Prokaryotic vs. Eukaryotic Cells

By
Dr. Carmen Rexach
Mt San Antonio College
Microbiology
Eukaryotes = true nucleus

- DNA in linear arrangement = chromosomes
- DNA associated with histone & nonhistone proteins
- DNA in nucleus surrounded by nuclear envelope
- Specialized mitotic apparatus involved in nuclear division
- Contain organelles
- Size: >10 \( \mu m \)
Prokaryotes = prenucleus

- DNA not enclosed in a membrane
- DNA not associated with histone proteins
- Usually single, circular DNA molecule
- No membrane bound organelles
- Cell walls almost always contain peptidoglycan
- Divide by binary fission
- Size: \(<5\mu m\)
Prokaryotic cells
Size and Shape

- **Kingdoms Bacteria and Archaea**
- **Size**
  - Diameter = 0.2-2µm, Length = 2-8µm
- **Shape**: representative with many variations
  - Coccus
  - Bacillus
  - Spiral
    - Vibrio=comma
    - Spirillum=corkscrew
    - Spirochete=helical/flexible
  - Other
    - Square flat, triangular, appendaged and filamentous
Shapes
Unusual shapes

(a) Star-shaped bacteria

(b) Rectangular bacteria
Arrangements

- Diplo-
- Strepto-
- Staphylo-
- Tetrads-
- Sarcinae-

- Monomorphc=retain single shape
- Pleomorphc=many shapes

(Corynebacterium)
Arrangement
Structures external to cell wall

• Glycocalyx
• Flagella
• Axial filaments
• Fimbriae and pili
Glycocalyx

- **Capsule** (organized, firmly attached) or **slime layer** (unorganized, loosely attached) surrounding cell
- Sticky polymer exported outside of cell wall composed of polysaccharides, polypeptides or both
- **Functions:**
  - Protection against phagocytosis (virulence factor)
  - Attachment to surfaces
  - Nutritional source
  - Protect against dessication
  - Prevents loss of nutrients away from cell (viscosity)
Glycocalyx
Flagella (whip)

- Long filamentous appendage, 20nm in diameter, for locomotion
- Arrangements

<table>
<thead>
<tr>
<th>Structure</th>
<th>Flagella Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monotrichous</td>
<td><em>Vibrio cholerae</em></td>
</tr>
<tr>
<td></td>
<td>Lophotrichous</td>
<td><em>Bartonella bacilliformis</em></td>
</tr>
<tr>
<td></td>
<td>Amphitrichous</td>
<td><em>Spinillum serpens</em></td>
</tr>
<tr>
<td></td>
<td>Peritrichous</td>
<td><em>Escherichia coli</em></td>
</tr>
</tbody>
</table>
Flagella
Flagella: structure

• Three parts
  - Filament = composed of flagellin
  - Hook=attached to filament
  - Basal body=anchors to cell membrane
    • Differences in structure of gram negative/gram positive
• Grows at tip
• Movement: clockwise or counterclockwise rotation initiated by basal body
  - Run and tumble
• Chemotaxis
  - movement towards a certain stimulus
• H Antigens
Structure of Flagella

(a) Parts and attachment of a flagellum of a gram-negative bacterium
Motile cells: flagella

(a) A bacterium running and tumbling. Notice that the direction of flagellar rotation determines which of these movements occurs.

(b) A *Proteus* cell in the swarming stage may have more than 1000 peritrichous flagella.
Axial filaments

- Spirochetes
- Filament arises at ends and wraps around cell under sheath
- Causes corkscrew like movement
- Endoflagella
- Ex: *T. pallidum, B. burgdorferi*
Axial filament structure
Axial filament
Fimbriae and pili

• Hairlike appendages on gram negative bacteria made of pilin

• Fimbriae
  - polar or evenly distributed
  - Cellular adhesion to surfaces

• Pili
  - Longer, one or two per cell
  - Attachment
  - Conjugation = sex pili

E. coli: EM showing pili
Cell wall

• External to cell membrane, semi rigid
• Functions
  - Protects cell from osmotic pressure changes (lysis)
  - Maintains shape
  - Anchor point for flagella
  - Involved in pathogenesis in some diseases
  - Site of most antibiotic action
    • Prevent formation
    • Disrupt existing use
Peptidoglycan

