Bacteriology

Lec2 Structure of bacteria

Morphology

Bacteria are the smallest organisms that all machinery required for growth and self-replication, their diameter is usually about 1 µm. The high microscope reveals two principles forms of Eubacteria, spherical organisms called **cocci** and cylindrical ones called **bacilli**.

Cocci appear in number of different patterns depending upon the planes in which they divide. When cocci appear in pairs they are known as **diplococci**, while if in chain they are called **streptococci**, and they are called **staphylococci** if they were in cluster. Cocci that remain adherent often splitting successively in two or three perpendicular direction yielding **tetrads** or cubical packets are known as **sarcina**.

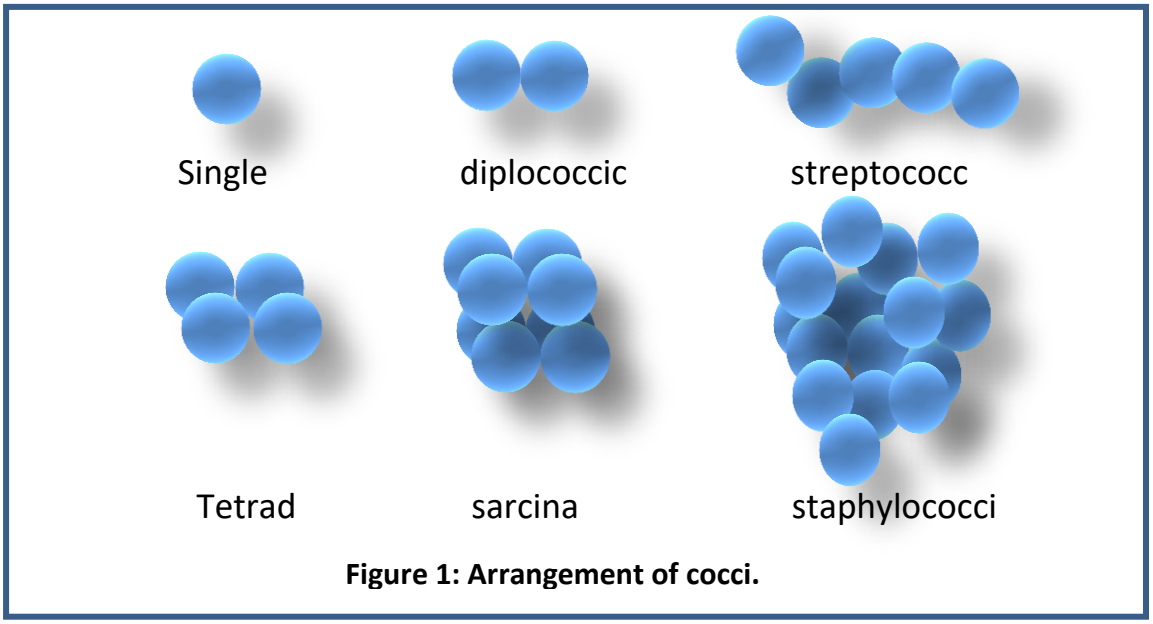


Figure 1: Arrangement of cocci.

Bacillus when unusually short are referred as **coccobacilli**, when tapered at both ends as **fusiform**, when growing in long threads as **filaments** form, when curved as **vibrio** and when spiral as **spirillum** or **spirochete**.

