Chapter 3

Cell Structure and Function in Bacteria and Archaea

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I. Cell Shape and Size

- 3.1 Cell Morphology
- 3.2 Cell Size and the Significance of Smallness
3.1 Cell Morphology

- **Morphology** = cell shape
- Major cell morphologies (Figure 3.1)
  - *Coccus* (*pl. cocci*): spherical or ovoid
  - *Rod*: cylindrical shape
  - *Spirillum*: spiral shape
- Cells with unusual shapes
  - Spirochetes, appendaged bacteria, and filamentous bacteria
- Many variations on basic morphological types
Figure 3.1 Representative cell morphologies of prokaryotes

Coccus

Coccus cells may also exist as short chains or grapelike clusters

Rod

Budding and appendaged bacteria

Spirillum

Filamentous bacteria

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3.1 Cell Morphology

• Morphology typically does not predict physiology\(^1\), ecology, phylogeny\(^2\), etc. of a prokaryotic cell

• **Selective forces** may be involved in setting the morphology
  – Optimization for nutrient uptake (small cells and those with high surface-to-volume ratio)
  – Swimming motility in viscous environments or near surfaces (helical or spiral-shaped cells)
  – Gliding motility (filamentous bacteria)

\(^1\) functions and activities of living organisms and their parts
\(^2\) the evolutionary history of a group of organisms
3.2 Cell Size and the Significance of Smallness

- Advantages to being small (Figure 3.3)
  - Small cells have more surface area relative to cell volume than large cells (i.e., higher S/V)
    - support greater nutrient exchange per unit cell volume
    - tend to grow faster than larger cells
Figure 3.3 Surface area and volume relationships in cells

$r = 1 \mu m$

$r = 2 \mu m$
II. The Cytoplasmic Membrane and Transport

- 3.3 The Cytoplasmic Membrane
- 3.4 Functions of the Cytoplasmic Membrane
- 3.5 Transport and Transport Systems
3.3 The Cytoplasmic Membrane in *Bacteria and Archaea*

- **Cytoplasmic membrane:**
  
  Cytoplasmic membrane = Cell membrane = plasma membrane

  - Thin structure that surrounds the cell
  - 6-8 nm thick
  - Vital barrier that separates cytoplasm from environment
  - Highly selective permeable barrier
  - Enables specific metabolites and excretion of waste products
3.3 The Cytoplasmic Membrane

• Composition of Membranes
  – General structure is phospholipid bilayer (Figure 3.4)
    • Contain both hydrophobic and hydrophilic components
  – Can exist in many different chemical forms as a result of variation in the groups attached to the glycerol backbone
  – Fatty acids point inward to form hydrophobic environment; hydrophilic portions remain exposed to external environment or the cytoplasm
Figure 3.4 Phospholipid bilayer membrane

General architecture of a bilayer membrane; the blue balls depict glycerol with phosphate and (or) other hydrophilic groups.

(a) Fatty acids

(b) Glycerophosphates

(c) Fatty acids
Figure 3.5 Structure of the cytoplasmic membrane

- Phospholipids
- Integral membrane proteins
- Peripheral membrane proteins
- 6–8 nm
- Hydrophilic groups
- Hydrophobic groups
- Out
- In
- Phospholipid molecule
3.3 The Cytoplasmic Membrane

Membrane Proteins

*Integral membrane proteins*  *Peripheral membrane proteins*

- Outer surface of cytoplasmic membrane can interact with a variety of proteins that bind substrates or process large molecules for transport

- Inner surface of cytoplasmic membrane interacts with proteins involved in energy-yielding reactions and other important cellular functions
3.3 The Cytoplasmic Membrane

- Archaeal Membranes
  - *Archaea* → *Ether* linkages in phospholipids
  - *Bacteria* and *Eukarya* → *ester* linkages in phospholipids

- Can exist as lipid monolayers, bilayers, or mixture (Figure 3.7d and e)
Figure 3.7 Membrane structure in *Archaea* may be bilayer or monolayer (or a mix of both)