- Polymer composed of repeating disaccharides attached by short chains of amino acids
- Disaccharides
  - N-acetylgucosamine (NAG) = similar to glucose
  - N-acetylmuramic acid (NAM)

(a) Structure of peptidoglycan in gram-positive bacteria
Gram positive cell wall
(thick/rigid)

• Ex) *Streptococcus spp.*
• Layers of peptidoglycan (90% of cell wall) + teichoic acid
• Teichoic acid
  - Lipoteichoic acid + wall teichoic acids
  - Negatively charged because of $\text{PO}_4^-$
  - Function
    • Effects movement of positive charged ions into/out of cell
    • Involved in cell growth by maintaining cell wall integrity
    • Primary contributor to antigenic specificity
Gram positive cell wall structure
Gram positive cell wall

N-acetylglucosamine (NAG)
N-acetylmuramic acid (NAM)
Side-chain amino acid
Cross-bridge amino acid

(b) Gram-positive cell wall
Gram negative cell wall

- Outer membrane composed of lipoprotein-lipopolysaccharide-phospholipid surrounding thin layer of peptidoglycan (like “peanut butter” in a lipid sandwich) in periplasmic space
- No teichoic acid = increased fragility
Gram negative cell wall structure
Gram negative cell wall

N-acetylglucosamine (NAG)
N-acetylmuramic acid (NAM)

- Side-chain amino acid
- Cross-bridge amino acid

Lipopolysaccharide

(c) Gram-negative cell wall
Gram negative cell wall:
Functions of outer membrane

- Evades phagocytosis & action of complement due to negative charge
- Barrier to some antibiotics (penicillin)
- Barrier to digestive enzymes, detergents, heavy metals, bile salts, dyes
- Prevents things from diffusing away once internalized
- Contains porins = membrane proteins allow for passage of nucleotides, disaccharides, peptides, amino acids, Fe, vitamin B12
- Attachment site for some viruses
- O-polysaccharide of outer membrane = antigenic
- Lipid A of lipopolysaccharide is endotoxin (GI/blood stream)
Atypical cell wall

• **Mycoplasma**
  - Smallest known extracellular bacteria
  - No cell wall
  - Sterols in plasma membrane protect against lysis

• **Archaea**
  - Some have no cell wall
  - Others have walls of pseudomurein (lack NAM and D amino acids)
Mycobacterial cell wall

- Thick outer coating of mycolic acid (hydroxy lipid) complexed to peptidoglycan of cell wall
Damage to cell wall

- Protoplast is a wall-less gram-positive cell
  - Ex) Exposure of gram + cell to lysozyme
  - Ex) Gram + cell exposed to penicillin
- Spheroplast is a wall-less gram-negative cell.
  - Ex) Exposure of gram- cell to lysozyme
- L forms are wall-less cells that swell into irregular shapes.
- Damaged cell walls subject to osmolysis
Structures internal to the cell wall

- Plasma membrane
- Nucleoid
- Ribosomes
- Inclusions
- Endospores
Plasma membrane

- Thickness: approx 8nm
- Function
  - Selective barrier: concentration of substances inside cell and excretion of wastes
- Composition
  - Phospholipid bilayer with embedded protein (no sterols)
    - Phospholipids separate internal from external environment = amphipathic
    - Proteins: integral and peripheral
    - Some special structures
      - Thylakoids = photosynthesis
      - Chromatophores = pigment
Fluid mosaic

- Viscosity dependent on type of phospholipids (saturated/unsaturated)
- Phospholipids move laterally
- Proteins moved, removed, inserted
Movement of materials across membrane

- Passive transport
  - Simple diffusion
  - Facilitated diffusion
  - osmosis
- Active transport
Passive transport: no energy required

• Simple diffusion
  - Movement of molecules from high concentration to low concentration (with the concentration gradient) by random molecular motion toward equilibrium

