Functional Anatomy of Prokaryotic and Eukaryotic Cells

Chapter 4
BIO 220

Prokaryotic cells

- DNA circular (usually) and not enclosed within a nucleus
- DNA not associated with histones (HU, IHF, H-NS)
- Generally lack membrane-enclosed organelles
- Cell wall contains peptidoglycan
- Divide by binary fission

Binary fission

Fig. 6.12

Fig. 10.1
Size, shape, and arrangement of bacterial cells

• Shape = coccus (cocci)

Fig. 4.1

• Shape = bacillus (bacilli)

Fig. 4.2

Size, shape, and arrangement of bacterial cells

• Shape = spiral
  • Vibrio – curved rods
    – Vibrio cholerae
  • Spirilla – corkscrew
    – Campylobacter jejuni
  •Spirochetes – axial filaments
    – Borrelia burgdorferi

Fig. 4.4

Bacterial cell shape is dependent on

• Genetics
  – Most bacteria are monomorphic – keep same shape
  – Some are pleomorphic – can change shape
    • May be due to genetics, environment, or lack of a cell wall
      – Rhizobium, Corynebacterium
Prokaryotic cell structure

• Structures external to cell wall

• Cell wall

• Structures internal to cell wall

Glycocalyx

• “Sugar coat” of cell
• The glycocalyx is a viscous, gelatinous layer located outside the cell wall that is composed of polysaccharides and/or polypeptides
• If it appears organized and firmly adheres to the outside of the cell wall it is called a capsule
• If instead it is unorganized in appearance and more loosely attached to the cell wall it is called a slime layer
### Glycocalyx functions

- Allows certain bacteria to resist phagocytic engulfment
  - Blocks the ability of phagocytes to recognize antigenic cell wall components (LPS, peptidoglycan)
  - *i.e.* *Streptococcus pneumoniae, Bacillus anthracis*
- Allows some bacteria to adhere to environmental surfaces
  - Biofilm formation
  - *i.e.* *Streptococcus mutans, Vibrio cholerae*

### Flagella

- Used for motility
- Flagellar arrangements include atrichous, peritrichous, polar (monotrichous, lophotrichous, amphitrichous)
Parts of a flagellum

- Filament
  - Composed of globular protein (flagellin)
  - $H$ antigens help distinguish between serovars (variations within a species) of gram (-) bacteria
- Hook
  - Attaches filament to cell
- Basal body
  - Anchors flagellum to cell wall and plasma membrane

Prokaryotic flagella

- Move like a propeller (rotates from basal body), whereas eukaryotic flagella move like a whip
- Not covered by membrane
- Motility patterns
  - Runs – bacterium moves in one direction for a period of time (moves 10-20 times its length)
  - Tumbles – periodic, abrupt, random changes in direction
Taxis

- Movement of a bacterium toward or away from a particular stimulus is called **taxis**
- Chemotaxis
- Phototaxis

Axial filaments

- Spirochetes use axial filaments for motility
- Axial filaments are similar to flagella, except that they wrap around the cell beneath an outer sheath
- Spirochetes move in a spiral fashion

Fimbriae

- Some gram-negative bacteria have hair-like appendages (pilin)
- Fimbriae can occur on cell poles or along cell surface, may be few to several hundred
- Fimbriae adhere to each other and to surfaces in and out of the body
- *Neisseria gonorrhoeae, Escherichia coli*

Pili

- Longer than fimbriae and only a few per cell
- Involved in motility
  - Twitching (grappling hook) and gliding motility
- Involved in DNA transfer
  - Conjugation
Cell wall functions

- Prevent osmotic lysis of bacterial cells
- Helps maintain shape of bacterium
- Point of anchorage for flagella (when present)

Cell wall composition

Peptidoglycan – composed of repeating disaccharide subunits connected by polypeptides
**Peptidoglycan (murein)**

Forms a lattice that surrounds and protects the cell.

*Fig. 4.13a*

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**Cell wall: gram–positive bacteria**

- Thick peptidoglycan layer (many layers)
- Contain teichoic acids (alcohol + phosphate)
  - Lipoteichoic acid – spans the peptidoglycan layer and is linked to the plasma membrane
  - Wall teichoic acid – linked to peptidoglycan
  - May regulate transport of cations in/out of cells, role in cell growth, prevent cell wall breakdown, provide much of the cell wall’s antigenic specificity
- Granular layer is between the cell wall and plasma membrane of cell

*Fig. 4.13b*

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**Gram–positive cell wall**

*Fig. 4.13b*

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**Cell wall: gram–negative bacteria**

- Thin peptidoglycan layer and an outer membrane

*Fig. 4.13c*
Outer membrane (OM)

- Lipopolysaccharides (LPS), lipoproteins, phospholipids
- LPS has three parts:
  - Lipid A – embedded in outer layer of OM (endotoxin)
  - Core polysaccharide – structural role
  - O polysaccharide – antigenic
- Lipoproteins – anchor peptidoglycan to OM
- Porins permit the passage of molecules such as nucleotides, disaccharides, peptides, amino acids, B₁₂, and iron
- Presence of OM helps bacteria evade complement and phagocytosis

Gram staining

- Why do we see differences in how gram (+) and gram (-) bacteria appear with the gram staining protocol?
- Gram stain protocol
  - Primary stain – crystal violet
  - Mordant – Grams iodine
  - Decolorizer
  - Counterstain – safranin

![Diagram of cell wall and outer membrane components](image.png)
Acid-fast cell walls

- Acid-fast staining protocol is used to identify the bacteria of the genus.

