells contain many small

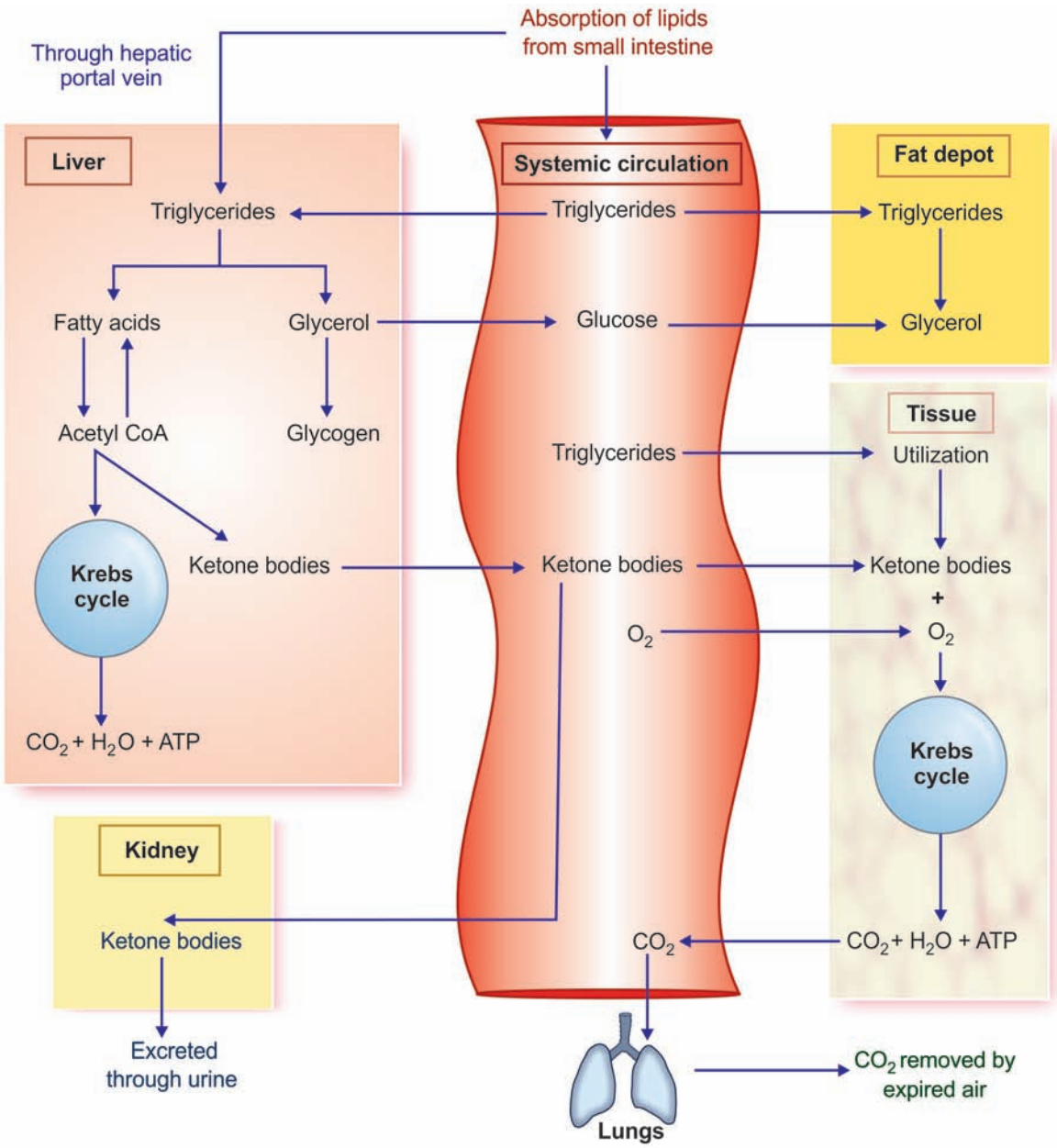

FIGURE 47.1: Schematic diagram of lipid metabolism

vacuoles filled with fat. The coloration of this adipose tissue is due to high vascularization and large number of **iron-rich mitochondria.**

Functions of Brown Adipose Tissue

Brown adipose tissue does not store lipids but generates heat by burning lipids. In infants and hibernating animals, brown adipose tissue plays an important role in regulating body temperature via **non-shivering thermogenesis.** Heat production in brown fat is very essential for survival of infants and small animals in cold environment. It is because, the lipid in this tissue releases energy directly as heat.

