Bacterial Cell Structure

Jacquelyn G. Black, Microbiology, 9th Edition

Chapter 4 – Page 77

Mahmoud Alkawareek, PhD

Prokaryotes vs. Eukaryotes

- All living cells are classified to prokaryotes & eukaryotes
- Prokaryotes
  - Lack true nucleus
  - Single-celled
  - Bacteria & Archaea
- Eukaryotes
  - True nucleus
  - Single-celled or multicellular
  - Plants, animals, fungi, protists (amoeba, paramecium, malaria parasite)

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Prokaryotes vs. Eukaryotes

- Similarities
  - Surrounded by **cell membrane** (plasma membrane) which defines the boundaries of living cell
  - Encodes genetic information in **DNA**
- Major differences

Prokaryotes	Eukaryotes
DNA in circular chromosome, in nuclear region (nucleoid) not surrounded by membrane	DNA in paired chromosomes, in nucleus surrounded by membrane nuclear envelope
Lack organelles that are membrane enclosed	Organelles surrounded by membranes
Reproduction by binary fission	Mitosis and/or meiosis

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Prokaryotes: Size, Shape & Arrangement

- Size
  - Bacteria are among the smallest organisms
  - Most bacterial cells are 0.5-2.0 µm (or 0.5-5.0 µm) in diameter
  - Exceptions:

    Mycoplasma only measures 0.3 µm while Cyanobacteria can be up to 60 µm long
- Shape
  - Spherical (coccus/cocci)
  - Rod-shaped (bacillus/bacilli)

    Some bacteria are considered coccobacilli
  - Spiral: which can be be comma-shaped (vibrio), rigid wavy-shaped (spirillum) or corkscrew-shaped (spirochete)
  - Other atypical shapes: spindle shape, square, lobed, triangular
  - Some bacteria vary widely in single culture, a phenomenon known as **pleomorphism**

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Prokaryotes: Size, Shape & Arrangement

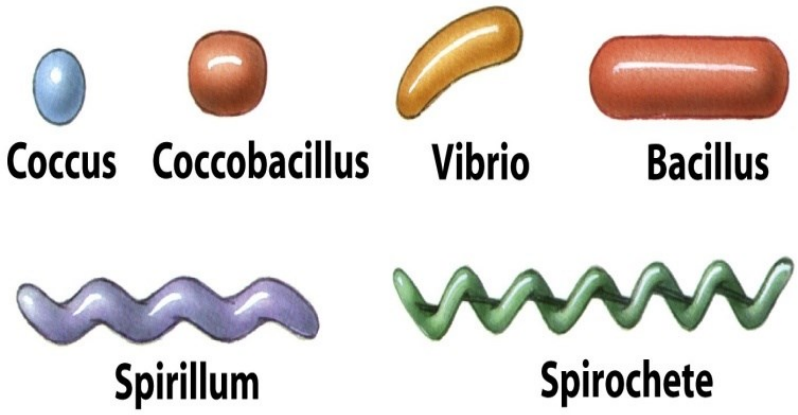

Figure 4-1 Microbiology, 7/e
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Prokaryotes: Size, Shape & Arrangement

- Arrangement
  - Variable arrangements of groups of cells may result due to **cell division without full separation**
  - Cocci
    - Division in 1 plane → diplo (pair)
    - Division in 2 planes → tetrads (4 cells in a cube)
    - Division in 3 planes → sarcinae (8 cells in a cube)
    - Division in chains → strepto
    - Random division → grapelike clusters (staphylo)
  - Bacilli
    - Can only divide in one plane; either end-to-end or side-by-side
  - Spiral bacteria
    - Not generally grouped together

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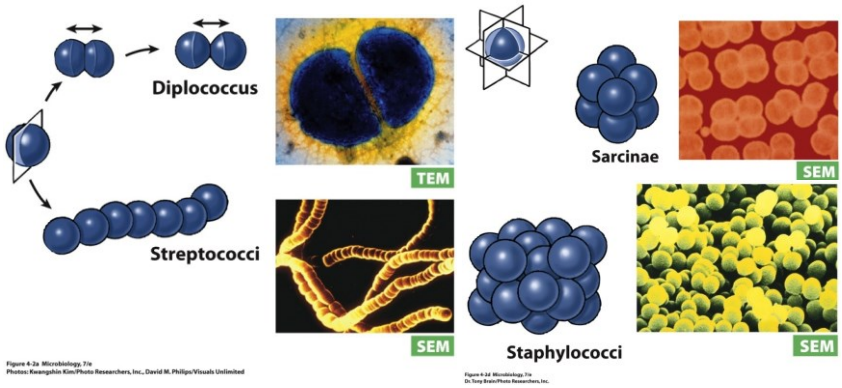
Prokaryotes: Size, Shape & Arrangement