- Cell walls contain a high concentration of a hydrophobic waxy lipid (mycolic acid) surrounding a thin layer of peptidoglycan.
Plasma membrane functions

- Selective permeability
- Breakdown of nutrients and the production of energy

PM transport

- Passive transport
  - Simple diffusion
  - Facilitated diffusion
  - Osmosis
- Active transport
  - Group translocation

Simple diffusion
Facilitated diffusion

- Non-specific transporter
- Transported substance
- Specific transporter

Osmosis

- Aquaporin
- Osmosis through the lipid bilayer (left) and an aquaporin (right)

Active transport

- Requires the use of energy
- Requires a transport protein (more specific)
- In group translocation, as a substance is transported across the wall of a prokaryotic cell, the substance is chemically altered which effectively traps it within the cell
Cytoplasm

- Thick, aqueous, semitransparent, and elastic
- Mostly water, but also contains proteins, CHOs, lipids, inorganic ions
- Cytoskeleton present, but made of different proteins from those found in eukaryotic cells (MreB and ParM, crescentin, FtsZ)

Nucleoid

- Lacks a nuclear envelope
- Contains bacterial chromosome
- Plasmids – small, circular dsDNA that replicates independently of bacterial chromosome

Ribosomes

- What is the function of ribosomes?
- Ribosomal subunits

(a) Small subunit
(b) Large subunit
(c) Complete 70S ribosome
Inclusions

- Metachromatic granules (volutin)
  - Reserve of inorganic phosphate for ATP synthesis
  - *Corynebacterium diphtheriae*
- Polysaccharide granules
- Lipid inclusions
  - *Mycobacterium, Bacillus, Spirillum*
- Sulfur granules
  - *Acidithiobacillus*

- Carboxysomes
  - Ribulose 1,5-diphosphate carboxylase (CO$_2$ fixation)
- Gas vacuoles
- Magnetosomes
  - Fe$_3$O$_4$
  - Decompose H$_2$O$_2$
  - *Magnetospirillum*

Endospores

- Members of *Clostridium* and *Bacillus* can form endospores, which are essentially dehydrated, stripped-down, “resting” bacterial cells

- When released into the environment, endospores can survive extremes in heat, dehydration, toxic chemical and radiation exposure

Sporulation (sporogenesis)
Endospores

- Contain a large amount of dipicolinic acid (DPA), which may serve to protect bacterial DNA
- Endospore core contains DNA, a little RNA, ribosomes, enzymes, small molecules
- Germination is the process by which an endospore returns to its vegetative state
- Germination is triggered by high heat or molecules called germinants (alanine & inosine)

Endospores – Why should I care?

- Endospores are resistant to processes that normally kill vegetative cells
- Home canning – botulism — *Clostridium botulinum*

Eukaryotic cells

- DNA organized into chromosomes contained within a nucleus
- DNA is associated with histones
- Do have membrane-enclosed organelles
- Cell walls lack peptidoglycan
- Cell division by mitosis/meiosis and cytokinesis
Cell wall and glycocalyx
- When present, eukaryotic cell walls tend to be simpler than prokaryotic cell walls and have a different composition
- Algae & plants – cellulose
- Fungi – cellulose or chitin
- Yeasts – polysaccharides (mannan and glucan)
- Protozoa have an outer protein covering called a pellicle
- Glycocalyx

Plasma membrane
- Similar to prokaryotes
- Eukaryotic membranes contain carbohydrates and sterols
- Plasma membrane transport
  - No group translocation
Phagocytosis

Fig. 16.8

Cytoplasm

- Everything inside the plasma membrane with the exception of the nucleus
- Cytosol vs. cytoplasm
- Cytoskeleton
- Cytoplasmic streaming

Ribosomes

- Sites of protein production
- 80S (60S & 40S) vs 70S
- May be free or attached to ER
- 70S ribosomes found in chloroplasts and mitochondria

Nucleus

Fig. 4.24
Endoplasmic reticulum

Golgi complex & Lysosomes

Vacuoles (Plants)
- Derived from Golgi complex
- May serve as temporary storage organelles
- Help bring food into the cell
- Storage of wastes
- May accumulate water

Mitochondria
Chloroplasts (Algae + green plants)

Peroxisomes and centrosomes

Endosymbiotic theory

- Origin of eukaryotic cells
- Ancestral eukaryotic cell developed a “nucleus” when PM folded around DNA
- This cell likely ingested aerobic bacteria
- Support
  - Mitochondria/chloroplasts resemble bacteria
  - These organelles contain circular DNA
  - Organelles reproduce independently
  - Ribosomes resemble those of prokaryotes
  - Antibiotic action

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<thead>
<tr>
<th>TABLE 4.2 Principal Differences between Prokaryotic and Eukaryotic Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Size of Cell</td>
</tr>
<tr>
<td>Nucleus</td>
</tr>
<tr>
<td>Membrane-Enclosed Organelles</td>
</tr>
<tr>
<td>Flagella</td>
</tr>
<tr>
<td>鞭毛</td>
</tr>
<tr>
<td>Cortical Microtubule</td>
</tr>
<tr>
<td>Actin Filament</td>
</tr>
<tr>
<td>Nucleus Membrane</td>
</tr>
<tr>
<td>Cytoplasm</td>
</tr>
<tr>
<td>Ribosomes</td>
</tr>
<tr>
<td>Chromatolemes (DNA)</td>
</tr>
<tr>
<td>Cell Division</td>
</tr>
<tr>
<td>Sexual Reproduction</td>
</tr>
</tbody>
</table>

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