(d) Lipid bilayer

(e) Lipid monolayer

Lipid bilayer

Glycerophosphates

Phytanyl

Membrane protein

Out

In

Biphytanyl

In

Out
3.4 Functions of the Cytoplasmic Membrane (Figure 3.8)

- **Permeability Barrier**
  - Polar and charged molecules must be transported
  - Transport proteins accumulate solutes against the concentration gradient

- **Protein Anchor**
  - Holds transport proteins in place

- **Energy Conservation**
Although structurally weak, the cytoplasmic membrane has many important cellular functions.
3.5 Transport and Transport Systems

• Carrier-Mediated Transport Systems (Figure 3.9)
  – Show saturation effect
  – Highly specific
In transport, the uptake rate shows saturation at relatively low external concentrations.
III. Cell Walls of Prokaryotes

• 3.6 The Cell Wall of *Bacteria*: Peptidoglycan
• 3.7 The Outer Membrane
• 3.8 Cell Walls of *Archaea*
3.6 The Cell Wall of *Bacteria*: Peptidoglycan

_Peptidoglycan_ (Figure 3.16)
- Rigid layer that provides strength to cell wall
- Polysaccharide composed of
  - \(N\)-acetylglucosamine and \(N\)-acetylmuramic acid
  - Amino acids
  - Lysine or diaminopimelic acid (DAP)
  - Cross-linked differently in gram-negative bacteria and gram-positive bacteria (Figure 3.17)
Gram Positive vs Gram Negative Bacteria

• https://www.youtube.com/watch?v=Jvo6IGKTvxA
Figure 3.16 Cell walls of Bacteria. (a, b) Schematic diagrams of gram-positive and gram-negative cell walls.
3.6 The Cell Wall of *Bacteria*: Peptidoglycan

- **Gram-Positive Cell Walls (Figure 3.18)**
  - Can contain up to 90% peptidoglycan
  - Common to have *teichoic acids* (acidic substances) embedded in the cell wall
    - *Lipoteichoic acids*: teichoic acids covalently bound to membrane lipids
3.7 The Outer Membrane

- Total cell wall contains ~10% peptidoglycan (Figure 3.20a)
- Most of cell wall composed of outer membrane (lipopolysaccharide [LPS] layer)
- Structural differences between cell walls of gram-positive and gram-negative Bacteria are responsible for differences in the Gram stain reaction
Figure 3.20a The gram-negative cell wall. Arrangement of lipopolysaccharide, lipid A, phospholipid, porins, and lipoprotein in the outer membrane.
3.8 Cell Walls of *Archaea*

- No peptidoglycan
- Typically no outer membrane
- *Pseudomurein*
  - Polysaccharide similar to peptidoglycan
    Composed of *N*-acetylglucosamine and *N*-acetyltalosaminuronic acid
  - Found in cell walls of certain methanogenic *Archaea*
- Cell walls of some *Archaea* lack pseudomurein
IV. Other Cell Surface Structures and Inclusions

- 3.9 Cell Surface Structures
- 3.10 Cell Inclusions
- 3.11 Gas Vesicles
- 3.12 Endospores
3.9 Cell Surface Structures

- **Capsules and Slime Layers**
  - Polysaccharide layers (Figure 3.23)
    - May be thick or thin, rigid or flexible
  - Assist in attachment to surfaces
  - Protect against phagocytosis
  - Resist desiccation
Capsules of *Acinetobacter* species observed by phase-contrast microscopy after negative staining of cells with India ink. India ink does not penetrate the capsule, so the capsule appears as a light area surrounding the cell, which appears black.

Transmission electron micrograph of a thin section of cells of *Rhodobacter capsulatus* with capsules (arrows) clearly evident; cells are about 0.9 µm wide.

