

# STRUKTUR SEL MIKROORGANISME

## Procaryotic Cell Structure and Function

### Chapter Overview

This chapter provides a description of the procaryotic cell, beginning with the general features of size, shape, and arrangement. Then the general features of biological membranes and the specific features of procaryotic membranes are given. Important internal structures of procaryotes, such as the cytoplasmic matrix, the ribosomes, the inclusion bodies, and the nucleoid are described, in addition to structures external to the cell, such as the cell wall, capsule, pili, and flagella. The differences between the cell walls of gram-positive organisms and gram-negative organisms are investigated and the mechanism of this differential staining reaction is explained. The chapter concludes with an investigation of bacterial chemotaxis and bacterial endospores.

### Chapter Objectives

#### After reading this chapter you should be able to:

1. describe the various sizes, shapes, and cellular arrangements exhibited by bacteria
2. describe the bacterial plasma membrane and the limited internal membrane structures found in procaryotes
3. describe the appearance, composition, and function of the various internal structures found in procaryotic organisms (such as inclusion bodies, ribosomes, and the nucleoid)
4. define the composition of gram-positive and gram-negative cell walls and explain how these differences contribute to the differential reaction to the Gram-staining procedure
5. describe external structures such as capsules, fimbriae and flagella
6. diagram and describe the various arrangements of bacterial flagella
7. describe how bacteria use their locomotive ability to swim toward chemical attractants and away from chemical repellents
8. describe the production of the bacterial endospore and how it enables spore-forming bacteria to survive harsh environmental conditions and renew growth when the environment becomes conducive to growth

#### These are the most important concepts you are learning in this chapter:

1. Bacteria are small and simple in structure when compared with eucaryotes, yet they often have characteristic shapes and sizes.
2. Although they have a plasma membrane, which is required by all living cells, bacteria generally lack extensive, complex, internal membrane systems.
3. The cytoplasmic matrix typically contains several constituents that are not membrane-enclosed: inclusion bodies, ribosomes, and the nucleoid with its genetic material.
4. The procaryotic cell wall almost always has peptidoglycan and is chemically and morphologically complex.
5. Most bacteria can be divided into gram-positive and gram-negative groups based on their cell wall structure and response to the Gram stain.
6. Components like capsules and fimbriae are located outside the cell wall. One of these is the flagellum which many bacteria use like a propeller to swim toward attractants and away from repellents.
7. Some bacteria form resistant endospores to survive harsh environmental conditions in a dormant state.

### Study Outline

#### I. An Overview of Procaryotic Cell Structure

##### A. Size, shape, and arrangement

1. Procaryotes come in a variety of shapes including spheres (cocci), rods (bacilli), ovals (coccobacilli), curved rods (vibrios), rigid helices (spirilla), and flexible helices (spirochetes)

2. During the reproductive process, some cells remain attached to each other to form chains, clusters, square planar configurations (tetrads), or cubic configurations (sarcinae)
  3. A few bacteria are flat and some lack a single, characteristic form and are called pleomorphic
  4. Prokaryotic cells vary in size although they are generally smaller than most eucaryotic cells; recently, however, several large prokaryotes have been discovered, which grow as large as 750  $\mu\text{m}$  in diameter and can be seen without the aid of a microscope
- B. Prokaryotic cells contain a variety of internal structures, although not all structures are found in every genus; prokaryotes are morphologically distinct from eucaryotic cells and have fewer internal structures.

## II. Prokaryotic Cell Membranes

- A. The plasma membrane
1. The plasma membrane of bacteria consists of a phospholipid bilayer with hydrophilic surfaces (interact with water) and a hydrophobic interior (insoluble in water); such asymmetric molecules are said to be amphipathic; most bacterial membranes lack sterols
  2. Many archaeal membranes have a monolayer instead of a bilayer; archaeal membranes are describe in more detail in chapter 20
  3. The fluid mosaic model is the most widely accepted model of membrane structure. It distinguishes two types of proteins associated with the membrane: peripheral (loosely associated and easily removed) and integral (embedded within the membrane and not easily removed)
  4. The membrane is highly organized, asymmetric, flexible, and dynamic
  5. The plasma membrane serves several functions
    - a. It retains the cytoplasm and separates the cell from its environment
    - b. It serves as a selectively permeable barrier, allowing some molecules to pass into or out of the cell while preventing passage of other molecules
    - c. It is the location of a variety of crucial metabolic processes including respiration, photosynthesis, lipid synthesis, and cell wall synthesis
    - d. It may contain special receptor molecules that enable detection of and response to chemicals in the surroundings
- B. Internal membrane systems
1. Mesosomes are structures formed by invaginations of the plasma membrane that may play a role in cell wall formation during cell division and in chromosome replication and distribution; however, mesosomes may be artifacts generated during chemical fixation for electron microscopy
  2. Photosynthetic bacteria may have complex infoldings of the plasma membrane that increase the surface area available for photosynthesis
  3. Bacteria with high respiratory activity may also have extensive infoldings that provide a large surface area for greater metabolic activity
  4. These internal membranes may be aggregates of spherical vesicles, flattened vesicles, or tubular membranes

