The Bacterial Cell Wall

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Cell Envelope: Cell Wall

- A rigid cell wall surrounds all eubacterial cells except mycoplasmas.
- The structure and function of the bacterial wall is distinctive; it constitutes a hallmark of the prokaryotes.
- Unlike the capsule, which is dispensable for survival outside the body of the host, the wall has vital functions.
Cell Wall: Function

- It protects the cell from mechanical disruption and from being burst by osmotic pressure (the cell interior is hypertonic relative to the environment).
- The wall also provides a barrier against certain toxic chemical and biological agents.
- Being rigid, it is responsible for the shape of the cell.
Cell Wall

Functions

- Providing attachment sites for bacteriophage-teichoic acids
- Providing a rigid platform for surface appendages - flagella, fimbriae, and pili
The Cell Wall

Bacteria may be conveniently divided into two further groups, depending upon their ability to retain a crystal violet-iodine dye complex when cells are treated with acetone or alcohol. This reaction is referred to as the **Gram reaction**; named after Christian Gram, who developed the staining protocol in 1884.
Bacterial Cell Wall

G +ve
Cell wall

G –ve
Cell wall
The cell wall of Gram-positive bacteria is composed of:

- Peptidoglycan; may be up to 40 layers of this polymer
- teichoic and teichuronic acids - surface antigens

The cell wall of Gram-negative bacteria is complex and consists of:

- a periplasmic space – enzymes
- An inner membrane - one or two layers of peptidoglycan beyond the periplasm
- Outer membrane (LPS) – external to peptidoglycan
- Braun’s lipoproteins – anchoring outer membrane to inner
- Porins - through which some molecules may pass easily.
Gram-Positive Cell Wall

peptidoglycan

cytoplasm

cytoplasmic membrane
Gram Positive Cell Wall:

- The Gram-positive cell wall contains two major components
  - peptidoglycan and
  - teichoic acids
  - there are also additional carbohydrates and proteins depending on the species of organism
- The Gram positive cell wall is much thicker than that of Gram negative cells
Structure of a Gram-Positive Cell Wall
Peptidoglycan

- single macromolecule
- highly cross-linked
- surrounds cell
- provides rigidity
Gram Positive Cell Wall: Peptidoglycan

- The chief component of the Gram positive cell wall is murein, a peptidoglycan, which is found nowhere except in eubacteria.

- Murein consists of a linear glycan chain (1:4 linkages) of two alternating sugars:
  - N-acetylglucosamine (NAG)
  - N-acetylmuramic acid (NAM)
There are two types of peptide chains:

1. A tetra peptide side chain linked to N-acetyl-muramic acid and containing the common amino acids L-alanine and L-lysine and the unusual amino acids D-glutamic acid, D-alanine and meso-diaminopimelic acid (DAP).

2. A penta-glycine bridge in Gram –positive bacteria, such as Staphylococcus aureus, linking the linear peptide / polysaccharide chains to form a 2-D network.

NOTE: Muramic acid, D-amino acids, and diaminopimelic acid are not synthesized by mammals
Peptidoglycan

- L-alanine
- D-glutamic acid
- L-lysine/Diaminopimelic acid
- D-alanine

Muramic acid
Glucosamine
In many Gram-negative bacteria the tetra peptide side chains are cross linked directly via a covalent peptide bond between the carboxyl-group of the terminal D-alanine and amino-group of L-lysine or meso-diaminopimelic acid without the involvement of a separate penta-glycine bridge.
Gram Positive Cell Wall: Teichoic Acid

• Some teichoic acid is covalently linked to:
  – NAM residues of the murein or
  – a glycolipid in the underlying cell to form lipoteichoic acid
    • plays a role in anchoring the wall to the cell

• Teichoic acids are found only in Gram positive cells and constitute the major antigenic determinants of the cell surface
Gram Positive Cell Envelope

- **Teichoic acid**
  - Polymer
  - phosphorus
  - ribitol or glycerol backbone

- **Teichuronic acid**
  - polymer
  - no phosphorus
  - glucuronic acid backbone
Gram Negative Cell Wall:

- The Gram negative cell wall, except for the presence of a limited amount of murein, has little chemical resemblance to cell walls of Gram positive bacteria.
- The architecture of the Gram negative cell wall is fundamentally different.
The Gram-negative cell wall is composed of:

- periplasmic space
- peptidoglycan (thin layer)
- Braun’s lipoproteins
- Lipopolysacccharides
- Porins
Gram-Negative Cell Wall

- outer membrane
- peptidoglycan
- cytoplasm
- cytoplasmic membrane
Gram Negative Cell Wall: Periplasm

