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CLINICAL MICROBIOLOGY & PARASITOLOGY

For DMLT Students

Highlight

- Based on latest syllabus from universities and paramedical council.
- Concepts are supported with flowcharts and colorful images.
- Fantastic facts are provided for every chapter to make it more interesting.
- Simple and lucid language.
- Summary for quick recap of every chapter.











Nanda Maheshwari

FOURTH EDITION

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CHAPTER

3 Structure of Bacterial Cell

INTRODUCTION

The term "microorganism" represents an incredibly wide range of organisms, which includes bacteria, fungi, protozoa, and algae. While viruses are not considered to be living organisms, they are often thought to be microbes due to their extremely small size.

- **Bacteria** are typically unicellular, microscopic, and prokaryotic organisms that reproduce by binary fission.
- **Fungi** (yeasts and molds) are typically unicellular, microscopic, eukaryotic fungi that reproduce asexually by budding. Molds are typically filamentous, eukaryotic fungi that reproduce by producing asexual reproductive spores.
- **Viruses** are typically submicroscopic, acellular infectious particles that can only replicate inside a living host cell. The vast majority of viruses possess either DNA or RNA, but not both.
- **Protozoa** are typically unicellular, microscopic, eukaryotic organisms that lack a cell wall.
- **Algae** are typically eukaryotic microorganisms that carry out photosynthesis.

STRUCTURE OF BACTERIAL CELL

A typical bacterial cell has the following general property:

It is a prokaryotic cell. It contains both DNA and RNA. Most of bacteria grow in artificial media. Bacteria replicate by binary fission.

Bacterial cell structure is considered at three levels **(Fig. 3.1)**.

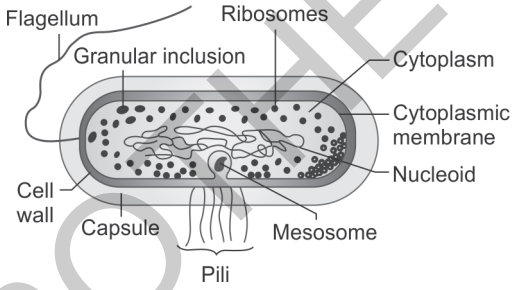

Fig. 3.1: Structure of a bacterial cell.

I. *Cell envelope*: Cell wall and cell membrane
II. *Cellular element*: These are enclosed within the cell envelope, e.g., mesosomes, ribosomes, nuclear apparatus, polyamines and cytoplasmic granules.
III. *Cellular element external to the cell envelope*: Flagellum, pilus, and glycocalyx

I. CELL ENVELOPE

The cell envelope consists of the cell membrane, cell wall, and associated structures.

1. Cell Wall

The cell wall of the bacterial cell is a complex, semirigid structure responsible for the shape of the cell. The cell wall surrounds the underlying, fragile plasma membrane and protects it and the interior elements of the cell from adverse changes in the outside environment. The major function of the cell wall is to prevent bacterial cells from rupturing due to osmotic changes in the surrounding. It also acts as an antigen.

Composition of Bacterial Cell Wall

The primary component of bacterial cell walls is peptidoglycan. Peptidoglycan is a

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macromolecule composed of sugars and amino acids that are assembled structurally like woven material. The amino sugar component consists of alternating molecules of N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM). These molecules are crosslinked together by short peptides, which help give peptidoglycan strength and structure. Peptidoglycan provides protection for bacteria and defines their shape.

On the basis of cell composition of wall, bacteria are of two types: (1) Gram-positive and (2) gram-negative bacteria.

- Gram-positive cell wall has several layers of peptidoglycan. Gram-positive cell walls also contain chains of teichoic acid that extend from the plasma membrane through the peptidoglycan cell wall. These sugar-containing polymers assist in maintaining cell shape and play a role in proper cell division.
- Gram-negative bacterial cell wall is composed of a single, thin layer of peptidoglycan. The cell wall structure of gram-negative bacteria is more complex than that of gram-positive bacteria. Located between the plasma membrane and the thin peptidoglycan layer is a gel-like matrix called periplasmic space. Gram-negative bacteria have an outer membrane layer that is external to the peptidoglycan cell wall. Membrane proteins, murein lipoproteins, attach the outer membrane to the cell wall.

2. Cytoplasmic Membrane

It is a phospholipid bilayer, majority of which is made of protein and lipid. It is a semipermeable membrane, which plays an important role of osmosis. Functions of cell membrane:

- It regulates the transport of nutrients and waste products into and out of the cell.
- It also contains enzymes, which function in external cell wall synthesis.
- It assists in DNA replication.
- It secretes protein.
- It carries on electron transport system and captures energy in the form of ATP.
- The membrane contains mechanisms for secreting toxins and certain enzymes into the extracellular medium.

Between the cytoplasmic membrane and the outer membrane is the periplasmic space where certain enzymes are located, especially enzymes degrading extracellular substances of high molecular weight.

