

Section A

NUTRITION

Nursing Knowledge Tree
An Initiative by CBS Nursing Division

SECTION OUTLINE

Unit I Introduction to Nutrition
Unit II Carbohydrates
Unit III Fats or Lipids
Unit IV Proteins
Unit V Energy
Unit VI Vitamins
Unit VII Minerals
Unit VIII Water and Electrolytes
Unit IX Cookery Rules and Preservation of Nutrients
Unit X Balanced Diet
Unit XI Role of Nurse in Nutritional Programs

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Carbohydrates

CHAPTER OUTLINE

- Classification of Carbohydrates
- Calorific Value of Carbohydrates
- Recommended Daily Allowances for Carbohydrates
- Dietary Sources of Carbohydrates
- Functions of Carbohydrates
- Malnutrition
  - Carbohydrates Deficiency
  - Overconsumption of Carbohydrates

Carbohydrates are macronutrients and are one of the three **main sources of energy**. They are called carbohydrates, because at the chemical level, they contain carbon, hydrogen and oxygen, where the last two are present in the ratio of 2:1. For example, glucose ($C_6H_{12}O_6$) contains 6 carbons, 12 hydrogens and 6 oxygen $(CH_2O)_6$.

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CLASSIFICATION OF CARBOHYDRATES

Carbohydrates can be classified into different types, according to the size of the molecules and their structures as well as according to their nutritional significance (Fig. 2.1).

Classification of Carbohydrates According to the Size of the Molecules and their Structures

According to the size of the molecules and their structures, carbohydrates are classified into four groups, i.e., monosaccharides, disaccharides, oligosaccharides, and polysaccharides.

- **Monosaccharides:** Monosaccharides are simple sugars, which can join in several ways to form di-, oligo- and polysaccharides. These are the aldehyde or ketone derivatives of the straight chain polyhydroxy alcohols which contain three or more carbons.

  Monosaccharides, in a closed-chain form, **can form glycosidic bonds with other monosaccharides**, **creating disaccharides** (such as sucrose) and **polysaccharides** (such as starch). Monosaccharides may be further converted into **structural polysaccharides such as cellulose** and pectin for cell wall construction, or into **energy reserves in the form of storage polysaccharides, such as starch** and glycogen.

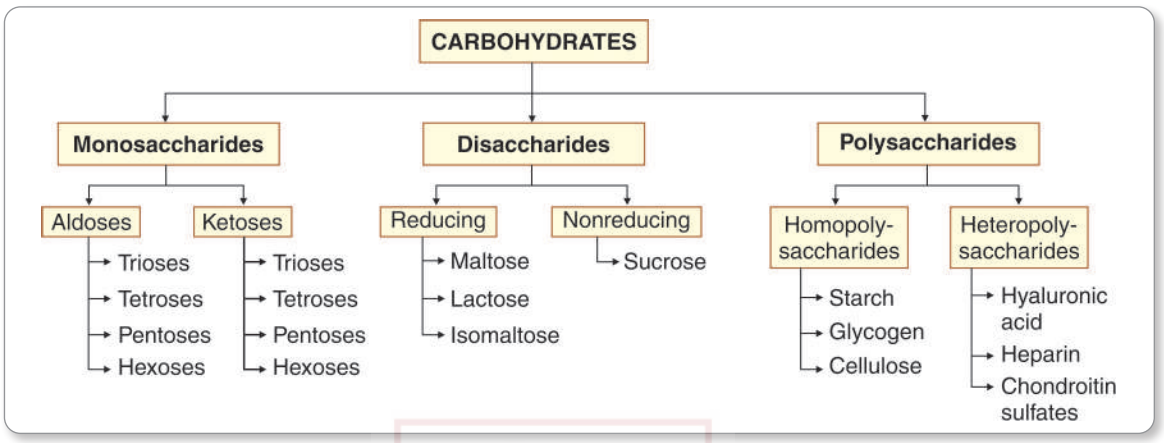


Fig. 2.1: Classification of carbohydrates

Classification of the Monosaccharides

Monosaccharides are divided into different groups:

1. According to the chemical nature of the carbonyl group, monosaccharides are divided into two groups as aldoses and ketoses:
   - ***Aldoses:*** The sugar is an aldose when it has an **aldehyde (–CHO) group** on carbon-1, e.g., glucose.
   - ***Ketoses:*** The sugar is a ketose when it has a **ketone (–CO)** group at carbon-2, e.g., fructose.

   Some of the ketoses are named by inserting '**-ul**' before the suffix '**-ose**' in the name of the corresponding aldose, e.g., **erythrulose**. It is a ketose corresponding to erythrose, which is an aldose.
2. According to the number of carbon atoms monosaccharides are designated as trioses, tetroses, pentoses, hexoses, etc. (Table 2.1):
   - ***Trioses:*** These are the smallest monosaccharides, with **three carbon atoms,** e.g., **glyceraldehyde** (an aldotriose) and **dihydroxyacetone** (a ketotriose). Both are of physiological significance because their phosphate esters, i.e., glyceraldehyde-3-phosphate and dihydroxyacetone phosphate, occur as intermediates in glycolysis.
   - ***Tetroses:*** These have **four carbon atoms**, e.g., **erythrose** (an aldotetrose) and erythrulose (a ketotetrose). Erythrose, as erythrose-4-phosphate, occurs as an intermediate in the hexose monophosphate (HMP) shunt.
   - ***Pentoses:*** These contain **five carbon atoms**, e.g., **ribose** (an aldopentose) and **xylulose** (a ketopentose). Both of these occur as intermediates of the HMP shunt. Ribose is also a constituent of nucleotides that are present in ribonucleic acids (RNAs).

TABLE 2.1: Classification of monosaccharides

Monosaccharides	Number of carbons	Aldoses	Ketoses
Trioses	3	Glyceraldehyde	Dihydroxyacetone
Tetroses	4	Erythrose	Erythrulose
Pentoses	5	Ribose	Ribulose
Hexoses	6	Glucose	Fructose

- ***Hexoses*:** These contain **six carbon atoms**, e.g., **glucose** (an aldohexose) and **fructose** (a ketohexose). Glucose, commonly known as dextrose, is used as a source of energy in the body. Galactose is a constituent of milk sugar lactose. Fructose is a constituent of the common sugar sucrose.

- **Disaccharides:** Disaccharides are formed by linking two monosaccharides with the removal of a molecule of water. Commonly available disaccharides include **lactose**, **maltose** and **sucrose**.
  - **Lactose** is formed when a molecule of glucose is linked to galactose. It is also called milk sugar, since it is found naturally in milk. Lactose is synthesized in the mammary glands during lactation and is secreted into the milk. During digestion, lactose is hydrolyzed to its monosaccharide units, i.e., glucose and galactose by the intestinal enzyme referred to as lactase.

