Ultra-structure of Prokaryotic Cells

Prokaryotic cells are the simplest of most primitive cells. The records of microfossils suggest that they have evolved 2.5 billion years ago and existed as the only organisms on earth for the next one billion years until eukaryotes evolved about 1.5 billion years ago.

The ultrastructure of a prokaryotic cell is a typical bacterial cell consists of cell envelope, cytoplasm, nucleoid, plasmids and surface appendage.

1. Cell envelope:
It is the protective covering of bacterial cell that has three basic layers: the outermost glvcocalyx, middle cell wall and innermost cell membrane (plasma membrane).

(i) Glycocalyx:
It is the outermost layer of cell envelope which is chemically composed of polysaccharides.When it is thick and tough, it is called capsule, and when it forms a loose sheath it is called slime layer.
It has many functions:
(a) Protects cell from desiccation, toxins and phagocytes.

(b) Helps in adhesion, immunogenicity and virulence.

(ii) Cell wall:

It is the rigid middle layer of cell envelope that provides shape.In Gram-positive bacteria, cell wall is single layered and almost uniform in thickness (10 to 80nm).It is composed of peptidoglycan (murein or mucopeptide), consists of two alternating amino sugars, N-acetylglucosamine (NAG) and N-acetylmuramicacid (NAM).

The walls of Gram- positive bacteria also contain teichoic acids Teichoic acids act as surface antigen. In Gram-negative bacteria cell wall is two- layered and only 7.5-12 nm thick. The inner layer in a thin peptidoglycan and the outer layer is a unit membrane called outer membrane. The outer membrane is a lipid bilayer consists of phospholipids, proteins and a unique lipid, lipopolysaccharide (LPS).

(iii) Cell membrane:

It is the innermost layer of cell envelope. It is a semi-permeable, similar to that of eukaryotic membrane. But the only difference is they lack sterols instead hopanoids present. The hopanoids are pentacyclic sterol-like molecules that stabilize the bacterial cell membrane.

In a bacterial cell, plasma membrane performs many functions:

1. It retains the cytoplasm
2. Prevent loss of essential components through leakage
3. Aids in the movement of nutrients, wastes and secretions across the membrane
4. Holds receptor molecules that detect and respond chemicals in their surroundings. Such as respiration, photosynthesis, synthesis of lipids and cell wall constituents
5. It invaginates to form mesosome and thylakoids of cyanobacteria.

***2.* Cytoplasm**: It is granular, crystallo-colloidal complex that fills the whole prokaryotic cell excluding nucleoid. The cytoplasm contains mesosome, chromatophores, ribosomes, inclusion bodies and plasmids.

(i) Mesosome (or chondrioids):
It is membranous infolding of the plasma membrane. Mesosome when connected with nucleoid is called septal mesosome and when not connected called lateral mesosome.They help in Cell wall formation, chromosome replication and distribution to daughter cells, secretory activity.

(ii) Chromatophores:
These are internal membrane systems of prokaryotic cells. In nitrifying bacteria the chromatophores increase metabolic area.

(iii) Ribosomes:
Prokaryotic ribosomes are 70S in nature that consist of larger 5OS and smaller 30S subunits. During protein synthesis, about 4-8 ribosomes attach to a single

mRNA to form polyribosomes or polysomes. Non functional ribosomes present in separated subunits.

(iv) Inclusion bodies: These are non-living structures present freely in the cytoplasm. Inclusion bodies may be organic or inorganic. They include mainly food reserve and special prokaryotic organelles like gas vacuoles, chromosomes. Except food reserve other inclusion bodies are surrounded by a single layer non-unit membrane which is 2-5 nm thick.

Food reserve:

These are reserve materials or storage granules which are not bounded by any membrane system. The volutin granules (= polyphosphate granules) and sulphur granules are inorganic inclusion bodies which store phosphate and sulphur respectively. These granules are also called meta-chromatic granules because of their ability to take different colours to basic dyes. The organic- food reserves present in some bacteria are glycogen granules, protein granules, and starch.

Gas vacuoles:

These are the organic inclusions of most aquatic, free floating forms. Each gas vacuole is an aggregate of variable number of hollow, cylindrical gas vesicles. Gas vacuoles help in floating, for proper positioning in water to trap sunlight for photosynthesis and protect against harmful radiations.

Chlorosomes:

These are cigar-shaped vesicles that enclose photosynthetic pigments like bacteriochlorophyll c, d, or e. Chlorosomes are distinct structures found just below the plasma membrane but tightly joint to it by a basal plate. These are found in the green bacteria.

Carboxysomes: These are principal sites of CO_2 fixation in case of autotrophic prokaryotes like cyanobacteria, purple bacteria, nitrifying bacteria etc.

Magnetosomes:

These are the vesicles filled with crystals of magnetite (Fe_3O_4). Magneto-somes help the bacteria to orient themselves in a magnetic field and determine the direction of swimming.

(v) Plasmids:

Laderberg and Hays (1952) introduced the term ‘plasmid’ to those ring-like self replicating extra chromosomal double stranded DNA that are found in the cytoplasm of prokaryotes.

