

Chapter 6

Cellular structure of bacteria

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Abstract: Bacteria are unicellular with absence of compartmentalization of cellular structures and devoid of cellular organelles. Genome is scattered in the cytoplasm as nucleoid and there is no differentiation in to true nucleus. Several cytoplasmic inclusions like fat granules, gas vesicles, Carboxysomes and Glycogen granules etc., are scattered inside the bacterial cell in the cytosol.

Keywords: Carboxysomes, Cytosol, Genome, Gas Vesicles, Nucleoid

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1. Cytoplasmic inclusions:

1.1. Vacuoles:

Vacuoles are the membrane bound structures with organic and inorganic compounds including enzymes, pigments and other metabolic products. Mostly plant cells will possess vacuoles and even fungal cells and protists are included under few examples of organisms that possess vacuoles. Animal cells possess numerous vacuoles which are small and more significant in function compared to bacteria.

Basically vacuoles are of three categories namely:

1. Storage vacuoles
2. Contractile vacuoles
3. Vacuoles involved in Autophagy

Plant cells have large vacuoles. They help in maintenance of turgor pressure, storage of pigments and nutrients, disposal of metabolic waste products and maintain shape of the cell. In animals they involve in major processes like Endocytosis and Exocytosis.

1. Ribosomes: Ribosomes in bacteria are small with 10- 20 nm in diameter. Ribosomes are usually made up of protein and rRNA. In some cases many ribosomes will form in to poly ribosomes or polysomes when many ribosomes start to translate single mRNA during translation.

2. Polyphosphates: Many bacteria and micro algae accumulate inorganic phosphates joined to each other called polyphosphates by ester bonds. They also show metachromic effect like appearing red or shade of blue when stained with dyes like methylene blue known as metachromic granules or Volutin granules which is first described in *Spirillum volutans*.

3. Poly-β-hydroxybutyrate (PHB): Poly- β -hydroxybutyrate (PHB) is a polymer formed by linking of carboxyl group with hydroxyl group of adjacent β - hydroxy butyrate monomers which finally aggregate in to granules of 0.2-0.7µm in diameter. Poly- β -hydroxybutyrate (PHB) can be readily stained with the Sudan black and appear prominent under electron microscope.

4. Glycogen: Glycogen as Poly- β -hydroxybutyrate (PHB) a storage polymer and made up of glucose units with α(1→ 4) and α(1 → 6) glycosidic bonds. Glycogen is dispersed evenly through out the cytoplasm and in eukaryotes it is a reservoir of carbohydrates and energy. It is also termed as Animal starch.

5. Gas vacuoles: Gas vacuoles are the buoyant structures formed by combining of individual hollow cylinders termed as gas vesicles. These structures will confer buoyancy to aquatic microorganisms enabling them to float on the surface of the lakes. Most of the aquatic bacteria will possess gas vacuoles in addition the non photosynthetic organisms like *Halobacterium* and *Thiothrix* will also possess them.

Other types of cytoplasmic inclusions include Magnetosomes, Carboxysomes and Sulphur globules.

2. Differences between Prokaryotes and Eukaryotes:

Contents	Prokaryotes	Eukaryotes
Ribosomes	Present	Present
Mitochondria	Absent	Present
Centrioles	Absent	Present
Nucleus	Not well organized	Well organized
Lysosomes	Absent	Present
Chloroplast	Present	Absent
Transcription	Takes place in cytoplasm	Takes place in Nucleus
Translation	Coupled	Not Coupled
Reproduction	Asexual and sexual	Sexual
Nuclear membrane	Absent	Present
Nucleolus	Absent	Present

3. Cytoskeletal structure of bacteria:

Cytoskeleton in bacteria is made up of single type of protein organized in to long thread like structures capable of self assembling in vitro in to polymeric filaments. In bacteria the three actin homologs isolated shows similarity to the actin protein of eukaryotes with a shared actin domain and an active actin ATPase domain.

4. Endospore and its germination:

Most of the bacteria adapt to harsh conditions by designing strategies and synthesise new enzymes and being motile to procure the nutrients outside the environment. Some of the low G+C content bacteria can produce resistant structures called Endospores to thrive harsh conditions and their Nucleic acid material becomes highly resistant to adapt the adverse conditions such as radiation.

4.1. Germination of Endospore:

Endospore germination involves breaking out the spore coat and synthesis of new enzymes that helps in metabolic activity. This majorly occurs in three steps like Activation, Germination and outgrowth.