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Structure of Bacterial Cells: Cell Wall

- The cell wall is a semi-rigid structure that lies outside the cell membrane
- **Functions of the bacterial cell wall:**
  - Maintains the characteristic cell shape

    if the cell wall is digested by certain enzymes, the cell will become spherical
  - Prevents the cell from bursting when fluids flow into the cell by osmosis (allows a high cell turgidity)
- Bacterial cell wall is highly **porous** and as such it doesn't form a permeability barrier *per se*, i.e. it has no significant role in regulating entry of molecules into the cell

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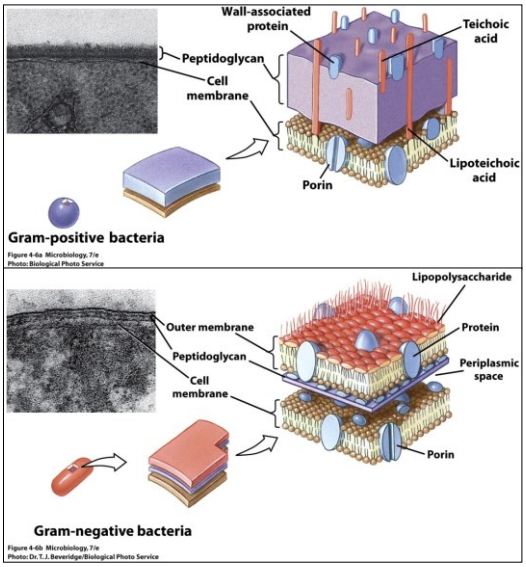
Structure of Bacterial Cells: Cell Wall

- Components of the bacterial cell wall:

1. Peptidoglycan
2. Outer membrane (G-ve)
3. Periplasmic space (periplasm only in G+ve)



Structure of Bacterial Cells: Cell Wall

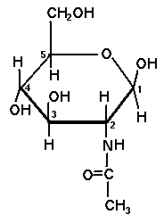
1. Peptidoglycan (murein)
   - Most important component of bacterial cell wall
   - It forms a supporting net around bacteria like multiple chain-link fence
   - It is a covalently linked polymer composed of alternating molecules of **N-acetylglucoseamine** (gluNAc) and **N-acetylmuramic acid** (murNAc)

     (Autolysin enzyme works here!)
   - These polymer chains are **cross-linked** by tetrapeptides (chains of 4 amino acids)

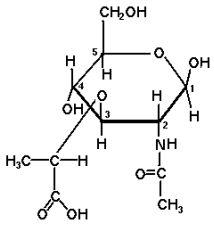
     Different bacteria can have different amino acids in the terapeptide chain
   - **G+ve** bacteria have an additional molecule on the cell wall called **teichoic acid** (phosphate-glycerol-sugar alcohol) which extends beyond the rest of cell wall and even the capsule

     The exact function of teichoic acid is still unclear but it is thought to act as a passageway to ions movement and to facilitate the attachment of bacteriophages

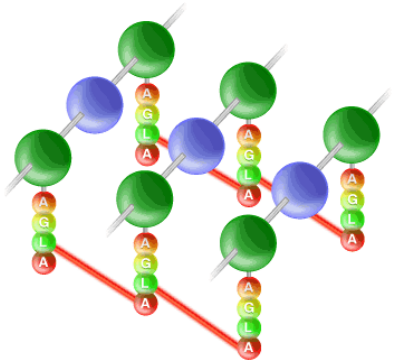
Structure of Bacterial Cells: Cell Wall



N–acetylglucosamine



N–acetylmuramic acid



Structure of Bacterial Cells: Cell Wall

2. Outer membrane
   - A phospholipid bilayer that forms the outermost layer of the cell wall of **G-ve** bacteria
   - It is attached to peptidoglycan by **lipoproteins**
   - Acts as a **coarse sieve** & has little control on movement of substances in & out of cells