Plasmids are generally double stranded closed circles of D.N A with sizes vary from 1-3 00 kilobase pairs (1 Kbp = 1000bp) and carries 5-100 genes. Hence, plasmids are often called as minichromosomes. They are also known as dispensable autonomous elements because the genes they carry have no role in viability and bacterial growth.

Plasmid Types:

On the basis of function, plasmids are of following types –

(a) Sex plasmid:

It carries fertility factor (F-factor) responsible for the formation of sex-pili and conjugation. Hence, often called F-plasmid.

(b) R-Plasmid:

It carries resistance (R) factor which provide resistance against antibiotics, heavy metals, UV-radiation etc., e.g. Rl.R4G etc.

(c) Col-plasmid:

It carries colicinogenic factor that, produce colicins (bacteriocins) to kill other bacterial.

(d) Degradative plasmid: They carry genes that has the ability to degrade the organic compounds.

(e) Ti-plasmids:

These are tumour including plasmids carried by the *Agrabacterium tumefaciens.* Ti-plasmid carries

T-DNA (transforming DNA) which is 200 Kbp long and causes crown gall disease in plants, T- DNA is an ideal vector for gene transfer in plants.

3. Nucleoid

Nucleoid is the genetic material of a prokaryotic cell .It is represented by a single circular naked ds DNA which is highly looped and super coiled with the help of nucleoid proteins and RNA. Nucleoid is a compact structure and it is not an organized nucleus rather an incipent nucleus.

4. Appendages:
The surface appendages present on bacterial cell may be motile flagellum or non-motile pili and fimbriae.

(a) Flagella: These are long (1-71m) fine hairy locomotary appendages present on bacterial surface for swimming. Some bacteria bear sheath flagella surrounded by extension of cell membrane.
The ultrastructure of each flagellum shows 3 parts – basal body, hook and filament.

The hook is slightly wider and curved structure about45 nm long that connects, basal body with the filament. The filament is hollow cylindrical structure about 1-70 nm long and 20 nm in diameter. Filament composed of 3-8 spiral of flagellian proteins. But hook is made up of a different kind of proteins.

The bacterial flageilum rotate by 360″ rather than a whip like back and forth movement. As a result the bacterial cell spins in the opposite direction and pushes the bacterium in forward direction.

(b) Pili and fimbriae:
The pili are tubular outgrowths of about 18-20 nm made up of pilin protein. They are reported only in donor cell Gram negative bacteria where they help in conjugation. Hence, pili are also called sex-pili or F-pili.

Fimbriae are bristle like surface appendages help in adhesion and mutual clinging length varies from 6.1 – 7.5 nm and diameter 3-10 nm.

Ultrastructure of Eukaryotic Cell

Eukaryotic cells are defined as cells containing organized nucleus and organelles which are enveloped by membrane-bound organelles. Examples of eukaryotic cells are plants, animals, protists, fungi. Their genetic material is organized in chromosomes.

Golgi apparatus, Mitochondria, Ribosomes, Nucleus are parts of Eukaryotic Cells.

1.Cell Wall: The cell wall is a non-living, rigid structure outside the plasma membrane in plant cells and fungi. It is absent in Eukaryotic cells of animals

Structure and composition: It is made of different components in different Eukaryotes:

- Cellulose, hemicellulose, proteins, and pectin – in plants.
- Cellulose, galactans, mannans and calcium carbonate – in fungi.

  The cell wall is divided into the following three layers:

- Middle lamella – It is the outermost layer and is made of calcium pectates. It holds adjoining cells together.
- Primary wall – It is the middle layer and is made of cellulose and hemicellulose. It is present in young, growing cells and is capable of growth.
- Secondary wall – It is the innermost layer and similar in composition to the primary wall.

Functions

- Provides shape to the cell.
- Helps in cell-cell interaction.
- Protects the cell from injury, undesirable molecules and pathogens.

2.Cytoplasmic Membrane: It is also called plasma membrane or cell membrane. The plasma membrane is a semi-permeable membrane that separates the inside of a cell from the outside.

Structure and Composition: In eukaryotic cells, the plasma membrane consists of proteins, carbohydrates and two layers of phospholipids (i.e. lipid with a phosphate group). These phospholipids are arranged as follows:

- The polar, hydrophilic (water-loving) heads face the outside and inside of the cell. These heads interact with the aqueous environment outside and within a cell.

- The non-polar, hydrophobic (water-repelling) tails are sandwiched between the heads and are protected from the aqueous environments.

Scientists Singer and Nicolson described the structure of the phospholipid bilayer as the 'Fluid Mosaic Model'. It looks like a mosaic and has a semi-fluid nature that allows lateral movement of proteins within the bilayer.