Transmission electron micrograph of *Rhizobium trifolii* stained with ruthenium red to reveal the capsule. The cell is about 0.7 µm wide.
3.9 Cell Surface Structures

- **Fimbriae**
  - Filamentous protein structures (Figure 3.24)
  - Enable organisms to stick to surfaces or form pellicles (film)
Electron micrograph of a dividing cell of *Salmonella typhi*, showing flagella and fimbriae. A single cell is about 0.9 µm wide.
3.9 Cell Surface Structures

- **Pili**
  - Filamentous protein structures (Figure 3.25)
  - Typically longer than fimbriae
  - Assist in surface attachment
  - Facilitate genetic exchange between cells (conjugation)
  - Type IV pili involved in motility
The pilus on an *Escherichia coli* cell that is undergoing conjugation (a form of genetic transfer) with a second cell is better resolved because viruses have adhered to it. The cells are about 0.8 m wide.
3.10 Cell Inclusions

• Carbon storage polymers
  – *Poly-β-hydroxybutyric acid (PHB)*: lipid (Figure 3.26)
  – *Glycogen*: glucose polymer
• *Polyphosphates*: accumulations of inorganic phosphate (Figure 3.27)
• *Sulfur globules*: composed of elemental sulfur
• *Magnetosomes*: magnetic storage inclusions (Figure 3.28)
Electron micrograph of a thin section of cells of a bacterium containing granules of PHA. Nile red–stained cells of a PHA-containing bacterium.
3.11 Gas Vesicles

- **Gas Vesicles**
  - Confer buoyancy in planktonic cells (Figure 3.29)
  - Spindle-shaped, gas-filled structures made of protein (Figure 3.30)
  - Gas vesicle impermeable to water
  - Decrease cell density
Flotation of gas-vesiculate cyanobacteria that formed a bloom in a freshwater lake, Lake Mendota, Madison, Wisconsin (USA).
3.12 Endospores

- **Endospores**
  - Highly differentiated cells resistant to heat, harsh chemicals, and radiation (Figure 3.32)
  - “Dormant” stage of bacterial life cycle (Figure 3.33)
  - Ideal for dispersal via wind, water, or animal gut
  - Only present in some gram-positive bacteria
Phase-contrast photomicrographs illustrating endospore morphologies and intracellular locations in different species of endospore-forming bacteria. Endospores appear bright by phase-contrast microscopy.
Figure 3.33 The life cycle of an endospore-forming bacterium.

The phase-contrast photomicrographs are of cells of *Clostridium pascui*. A cell is about 0.8 m wide.
3.12 Endospores

- Endospore Structure (Figure 3.35)
  - Structurally complex
  - Contains dipicolinic acid
  - Enriched in Ca$^{2+}$
  - Core contains small acid-soluble proteins (SASPs)
3.12 Endospores

- The Sporulation Process
  - Complex series of events (Figure 3.37)
  - Genetically directed
Stages are defined from genetic and microscopic analyses of sporulation in *Bacillus subtilis*, the model organism for studies of sporulation.
V. Microbial Locomotion

- 3.13 Flagella and Motility
- 3.14 Gliding Motility
- 3.15 Microbial Taxes
3.13 Flagella and Motility

- **Flagellum (pl. flagella):** structure that assists in swimming
  - Different arrangements: *peritrichous, polar, lophotrichous*
  - Helical in shape
3.13 Flagella and Motility

- Flagella increase or decrease rotational speed in relation to strength of the proton motive force
- Differences in swimming motions
  - Peritrichously flagellated cells move slowly in a straight line
  - Polarly flagellated cells move more rapidly and typically spin around
3.14 Gliding Motility

- **Gliding Motility**
  - Flagella-independent motility
  - Slower and smoother than swimming
  - Movement typically occurs along long axis of cell
  - Requires surface contact
  - Mechanisms
    - Excretion of polysaccharide slime
    - Type IV pili
    - Gliding-specific proteins
3.15 Microbial Taxes

- *Taxis*: directed movement in response to chemical or physical gradients
  - *Chemotaxis*: response to chemicals
  - *Phototaxis*: response to light
  - *Aerotaxis*: response to oxygen
  - *Osmotaxis*: response to ionic strength
  - *Hydrotaxis*: response to water