• Facilitated diffusion
  - Movement with concentration gradient but requires transporter protein

• Osmosis
  - Movement of water across a selectively permeable barrier with the concentration gradient
Passive transport

(a) At beginning of osmotic pressure experiment

(b)

osmosis
(c) **Isotonic solution**—no net movement of water

(d) **Hypotonic solution**—water moves into the cell and may cause the cell to burst if the wall is weak or damaged (osmotic lysis)

(e) **Hypertonic solution**—water moves out of the cell, causing its cytoplasm to shrink (plasmolysis)
Active transport: Energy required

- Movement against the concentration gradient
- Requires ATP (energy) and a specific transporter protein for each substance
- Group translocation
  - Occurs only in prokaryotes
  - Substance being transported is altered during transport (often phosphorylation)
  - Membrane is impermeable to the new product
Nucleoid

• Region in bacteria where single circular dsDNA chromosome is located and attached to cell membrane

• Plasmids
  - Extrachromosomal genetic elements
  - 5-100 genes
  - Confer properties such as antibiotic resistance
  - Can be transferred from one bacterium to another
  - Manipulated in biotechnology
Nucleiod
Ribosomes

- Sites of protein synthesis
- Found in both prokaryotic and eukaryotic cells
- Structure
  - 2 subunits (70S)
  - Each composed of protein and ribosomal RNA
  - Smaller and denser than in eukaryotic cells
  - Protein synthesis is inhibited by streptomycin, neomycine, and tetracyclines
Prokaryotic vs. Eukaryotic ribosomes

**Prokaryotic**
- rRNA: 23S (2900 bases), 5S (120 bases)
- Proteins: L1, L2, L3 (Total: 31)
- Subunits: 5S, 23S, 50S
- Assembled ribosomes: 70S

**Eukaryotic (mammalian)**
- rRNA: 28S (4800 bases), 5.8S (160 bases), 5S (120 bases)
- Proteins: L1, L2, L3 (Total: 50)
- Subunits: 5.8S, 5S, 28S, 60S
- Assembled ribosomes: 80S
Inclusions

• Reserve deposits found in both prokaryotic and eukaryotic cells

• Many different types, some specific
  - Metachromatic granules composed of volutin provide reserve for inorganic phosphate diagnostic for *Corynebacterium diptheriae*
  - Polysaccharide granules, lipid inclusions, sulfur granules, carboxysomes (enzymes for carbon fixation), gas vacuoles (buoyancy in aquatic forms)
Inclusions

Magnetosomes

TEM 1 μm
Endospores

- **Gram positive bacteria, especially** *Clostridium* and *Bacillus*
  - Exception= *Coxiella burnetti* (gram negative)
- **Resistance**
  - Severe heat, desiccation, toxic chemicals, radiation
- **Process**
  - Sporulation or sporogenesis
- **Location**
  - Terminal, subterminal, central
- **Germination**
  - Return to vegetative state
Light Microscope Image of Endospores
(b) An endospore in *Bacillus anthracis*
Eukaryotic cells
Eukaryotic cells

- Eukaryotic microbes include fungi, protozoa, algae, animals
- Size: 10-100μm
- Contain membrane-bound organelles
- Membrane-bound chromosomes associated with histones and other proteins
Flagella and cilia

- Flagella: few and long
- Cilia: short and numerous
- Both involved in movement
- Cilia may also move things across the surface of a cell
- Different structure than in prokaryotes
  - Composed of nine pairs of microtubules surrounding two singles
  - Thicker
  - Moves in a wavelike or undulating motion
Flagella and cilia

(a) TEM 25 μm (b) SEM 20 μm
Cell wall and glycocalyx

• Not all cells have cell wall
• Simpler cell wall construction than in prokaryotes
• Cellulose
  - Most algae, plants, some fungi (chitin)
• Polysaccharides glucan and mannan
  - yeast
• Pellicle (not cell wall, atypical covering)
  - protozoans
• Glycocalyx
  - Sugar coating
  - Increases cell strength, involved in attachment, cell to cell recognition
Cell Walls
Plasma membrane