II. CELLULAR ELEMENT

Cytoplasm is a jelly-like substance, composed largely of water (80%), proteins, nucleic acids, lipids, salts, sugars, and various low-molecular-weight molecules. Bacterial cell harbors the following cellular elements:

- *Nucleoid*: No well-defined nucleus is present in bacteria. The nuclear region of bacteria is named as nuclear body/nuclear apparatus/nucleoid. Bacterial genome consists of a single molecule of double-stranded DNA arranged in a circular form. It is free-floating haploid DNA. Besides nuclear apparatus, bacteria may have extra-chromosomal genetic material named as plasmids. Plasmids do not play any role in the normal function of the bacterial cell but may confer certain additional properties (e.g., virulence, drug resistance), which may facilitate survival and propagation of the microorganisms.
- *Polyamines*: They are of three types: (1) putrescine (2) spermidine, and (3) spermine. They are found in association with bacterial DNA, ribosomes, and cell membrane. Functions of polyamines are:
  - Antimutagenic
  - Prevent dissociation of 70s ribosome into subunits
  - Increase resistance of protoplast lysis
- *Ribosome*: It translates messenger RNAs (mRNA) into proteins; therefore, it is also known as the sites of protein synthesis. Bacterial cell contains multiple copies (usually thousands) of RNA. It may be free floating or attached to the cell membrane. It is made of ribosomal RNA (rRNA) and proteins. In bacteria, the ribosomes present are 70s. It is typically composed of two subunits—one large (50S) and one small (20S).
- *Mesosome*: Mesosomes are the invaginations of the plasma membrane in the shape of vesicles, tubules, or lamellae.

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The exact function of the mesosome is yet to be found. They are believed to be involved in respiratory enzyme activity, in formation of cell wall during cell division, and in chromosome replication, as they are normally found next to the septa or cross cell walls in the dividing cells.

- *Cytoplasmic inclusion*: Inclusion bodies within the cytoplasm of bacterial cells are several kinds of reserve deposits, known as cytoplasmic inclusions. Cells may accumulate certain nutrients when they are plentiful and use them when the environment is deficient. Some inclusions are common to a wide variety of bacteria, whereas others are limited to a small number of species and therefore serve as a basis for identification. For example, lipid inclusion is a common lipid-storage material which appear in various species of *Mycobacterium*, *Bacillus*, *Azotobacter*, *Spirillum*, and other genera.
- *Gas vacuoles*: These are hollow cavities found in bacteria and are called gas vacuoles. Each vacuole consists of rows of several individual gas vesicles. It maintains buoyancy so that the cells can remain at the depth in the water appropriate for them to receive sufficient amounts of oxygen, light, and nutrients. These gas vacuoles are found in cyanobacteria, anoxygenic photosynthetic bacteria.

III. CELLULAR ELEMENT EXTERNAL TO THE CELL ENVELOPE

1. Glycocalyx

Some bacteria secrete a substance outside the cell wall known as glycocalyx. It is composed of polysaccharide and protein. If the substance is organized and is firmly attached to the cell wall, the glycocalyx is described as a capsule. If the substance is unorganized and only loosely attached to the cell wall, the glycocalyx is described as a slime layer. If a number of bacteria are present close together, then the capsule of a single cell cannot identify the layer formed. This is known as slime layer. Functions include the following:

- Capsule contributes to virulence of pathogens and protects them against phagocytosis and antimicrobial compounds secreted by host cells.
- Capsule and slime layer help in surface attachment and nutrient absorption. It prevents dehydration of cell.
- Not essential for viability.
- Capsulated strains are invariably nonmotile. They can be visualized by negative staining and capsule staining.
- Example of capsule-producing bacteria: *Bacillus anthracis*

2. Flagellum

It is the organ of locomotion in bacterial cell. It consists of three parts. These are filament, hook, and basal body. The basal body and hook are embedded in the cell surface, which anchors the flagellum to the cell wall and plasma membrane**.** The filament is the long, outermost free region on the surface of bacterial cell. Each prokaryotic flagellum is a semirigid, helical structure that moves the cell by rotating from the basal body. The rotation of a flagellum is either clockwise or counter-clockwise. When flagellum rotates around its long axis, it forms a bundle that pushes against the surrounding liquid and propels the bacterium. It is composed of protein named as flagellin. The flagellar antigen in motile bacterium is named as Hauch (H) antigen.

Different types of flagellar arrangement are observed in bacteria:

- *Atrichous*: Bacteria with no flagellum, e.g., *Lactobacilli, Diphtheria bacillus*
- *Monotrichous*: Bacteria with a single polar flagellum, e.g., *Vibrio cholerae*
- *Lophotrichous:* Bacteria with a bunch of flagella at one pole, e.g., *Pseudomonas*
- *Amphitrichous*: Bacteria with flagella at both poles, e.g., *Alcaligenes faecalis*
- *Peritrichous*: Bacteria with flagella all over their surface, e.g., *Salmonella typhi*, *Escherichia coli*
- *Endoflagella* (axial filament): It is the organ of motility found in periplasmic space of spirochetes, e.g., *Treponema pallidum*

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Fantastic Facts !

Escherichia coli produce 5–10 flagella that are randomly distributed across the cell surface.