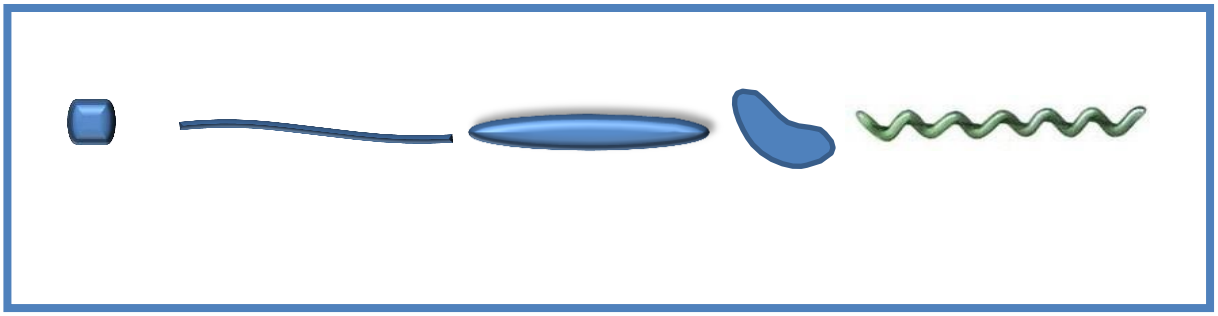


Figure 2: Arrangement of bacilli

In 1981, **square** bacteria had been discovered; they 2-4 µm in diameter, halophilic (Archaebacteria), produce stains similar to bacterial rhodopsin.

Pleomorphism

Bacteria appear in number of different forms. Environmental conditions are affecting the size and shape of bacteria, which is seen obviously in bacilli forms other than cocci forms.

Structure of bacterial cell

The cell envelope

The layers that surround the prokaryotic cell are called cell **envelope**. The structure and organization of the cell envelope differ in Gram positive and Gram negative bacteria.

The Gram positive cell envelope

It is relatively simple, consisting of two or three layers: the **cytoplasmic membrane**, a thick **peptidoglycan layer** (PG) and in some bacteria an outer layer called **capsule**.

The Gram negative cell envelope

It is a highly complex, multilayered structure. The **cytoplasmic membrane** (called inner membrane) is surrounded by a single layer of

peptidoglycan to which is anchored a complex layer known as **outer membrane**, and the **capsule** may also be present. The space between inner membrane and outer membrane referred to as **periplasmic space**.

Extracellular polysaccharides

Many bacteria synthesize large amounts of extracellular polymer when growing in their natural environment. With one exception (the poly D-glutamic acid capsule of *Bacillus anthracis*) the extracellular material is polysaccharides which is also called **glycocalyx**. When the glycocalyx forms a condensed well defined layer closely surrounding the cell, it is called **capsule**; when it forms masses of polymers are formed that appear to be totally detached from the cell in which cells may be entrapped, in these instances the extracellular polymers may be referred to simply as a **slime layer**.

The glycocalyx layer contributes to the invasiveness of pathogenic bacteria in protecting them from phagocytosis. Furthermore, it plays a role in the adherence of bacteria to surfaces in their environment, including the cells of plant and animal hosts. A **biofilm** is an aggregate of interactive bacteria attached to a solid surface or to each other. Biofilms are important in human infections that are persistent and difficult to treat.

The cell wall

The layers of the cell envelope lying between the cytoplasmic membrane and the capsule are called **cell wall**. In Gram positive bacteria, the cell wall consists mainly of peptidoglycan, teichoic acids, and polysaccharides. While in Gram negative bacteria, the cell wall includes the peptidoglycan, outer membrane, lipopolysaccharide (LPS), and lipoprotein (Figure 3).