Clinical Correlation

Lactose Intolerance

Many adults are unable to metabolize the milk sugar lactose and experience gastrointestinal disturbances, if they drink milk. This condition is referred to as **lactose intolerance** *or hypolactasia. It is most commonly caused by a* **deficiency of the enzyme lactase**, *which cleaves lactose into glucose and galactose. The lactose is a good energy source for microorganisms in the colon and they ferment it to lactic acid while also generating methane and hydrogen gas. The gas produced creates uncomfortable feeling of gut distension and flatulence. The lactate produced by the microorganisms is osmotically active and draws water into the intestine, resulting in diarrhea. If severe enough, the gas and diarrhea hinder the absorption of other nutrients such as fat and protein. The simplest treatment is to avoid the consumption of milk and milk products (containing lactose).*

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  - **Maltose** is formed when a molecule of **glucose** is linked to another molecule of **glucose**. It is obtained during hydrolysis of starch. During digestion, maltose is hydrolyzed to its monosaccharide units, i.e., glucose and glucose by the intestinal enzyme referred to as maltase.
  - **Sucrose** is formed when a molecule of glucose is linked to fructose. It is also referred to as **table sugar** since it is commonly used on the table for routine use in home-made drinks. Sucrose is also referred to as cane sugar since it is obtained from the stems of sugarcane and roots of sugar beet. During digestion, sucrose is split into its constituent monosaccharides glucose and fructose by the enzyme **sucrase** (also called **invertase**).

    Sucrose is used by people as a sweetener for foods (e.g., toast and cereal) and beverages (e.g., coffee and tea).

- **Oligosaccharides:** Oligosaccharides are carbohydrates formed by linking more than two (generally 3–10) monosaccharide units through O-glycosidic bonds, e.g., maltotriose, raffinose, etc. Most of these are not digested in human. A high extent of O-linked oligosaccharides occurs in mucin.

  Oligosaccharides are usually attached to proteins at the sequences that form surface loops or turns. Some oligosaccharides also play structural roles. A single protein may contain several N- and O-linked oligosaccharide chains. Glycosylation may affect the structure, stability or activity of a protein.

- **Polysaccharides:** Polysaccharides are made up of many monosaccharide molecules. Examples of polysaccharides are **starch**, **glycogen** (the form in which glucose is stored in the body), and **cellulose** and pectin (components classed as dietary fiber), etc.
  - **Starches: Starch** or **amylum** is a polymeric carbohydrate consisting of numerous glucose units joined by glycosidic bonds. This **polysaccharide is produced by most green plants as energy storage**. Starch molecules arrange themselves in the plant in semi-crystalline granules. Each plant species has a unique starch granular size, e.g., rice starch is relatively small while potato starches have

larger granules. **Starch content of different foods varies, e.g., potatoes 15%, wheat 55%, corn 65% and rice 75%.**

Starch is a mixture of two polymers, i.e., amylose and amylopectin. Natural starches consist of about 10–30% amylose and 70–90% amylopectin.

- **Amylose** is **a linear polysaccharide**, composed entirely of D-glucose units joined by the α-1,4-glycosidic linkages.
- **Amylopectin** is **a branched-chain polysaccharide**, composed of glucose units linked primarily by α-1,4-glycosidic bonds but with occasionally α-1,6-glycosidic bonds, which are responsible for the branching. A molecule of amylopectin may contain many thousands of glucose units with **branch points occurring after about every 25–30 units**.

In the human body, several enzymes known collectively as **amylases degrade starch** sequentially into usable glucose units. Alpha-amylases are found in plants and animals. **Human saliva is rich in amylase** and the **pancreas also secretes the enzyme**.

The complete hydrolysis of starch yields, in successive stages, glucose:

Starch → Dextrin → Maltose → Glucose

Starch is the ***most common carbohydrate in the human diet*** and is contained in many staple foods. The major sources of starch intake worldwide are the cereals (**rice, wheat and maize**) and the root vegetables (**potatoes and cassava**). Widely used prepared foods containing starch are bread, pancakes, cereals, noodles and pasta.

- **Glycogen:** Glycogen is the energy reserve carbohydrate of animals including humans, hence is also referred to as **animal starch**. Like starch in plants, glycogen is found as granules **in liver** (4–8% by weight of tissue) **and in skeletal muscle cells** (0.5–1.0%). When fasting, humans draw on these glycogen reserves during the first day without food to obtain the glucose needed to maintain metabolic balance.

  Glycogen is **structurally quite similar to amylopectin**, however glycogen is more branched (8–12 glucose units between branches) and the branches are shorter. Enzyme **phosphorylase catalyzes the breakdown of glycogen to glucose**, when energy is needed, by a process called glycogenolysis.
- **Cellulose:** Cellulose is a **polysaccharide** (**homopolysaccharide**) like amylose, but it differs from amylose in the way that **glucose molecules**, in cellulose **are linked together by β-1,4-glycosidic linkages** instead of α-1,4-glycosidic linkages present in amylose. Cellulose is found in plants, as a structural component of their cell wall. **We are**, however, **unable to digest cellulose** due to the reason that **human beings do not contain enzyme β-amylase**, which is required for the digestion of cellulose.

According to their Nutritional Significance

According to their significance in nutrition, carbohydrates are classified as simple sugars and complex carbohydrates, including fiber.

- **Simple sugars:**
  - **Intrinsic sugars**, which are incorporated into the cellular structure of foods, e.g., **glucose, fructose, pentoses**, etc., i.e., the sugars **found in whole fruits** and **vegetables**.
  - **Extrinsic sugars,** which are not bound into a cellular structure, e.g., **lactose** (**milk sugar**) **found in dairy products**, **sucrose (table sugar) found in** confectionery, etc.

- **Complex carbohydrates:**
  - **Starch:** It is found in potatoes, bread, rice and pasta.
  - **Fiber:** Fiber, also referred to as dietary fiber, include carbohydrate polymers, which are neither digested nor absorbed in the small intestine, e.g., cellulose, pectin, etc. They refer to indigestible carbohydrates, such as cellulose, hemicellulose, pectin, lignin, gums and mucilage. Pectin, gums, mucilages and some of the hemicelluloses are soluble in water and hence are also called **soluble fibers**. On the other hand, cellulose, various hemicelluloses and lignin are insoluble in water and are referred to as **insoluble fibers**.