## III. The Cytoplasmic Matrix

- A. The cytoplasmic matrix is the substance between the membrane and the nucleoid; it is featureless in electron micrographs but is often packed with ribosomes and inclusion bodies; although lacking a true cytoskeleton, the cytoplasmic matrix of bacteria does have a cytoskeleton-like system of proteins
- B. Inclusion Bodies
1. Many inclusion bodies are granules of organic or inorganic material that are stockpiled by the cell for future use; some are not bounded by a membrane, but others are enclosed by a single-layered membrane
  2. Gas vacuoles are a type of inclusion body found in cyanobacteria and some other aquatic forms; they provide buoyancy for these organisms and keep them at or near the surface of their aqueous habitat
  3. Magnetosomes are inclusion bodies that contain iron in the form of magnetite; they are used by some bacteria to orient in the Earth's magnetic field

- C. Ribosomes
  1. Ribosomes are complex structures consisting of protein and RNA
  2. They are responsible for the synthesis of cellular proteins
  3. Prokaryotic ribosomes are similar in structure to, but smaller than, eucaryotic ribosomes
- D. The Nucleoid
  1. The nucleoid is an irregularly shaped region in which the chromosome of the prokaryote is found
  2. In most prokaryotes, the nucleoid contains a single circular chromosome, though some have more than one chromosome or have one or more linear chromosomes
  3. The nucleoid is not bounded by a membrane, but it is sometimes found to be associated with the plasma membrane or with mesosomes
  4. The bacterial chromosome is an efficiently packed DNA molecule that is looped and coiled extensively
  5. In addition to the chromosome, many bacteria contain plasmids; plasmids are usually small, closed circular DNA molecules
    - a. They can exist and replicate independently of the bacterial chromosome
    - b. They are not required for bacterial growth and reproduction, but they may carry genes that give the bacterium a selective advantage (e.g., drug resistance, enhanced metabolic activities, etc.)

#### IV. The Prokaryotic Cell Wall

- A. The cell wall is a rigid structure that lies just outside the plasma membrane; it provides the characteristic shapes of the various prokaryotes and protects them from osmotic lysis
  1. The cell walls of most bacteria contain peptidoglycan; the cell walls of archaea lack peptidoglycan and instead are composed of proteins, glycoproteins, or polysaccharides
  2. The cell walls of gram-positive bacteria and gram-negative bacteria differ greatly, but both have a periplasmic space, which usually contains a variety of proteins; these proteins can be involved in nutrient acquisition, electron transport, peptidoglycan synthesis or in modification of toxic compounds
- B. Peptidoglycan (murein) is a polysaccharide polymer found in bacterial cell walls; it consists of polysaccharide chains cross-linked by peptide bridges
- C. Gram-positive cell walls-consist of a thick layer of peptidoglycan and large amounts of teichoic acids
- D. Gram-negative cell walls
  1. They consist of a thin layer of peptidoglycan surrounded by an outer membrane composed of lipids, lipoproteins, and a large molecule known as lipopolysaccharide (LPS). LPS can play a protective role and can also act as an endotoxin, causing some of the symptoms characteristic of gram-negative bacterial infections; there are no teichoic acids in gram-negative cell walls.
  2. The outer membrane is more permeable than the plasma membrane because of porin proteins that form channels through which small molecules (600-700 daltons) can pass
- E. The mechanism of Gram staining-involves constricting the thick peptidoglycan layer of gram-positive cells, thereby preventing the loss of the crystal violet stain during the brief decolorization step; the thinner, less cross-linked peptidoglycan layer of gram-negative bacteria cannot retain the stain as well, and these bacteria are thus more readily decolorized when treated with alcohol
- F. The cell wall and osmotic protection-the cell wall prevents swelling and lysis of bacteria in hypotonic solutions. However, in hypertonic habitats, the plasma membrane shrinks away from the cell wall in a process known as plasmolysis