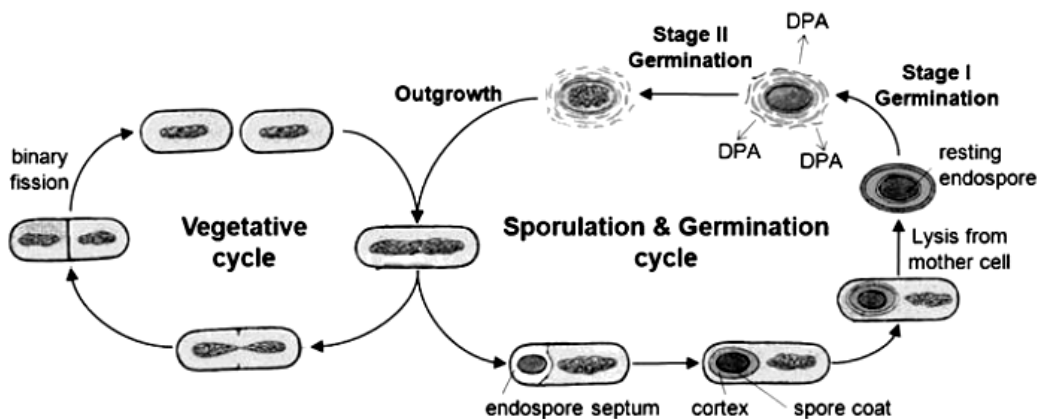


Figure: 7 Sporulation and Germination of Endospore [Taken from Prescott, L. M. (2002). *Microbiology* (5th edition). The McGraw-Hill Companies].

Germination of the endospore would not occur until proper activation and can be done by heating the endospore. Germination usually begins with rupture of spore coat, increase in metabolic activity and loss of resistance to tolerate the environment stress. Out growth involves manufacturing new chemical components by the core of the endospore and

exiting the old spore coat and development in to the new vegetative bacterial cell able to divide to produce more cells.

5. Cytosol:

- Cytosol is the gel like substance present inside the cell where various metabolic activities takes place.
- It is the place where enzymes of metabolic activity and cell organelles are distributed inside the cell.
- Cytoskeleton distributed in the cytoplasm will determine the shape and structure of the cell.
- Cytosol remains the region where cytoplasmic inclusions are scattered and it is the region where protein synthesis and respiration of the cell will takes place.
- Cytosol and proteins will prevent the grouping of organelles that will impede their function.
- It is the place where sugars and ions are distributed and it is means of transport for genetic material
- It also transports the products of cellular respiration
- It is sometime described as non nuclear compartment of protoplasm.

6. Cell Membrane:

Cell membrane is a biological membrane that separates interior from the exterior of the cell. Membrane is made up of three important bio molecules like carbohydrates, lipids and proteins. Cell membrane is made up of three kinds of lipids like Phospholids (accounts major portion), spingholipids, Glycolipids and cholesterol. Cholesterol is found to be absent in prokaryotes.

Phospholipids is made up of polar head and hydrophobic tail and found to be distributed in both outer and inner leaflet of the membrane. Plasma membrane accounts for about 50 % of the total protein, Myelin consists of around 25% of the protein and membranes of chloroplast and mitochondria constitute around 50% of the total protein. Cholesterol concentration may varies and one cholesterol molecule is found associated with one phospholipid.

Functions:

- Keeps the cell intact
- Acts as a protective barrier
- Regulate transport in and out of the cell

- Small lipid molecules and gases like CO₂ and O₂ can exchange easily through the membrane.
- Large molecules and ions cannot cross the barrier.
- Allow cell to cell recognition
- Acts as anchoring sites for cytoskeleton filaments
- Maintains semi permeability and protects the content of cytoplasm from leakage.

7. Membrane Transport systems:

Membrane transport system is the system by means of which ions and molecules transport in and out of the membrane. Membrane transport is the process by which molecules and ions pass or enter in to the cell in a regulated process with the help of the biological membrane with embedded proteins in it.

Membrane transport occurs by means of two ways:

1. Passive Transport
2. Active Transport

7.1. Passive Transport:

Passive transport is of three types:

1. Osmosis
2. Passive diffusion
3. Facilitated diffusion

Osmosis: Transport of molecules occur through the semipermeable membrane from higher concentration to the lower concentration.

Passive diffusion: Transport of molecules takes place from higher concentration to lower concentration with out any use of energy.

Facilitated Diffusion: Facilitated diffusion involves transport of molecules through a carrier or Ion channel or protein from higher concentration to lower concentration with out utilizing ATP.

7.2.Active transport:

Active transport involves transport of molecules from lower concentration to higher concentration by utilizing the ATP or electro chemical gradient generated by the movement of other ion from high concentration to low concentration.

Depending on the kind of energy they utilize active transport is majorly classified in to :

1. Primary active transport
2. Secondary active transport

7.2.1. Primary active transport: Primary active transport utilize ATP molecules for the transport of ions from lower concentration to higher concentration.