    Fiber cannot be digested by human beings due to the absence of the required digestive enzymes but is essential for digestion. Fiber promotes healthy bowel movement and decreases the risk of chronic diseases, such as coronary heart disease and diabetes. However, unlike sugars and starches, fiber is not absorbed in the small intestine and is not converted to glucose. Instead, fiber passes into the large intestine, relatively intact, where it is converted to hydrogen, carbon dioxide and fatty acids. Sources of fiber include fruits, grains and vegetables, especially, legumes.
    - **Significance of dietary fiber:** High intake of dietary fiber has many **health benefits**. For example, diets rich in fiber decreases risk of obesity, type 2 diabetes, colon cancer, cardiovascular diseases and gastrointestinal disorders:
      - Diets rich in fiber are usually, low in fat and provide lesser calories since such a diet forms bulk of the food, which takes longer to eat, and gives a feeling of fullness. Dietary fiber not only regulates body weight but also **lowers the risk of obesity**.
      - Higher intake of soluble fiber also delays stomach emptying and thus, regulates blood glucose level. This in turn also **reduces the risk of type 2 diabetes.**
      - Diet rich in fiber also lowers the risk of certain types of cancer. It is due to the reason that food with large amounts of fruits and vegetables, provides antioxidants, which protect our body against cell damage and **cancer**.
      - Soluble fiber also lowers serum cholesterol, thus, **reduces the risk of a cardiovascular disease**.
      - Diet rich in insoluble fiber also adds bulk to feces and softens stool for its easy passage. Thus, dietary fiber helps in **prevention of constipation and hemorrhoids**, particularly, when fluid intake is high**.**
      - **Excess of fiber** in the diet may, however, cause deficiency of some minerals, such as zinc, calcium, magnesium and iron. It is due to the reason that dietary fiber binds these minerals and thus reduces their absorption.

Good Carbohydrates versus Bad Carbohydrates

Carbohydrates form the basis of most diets, making up half of total energy (calorie) intake. Dietary carbohydrates can be separated into two types, as complex (good) carbohydrates and simple (bad) carbohydrates.

1. **Good carbohydrates:** Carbohydrates usually considered to be **good** include complex carbohydrates such as those obtained from whole grains, fruits, vegetables, beans and legumes. They contain larger chains of sugar molecules and take longer to digest than processed grains. They are not only digested slowly, but also contain a bounty of other nutrients (Fig. 2.2).

   Good carbohydrates are:
   - Low or moderate in calories
   - High in nutrients



Fig. 2.2: Sources of good carbohydrates



Fig. 2.3: Sources of bad carbohydrates

- Devoid of refined grains and sugar
- High in naturally occurring fiber
- Low in sodium
- Low in saturated fat
- Very low in, or devoid of, cholesterol and trans fat

2. **Bad carbohydrates:** Carbohydrates usually considered **bad** include refined sugars, such as those obtained from pastries, white sugar, honey, fruit juices and soda, highly processed foods, white rice, white bread and other white-flour foods (Fig. 2.3).

   They are digested more quickly by the body. This makes them a faster source of energy. Also, these types of carbohydrates do not offer as many additional nutrients.

   Bad carbohydrates are:
   - High in calories
   - Full of refined sugars
   - Low in many nutrients
   - Low in fiber
   - High in sodium
   - High in saturated fat, cholesterol and trans fat

CALORIFIC VALUE OF CARBOHYDRATES

Calorific value or caloric value of the food is the amount of heat produced by combustion of one gram of fuel. It is expressed in terms of calories per gram or joules per kilogram. Calorific value of carbohydrate is 4 kcal/g.

RECOMMENDED DAILY ALLOWANCES FOR CARBOHYDRATES

Carbohydrates intake, for most people, should be such that it provides nearly 45–65% of total calories. Since, one gram of carbohydrate provides 4 calories, so a diet to provide 1800 calories per day, should have between 200 and 300 grams of carbohydrates. However, people with diabetes should not eat >200 grams, while pregnant women need at least 175 grams of carbohydrates per day.

DIETARY SOURCES OF CARBOHYDRATES

Main dietary sources of carbohydrates include grains, vegetables and fruits. Complex carbohydrates are present in whole grains (such as cereals and rice), bran, beans, bread and pasta. Milk and milk products provide lactose, while beverages, jams, jellies and candies provide refined sugar, such as glucose and fructose (Fig. 2.4).

Foods which are rich in carbohydrates include:

- **Dairy:** Milk, yogurt and ice cream
- **Fruits:** Whole fruits and fruit juice
- **Grains:** Cereal grains, bread and rice
- **Legumes:** Beans and pulses
- **Starchy vegetables:** Potatoes and corn
- **Sugary sweets:** Soda (when fluid intake is high), candy, cookies and other desserts.



Fig. 2.4: Dietary sources of carbohydrates

FUNCTIONS OF CARBOHYDRATES

Carbohydrates are necessary for good health and give a variety of benefits:

- **Brain health:** Carbohydrates are important for brain functions. They are a quick source of energy and have influence on mood and memory.
- **Weight loss:** Although, carbohydrates are often blamed for weight gain, the right kind of carbohydrate can actually help to maintain a healthy weight. This can happen due to the consumption of many good carbohydrates, especially, whole grains and vegetables with skin, which contain fiber.
- **Good sources of nutrients:** Whole, unprocessed fruits and vegetables are well known for their nutrients contents. Due the same reason, some of the food stuffs are even considered super foods, such as the green leafy vegetables, sweet potatoes, berries, citruses and apples. Whole grains also have significantly higher amounts of fiber, energy and polyunsaturated fats, as well as all micronutrients (except vitamin B_{12} and sodium). Further, whole grains have also been shown to contain antioxidants.
- **Heart health:** Fiber also helps to lower cholesterol. This is due to the reason that the digestive process requires bile acids, which are made, partly, from cholesterol. As the digestion improves, liver pulls cholesterol from blood, to form more bile acid, thereby, reducing the amount of LDL (the bad cholesterol).

STORAGE OF CARBOHYDRATES

Carbohydrates, mainly **glucose**, are **stored as glycogen in the liver and muscle**. Liver glycogen is hydrolyzed to glucose during fasting, whereas muscle glycogen is used as a source of energy during exercise. **Excess of glucose is also converted to fat and is stored in the adipose tissue as triacylglycerols (fat)**.

METABOLISM OF GLUCOSE

Glucose is metabolized in the liver and is utilized in various organs of the body, by different processes.