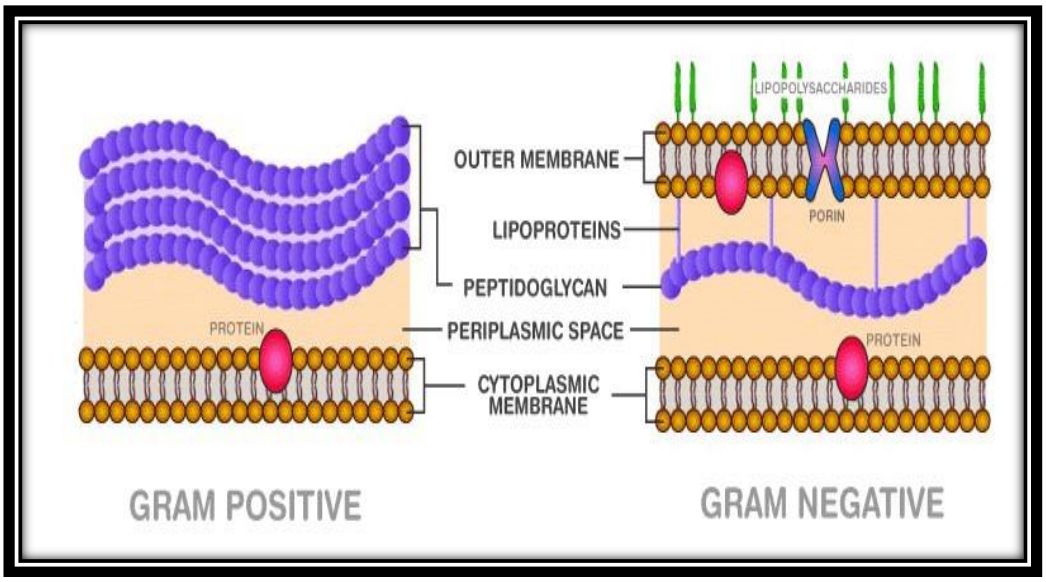


Figure 3: Gram positive and Gram negative cell wall

The functions of cell wall

1- Protects the cell from osmotic pressure.

2- 2- Plays an essential role in cell division.

3- Various layers of the wall are the sites of major antigenic determination of the cell surface.

4- Lipopolysaccharide is responsible for the endotoxin activity.

Chemical composition of the cell wall

A- The peptidoglycan layer

It is a complex polymer consisting or three parts (Figure 4):

1. A **backbone** composed of alternating subunit of *N*-acetyl glucosamine and *N*-acetylmuramic acid linked together by β 1-4 glycosidic bond.
2. A set of identical tetrapeptide **side chains** attached to *N*- acetylmuramic acid.
3. A set of identical peptide **cross-bridge** (the terminal COOH to NH_2 of neighboring tetrapeptide).

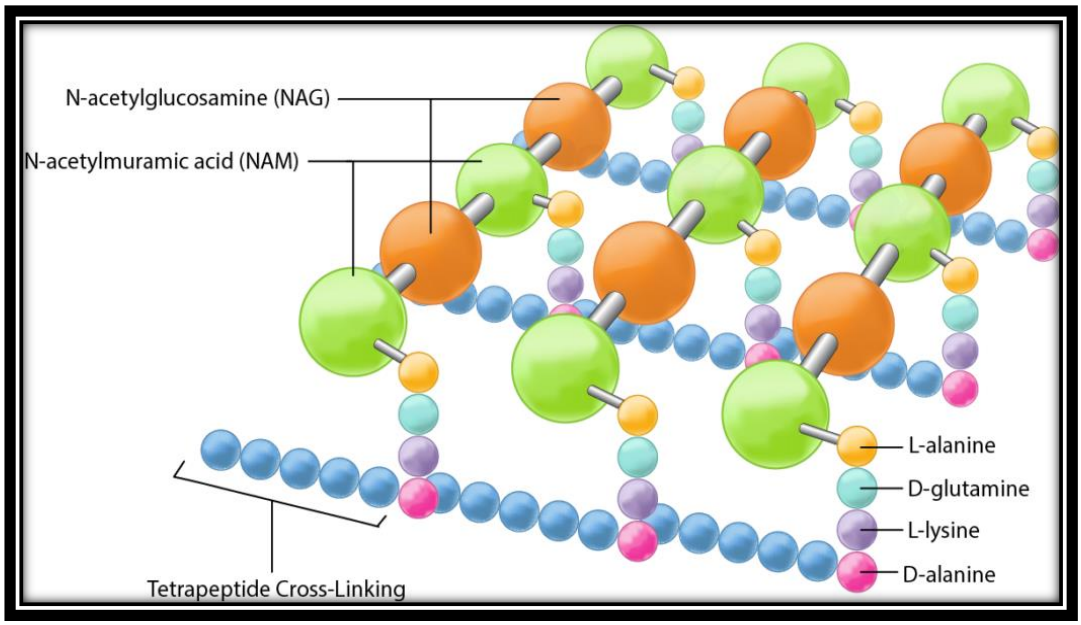


Figure 4: Peptidoglycan structure

All peptidoglycan layers are cross linked, which means that each peptidoglycan layer represents a single giant molecule.