E. coli can travel 25 times their own length in 1 second, equivalent to a horse running 135 miles per hour.

Their presence in bacterial cell is detected by Hanging drop preparation, swarming phenomenon on surface of plate agar, special staining methods, silver impregnation methods, and dark-field microscopy. Electron microscopy can detect dimensions of flagella. Normally, the range of length is 3–20 μm and that of diameter is 0.01–0.013 μm.

3. Fimbria

It is a hair-like structure composed of protein fimbrin. The number of fimbriae range in hundreds. It helps in motility and jerky movement. Fimbria acts as a poor antigen and thus helps in recognition of cell. It is used for attachments and formation of biofilms.

For example, fimbria of bacteria *Neisseria gonorrhoeae* helps to colonize in mucous membrane whereas fimbria of *E. coli* helps to adhere in the small intestine. It acts as a disease-causing agent after attachment. It causes infection in the excretory system.

4. Pilli

They are longer than fimbriae and range in number from 1 to 10. They are made up of pilin protein. Two types based on function are:

- *Common pilli:* The structure for adherence to cell surface
- *Sex pilli*: Its function is reproduction. Sexual reproduction in bacteria known as conjugation (F^+, the bacteria which give genetic material and F^-, which receive). Sex pilli are responsible for transfer of genetic material from the donor to the recipient during the process of conjugation. The rest of the functions are the same as fimbriae.

5. Endospores

These are the specialized resting cells produced by gram-positive bacteria when the essential nutrients are not available. The process of formation of endospore within a vegetative cell is known as sporulation or sporogenesis. It takes several hours. Endospore can remain dormant for thousands of years and when an endospore return to its vegetative state, the process is given the name of germination. Endospores are highly durable dehydrated cells with thick walls and additional layers. They are formed internal to the bacterial cell membrane. When released into the environment, they can survive extreme heat, lack of water, and exposure to many toxic chemicals and radiation. The diameter of the endospore may be smaller or larger than the size of the vegetative cell. The endospore may be located terminally, subterminally, or centrally inside the vegetative cell. The endospore contains a large amount of organic acid called dipicolinic acid (DPA), which is accompanied by a large number of calcium ions. One vegetative cell produces only one endospore and one endospore converts to one vegetative cell only.

Stages in endospore formation:

- In the first observable stage, a newly replicated bacterial chromosome and a small portion of cytoplasm are separated by an inward growth of cell membrane spore septum.
- The spore septum becomes a double-layered membrane that surrounds the cytoplasm and chromosome and a thick layer of peptidoglycan is laid down between the two membrane layers. This structure is entirely enclosed within the original cell and is called a forespore.
- A thick spore coat of protein forms around the outside membrane, responsible for resistance of endospore to many harsh chemicals. The original cell is degraded or ruptured and endospore is released.

Examples of bacteria that can form endospores include *Bacillus* and *Clostridium*.

Endospores can be seen by staining them with special endospore stains.

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SUMMARY

- Microorganisms consist of bacteria, fungi, algae, protozoa, and viruses.
- Cell envelope is formed by cell wall and cell membrane.
- Gram-positive cell wall has several layers of peptidoglycan whereas gram-negative bacterial cell wall is composed of a single thin layer of peptidoglycan.
- Cellular elements are enclosed within the cell envelope.
- Bacterial genome consists of a single molecule of double-stranded DNA arranged in a circular form.
- Ribosome translates mRNA into proteins; therefore, it is also known as the sites of protein synthesis.
- Mesosomes are the invaginations of the plasma membrane in the shape of vesicles, tubules, or lamellae.
- Within the cytoplasm of bacterial cells, there are several kinds of reserve deposits, known as cytoplasmic inclusions.
- There are hollow cavities found in bacteria called gas vacuoles.
- Cellular elements external to the cell envelope are flagellum, pilus, and glycocalyx.
- Capsule and slime layer help in surface attachment and nutrient absorption. They prevent dehydration of cell.
- The process of formation of endospore within a vegetative cell is known as sporulation or sporogenesis.

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Nanda Maheshwari MSc BEd (Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India) started her career as a Laboratory Technician. She further completed various diplomas in Laboratory Technology, Food and Nutrition, Biomedical Instrumentation, etc. Owing to her keen interest in academics, she took up teaching as a profession. She built an exemplary career as a lecturer and visiting faculty for various colleges all over Maharashtra. At present, she is working as a Lecturer at Suburban College of Paramedical Education (SCOPE), Mumbai, Maharashtra. In the course of her career, she interacted with many students and realized that many paramedic students come from a vernacular medium and hence face difficulty in understanding the subject from complex medical books as reference material. With the intention of helping such students, she thought of writing books on the subject with a simpler format and lucid content. She has successfully written books on subjects like Clinical Pathology, Hematology and Blood Banking, Clinical Microbiology and Parasitology, and Clinical Biochemistry, which are extremely helpful and popular because of the usage of easy language without compromising on information and content. Her books have been widely appreciated by students and teachers and have proven to be highly successful as a course-learning material. These books are recommended by many universities and educational councils for the paramedical and undergraduate courses.

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