- Glucose is oxidized to produce energy, where it is converted to pyruvate, by the process of **glycolysis**. Thereafter, pyruvate is converted to acetyl-CoA, which enters **citric acid cycle**, and produces energy

(ATP) through **electron transport chain** and **oxidative phosphorylation** (*see* Chapter 25).

- Glucose is also converted to glycogen, and is stored in the liver and muscle, by the process of **glycogenesis**. When blood glucose level is low, glycogen is converted to glucose, by the process of **glycogenolysis** (Fig. 2.5).

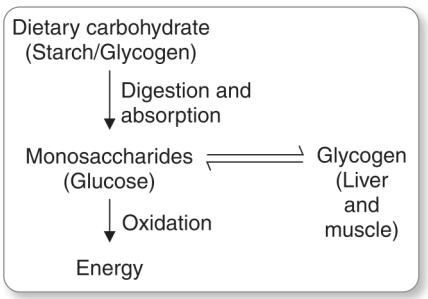


Fig. 2.5: Metabolic fate of glucose

Glycemic Index

Glycemic index (GI) refers to the effect of a particular type of food stuff on blood glucose level, i.e., it is a measure of how quickly the glucose is released into the bloodstream, after eating it. GI, thus, measures how quickly, and how much, a carbohydrate raises blood sugar. High-glycemic foods, like pastries, raise blood sugar rapidly, whereas low-glycemic foods raise it gently and to a lesser degree. Low GI foods, that are rich in fiber, should form an important component of a healthy diet.

MALNUTRITION

Carbohydrates Deficiency

When a person is on a carbohydrate-free diet, protein and fat are used as alternate sources of energy. Excessive breakdown of these substances, in turn, leads to the excessive formation of ketone bodies. Such individuals exhibit symptoms, similar to those seen during starvation, i.e., abnormal fat metabolism, breakdown of tissue proteins, increased sodium excretion, loss of energy and fatigue. Small amount of carbohydrates (50–100 g) prevent these symptoms. Not getting enough carbohydrate can cause problems, such as:

- Without sufficient fuel, body gets no energy.
- Additionally, without sufficient glucose, central nervous system suffers, which may cause dizziness, and mental and physical weakness.
- If body has insufficient carbohydrates intake, or stores, it will consume protein, as a source of fuel. This is problematic, because the body needs protein to make muscles. Using protein for fuel, instead of carbohydrates, also puts stress on the kidneys leading to the passage of painful by-products, such as urea, in the urine.
- People, who do not consume enough carbohydrates, may also suffer from deficiency of dietary fiber, which can cause digestive problems and constipation.

Overconsumption of Carbohydrates

Overconsumption of carbohydrates, in turn, leads to increased calories intake and causes obesity. This can also lead to diabetes mellitus and a cardiac disorder.

- **Weight gain and obesity:** Carbohydrates are the preferred source of energy for the body. When we eat any type of carbohydrate, our body breaks it to glucose, which is released into the blood stream and causes a rise in blood glucose level. If we eat moderate amount of carbohydrates, body's cells use, what they need for energy and store excess of it as glycogen. However, glycogen stores are limited, and once stores are saturated, excess of glucose is stored as fat. Thus, over consumption of carbohydrates, for a longer period, results in weight gain and obesity.

- **Poor appetite control:** Eating too much of carbohydrates, in one sitting, causes large increase in blood glucose level. This, in turn, causes pancreas to release a large amount of insulin, which leads to an equally large decrease in blood glucose level. When blood glucose level suddenly falls, brain sends hunger signals, meaning that one demands more food. Thus, the overall result is poor appetite control, as one is constantly craving for food, despite eating regularly.
- **Fatigue:** As overconsumption of carbohydrates causes a rapid surge and thereafter, a rapid fall in blood glucose level. This has a direct effect on overall energy levels. As a result of it, one will suddenly feel full of energy, and thereafter, shortly the energy level will crash. Fluctuating energy levels affect proper functioning of the body, since one will be constantly switching between the feelings of too much energy and not enough energy.
- **Dental caries:** Dental caries is the progressive destruction (demineralization) of teeth, by the acids produced by bacteria acting on sugars and other fermentable carbohydrates on the tooth's surfaces. Longer a carbohydrate remains in the mouth, more likely it will promote dental caries. Foods that stick to the teeth, such as candies, cookies and beverages like cola, are more likely to cause dental caries. The most important way to protect dental caries is regular brushing of teeth with a fluoride containing toothpaste (twice daily). Fluoride strengthens tooth enamel and provides resistance to decay.
- **Risk of type 2 diabetes:** Level of glucose in blood is carefully monitored and maintained within the narrow limits, by the action of the hormone insulin. Over consumption of carbohydrates cause pancreas to produce, and release, increased amount of insulin. Pushing the pancreas to over exert, ultimately, interferes with its ability to produce insulin. Both, insulin resistance and pancreas failing to produce enough insulin, are characteristics of type 2 diabetes. This, in turn, also causes permanent damage to the body and affects all major organs and vessels including heart, kidneys, eyes, nerves and blood vessels.
- **Risk of a cardiovascular disease (CVD):** A high blood cholesterol level is also associated with increased risk of CVD. Some forms of complex carbohydrates, such as pectin in fruits and beta-glucan in oats, may, slightly, reduce the level of cholesterol in blood. These are the forms of soluble fiber. There is also some evidence that resistant starch may have a slight beneficial effect on the risk CVD. Regular consumption of wholegrain foods has also been linked with heart health, possibly, as a result of the breakdown products (e.g., short chain fatty acids), which are formed and absorbed in large bowel.
- **Risk of cancer:** Some studies suggest that population with a high intake of fiber-rich foods, experiences lower incidence of large bowel cancer than the population with low intakes of these foods.