#### V. Components External to the Cell Wall

- A. Capsules, slime layers and S layers
  1. Capsules and slime layers (also known as glycocalyx) are layers of polysaccharides lying outside the cell wall; they protect the bacteria from phagocytosis, desiccation, viral infection, and hydrophobic toxic materials such as detergents; they also aid bacterial attachment to surfaces and gliding motility
    - a. Capsules are well organized
    - b. Slime layers are diffuse and unorganized

2. S layers are regularly structured layers of protein or glycoprotein observed in both bacteria and archaea, where it may be the only structure outside the plasma membrane; they protect against ion and pH fluctuations, osmotic stress, hydrolytic enzymes, or the predacious bacterium *Bdellovibrio*
- B. Pili and fimbriae are short, thin, hairlike appendages that mediate bacterial attachment to surfaces (fimbriae) or to other bacteria during sexual mating (pili)
- C. Flagella and motility
  1. Flagella are threadlike locomotor appendages extending outward from the plasma membrane and cell wall; they may be arranged in various patterns:
    - a. Monotrichous-a single flagellum
    - b. Amphitrichous-a single flagellum at each pole
    - c. Lophotrichous-a cluster (tuft) of flagella at one or both ends
    - d. Peritrichous-a relatively even distribution of flagella over the entire surface of the bacterium
  2. Flagellar ultrastructure:
    - a. The flagellum consists of a hollow filament composed of a single protein known as flagellin.
    - b. The hook is a short curved segment that links the filament to the basal body, a series of rings that drives flagellar rotation.
    - c. Flagellar synthesis involves many genes for the hook and basal body, as well as the gene for flagellin. New molecules of flagellin are transported through the hollow filament so that the growth of the flagellum is from the tip, not from the base.
  3. The mechanism of flagellar movement appears to be rotation; the hook and helical structure of the flagellum causes the flagellum to act as a propeller, thus driving the bacterium through its watery environment
    - a. Counterclockwise rotation causes forward motion (called a run)
    - b. Clockwise rotation disrupts forward motion (resulting in a tumble)
- D. Prokaryotes can move by other mechanisms; in spirochetes, axial filaments cause movement by flexing and spinning; other prokaryotes exhibit gliding motility-a mechanism by which they coast along solid surfaces; no visible structure is associated with gliding motility

## VI. Chemotaxis

- A. Chemotaxis is directed movement of bacteria either towards a chemical attractant or away from a chemical repellent
- B. The concentrations of these attractants and repellents are detected by chemoreceptors in the surfaces of the bacteria
- C. Directional travel toward a chemoattractant (biased random walk toward attractant) is caused by lowering the frequency of tumbles (twiddles), thereby lengthening the runs when traveling up the gradient, but allowing tumbling to occur at normal frequency when traveling down the gradient
- D. Directional travel away from a chemorepellent (biased random walk away from repellent) involves similar but opposite responses
- E. The mechanism of control of tumbles and runs is complex, involving numerous proteins and several mechanisms (conformation changes, methylation, and phosphorylation) to modulate their activity; despite this complexity chemotaxis is fast, with responses occurring in as little as 200 meters/second

## VII. The Bacterial Endospore

- A. The bacterial endospore is a special, resistant, dormant structure formed by some bacteria, which enables them to resist harsh environmental conditions
- B. Endospore formation (sporulation) normally commences when growth ceases because of lack of nutrients; it is a complex, multistage process
- C. Transformation of dormant endospores into active vegetative cells is also a complex, multistage process that includes activation (preparation) of the endospore, germination (breaking of the endospore's dormant state), and outgrowth (emergence of the new vegetative cell)

# Eucaryotic Cell Structure and Function

## Chapter Overview

This chapter focuses on eucaryotic cell structure and function. Although procaryotic organisms are immensely important in microbiology, eucaryotic microorganisms-such as fungi, algae, and protozoa-are also prominent members of many ecosystems, and some have medical significance as etiological agents of disease as well. The chapter concludes with a comparison of eucaryotic and procaryotic cells.