Ex: Na^+/K^+ ATPase, Ca^{2+} - ATPase, H^+ - ATPase

7.2.2. Secondary active transport: Secondary active transport utilize ion gradient generated by the ions to transport ions or molecules from lower concentration to higher concentration.

Ex: $\text{Na}^+/\text{Glucose}$ transporter, Na^+/H^+ exchanger

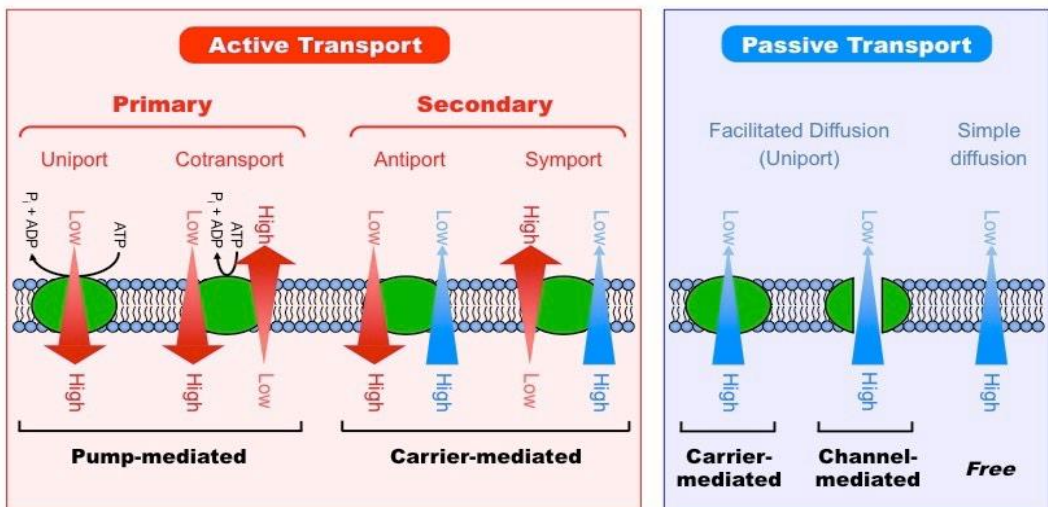


Figure:8 Overview of membrane transport [Taken from Human Genome Organization (<http://www.hugo-international.org/>) nomenclature page (<http://www.genenames.org/>)].

Symport: Involves transport of two molecules from lower concentration gradient to higher concentration gradient in the same direction across the membrane. **Ex:** Na^+ - Glucose Transporter

Antiport: Involves transport of two molecules from lower concentration gradient to higher concentration gradient in the opposite direction across the membrane. **Ex:** Na^+/K^+ antiporter

8. Cell wall:

Cell wall is made up of peptidoglycan majorly and responsible for the following functions:

1. Maintains the shape of the cell
2. Acts as protective barrier
3. Help as osmotic regulator of the cell.

8.1. Peptidoglycan:

- Peptidoglycan or murein is a polymer of two sugars namely N- acetyl glucosamine and N- acetyl neuraminic acid linked together with β (1 \rightarrow 4) glycosidic bond.
- Gram positive bacteria is made up of thick peptidoglycan layer and contribute about 50- 90 % of the dry weight
- Teichoic acids are present only in gram positive bacteria and absent in gram negative bacteria. Teichoic acids are the polymers of ribitols or glycerol joined with phosphate groups.
- Teichoic acids contribute to antigenic nature of the cell, Regulate normal cell division and helps in providing Mg^{2+} to the cells.

8.2. Periplasm: Periplasm refers to the space present between the cell membrane and the outer membrane. Periplasm consists of proteins involved in numerous activities like nutrient degradation and transport.

Outer membrane:

Membrane surrounding the peptidoglycan refers to outer membrane and acts as barrier for the toxic molecules to enter inside the cell. Outer membrane is made up of mostly lipopolysaccharides hence it is referred as lipopolysaccharide layer or LPS.

LPS consists of three components:

- Lipid A
- Core Component
- O- antigen

Lipid A is found to be embedded in the membrane. Core component is found surface of the membrane. O-Antigen is protruded out to the membrane and extended from the core.