STUDENT ASSIGNMENT

LONG AND SHORT ANSWER QUESTIONS

1. Define carbohydrates. Describe the classification of carbohydrates.
2. Describe calorific value, RDA, dietary sources, and functions of carbohydrates.
3. Describe various disorders which may occur as a result of overconsumption of carbohydrates.
4. Differentiate between:
   a. Simple sugars and complex carbohydrates
   b. Good carbohydrates and bad carbohydrates

5. Write notes on:
   a. Dietary fiber
   b. Starches
   c. Cellulose
   d. Functions of carbohydrates
   e. Calorific value of carbohydrates
   f. Glycemic index

MULTIPLE CHOICE QUESTIONS

1. Which of the following is a nonreducing sugar?
   a. Sucrose
   b. Maltose
   c. Glucose
   d. Lactose

2. Sucrose is composed of glucose and ……
   a. Maltose
   b. Fructose
   c. Glycogen
   d. Galactose

3. An aldose sugar is converted to ketose sugar by:
   a. Oxidoreductase
   b. Aldolase
   c. Decarboxylase
   d. Isomerase

4. The enzyme that hydrolyzes sucrose is:
   a. Invertase
   b. Amylase
   c. Lactase
   d. Maltase

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Section **B**

Biochemistry

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SECTION OUTLINE

Unit XII Cell Structure and Functions
Unit XIII Metabolism of Carbohydrates
Unit XIV Metabolism of Lipids
Unit XV Metabolism of Amino Acids and Proteins
Unit XVI Clinical Enzymology
Unit XVII Vitamins and Minerals
Unit XVIII Acid Base Balance
Unit XIX Organ Function Tests
Unit XX Metabolism of Hemoglobin
Unit XXI Immunochemistry and Free Radicals

22

Cell Structure and Functions



CHAPTER OUTLINE

- Prokaryotic Cells
- Eukaryotic Cells
- Differences Between Prokaryotic and Eukaryotic Cell Structures
- Structure and Functions of Intracellular Components
  - Nucleus
  - Endoplasmic Reticulum
  - Ribosomes
  - Golgi Apparatus
  - Mitochondria
  - Lysosomes
  - Peroxisomes
  - Cytosol
  - Plasma Membrane

The cell is a structural and functional unit of life. All animals and plants are made up of a large number of such units, in a manner to the utilization of bricks in the construction of a building.

Living cells are divided into two groups, i.e., the **prokaryotic cells** and the **eukaryotic cells**. As their name suggests (pro = prior to; karyot = nucleus; eu = true), the fundamental difference between them is the absence or presence of a true nucleus.

PROKARYOTIC CELLS

The simplest form of the cell is a prokaryotic cell. Prokaryotes, e.g., bacteria are **unicellular** and have one of the three basic shapes, viz. spheroidal (Cocci), rodlike (Bacilli) and helically-coiled (Spirilla).

- A prokaryotic cell is **small in size** (1–10 nm), relatively **simple in structure** and has only a single membrane, called **cell membrane,** which is usually surrounded by a rigid **cell wall** of characteristic structure.
- There may or may not be a surrounding **capsule.**
- Besides, there is a **single chromosome** comprised of a molecule of double helical DNA which is densely coiled to form a **nuclear zone**.
- Reproduction is by **asexual division**. The best characterized prokaryotic cell is *Escherichia coli*.
- Some prokaryotes **possess pili** and **flagella** for adhesion and movement, respectively (Fig. 22.1).

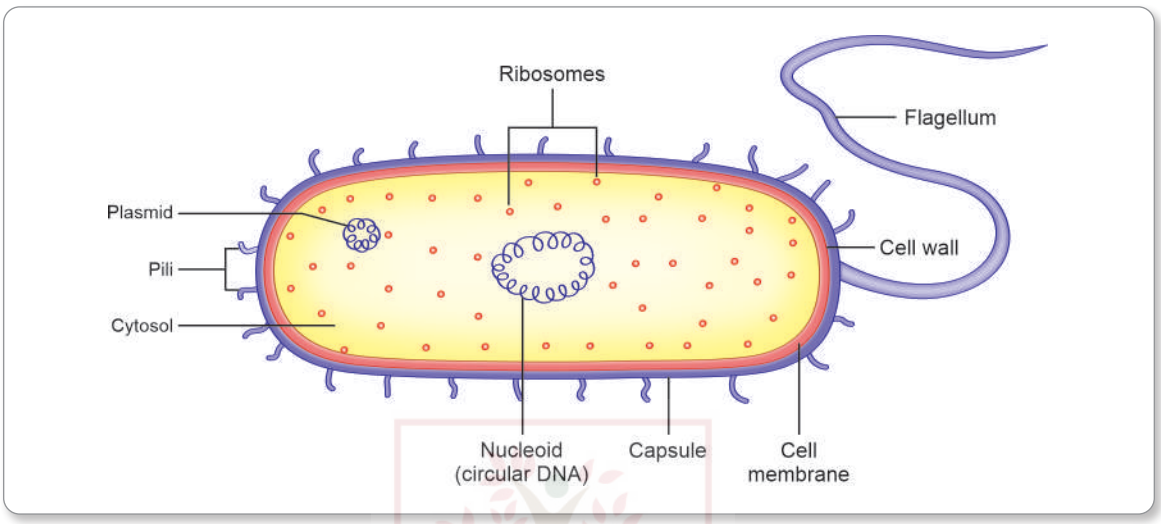


Fig. 22.1: A prokaryotic cell

Organelles of Prokaryotic Cell

Cell Wall

- Found only in prokaryotic cells
- Surrounds the plasma membrane
- Gives the cell its shape
- Prevents bursting when turgid pressure is high
- Helps anchor appendages like pili and flagella
- Composed of cellulose microfibers which form a thick wall
- Grows with the cell
- Helps the cell maintain osmotic balance.

Plasma Membrane

- Found in both prokaryotic and eukaryotic cells
- Encloses the interior of the cell
- Regulates the flow of material in and out of the cell.

Ribosomes

- 70S ribosome is made up of 50S and 30S components
- Translates the genetic code from the DNA to make proteins
- They can be either free or attached to endoplasmic reticulum.

Nucleoid

- There is no clear nuclear cytoplasmic difference
- Not a membrane bound nucleus
- An area of the cytoplasm where the strands of DNA are found.

Organelles not found in Prokaryotic Cells

- *Endoplasmic reticulum*
- *Golgi apparatus*
- *Mitochondria*
- *Nucleus*

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Pili

- Small hairlike projections emerging from the outside cell surface
- Assist in the cell attaching to other cells and surfaces. Thus help in pathogenic organisms to stick to the surface.

Flagella

- Flagella are hairlike structures that allow the cell to move by beating in a propeller-like motion.
- They help bacterium to move toward nutrients, away from toxic chemicals, etc.

EUKARYOTIC CELLS

Animals, plants, fungi and **protozoa** are called eukaryotes which may be **unicellular** or **multicellular**.

- Eukaryotic cells are one to ten thousand times **large in size** and are more **complex in structure** than the prokaryotic cells.
- They may **vary from one tissue to another** with respect to their functions, e.g., the liver parenchymal cell, adipose cell, nerve cell, renal tubular cell, white blood cell, etc.
- Generally, a eukaryotic cell has a well-defined membrane-bound nucleus containing several chromosomes.
- Their chromosomes undergo replication of DNA during mitosis and get separated into daughter chromosomes, i.e., these cells reproduce by cell division.
- A typical eukaryotic cell contains various organelles such as nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, etc. (Fig. 22.2).