Chapter Objectives

### After reading this chapter you should be able to:

1. identify major eucaryotic cell structures in a drawing or photomicrograph
2. discuss the various elements of the cytoskeleton (microfilaments, intermediate filaments, microtubules) with regard to their structure and various functions within the cell
3. discuss the composition, structure, and function of each of the internal organelles, such as the endoplasmic reticulum, Golgi apparatus, lysosomes, ribosomes, mitochondria, chloroplasts, nucleus, and nucleolus
4. discuss the mechanism of endocytosis and the difference between phagocytosis and pinocytosis
5. compare mitosis and meiosis
6. compare and contrast procaryotes and eucaryotes

### These are the most important concepts you are learning in this chapter:

1. Eucaryotic cells differ most obviously from procaryotic cells in having a variety of complex membranous organelles in the cytoplasmic matrix, and the majority of their genetic material within membrane-delimited nuclei.
2. A cytoskeleton composed of microtubules and microfilaments helps give eucaryotic cells shape.
3. In eucaryotes, genetic material is distributed between cells by the highly organized, complex processes called mitosis and meiosis.
4. Despite great difference between eucaryotes and procaryotes with respect to morphology, they are similar on the biochemical level.

## Study Outline

### I. An Overview of Eucaryotic Cell Structure

- A. Eucaryotic cells have membrane-delimited nuclei
- B. In addition to the nucleus, eucaryotic cells have other membrane-bound organelles that perform specific functions within the cells; this allows simultaneous independent control
- C. The large membrane surface area of eucaryotic cells allows greater respiratory and photosynthetic activity

### II. The Cytoplasmic Matrix, Microfilaments, Intermediate Filaments, and Microtubules

- A. The cytoplasmic matrix, although superficially featureless, provides the complex environment required for many cellular activities
- B. Microfilaments (4 to 7 nm) may be scattered throughout the matrix or organized into networks and parallel arrays; they play a major role in cell motion and cell shape changes
- C. Microtubules are hollow cylinders (25 nm) that help maintain cell shape, are involved (with microfilaments) in cellular movement, participate in intracellular transport of substances, and participate in organelle movements; they also form the mitotic spindle during cell division and are present in cilia and flagella
- D. Intermediate filaments (8 to 10 nm), along with microfilaments and microtubules, are major components of the cytoskeleton, an intricate network of interconnected filaments that helps maintain cell shape and contributes to cellular movement

### III. The Endoplasmic Reticulum

- A. The endoplasmic reticulum (ER) is a complex set of internal membranes that may have ribosomes attached (rough or granular endoplasmic reticulum; RER or GET) or may be devoid of ribosomes (smooth or agranular endoplasmic reticulum; SER or AER)
- B. The ER has many important functions:
  1. It transports proteins, lipids, and other materials within the cell
  2. It is a major site of cell membrane synthesis
  3. ER-associated enzymes and ribosomes synthesize lipids and many proteins
  4. New ER is produced through expansion of old ER

### IV. The Golgi Apparatus

- A. The Golgi Apparatus is a set of membrane sacs (cisternae) that is involved in the modification, packaging, and secretion of materials; they exist in stacks called dictyosomes
- B. The Golgi Apparatus is present in many eucaryotic cells, but many fungi and ciliated protozoa lack it

### V. Lysosomes and Endocytosis

- A. Lysosomes are membrane-bound vesicles that contain enzymes needed for intracellular digestion of all types of macromolecules
- B. Endocytosis is the process in which the cell takes up solutes or particles by enclosing them in vesicles (endosomes) pinched off from the plasma membrane
  1. Phagocytosis-endocytosis of large particles by engulfing them into a phagocytic vacuole (phagosome)
  2. Pinocytosis-endocytosis of small amounts of liquid with its solute molecules
- C. Material in endosomes is digested with the aid of lysosomes, which fuse with the endosomes
- D. Lysosomes join with phagosomes for defensive purposes such as to destroy invading bacteria
- E. Autophagic vacuoles are lysosomes that selectively digest portions of the cell's own cytoplasm as part of the normal turnover of cellular components
- F. Proteasomes are a nonlysosomal protein degradation system that has been recently discovered in eucaryotic cells, a few bacteria, and many archaea

### VI. Eucaryotic Ribosomes

- A. Eucaryotic ribosomes are generally larger than procaryotic ribosomes,
- B. Eucaryotic ribosomes, like their procaryotic counterparts, are responsible for synthesis of cellular proteins; they can either be attached to the ER or free in the cytoplasm
  1. ER-associated ribosomes synthesize integral membrane proteins or proteins that are secreted out of the cell
  2. Free ribosomes synthesize nonsecretory, nonmembrane proteins
  3. Several ribosomes can attach to a single mRNA; these complexes are called polyribosomes or polysomes