• External covering in cell when cell wall absent
• Composition
  - Phospholipid bilayer with associated proteins, sterols, and carbohydrates attached to proteins
• Same transport mechanisms as prokaryotic cells
• Additional transport mechanisms in cells without cell wall
  - Endocytosis (pinocytosis/phagocytosis)
Cytoplasm

• Prokaryotic cells have homogenous cytoplasm, otherwise similar
  - Many enzymes found in prokaryotic cytoplasm are isolated in organelles
• Describes region between nuclear envelope and plasma membrane
• Cytoskeleton
  - Microfilaments, intermediate filaments, microtubules
  - Cytoplasmic streaming = movement of cytoplasm from one part of cell to another
Cytoskeleton

Intermediate filaments

Microfilaments with fluorescent label
Organelles

- Specialized structures in eukaryotic cells
- Most membrane bound
  - Nucleus
  - Endoplasmic reticulum
  - Ribosomes (80S)
  - Golgi
  - Mitochondria
  - Chloroplasts
  - Lysosomes
  - Vacuoles
  - Centrioles
Nucleus

- Genetic material
- Nuclear envelope
- Nuclear pores—endoplasmic reticulum
- Nucleoli
- DNA
  - Histones and nonhistones
  - Chromatin vs. chromosomes
- Division
  - Mitosis/meiosis
Endoplasmic reticulum (ER)

- Series of fluid filled channels connecting nuclear pores with the plasma membrane
- Two general types
  - Rough
    - Dotted with ribosomes
    - Protein synthesis for export
  - Smooth
    - Synthesis and storage of lipids and Ca$^{+2}$
Ribosomes (80S)

- On ER or free in cytoplasm
- Sites of protein synthesis
- 2 subunits, larger and denser than prokaryotes
- Mitochondria and chloroplasts have own DNA and ribosomes (70S) like prokaryotes
Golgi Apparatus

- Stack of flattened sacks located in cytoplasm
- Packages substances synthesized in ER and sort by destination
- Important site of modification of substances
- Altered products leave via secretory vesicles
• **Powerhouse**
  - Respiration and oxidative phosphorylation
  - Where cellular energy is produced

• **Structure**
  - Double membrane
  - Cristae, matrix
  - Capable of independent division
    - Contains own DNA and 70S ribosomes
Chloroplasts

• Found in green algae and plants
• Pigments and enzymes for photosynthesis
• Structure
  - Double membrane
  - Thylakoids and grana
  - Stroma
  - Capable of independent division
    • Contains own DNA and 70S ribosomes
Lysosomes and vacuoles

- **Lysosomes**
  - Digestive enzymes enclosed in single membrane
  - Responsible for decomposition of phagocytosed products
  - Autophagy

- **Vacuoles**
  - Space or cavity in cytoplasm enclosed by tonoplast = membrane
  - Storage for poisons, metabolic wastes, pigments, water
  - Can act as lysosome
  - In plants = turgor pressure
Lysosomes & vacuoles

(b) Transmission electron micrographs of plant and animal cells

Animal cell, an antibody-secreting plasma cell
Centrioles

• Bundles of microtubules stored at 90° angles to each other in cytoplasm near nucleus
• Involved in cell division in animal cells
• Arise from microtubule organizing center
  – Flagella and cilia
centrioles

vacuoles
Evolution of eukaryotic cells

• Autogenous hypothesis
  - Organelles developed from cellular involusions of the plasma membrane
  - Endomembrane system
  - Endoplasmic reticulum, golgi, nuclear envelope
Evolution of eukaryotic cells

- Endosymbiotic hypothesis of Margulis
  - Organelles arose as result of symbiosis between larger and smaller prokaryotic cells
  - One prokaryote would engulf another
    - Mitochondria = descended from association between heterotrophic aerobic prokaryotes
    - Chloroplasts = descended from association of photosynthetic (autotrophic) prokaryotes
Endosymbiotic theory

Diagram showing the evolution from Universal ancestor to Eukarya, including the incorporation of Bacteria, Archaea, Chloroplast, and Mitochondrion.