The mitochondria found in brown adipose tissue contain a unique uncoupling protein called **mitochondrial uncoupling protein 1** (UCP1). Also called **thermogenin,** this protein allows the controlled entry of protons without adenosine triphosphate (ATP) synthesis, in order to generate heat.

TABLE 47.4: Values of lipid profile

Lipids	Desirable optimal level	Borderline range	High-risk level
Total cholesterol	< 200 mg/dL	200 to 240 mg/dL	> 240 mg/dL
Triglycerides	< 150 mg/dL	150 to 200 mg/dL	> 200 mg/dL
HDL	> 60 mg/dL	40 to 60 mg/dL	< 40 mg/dL
LDL	< 60 mg/dL	60 to 100 mg/dL	> 100 mg/dL
Total cholesterol – HDL ratio	< 2	2 to 6	> 6

METABOLISM OF LIPIDS

Metabolism of lipids is given in the form of schematic diagram (Fig. 47.1).

LIPID PROFILE

Lipid profile is a group of **blood tests** which are carried out to determine the risk of **coronary artery diseases** (CAD). Results of lipid profile are considered as good indicators of whether someone is prone to develop **stroke** or **heart attack,** caused by **atherosclerosis.** In order to plan the course of treatment, the results of the lipid profile are correlated with age, sex and other risk factors of heart disease.

Tests included in lipid profile are total cholesterol, triglyceride, HDL, LDL, VLDL and total cholesterol – HDL ratio.

Total cholesterol to HDL ratio is helpful in predicting atherosclerosis and CAD. It is obtained by dividing total cholesterol by HDL. High total cholesterol and low HDL increases the ratio. The increase in the ratio is undesirable. Conversely, high HDL and low total cholesterol lowers the ratio and the decrease in the ratio is desirable. The values of lipid profile are given in Table 47.4.

QUESTIONS IN DIGESTIVE SYSTEM

LONG QUESTIONS

1. What are the different types of salivary glands? Describe the composition, functions and regulation of secretion of saliva.
2. Explain the composition and functions of gastric juice and give an account of hormonal regulation of gastric secretion.
3. Describe the different phases of gastric secretion with experimental evidences.
4. Explain the composition, functions and regulation of secretion of pancreatic juice.
5. Describe the composition, functions and regulation of secretion of bile. Enumerate the differences between the liver bile and gallbladder bile. Add a note on enterohepatic circulation.
6. Give an account of succus entericus.
7. Write an essay on gastric motility. What are the factors influencing gastric emptying?
8. Describe in detail, the gastrointestinal movements.

SHORT QUESTIONS

1. Properties and composition of saliva.
2. Functions of saliva.
3. Nerve supply to salivary glands.
4. Glands of stomach.
5. Functions of stomach.
6. Properties and composition of gastric juice.
7. Functions of gastric juice
8. Mechanism of secretion of hydrochloric acid in stomach.
9. Pavlov's pouch.
10. Sham feeding.
11. Cephalic phase of gastric secretion.
12. Gastrin.
13. Hormones acting on stomach.
14. FTM.
15. Peptic ulcer.
16. Exocrine function of pancreas.
17. Properties and composition of pancreatic juice.
18. Functions of pancreatic juice.
19. Regulation of exocrine function of pancreas.
20. Steatorrhea.
21. Secretin.
22. Cholecystokinin.
23. Composition of bile.
24. Functions of bile.
25. Bile salts.
26. Bile pigments.
27. Enterohepatic circulation.
28. Functions of liver.
29. Differences between liver bile and gallbladder bile.
30. Functions of gallbladder.
31. Jaundice.
32. Hepatitis.
33. Gallstones.
34. Succus entericus.
35. Functions of small intestine.
36. Functions of large intestine.
37. Mastication.
38. Swallowing.
39. Dysphagia.
40. Movements of stomach.
41. Filling and emptying of stomach.
42. Hunger contractions.
43. Vomiting.
44. Movements of small intestine.
45. Peristalsis.
46. Movements of large intestine.
47. Defecation.
48. Constipation.
49. Diarrhea.
50. Gastrointestinal hormones.
51. Digestion and absorption of carbohydrates.
52. Dietary fiber.
53. Digestion and absorption of proteins.
54. Digestion and absorption of lipids.
55. Lipoproteins.
56. Brown fat.