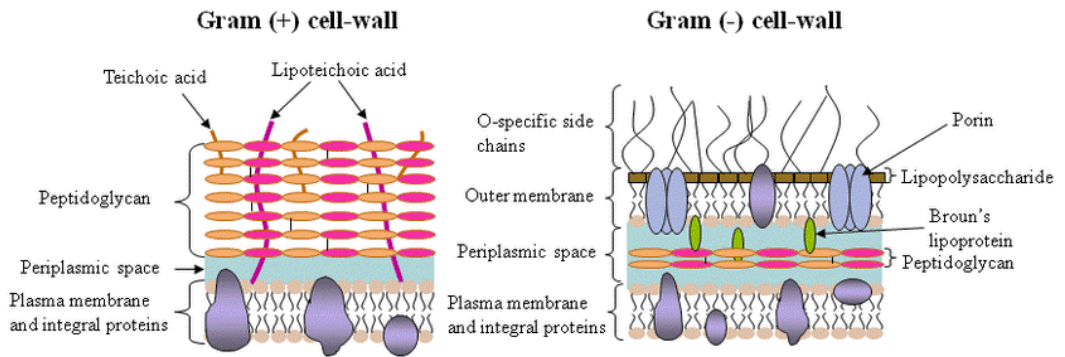


Figure:9 Structure of Gram positive and Gram negative cell wall [Taken from Prescott, L. M. (2002). *Microbiology* (5th edition). The McGraw-Hill Companies].

9. Flagella and Cilia:

- These are the filamentous structures that projects outward from the outer surface of the plasma membrane.
- Cells will move perpendicular to the beating pattern or movement of cilia.
- Flagella usually occur single or in pair and can produce variety of beating patterns depending on the cell type.

9.1 Structure of cilia and Flagella:

- Cilia or flagellar out portion is surrounded by a membrane continuous with that of the plasma membrane of the cell.
- Core component of cilium is known as Axoneme, and contains array of micro tubules.
- Axoneme of a motile cilium or flagellum consists of nine peripheral doublets and with one central doublet i.e., (9+2) arrangement.
- All microtubules will have same polarity (all +ve ends will project upwards and all -ve ends will projects towards base).
- Each Peripheral doublet consists of one complete tubule called A tubule and one incomplete tubule B Tubule.
- Structure of axoneme is first depicted by Manton (Plants) and Fawcett and Porter (animals) in 1952.
- Central tubules are surrounded by a sheath and connected to the A tubule by radial spokes.
- Doublets are connected to each other by inter doublet bridge composed of nexin.
- A pair of arms called Dynenin arms projects from the A tubule.
- Cilia or flagella arises from the basal body

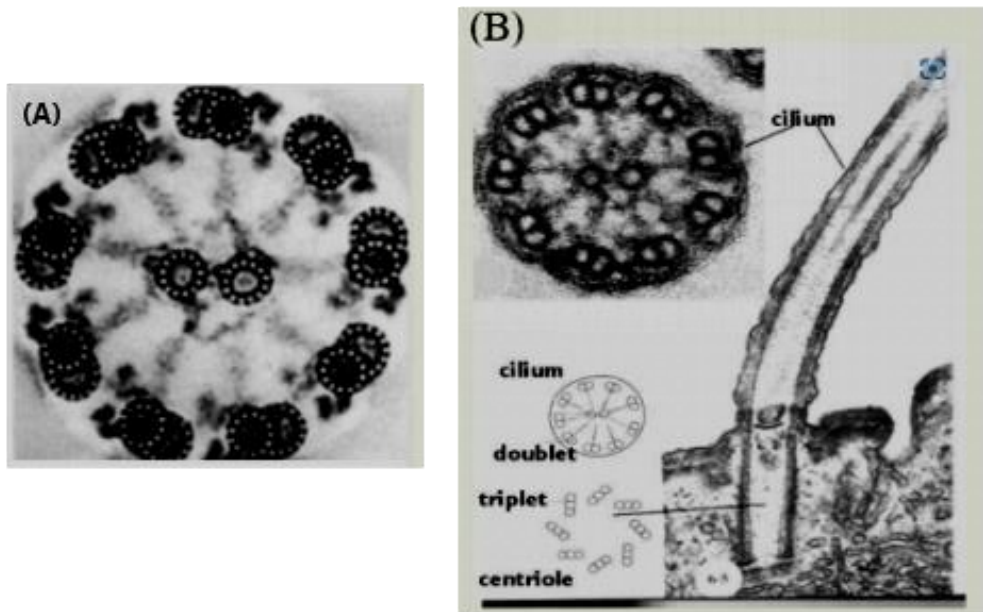


Figure:10 (A) Electromicrograph showing the structure of Axoneme (B) Structure of Cilia or Flagella. [Taken from Thomas D. Loreng and Elizabeth F. Smith (2017). The Central Apparatus of Cilia and Eukaryotic Flagella. Cold Spring Harb Perspect Biol. 2017 Feb; 9(2): a028118. doi: 10.1101/cshperspect.a028118].

Basal Bodies:

Flagellum or cilium arises from a short spherical or granular body called basal body known as Kinetosome or basal granule or Proximal centriole. Basal body is functionally similar to centrioles. It is a acylindrical body with 9 groups of tubules present in its protoplasm. Each tubule consists of 3 components in which two will extends in to flagellum and one will ends up between basal body and flagellum.

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