     Considered as one of the reasons why G-ve bacteria are less sensitive to penicillin (prevents their entry)
   - Contains proteins that are called '**porins**' which form water-filled channels allowing the transport of small to medium-sized molecules
   - **Lipopolysaccharides** (LPS) are also important part of G-ve outer membrane

Structure of Bacterial Cells: Cell Wall

- Lipopolysaccharides (LPS)
  - Also known as **endotoxins (pyrogens)**
  - Used to identify G-ve bacteria
  - Integral part of outer membrane & not released unless the cell wall of dead bacteria is broken down
  - LPS consists of polysaccharide and lipid A
    - **Polysaccharide part**: repeating units of sugars, used to identify different G-ve bacteria and includes the 'O-antigen'
    - **Lipid A**: responsible for most toxic properties of G-ve bacteria and may cause fever & blood vessel dilatation (systemic vasodilation) → septic shock

Structure of Bacterial Cells: Cell Wall

3. Periplasmic space
   - It is the gap between cell membrane & outer membrane (cell wall)
   - More observed in **G-ve** bacteria
   - It represents an active area of **metabolism**

     i.e. it contains digestive enzymes to destroy harmful substances
   - It also contains 'transport proteins' to transfer metabolites into the bacterial cytoplasm
   - The '**periplasm**' consists of peptidoglycan, proteins & metabolites usually found in the periplasmic space
   - G+ve is considered to have a periplasm but not a periplasmic space

Structure of Bacterial Cells: Cell Wall

Characteristics of the Cell Walls of Gram-Positive, Gram-Negative, and Acid-Fast Bacteria

Characteristic	Gram-Positive Bacteria	Gram-Negative Bacteria	Acid-Fast Bacteria
Peptidoglycan	Thick layer	Thin layer	Relatively small amount
Teichoic acid	Often present	Absent	Absent
Lipids	Very little present	Lipopolysaccharide	Mycolic acid and other waxes and glycolipids
Outer membrane	Absent	Present	Absent
Periplasmic space	Absent	Present	Absent
Cell shape	Always rigid	Rigid or flexible	Rigid or flexible
Results of enzyme digestion	Protoplast	Spheroplast	Difficult to digest
Sensitivity to dyes and antibiotics	Most sensitive	Moderately sensitive	Least sensitive

Table 4-2 Microbiology, 7/e

Structure of Bacterial Cells: Cell Membrane

- **Cell membrane** (plasma membrane) forms boundary between the cell & its environment
- It has general structure as a membrane of all cells, consists of phospholipids & proteins
- Membrane phospholipids form bilayer: phosphate (hydrophilic), fatty acid non polar chains (hydrophobic). Mycoplasma has additional sterols to add rigidity
- It is dynamic constantly changing membrane
  - Fluid mosaic model: phospholipid in fluid state, proteins form mosaic pattern.
- Among lipids are protein molecules, some extend through membrane & act as carriers or form pores for material entry.

Structure of Bacterial Cells: Cell Membrane

- Functions of cell membrane:
  - Regulates movement of materials in & out the cell (permeability barrier).
  - Performs some functions carried out by other organelles in eukaryotes
    - ✓ synthesis of cell wall component,
    - ✓ assists in DNA replication,
    - ✓ secretes proteins,
    - ✓ respiration (instead of mitochondria) & captures energy as ATP,
    - ✓ contains bases of appendages (e.g. flagella)
- Cell membrane is dynamic: lipids & proteins change position, materials flow through pores & through lipids selectively. Some antimicrobials kill bacteria by causing leaks in cell membrane (i.e. polymyxin and daptomycin)

Structure of Bacterial Cells: Internal Structures

- Cytosol
  - Semifluid substance inside cell membrane
  - Composed of 4/5 water, 1/5 of substances dissolved in water (enzymes, proteins, carbohydrates, lipids, & ions)
  - Most anabolic & catabolic rxns occur in cytoplasm
- Ribosomes
  - Consist of RNA & protein
  - Function : protein synthesis
  - Abundant in cytoplasm of bacteria & often grouped in long chains (polyribosomes)
  - Ribosomes: spherical, contain large & small subunits
  - Size & subunit of ribosome is determined by sedimentation rate (Svedberg units).