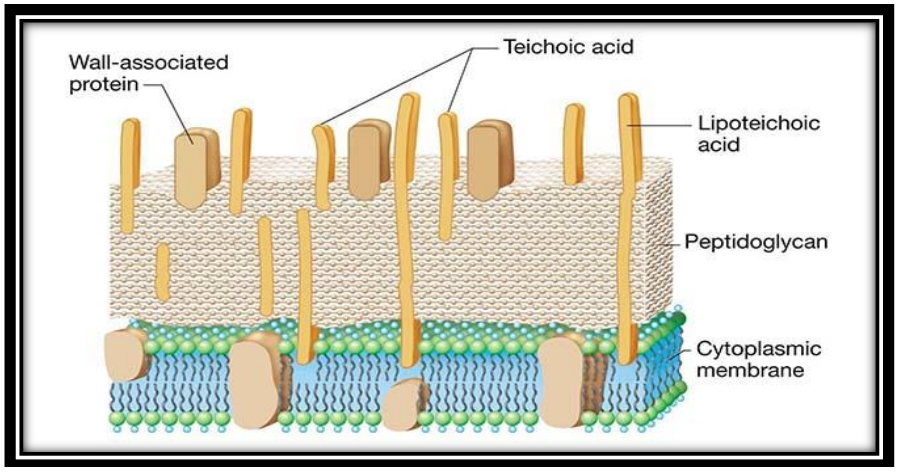
In Gram positive bacteria there are as many as 40 sheets of peptidoglycan, comprising up to 50% of the cell wall materials. In Gram negative bacteria, it appears to be only one or two sheets, comprising 5- 10% of the wall materials.

B- Special components of Gram positive cell wall

1- Teichoic acid

Most Gram positive cell walls contain amount of teichoic acid, which may account for up to 50% of the dry weight of the wall and 10% of the dry weight of total cell. Teichoic acids are water soluble polymers containing ribitol or glycerol residues joined through phosphodiester linkage. There are two types of teichoic acids; **wall teichoic acid** covalently linked to peptidoglycan; and **lipoteichoic acid** (membrane teichoic acid), covalently linked to membrane glycolipid and concentrated in mesosome. Some Gram positive species lack wall teichoic acid but all appears to contain lipoteichoic acid. The function of teichoic acids is still a matter of speculation:

a. The main function of teichoic acids is to provide rigidity to the cell wall by attracting cations such as magnesium and sodium.
b. Teichoic acids provide an external permeability barrier to Gram positive bacteria.
c. Limiting the ability of autolysins to break the β (1-4) bond between the *N*-acetyl glucosamine and the *N*-acetylmuramic acid.
d. They have role in cell elongation and division.
e. Functions in biofilm formation and adhesion.



2- Teichuronic acid

The teichuronic acids are similar polymers, but the repeat units include sugar acids instead of phosphoric acids. They are synthesized in place of teichoic acids when phosphate is limiting.

3- Polysaccharides

The hydrolysis of Gram positive cell wall has yielded neutral sugars such as mannose, arabinose, galactose, rhamnose, glucosamine and acidic sugars.

C- Special components of Gram negative cell wall

1- Lipoprotein

Molecules of an unusual lipoprotein cross-link the outer membrane and

peptidoglycan layers. The lipoprotein contains 57 amino acids. Their function is to stabilize the outer membrane and anchor it to the peptidoglycan layer.

2- Outer membrane

The outer membrane is a bilayered structure; its inner leaflet resembles in composition that of the cytoplasmic membrane while the phospholipids of the outer leaflet are replaced by lipopolysaccharide (LPS) molecules.

The functions of outer membrane are:

a. Prevents leakage of periplasmic space proteins.
b. Protects the enteric bacteria from bile salts and hydrolytic enzymes.
c. Contains the minor proteins, which are involved in the transport of specific molecules such as vitamin B12 and iron-siderophore complexes.
d. Has a special channels, consisting of proteins called **porins** that permit the passive diffusion of low molecular weight hydrophilic compounds like sugars, amino acids, and certain ions.
e. Contains numbers of enzymes like proteases and phospholipases.