DIFFERENCES BETWEEN PROKARYOTIC AND EUKARYOTIC CELL STRUCTURES

Major differences between prokaryotic and eukaryotic cell structures are given in Table 22.1.

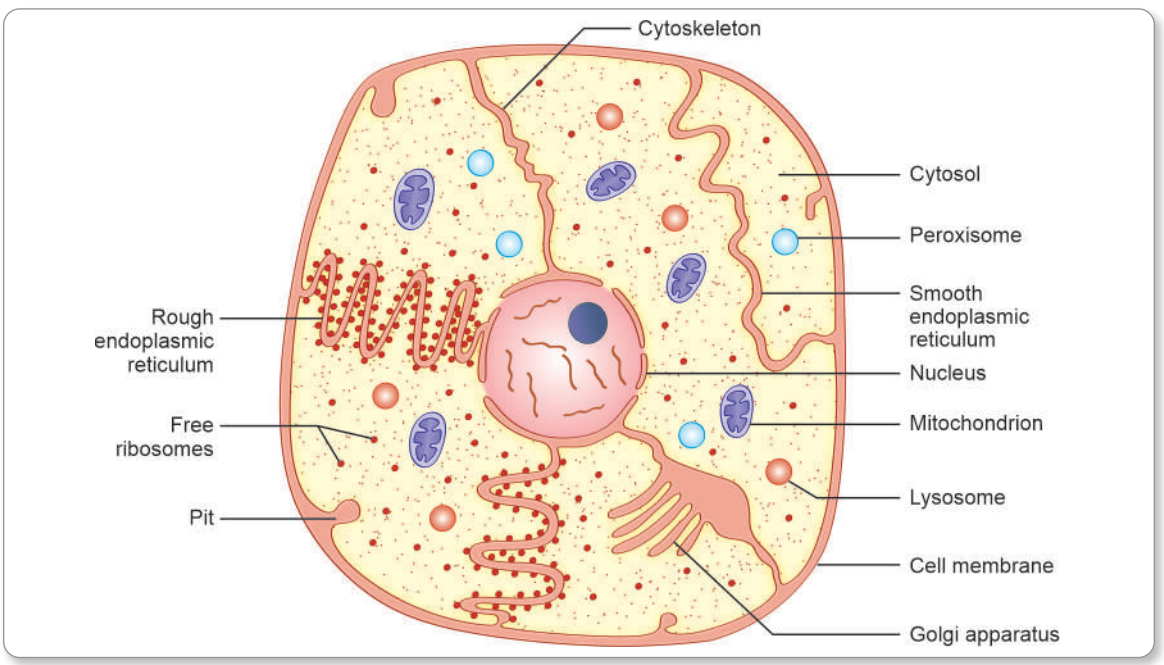


Fig. 22.2: A eukaryotic cell

TABLE 22.1: Major differences between prokaryotic and eukaryotic cell structures

Parameters	Prokaryotic cells	Eukaryotic cells
Cell size	Small	Large
Overall organization	Simple	Complex
Boundary	Cell membrane and cell wall, sometimes surrounded by a capsule	Cell membrane
Subcellular entities	Few	Many
Nucleus	They have a single nucleus which contains double helix DNA that is present in a poorly defined region called nucleoid	Well-defined nucleus with a membrane and multiple DNA double helices organized into chromatin
Reproduction	Asexual	Sexual
Examples	Bacteria and blue-green algae	Plant and animal cells

STRUCTURE AND FUNCTIONS OF INTRACELLULAR COMPONENTS

Nucleus

- The nucleus is the largest component of the cell, containing DNA organized into separate chromosomes and is surrounded by a membrane called nuclear membrane.
- The **nuclear membrane** consists of two layers which are separated by an intermembrane space termed perinuclear space **(cisterns)**. The **outer membrane** though is continuous with the endoplasmic reticulum but the two layers of the nuclear membrane are fused together at several places producing nuclear pores for the exchange of materials between the nucleus and the cytoplasm.
- The nucleus is filled with the **nucleoplasm** which has a discrete body called nucleolus and a thread-like structure called chromatin (Fig. 22.3).
- **Nucleolus:** The number of nucleoli may vary from one cell type to another. The genes for three of the four ribosomal RNA molecules are located in the nucleolus. Nucleoli are rich in RNA and disappear during cell division.

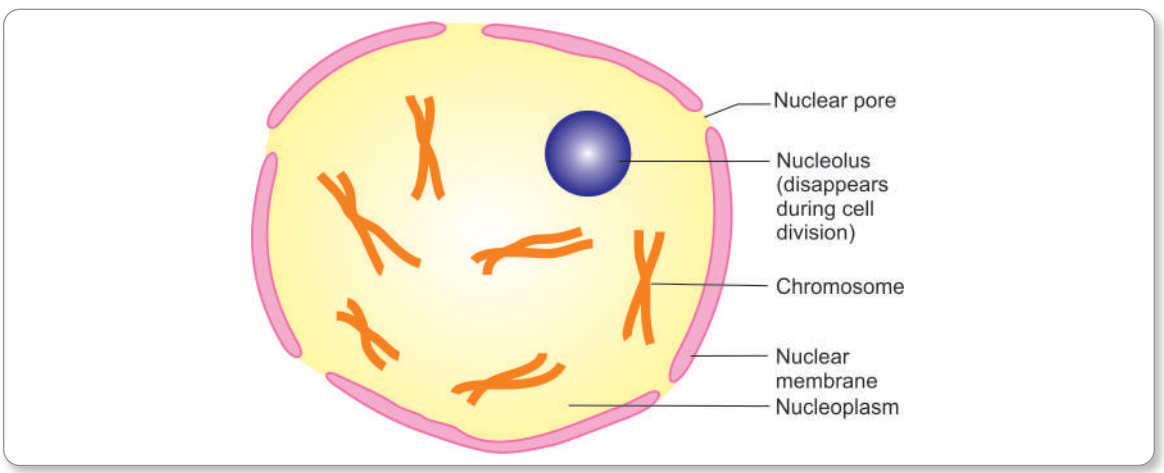


Fig. 22.3: Nucleus

- **Chromatin:** It contains most of the cellular DNA in association with basic proteins, termed histones. At the time of cell division, the chromatin is organized into small thread-like structures called **chromosomes**. Human somatic cell contains 23 pairs of chromosomes.

Important Functions of the Nucleus

Important functions of the nucleus include:

- **Control of cell division** (DNA replication)
- **Protein synthesis** (by controlling the synthesis of RNA)

The regulation of DNA synthesis and other functions of the nucleus are severely disturbed in some pathological conditions such as cancer.

