LECTURE 2. STRUCTURE AND FUNCTION OF THE PROKARYOTIC CELL

1. Size and morphology
2. The nucleoid
3. Cytoplasmic and prokaryotic organelia
4. Cytoplasmic membrane
5. Cell walls in prokaryotes
6. Outer structures
7. Exoflagella and endoflagella
8. The bacterial endospore
9. Other structures

For copyright reasons, images have been deleted.
1. SIZE AND MORPHOLOGY

1.1. SIZE

**LENGTH: 0.2 – 50 μm (1-5 μm)**

“Nanobacteria”
1. SIZE AND MORPHOLOGY

1.2. MORPHOLOGY

- Cocci
- Rods
- Vibrios
- Spirilla
- Spirochetes
- Pleomorphic
1. SIZE AND MORPHOLOGY

1.3. GROUPS

RODS

Pairs
Chains

COCCI

Diplococci
Tetrads
Sarcines
Streptococci
Staphylococci
2. THE NUCLEOID

DNA mass (10% cell volume) not clearly defined, extruding to the cytoplasm

One chromosome (EXCEPTIONS!) (0,5 - 8 Mb); More than one copy per growing cell
cccDNA, supercoiled
Condensed: basic proteins, poliamynes (spermidine, spermine), Mg$^{2+}$
Segregation

Supercoiling domains
3. CYTOPLASM AND PROKARYOTIC ORGANELLA

3.2. RIBOSOMES

<table>
<thead>
<tr>
<th>TRAIT</th>
<th>PROKARYOTIC</th>
<th>EUKARYOTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global size</td>
<td>70S</td>
<td>80S</td>
</tr>
<tr>
<td>Small subunit (SSU)</td>
<td>30S</td>
<td>40S</td>
</tr>
<tr>
<td>Number of proteins in SSU</td>
<td>~21</td>
<td>~30</td>
</tr>
<tr>
<td>SSU rRNA size</td>
<td>16S (1500 nt)</td>
<td>18S (2300 nt)</td>
</tr>
<tr>
<td>Large subunit (LSU)</td>
<td>50S</td>
<td>60S</td>
</tr>
<tr>
<td>Number of proteins in LSU</td>
<td>~34</td>
<td>~50</td>
</tr>
<tr>
<td>LSU rRNA size</td>
<td>23S (2900 nt)</td>
<td>28S (4200 nt)</td>
</tr>
<tr>
<td></td>
<td>5S (120 nt)</td>
<td>5S (120 nt)</td>
</tr>
</tbody>
</table>

Ribosomes in mitochondria and chloroplasts (eukaryotic organella) are similar to prokaryotic ribosomes.
3. CYTOPLASM AND PROKARYOTIC ORGANELLA

3.2. RIBOSOMES
3. CYTOPLASM AND PROKARYOTIC ORGANELLA

3.3. PROKARYOTIC ORGANELLA

Surrounded by non-unit membranes

GAS VESICLES

Frequent in aquatic prokaryotes:

* Cyanobacteria
* Archaea

Spindle-shaped
Refrigent under the microscope
Made of rigid and hollow protein vesicles
Pressure and composition of the contents depend on the gasses dissolved in the surrounding media
They confer buoyancy on the cells (allow cells to float up and down in a water column in response to environmental factors).

CHLOROSOMES

Green bacteria photosynthetic organella
Cylindrical structures “stuck” to the cytoplasmic membrane
Surrounded by a non-unit membrane (3-5 nm)
Photosynthetic pigments (BChl)
3. CYTOPLASM AND PROKARYOTIC ORGANELLA

3.3. PROKARYOTIC ORGANELLA

**CARBOXYSOMES**

Present in some strictly autotrophic bacteria
Polyhedral inclusions made of crystalline RuBisCo

**MAGNETOSOMES**

Magnetotactic bacteria
Made of magnetic material (Fe$_3$O$_4$)
They orient the cell in a particular direction in the magnetic field
**Selective advantage:** microaerophilic and anaerobic aquatic bacteria
3. CYTOPLASM AND PROKARYOTIC ORGANELLA
3.3. PROKARYOTIC ORGANELLA

**PHYCOBILISOMES**
(LIGHT HARVESTING PIGMENTS)

- Phycoerythrin
- Phycocyanin
- Allophycocyanin

Phycobilines + Protein → Phycobiliproteins → Phycobilisomes
3. CYTOPLASM AND PROKARYOTIC ORGANELLA

3.4. STORAGE MATERIALS

**C STORAGE**: starch, glucogen, PHB, PHA

**N STORAGE**: cyanophycin granules (Asp-Arg)

**P STORAGE**: polyphosphate granules (“volutina/gránulos policromáticos”)

**S STORAGE**: elemental S granules

**Halofexx mediterranei**

Only in prokaryotes

Biodegradable plastics

Cyanobacteria

H₂S, S⁰ oxidizing bacteria

Anoxygenic phototrophic bacteria
4. CYTPlASMIC MEMBRANE

4.1. PHYSICAL CHARACTERISTICS

Phospholipid bilayer (amphipathic) with proteins (8 nm)