Functions

- The plasma membrane is selectively permeable i.e. it allows only selected substances to pass through.
- It protects the cells from shock and injuries.
- The fluid nature of the membrane allows the interaction of molecules within the membrane. It is also important for secretion, cell growth, and division etc.
- It allows transport of molecules across the membrane. This transport can be of two types:
  - Active transport – This transport occurs against the concentration gradient and therefore, requires energy. It also needs carrier proteins and is a highly selective process.
  - Passive transport – This transport occurs along the concentration gradient and therefore, does not require energy. Thus, it does not need carrier proteins and is not selective.

3.Endoplasmic reticulum (ER)

It is a network of small, tubular structures. It divides the space inside of Eukaryotic cells into two parts – luminal (inside ER) and extra-luminal (cytoplasm).

Structure: ER can be of two types –

Functions

- SER is involved in lipid synthesis and RER is involved in protein synthesis.
- RER helps in folding proteins and transports it to the Golgi apparatus in vesicles.

4. Golgi Apparatus

It is named after the scientist who discovered it, Camillo Golgi. Golgi is made of many flat, disc-shaped structures called cisternae. It is present in all eukaryotic cells except human red blood cells and sieve cells of plants.

Structure: The cisternae are arranged in parallel and concentrically near the nucleus as follows:

- Cis face (forming face) – It faces the plasma membrane and receives secreted material in vesicles.
- Trans face (maturing face) – It faces the nucleus and releases the received material into the cell.

Functions

- An important site for packaging material within the cell.
- Proteins are modified in the Golgi.
- An important site for the formation of glycolipids (i.e. lipids with carbohydrate) and glycoproteins (i.e. proteins with carbohydrates).

5.Ribosomes

These structures are not bound by a membrane. Ribosomes are also called 'Protein factories' since they are the main site of protein synthesis.

Structure: They are made of ribonucleic acids and proteins. Eukaryotic ribosomes are of the 80S type, with 60S (large subunit) and 40S (small subunit).

Functions: A Major site for synthesis of proteins and polypeptides (chain of amino acids).

6.Mitochondria

They are membrane-bound organelles, also known as 'powerhouses of the cell'.

Structure: It has two membranes – outer and inner. The outer membrane forms a continuous boundary around the mitochondria. The inner membrane is semi-permeable and divided into folds called 'cristae'. The membranes divide the lumen of the mitochondria into an inner and outer compartment. The inner compartment is called matrix and outer compartment forms the intermembrane space.

Functions

- They produce energy (ATP) and therefore are called the 'powerhouse of the cell'.

- Helps in regulating cell metabolism.
- Mitochondria possess their own DNA, RNA and components required for protein synthesis.

7.Lysosomes

They are membrane-bound vesicles formed in the Golgi apparatus. Lysosomes are also called ‘suicidal bags’ since they are rich in hydrolytic enzymes such as lipases, proteases, carbohydrates etc. These enzymes are optimally active at acidic pH (less than 7).

Function: The main function of lysosomes is to digest lipids, proteins, carbohydrates and nucleic acids.

8. Nucleus

Nucleus is the main organelle of a cell. It is a double membrane structure with all the genetic information. Therefore, it is also called the ‘brain’ of a cell. The nucleus is found in all eukaryotic cells except human RBCs and sieve cells of plants.

Structure: A nucleus has the following parts:

Nuclear envelope – It is a double membrane structure that surrounds the nucleus. The outer membrane is continuous with the endoplasmic reticulum. The inner membrane has small pores called ‘nuclear pores’.

- Nucleoplasm – It is the fluid material in the nucleus that contains the nucleolus and chromatin.
- Nucleolus – Nucleoli are not membrane-bound and are active sites for ribosomal RNA synthesis.
- Chromatin – It consists of DNA and proteins called ‘histones’. The DNA is organised into chromosomes. Chromosomes have certain constriction sites called ‘centromeres’. Based on the position of the centromere, they can be divided as follows:
    - Metacentric – With centromere in the centre and having equal chromosome arms.
    - Sub-metacentric – Centromere is slightly off-centre creating one short and one long arm.

- Acrocentric – Centromere is extremely off-centre with one very long and one very short chromosome arm.
- Telocentric – Centromere is placed at one end of the chromosome. Humans do not possess telocentric chromosomes.

Functions

- It stores genetic information (in the form of DNA) necessary for development and reproduction.
- It contains all information necessary for protein synthesis and cellular functions.

9.Cytoskeleton

It is the filamentous network present in the cytoplasm of a cell.

Function: It provides mechanical support, maintains the shape of the cell and helps in motility.

10.Cilia and Flagella

They are both responsible for the movement of a cell.

11.Plastids

They are double membrane organelles found in plant cells. They contain pigments and are of three types:

- Chloroplasts – They contain chlorophyll and are involved in photosynthesis, where light energy is converted to chemical energy. Chloroplasts contain compartments called stroma and grana. Grana contains structures called thylakoids that contain chlorophyll. Stroma contains enzymes needed for carbohydrate and protein synthesis.
- Chromoplasts – These give plants yellow, red or orange colours because they contain pigments like carotene.
- Leucoplasts – These are colourless plastids that store either carbohydrates (Amyloplasts), oils and fats (Elaioplasts) or proteins (Aleuroplasts).

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