The **DNA** and **DNA polymerase** are the markers of the nucleus.

Endoplasmic Reticulum

Endoplasmic reticulum is a system of membranes (lipid bilayer structures) with a network of vesicular spaces. This network is present throughout the cytoplasmic matrix and grows by its own synthesis. These membranes run parallel to each other creating channels which are called **cisternae**. The interior of the endoplasmic reticulum thus is well connected with perinuclear spaces and through pores on the cell surface, with the extracellular space. Cisternae have a role in the exchange of materials between the cell and the extracellular fluid. The surface of the endoplasmic reticulum may or may not bear ribosomes. Accordingly, endoplasmic reticulum is of two types:

1. **Rough endoplasmic reticulum (RER):** It is also called the granular type of endoplasmic reticulum since it has small granules attached to it. These granules are termed ribosomes.
2. **Smooth endoplasmic reticulum (SER):** It is also called the agranular type of endoplasmic reticulum since it consists of the membranous structure only and does not contain ribosomes on its outer surface. The SER has enzymes for the biosynthesis of lipids and glycoproteins. Further, SER is very important in hepatocytes where these are primarily concerned with oxidative metabolism and for the detoxification of many drugs and other toxic organic molecules.

   Glucose-6-phosphatase is a marker enzyme for the endoplasmic reticulum.

Ribosomes

- Ribosomes consist of ribonucleoprotein particles of two sizes, i.e., 50S and 30S in prokaryotes or 60S and 40S in eukaryotes. Because of their high RNA content, ribosomes are the site of protein synthesis.
- **Ribosomes on the RER** are associated with the synthesis of proteins for export from the cell.
- **Free ribosomes,** on the other hand, are present in the cytoplasm and synthesize proteins for use within the cell.
- **RNA** is used as a marker for the ribosomes.

Golgi Apparatus

- The Golgi apparatus is a smooth membrane system with **vacuoles**. It is rich in lipids and is considered to be the site where secretions from other organelles are brought and assembled.

- The **newly synthesized proteins** are also transferred from RER and **stored in the Golgi apparatus**, temporarily.
- Some of the synthesized proteins also **undergo post-translational modifications** within the Golgi apparatus and thereafter, are transported to different destinations. The Golgi apparatus is thus, especially active in cells which produce proteins for export. They form secretory granules for the proteins after their synthesis on the ribosomes.
- **Galactosyl transferase** is a marker enzyme for the Golgi apparatus.

Mitochondria

The mitochondria are the major organelles of a eukaryotic cell lacking any direct structural relationship with other organelles and contain its own DNA (Fig. 22.4).

- A mitochondrion produces energy in the form of ATP (adenosine triphosphate) for the cellular functions and is thus, called **powerhouse of the cell**. Thus, depending upon energy requirement of the cell, mitochondria may vary in size, shape and number, from cell to cell.

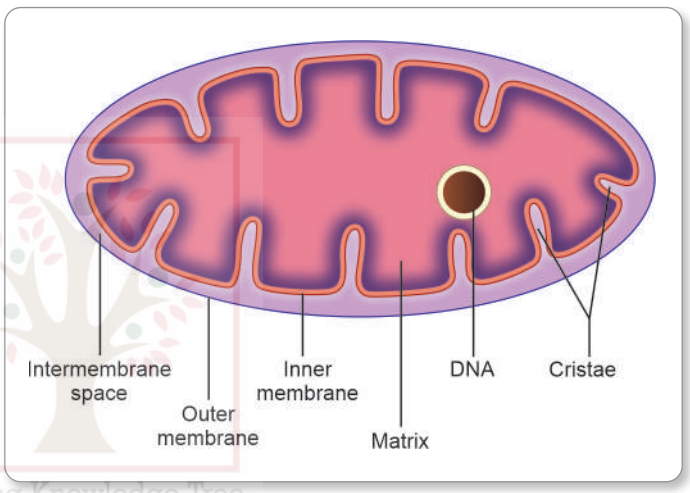


Fig. 22.4: A mitochondrion

- Besides producing energy, mitochondria also help to **control the level of calcium** in the cytoplasm.
- Most of the cells contain several hundred mitochondria.

Mitochondrial Membrane

It is a double-layered structure where the two layers are separated from each other by 50–100 Å intermembrane space. Several enzymes especially those involved in the nucleotide metabolism are located here.

- The **outer membrane** of the mitochondria has a smooth structure. It is composed of both lipids and proteins and is freely permeable to most of the small molecules. Several enzymes involved in lipid metabolism, such as the enzymes for fatty acid elongation, glycerol phosphate acyltransferase and phospholipase A, are associated with the outer membrane of the mitochondria.
- The **inner membrane** of the mitochondria has a denser structure. It has more proteins than lipids. The inner membrane has extensive irregular foldings, called **cristae**. Cytochromes, the enzymes of electron transport chain and flavoproteins are localized within the inner membrane of the mitochondria.

Matrix

The intra-mitochondrial space (enclosed within the inner membrane) is called mitochondrial matrix. This chamber contains enzymes for β-oxidation of fatty acids, citric acid cycle and glutamate dehydrogenase. In addition, mitochondria also have DNA, referred to as mtDNA (mitochondrial DNA).

Mitochondrial DNA: Mitochondria are the only cellular organelles that contain their own chromosomal DNA **(mtDNA)**, which is maternally inherited. Human mtDNA is a small double stranded circular molecule (about 16,000 base pairs), encoding 13 polypeptides that are integrated into the inner mitochondrial membrane along with other polypeptides encoded by nuclear genes. In addition, it encodes 2 rRNAs and 22 tRNAs that are used in protein synthesis within the organelle. mtDNA **differs** from nuclear DNA in several aspects.

Comparison between Nuclear DNA and mtDNA

Comparison between nuclear DNA and mtDNA is given in Table 22.2.

In contrast to nuclear DNA, the mtDNA is exposed to high levels of mutagenic free radicals and is not protected by the usual DNA repair mechanisms. This results in mutations in mtDNA that affect mitochondrial structure and function, leading to **various muscular** and **neurological disorders**, such as Leber's hereditary optic neuropathy, mitochondrial encephalopathy, chronic progressive external ophthalmoplegia, mitochondrial encephalopathy lactic acidosis and stroke like episode (MELAS), etc.

Succinate dehydrogenase and **glutamate dehydrogenase** are marker enzymes for mitochondria.