FLUID MOSAIC MODEL

UNIT MEMBRANE

STABILITY:
- Hydrogen bonds
- Hydrophobic interactions
- Ca$^{2+}$, Mg$^{2+}$, PO$_4^{3-}$
- Self-assemblage

FUNCTIONS:
- Highly selective permeability barrier (prevents passive leakage into or out of the cells)
- Protein anchor
- Energy conservation and transport
- Chromosome anchorage
### 4. CYTOPLASMIC MEMBRANE

#### 4.2. CHEMICAL COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>Eukarya + Bacteria</th>
<th>Archaea</th>
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</thead>
<tbody>
<tr>
<td>Chemical bonds in</td>
<td>Ester</td>
<td>Ether</td>
</tr>
<tr>
<td>phospholipids”</td>
<td>Fatty acid + glycerol</td>
<td>Isoprenoid + glycerol</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Eukarya</th>
<th>Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esterols</td>
<td>Yes</td>
<td>No* (hopanoids)</td>
</tr>
<tr>
<td>Polyunsaturated PL</td>
<td>Yes</td>
<td>No**</td>
</tr>
</tbody>
</table>

Exceptions:

*Methanotrophs and mycoplasms have sterols

**Cyanobacteria
4. CYTOPLASMIC MEMBRANE

4.2. CHEMICAL COMPOSITION
4. CYTOPLASMIC MEMBRANE

4.3. TRANSPORT

PASSIVE TRANSPORT

Simple diffusion: no transporters
Facilitated diffusion: permeases

ACTIVE TRANSPORT (USES ENERGY)

Chemical alteration: group translocation
No modification: proton motive force ATP (ABC)

IONOPHORS
5. PROKARYOTIC CELL WALLS

5.1. FUNCTIONS

- Protection against osmotic lysis
- Shape
- Division
- Motility
- Permeability barrier in Gram-

5.2. PEPTIDOGLYCAN

\[ \text{G} \quad \text{M} \quad \text{G} \quad \text{M} \quad \text{G} \quad \text{M} \quad \text{L-Alanine} \]

\[ \text{D-Glutamate} \]

\[ \text{DAP (diaminopimelic acid) / L-Lys} \]

\[ \text{D-Alanine} \]
5. PROKARYOTIC CELL WALLS

5.3. PEPTIDOGLYCAN SYNTHESIS

**Transpeptidation**

- **Transpeptidases/PBP**
- **Autolysins**
5. PROKARYOTIC CELL WALLS

5.4. GRAM STAINING

Useful in bacterial identification

Phylogeny?
5. PROKARYOTIC CELL WALLS

5.5. GRAM-POSITIVE CELL WALL

Many (20) peptidoglycan layers (90%)

Many transpeptidic bonds

TEICHOIC ACIDS (acidic polysaccharides)

- Stability
- Charge
- Autolysin regulation
- Surface antigens
- Phage binding sites

High resistance to mechanical stress (5-10 atm)

Sensitivity to antibiotics and chemical agents
5. PROKARYOTIC CELL WALLS
5.6. GRAM-NEGATIVE CELL WALL

One peptidoglycan layer (10%)

ADDITIONAL OUTER MEMBRANE

- FPM maintenance
- Avoids enzyme leaking out of the periplasm
- Negatively charged cell surface
- Partial permeability barrier
- Resistance to toxic agents: lipozyme, antibiotics, etc.
- Receptor for phage attachment, conjugation, etc.

Low resistance to mechanical stress (2-5 atm)

Resistance to antibiotics and chemical agents
5. PROKARYOTIC CELL WALLS
5.6. GRAM-NEGATIVE CELL WALL

OUTER MEMBRANE

Asymmetric bilayer
Phospholipid + LPS
Lipopolysaccharide LPS (O antigen, core, and lipid A)
Lipoproteins (anchor to PG)
Porines (transport)
Omp (outer membrane proteins)
5. PROKARYOTIC CELL WALLS
5.7. CELL WALLS IN *Archaea*

NO PG (NO MUREIN)
NO D-AMINOACIDS

**Pseudomurein / pseudopeptidoglycan**
(N-acetylglucosamine and N-acetyltalosaminuronic acid)

Sulphated polysacharides

Proteins, Glycoprotein (S-layers)
6. OUTER CELL SURFACE STRUCTURES

EXOCYTOPLASMIC POLYMERIC SUBSTANCES (EPS) - GLYCOCALIX

EXOPOYIPEPTIDES
EXOPOLYSACCHARIDES

Capsules: compacted, structured
Slime layers: loose and non-organized

- Thickener ("Xanthan Gum", sauces, syrups)
- Crystallization retarder (ice creams)
- Gelifier (cream, fillings)