### VII. Mitochondria

- A. Mitochondria are the site of tricarboxylic acid (TCA) cycle activity and the generation of ATP by electron transport and oxidative phosphorylation
- B. Mitochondria have both an inner membrane and an outer membrane enclosing a fluid matrix
  1. The inner and outer membranes have different lipids and enzymes
  2. The enzymes of the TCA cycle and the  $\beta$ -oxidation pathway for fatty acids are located within the matrix
  3. Electron transport and oxidative phosphorylation occur only on the inner mitochondrial membrane
- C. Mitochondria use their own DNA and their own ribosomes to synthesize some of their proteins; mitochondrial DNA and mitochondrial ribosomes are similar to bacterial DNA and ribosomes in terms of size and structure; mitochondria reproduce by binary fission

## VIII. Chloroplasts

- A. Chloroplasts are the site of photosynthesis
- B. Chloroplasts have an outer membrane and an inner membrane system of flattened sacs called thylakoids that often form stacks known as grana; the fluid matrix compartment is called the stroma
  1. The formation of carbohydrate from carbon dioxide and water (dark reaction) occurs in the stroma
  2. The trapping of light energy to generate ATP, NADPH, and oxygen (light reaction) occurs in the thylakoid membranes of the grana

## IX. The Nucleus and Cell Division

- A. Nuclei are membrane-bound structures that house most of the genetic material of the cell
- B. Nuclear Structure
  1. Chromatin is the dense fibrous material seen within the nucleoplasm of the nucleus; this is the DNA containing part of the nucleus; when the cell is dividing, chromatin condenses into visible chromosomes
  2. The nuclear envelope is a double-membrane structure penetrated by nuclear pores that allow materials to be transported into or out of the nucleus
  3. The nuclear lamina, a network of intermediate filaments, lies against the inner surface of the nuclear envelope and supports it
  4. Nuclear pores penetrate the nuclear envelope and allow materials to be transported into or out of the nucleus
- C. The nucleolus is involved in the synthesis of ribosomes
- D. Mitosis is a process of nuclear division in which the (duplicated) genetic material is distributed equally to two daughter nuclei so that each has a full set of chromosomes and genes
- E. Meiosis is a complex, two-stage process of nuclear division in which the number of chromosomes in the resulting daughter cells is reduced from the normal (diploid) number to one-half of that number (haploid)
- F. Cytokinesis is the process by which the cytoplasm and its components are distributed to the new daughter cells; it usually occurs following mitosis and meiosis

## X. External Cell Coverings

- A. Some cells have a rigid cell wall but many do not; cell walls of eucaryotic microbes vary in composition, but are generally chemically simpler than peptidoglycan
- B. Other cells, such as some protozoa, have a pellicle, which is a rigid layer of components just within the plasma membrane

## XI. Cilia and Flagella

- A. Cilia and flagella are locomotor structures that differ in length and how they propel the cell
- B. Cilia and flagella are structurally very similar; both are membrane-bound cylinders composed of microtubules, in a 9+2 arrangement, embedded in a matrix

## XII. Comparison of Prokaryotic and Eucaryotic Cells

- A. Eucaryotes have a membrane-delimited nucleus and many complex membrane-bound organelles, each of which perform a separate function for the cell
- B. Prokaryotes lack a membrane-delimited nucleus and internal membrane-bound organelles; they are functionally simpler and do not undergo mitosis, meiosis, endocytosis, and other complex activities performed by many eucaryotes
- C. Despite the significant differences between prokaryotes and eucaryotes, they have remarkable biochemical similarities: the same basic chemical composition, the same genetic code, and the same basic metabolic processes

## Chapter Web Links

Bacteria: Life History and Ecology  
 (<http://www.ucmp.berkeley.edu/bacteria/bacterialh.html>)

Bacteria Divide and Multiply  
(<http://www.cellsalive.com/ecoli.htm>)  
(CELLS Alive! from <http://www.cellsalive.com/> )

The Procaryotes  
(<http://www.bact.wisc.edu/Bact303/>)  
Biological Identity of Procaryotes. Kenneth Todar, University of Wisconsin-Madison, Department of Bacteriology

The stages of mitosis: a tour with pictures.  
(<http://www.inform.umd.edu/PBIO/wolniak/wolniakmitosis.html>)  
Stephen M. Wolniak, Department of Cell Biology Molecular Genetics, University of Maryland.

Virtual Cell  
(<http://ampere.scale.uiuc.edu/~m-lexa/cell/cell.html>)  
is a "collection of still images, texts and movies covering the structure and functioning of a typical plant cell".

The Cell Nucleus  
(<http://cellbio.utmb.edu/cellbio/nucleus.htm>)  
Cell Biology Graduate Program at The University of Texas Medical Branch.