    Whole bacterial ribosome = 70S, composed of 30S + 50S subunits; eukaryote's ribosome 80S composed of 40S + 60S. Certain antibiotics act on 70S but not 80S (selectivity).

Structure of Bacterial Cells: Internal Structures

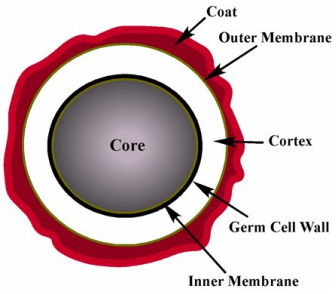
- Nuclear region
  - Bacteria has no nucleus instead they have nuclear region or nucleoid
  - Nuclear region consists of DNA & proteins associated with it, in addition to some RNA
  - Bacteria have one circular chromosome, some have 2, some bacteria also contain smaller circular molecules of DNA called plasmids
- Inclusions
  - Small bodies called either granules or vesicles
  - **Granules**: not bounded by membrane but have compacted substances that don't dissolve in cytoplasm, each granule has specific substance like, glycogen (glucose polymer), polyphosphate (phosphate polymer to supply PO4 for metabolism).
  - Certain bacteria have **vesicles** or vacuoles: membrane enclosed structures.
    - ✓ **Gas** filled vacuole: by regulating gas inside it, certain bacteria (aquatic photosynthetic bacteria) control the depth at which they flow to obtain optimum light
    - ✓ Another type of vesicles contains deposit of **lipids** which serves as storehouse of energy & as source of carbon for building new molecules.

Structure of Bacterial Cells: Internal Structures

- Endospores (bacterial spores)
  - Vegetative cells: cells that are metabolizing nutrients (metabolically active)
  - Some bacteria like bacillus & clostridium produce resting (dormant) stage called endospores; usually to adapt to environmental stress such as nutrient depletion
  - Spores help bacteria survive but not reproduce. While in fungi spores help organism survive & as means of reproduction
  - Endospores formed within cell contain very little water & are highly resistant to heat, drying, acids, bases, disinfectants & even radiation
  - Sporulation: a process where bacteria prepare for the possibility of future adverse conditions.

Structure of Bacterial Cells: Internal Structures

- Endospores (bacterial spores)
  - Spore consists of a core surrounded by cortex, spore coat & in some species a thin delicate layer called exosporium
  - Spores have **dipicolinic acid** (not found in vegetative cells) & large quantity of **Ca^{++}**, these & the low water content contribute to heat resistance
  - Spores can survive adverse environmental conditions for long periods of time > 10,000 yrs. When conditions become favourable, endospores germinate or begin to develop to functional vegetative cells



Structure of Bacterial Cells: External Structures

- Flagella
  - Flagellum is made of protein (flagellin) and is used for locomotion
  - The flagellum is hooked in the cell membrane and extended out of the cell
  - Bacteria can be
    - ✓ Atrichous: without flagella
    - ✓ Monotrichous: with single polar flagellum (located at one end or pole)
    - ✓ Amphitrichous: 2 flagella one at each end (both are polar)
    - ✓ Lophotrichous: bacteria with 2 or more flagella at one or both ends
    - ✓ Peritrichous: flagella all over the surface
  - Cocci rarely have flagella

Structure of Bacterial Cells: External Structures

- Flagella
  - Bacteria move forward or away from substances in the environment by a process called **chemotaxis**
    - ✓ Positive chemotaxis: movement toward an attractant
    - ✓ Negative chemotaxis: movement away from a repellent
  - Possible mechanism of chemotaxis: certain structures on bacteria cell surface detect changes in concentration overtime
  - Some bacteria move toward (positive) or away (negative) from light in a process called **phototaxis**
  - In some bacterial types (i.e. spirochetes) there is a special type of flagella that is tightly bound around the cell (not extending beyond cell wall) which is called **axial filament or endoflagella**