- The proteins in solution in the periplasm consist of:
  - enzymes with hydrolytic functions (such as alkaline phosphatase)
  - antibiotic-inactivating enzymes
  - various binding proteins with roles in chemotaxis and in the active transport of solutes into the cell

- Oligosaccharides secreted into the periplasm create an osmotic pressure buffer
Gram Negative Peptidoglycan

• Only one or two layers
• No pentaglycine bond
• Lesser cross-linking
• Braun’s lipoproteins
  – binds peptidoglycan layer to outer membrane
Outer Membrane

• major permeability barrier consisting of
  • lipopolysaccharide
  • phospholipids
  • Proteins
    – Porins
Gram Negative Cell Wall: Outer Membrane

- In the outer membrane, the inner leaflet consists of ordinary phospholipids, but the outer leaflet consists of a special molecule called lipopolysaccharide (LPS).
- LPS is extremely toxic to humans and other animals and is called endotoxin.
- Even minute amounts of LPS can produce fever and shock (Gram-negative shock, or endotoxic shock).
Outer Membrane: Endotoxin (LPS)

- LPS consists of:
  - lipid A (a phospholipid containing glucosamine rather than glycerol)- this is the toxic component of the endotoxin
  - a core polysaccharide (containing some unusual carbohydrate residues and fairly constant in structure among related species of bacteria)
  - O-antigen polysaccharide side chains- the major surface antigen of Gram-negative cells
LIPOPOLYSACCHARIDE

Four segments can be differentiated within the lipopolysaccharides:

1. **Lipid A** – a phospholipd consisting of two molecules of glucosamine which carry three fatty acids anchoring the LPS in the lipid bilayer.

2. **R-core**:
   - **Inner core** - 3 molecules of 2-keto-3-deoxyoctonate (KDO) and two heptose both linked to phosphoethanolamine.
   - **Outer core** - pentasaccharide of glucose, galactose and GNAc.

3. **O-side chain** (also known as O-antigen), consisting of unusual sugars such as mannose, rhamnose, abequose, fucose, colitose and others.
Gram Negative Cell Wall: Outer Membrane

- LPS in the outer membrane results in a barrier that blocks the passage of virtually every organic molecule into the cell
- The Gram negative cell must make provision for the rapid entry of nutrients
  - Special proteins, called porins or matrix proteins, form pores through the outer membrane
  - Porins allow hydrophilic molecules of <800 MW to diffuse into the periplasm
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<thead>
<tr>
<th>Characteristic</th>
<th>Gram positive</th>
<th>Gram negative</th>
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<tbody>
<tr>
<td>Peptidoglycan</td>
<td>Thick</td>
<td>Thin</td>
</tr>
<tr>
<td>Tetra peptide</td>
<td>Most have lysine</td>
<td>All have DAP</td>
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<tr>
<td>Cross-linkage</td>
<td>Generally pentapeptide</td>
<td>Direct bond</td>
</tr>
<tr>
<td>Teichoic/teichuronic acids</td>
<td>+</td>
<td>-</td>
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<tr>
<td>Lipoproteins</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Lipopolysaccharide</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Outer membrane</td>
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</tr>
<tr>
<td>Periplasmic space</td>
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<td>+</td>
</tr>
<tr>
<td>Polysaccharide</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Protein</td>
<td>+ or −</td>
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Acid fast and related bacteria
(mycobacteria, nocardia and corynebacteria)
The cell wall of acid-fast bacteria consists of:

- peptidoglycan layer linked to arabinogalactan
- arabinogalactan (D-arabinose and D-galactose) and mycolic acid layers
- mycolic acid layer is overlaid with a layer of polypeptides and free mycolic acids.
- Other glycolipids include lipoarabinomannan and phosphaetidyinositol mannosides (PIM).
Structure of an Acid-Fast Cell Wall
Wall-less forms

Wall-less bacteria that don’t replicate:

• Result from action of:
  • enzymes lytic for cell wall
  • antibiotics inhibiting peptidoglycan biosynthesis
• non-viable
• spheroplasts (with outer membrane) from Gram negative bacteria
• protoplasts (no outer membrane) from Gram positive bacteria

Wall-less bacteria that replicate: L-forms

Naturally occurring wall-less bacteria: Mycoplasmas (viable, replicate)
Some bacteria (e.g. *Bacillus anthracis*) may be covered by a regular arrangement of proteins called as S-layer.

S-layer is attached to the outermost portion of their cell wall.

composed of either a single protein or glycoproteins, depending upon the species.

protect bacteria from harmful enzymes, changes in pH, and the predatory bacterium.

can function as an adhesin.

may contribute to virulence by protecting the bacterium against complement attack and phagocytosis