Imp. in pathogenesis
6. OUTER CELL SURFACE STRUCTURES

WATER AND NUTRIENT BINDING
Protection against dessication
Nutrient “storage”

ADHESION TO SURFACES
Pathogenicity (Colonization)
Biofilms (normal microbiota, pipes)

PROTECTION AGAINST PHAGOCYTOSIS

Dental plaque: caries
*Streptococcus mutans
*Streptococcus sobrinus

Normal microbiota

Implants, medical devices
Motile responses to stimuli: Chemotaxis, Phototaxis, Aerotaxis

Bacteria respond to temporal gradients of the signal molecules.
Positive stimuli reduce the frequency of tumbles.
7. EXOFLAGELLA AND ENDOFLAGELLA
7.2. EXOFLAGELLA

Long, thin and semi-rigid appendages
Made of flagellin units (helically shaped)

MONOTRICHIOUS FLAGELLATION: 1 flagellum
POLAR (or not)
AMFITRICHIOUS: 1 flagellum at each pole
LOPHOTRICHIOUS: polar tuft(s) of flagella
PERITRICHIOUS: inserted at many places around the cell
7. EXOFLAGELLA AND ENDOFLAGELLA

7.2. EXOFLAGELLA

- Filament
- Hook
- Motor → L, P, S and M rings; proteins Mot and Fli
7. EXOFLAGELLA AND ENDOFLAGELLA

7.2. EXOFLAGELLA

| GRAM-NEGATIVE | GRAM-POSITIVE |
7. EXOFLAGELLA AND ENDOFLAGELLA
7.2. EXOFLAGELLA

Flagellar synthesis

Flagelline units
Self assembly
Tip extension

Energy: FMP
Flagellar distribution drives the type of movement
7. EXOFLAGELLA AND ENDOFLAGELLA
7.2. ENDOFLAGELLA

Phylum *Spirochaeta* “spirochetes”
7. EXOFLAGELLA AND ENDOFLAGELLA
7.4. GLIDING MOTILITY

"Myxobacteria"

Cyanobacteria
8. THE BACTERIAL ENDOSPORE
8. THE BACTERIAL ENDOSPORE

8.1. TYPES OF ENDOSPORES

Sporulated microorganisms

- Bacillus sp.
- Clostridium sp.
- Sporosarcina sp
- Desulfotomaculum sp.
- Thermoactinomyces sp.
8. THE BACTERIAL ENDOSPORE
8.2. PROPERTIES OF ENDOSPORES

RESISTANCE

Dessication
Temperature (autoclave)
Radiation
Acids, disinfectants, enzymes

Spores do not get stained with normal stains
8. THE BACTERIAL ENDOSPORE
8.3. ENDOSPORE STRUCTURE

**CORE (SPORE PROTOPLAST):**
- 10-25% H₂O
- Heat resistance
- Enzyme inactivation
- DNA protection

Dipicolinic acid + Ca²⁺ DNA and protein stability

**SASPs** DNA protection Carbon and Energy source

**CÓRTEX:** Loosely cross-linked peptidoglycan

**SPORE COAT:** Protein multilayer

**EXOSPORIUM:** Proteins
8. THE BACTERIAL ENDOSPORE

8.4. THE SPORULATION PROCESS

Vegetative cell → Sporulating cell → Mature endospore
8. THE BACTERIAL ENDOSPORE
8.5. GERMINATION

Vegetative cell → Sporulating cell → Mature endospore

ACTIVATION
- Heat shock
- Mechanical activation

GERMINATION
- Presence of specific nutrients

OUTGROWTH
8. THE BACTERIAL ENDOSPORE

8.6. SPORULATION-RELATED COMPOUNDS

**TOXINS**

- Botulinic toxin (*Clostridium botulinum*)
- Tetanus toxin (*Clostridium tetani*)
- Anthrax (*Bacillus anthracis*)
- Different disease (*Clostridium perfringens*)
- Parasporal crystal (*Bacillus thuringiensis*)

**ANTIBIOTICS**

- Bacitracine (*Bacillus subtilis*)
- Polymixine G (*Bacillus polymyxa*)
- Gramicidine

How long do endospores “survive”?
9. OTHER STRUCTURES

Similar to flagella but not involved in motility

FIMBRIAE
Shorter than flagella and more numerous
Adhesion to surfaces

PILI
Longer than fimbriae
Only a few per cell
Receptors for viruses
Conjugation
9. OTHER STRUCTURES

THYLAKOIDS
Cyanobacteria

Membrane structures

Invaginations of the plasmatic membrane
Phototrophs, methanotrophs, nitrifying bacteria..