3- Lipopolysaccharide

The lipopolysaccharide of Gram negative cell wall consists of a complex lipid called **lipid A**, to which is attached a polysaccharide made up of a **core** and a terminal series of **repeat units** (O antigen). Lipopolysaccharide is attached to the outer membrane by hydrophobic bound.

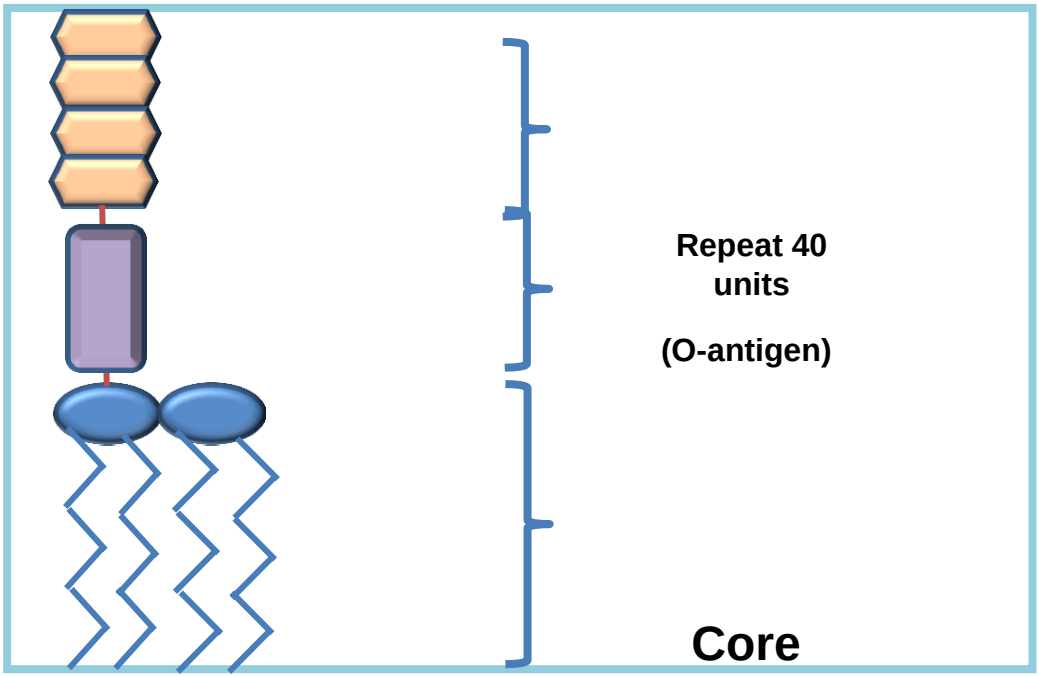


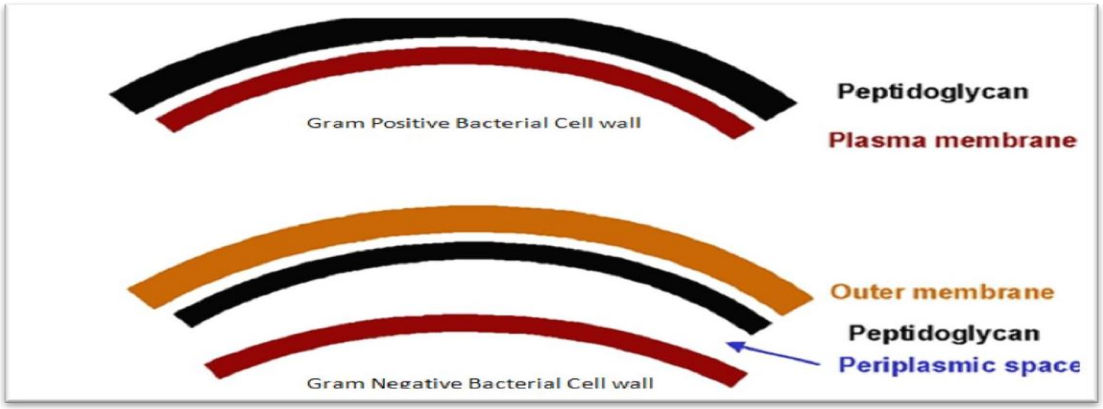
Figure 5: Lipopolysaccharides structure

The function of lipopolysaccharide:

a) Stabilizes the membrane and provides a barrier to hydrophobic molecules.
b) Lipopolysaccharide, which is toxic to animals, has been called the endotoxin of Gram negative bacteria because it is firmly bound to the cell surface and is released only when the cells are lysed. All of the toxicity is associated with the lipid A.
c) Polysaccharide represents a major surface antigen of the bacterial cell so called O-antigen, and is responsible for the antigenic specificity.

The periplasmic space

The space between the cytoplasmic membrane and outer membrane, called the periplasmic space, contains the peptidoglycan layer and a gel- like solution of proteins. The periplasmic space is approximately 20-40% of the cell volume. Its proteins include binding proteins for specific substrates (e.g. amino acids, sugars, vitamins, and ions) and the hydrolytic enzymes.



Cytoplasmic membrane

It is also called cell membrane, composed of proteins and phospholipids. The membrane of prokaryotic cell is differing from those of eukaryotic cells by the absence of sterols except Mycoplasma.

Function of cytoplasmic membrane are:

1- Selective permeability and transport of solutes.

2- Electron transport and oxidative phosphorylation, in aerobic species.

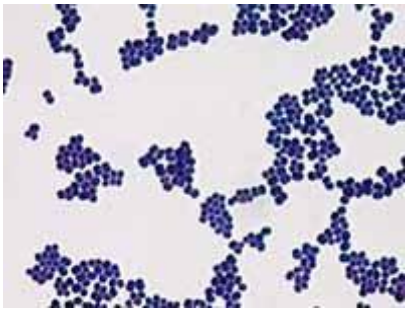
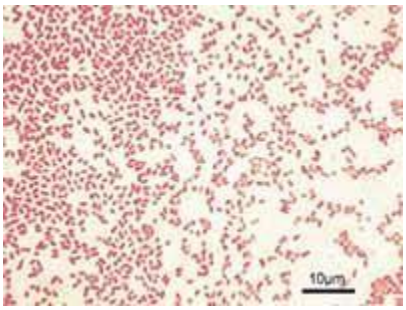
3- Excretion of hydrolytic exoenzymes.

4- Bearing the enzymes and carrier molecules that function in the biosynthesis of DNA, cell wall polymers, and membrane lipids.

5- Bearing the receptors and other proteins of the chemotactic and other sensory transduction systems.

At least 50% of the cytoplasmic membrane must be in the **semifluid state** in order for cell growth to occur.

Differences between Gram positive and Gram negative bacteria

	Characteristics	Gram Positive	Gram Negative
1	**Gram Reaction**	 Retain crystal violet dye and stain blue or purple	 Can be decolorized to accept counterstain (safranin) and stain pink or red
2	**Cell Wall**	Cell Wall is 20-30 nm thick.	Cell Wall is 8-12 nm thick.
3	**Cell Wall**	The wall is Smooth.	The wall is wavy.
4	**Peptidoglycan Layer**	Thick (multilayered)	Thin (single-layered)
5	**Teichoic Acids**	Present in many	Absent
6	**Periplasmic Space**	Absent	Present
7	**Outer Membrane**	Absent	Present
8	**Porins**	Absent	Occurs in Outer Membrane
9	**Lipopolysaccharide (LPS) Content**	Virtually None	High
10	**Lipid and Lipoprotein Content**	Low (acid-fast bacteria have lipids linked to peptidoglycan)	High (because of presence of outer membrane)
11	**Toxin Produced**	Exotoxins	Endotoxins or Exotoxins
12	**Resistance to Drying**	High	Low