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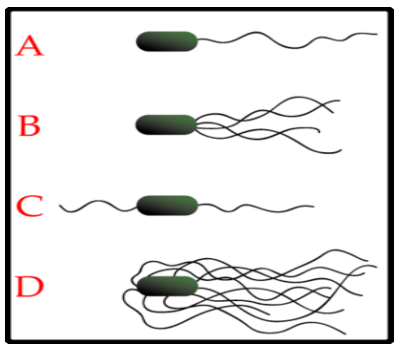
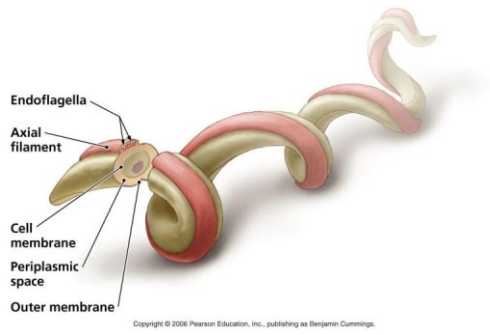
Structure of Bacterial Cells: External Structures





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Structure of Bacterial Cells: External Structures

- Pili (pilus)
  - Tiny hollow projections composed of a protein called 'pilin' and used for bacterial attachment (not for movement)
  - Conjugation pili (sex pili):
    - ✓ A relatively long pili found in some groups of bacteria,
    - ✓ Attach 2 bacterial cells where DNA is transferred through them in a process called conjugation (like sexual reproduction).
    - ✓ Conjugation may result in the transfer of antibiotic resistance genes between bacteria
  - Attachment pili (fimbriae):
    - ✓ Short type that attach bacteria to surfaces or air-water interface.
    - ✓ Contributes to the pathogenicity (ability to produce disease) of certain bacteria by enhancing colonization on surface of cells of other organisms

Structure of Bacterial Cells: External Structures

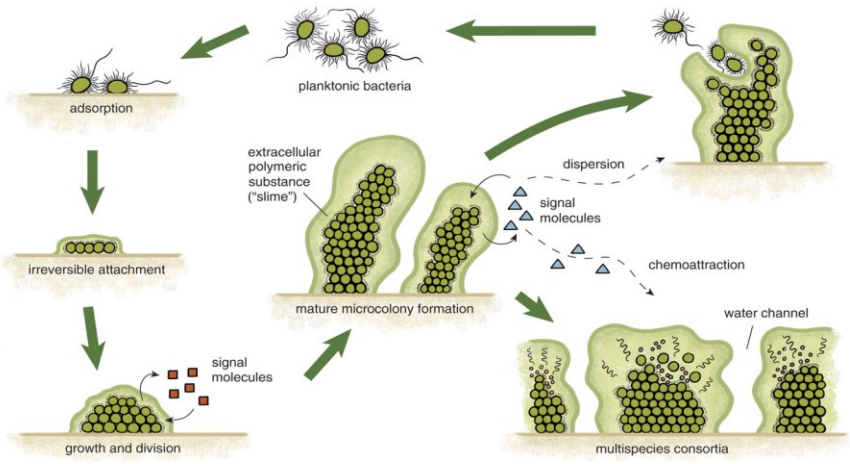
- Glycocalyx

  All polysaccharide-containing substances found external to cell wall, it includes capsule & slime
- Capsule
  - Protective structure outside cell wall that is found in certain bacteria (but not all members of a species necessarily have it)

    e.g. *Bacillus anthracis* has no capsule when outside an organism, but does have it (mostly protein) when it infects the animal, to protect it from host defence
  - It contains polysaccharide molecules arranged in loose gel with unique composition according to the strain

Structure of Bacterial Cells: External Structures

- Slime layer (biofilm)
  - Less tightly bound to cell wall than a capsule
  - When present, it protects the cell against drying, helps trap nutrient & binds cells together
  - It also allows bacteria to adhere to objects & surfaces (environment, human)
  - Microbial biofilms are surface-associated, organised, **multicellular communities** held together by a self-produced extracellular **matrix** forming architecturally complex structures
  - Dental plaque is an example on biofilms, extremely tightly bound to the tooth surface & can cause dental caries
  - Biofilms are estimated to be implicated in around 80% of all chronic human infections and are important mediators of hospital-acquired infections.
  - Biofilms constitute a **protected mode of growth** and bacteria within biofilms typically exhibit significantly **enhanced tolerance/resistance** to antimicrobial challenge and host defences



Stages of biofilm formation