Lysosomes

Lysosomes (derived from the Greek words lysis, meaning **to loosen** and soma, meaning **body**) are the membrane-bound cell organelles found in animal cells. They are absent in red blood cells. Lysosomes are structurally and chemically spherical vesicles containing hydrolytic enzymes which are capable of breaking down all kinds of biomolecules including proteins, lipids, carbohydrates, nucleic acids and cellular debris.

- Lysosomes are known to contain >50 different enzymes which are all active at an acidic environment of about pH 5. Thus, lysosomes act as **waste disposal system of the cell** by digesting unwanted materials in the cytoplasm both from outside of the cell and obsolete components inside the cell.
- Further, lysosomes are responsible for **cellular homeostasis** for their involvements in secretion, plasma membrane repair, cell signaling and energy metabolism, which are related to health and diseases.
- Depending on their functional activity their sizes can vary.
- **Acid phosphatase** is a marker enzyme of the lysosomes.

TABLE 22.2: Comparison between nuclear DNA and mitochondrial DNA (mtDNA)

Parameters	Nuclear DNA	mtDNA
Location	Nucleoplasm	Mitochondrial matrix
Inheritance	Both paternal and maternal	Maternal
Shape	Linear	Circular
Base pairs	3×10^9	16×10^3
Introns	Present	Absent
Histones	Present	Absent
Encoded proteins	Used within the cell as well as exported	Used within mitochondria
Repair mechanisms	Well developed	Poorly developed
Mutation rate	Low	High

Suicide Bags

Lysosome is a bag (oval, rounded) that is loaded with digestive enzymes which, when activated, act upon cellular structures and demolish them leading to cell death. They are referred to as suicide bags due to their role in **autolysis**, a process by which a biological cell self-destructs, i.e., during the period of starvation it engulfs or eats the whole cell.

Residual Bodies

Cytoplasmic vacuole containing the leftover products of digestion (e.g., membrane fragments or ferritin-like particles) after fusion with the contents of a lysosome is referred to as a residual body. Residual bodies are either secreted by the cell *via* exocytosis (generally in macrophages) or become **lipofuscin granules** that remain in the cytosol indefinitely. Longer-living cells like neurons and muscle cells usually have a higher concentration of lipofuscin than other more rapidly proliferating cells.

Clinical Correlation

Lysosomal Storage Diseases

Lysosomes are responsible for a group of genetically inherited disorders called lysosomal storage diseases (LSD). They are a type of inborn errors of metabolism caused by malfunction of one of the enzymes. The rate of incidence is estimated to be 1 in 5000 live births.

The primary cause is **deficiency of an acidic hydrolase** *while there are conditions of* **defects in lysosomal membrane proteins** *that fail to transport the enzyme or non-enzymatic soluble lysosomal proteins. The initial effect is accumulation of specific macromolecules or monomeric compounds inside the endosomal–autophagic–lysosomal system. This results in abnormal signaling pathways, calcium homeostasis, lipid biosynthesis and degradation and intracellular trafficking, ultimately leading to pathogenic disorders. The organs most affected are brain, viscera, bone and cartilage. There is no direct medical treatment to cure LSDs.*

Gaucher's disease: *Gaucher's disease is due to deficiency of the enzyme glucocerebrosidase. Consequently, the enzyme substrate, the fatty acid glucosylceramide accumulates, particularly in white blood cells. This in turn affects spleen, liver, kidneys, lungs, brain and bone marrow. The disease is characterized by bruises, fatigue, anemia, low blood platelets, osteoporosis and enlargement of the liver and spleen.*

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Peroxisomes

- Peroxisomes, also called **microbodies**, contain certain oxidative enzymes, e.g., uric acid oxidase, D-amino acid oxidase and catalase, etc.
- The major function of the peroxisomes is in hepatocytes where they are involved in the oxidation of fatty acids by a modified α-oxidation pathway.
- Besides, peroxisomes also represent very primitive cellular organelles which provides protection to the cell from the toxicity of hydrogen peroxide (H_2O_2).
- **Catalase** and **uric acid oxidase** are marker enzymes of the peroxisomes.

Clinical Correlation

Zellweger Syndrome

Absence of the functional peroxisomes results in a rare autosomal recessive disease referred to as Zellweger syndrome. It is characterized by abnormalities of the several organs due to the decreased levels of plasmalogens.

Cytosol

- The cytosol or **cell sap** is a structureless material filling the cell (aqueous matrix) in which all the cellular organelles float.
- It is a colloidal solution of proteins containing nearly 70% water.
- Besides proteins, the cytosolic fraction also contains various enzymes for glycolysis, gluconeogenesis and Hexose Monophosphate (HMP) shunt, and a variety of organic as well as inorganic substances such as glucose, potassium and magnesium.

- The cytosol is in contact with all the cellular organelles and an important vehicle for the transport of metabolites from one organelle to the other.
- The cytosol of all eukaryotic cells also contains a network of fibers, collectively called **cytoskeleton,** which includes microtubules, intermediate filaments and microfilaments.
- **Lactate dehydrogenase** is a marker enzyme of the cytosol fraction of the cell.

Plasma Membrane

Plasma membrane or cell membrane is the outer membrane of the cell. It is in contact with the extracellular with matrix (*see Chapter 23*).

STUDENT ASSIGNMENT

LONG AND SHORT ANSWER QUESTIONS

1. Describe structure, functions and biochemical markers of various subcellular entities of a eukaryotic cell.
2. Explain:
   a. Mitochondria as a power-house of the cell
   b. Functions of the rough endoplasmic reticulum
   c. Differences between nuclear and mitochondrial DNA
3. Write short notes on:
   a. Nucleus
   b. Ribosomes
   c. Golgi apparatus
   d. Matrix
   e. Suicide bags
   f. Age-pigments
   g. Lysosomal storage diseases
   h. Lysosomes and peroxisomes

Nursing Knowledge Tree
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MULTIPLE CHOICE QUESTIONS

1. **Protein synthesis takes place mainly in:**
   a. Ribosomes
   b. Mitochondria
   c. Centrosome
   d. Golgi apparatus
2. **In Lysosomal storage disorders, true is:**
   a. The lysosomes are deficient in enzyme hydrolase
   b. There is a defect in fusion of lysosomes and phagosomes
   c. There is a defect in lysosomal membrane
   d. There is increased degradation of heteroglycans
3. **False about Mitochondria is:**
   a. Absent in RBCs
   b. Powerhouse of the cell
   c. Electron transport chain enzymes are present in outer membrane
   d. Cytochrome P450 in inner membrane
4. **Mitochondrial DNA is:**
   a. Closed circular
   b. Nicked circular
   c. Linear
   d. Open circular