Lecture 2 – The Morphology & Fine structure of bacteria

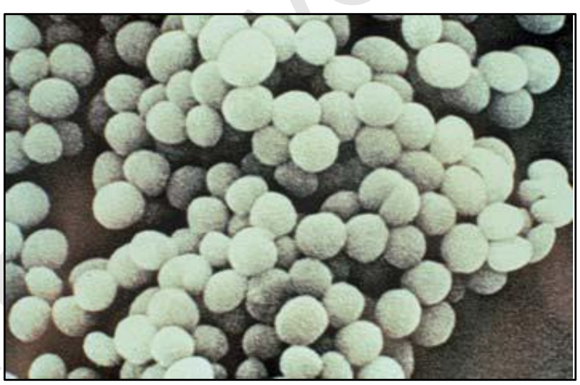
The main characteristics that distinguish prokaryotes from eukaryotes are the following:

1) Eukaryotic cells are generally more complex than prokaryotic cells.
2) DNA is enclosed in a nuclear membrane and is associated with histones and other proteins only in eukaryotes.
3) Organelles are membrane-bound in eukaryotes.
4) Prokaryotes divide by binary fission whereas eukaryotes divide by mitosis.
5) Some structures are absent in prokaryotes: for example, Golgi complex, endoplasmic reticulum, mitochondria, and chloroplasts.

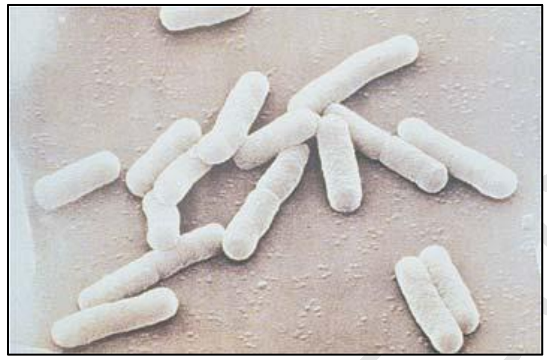
There are more other differences between prokaryotes and eukaryotes you can find them in reference text books.

The Morphology of Bacteria

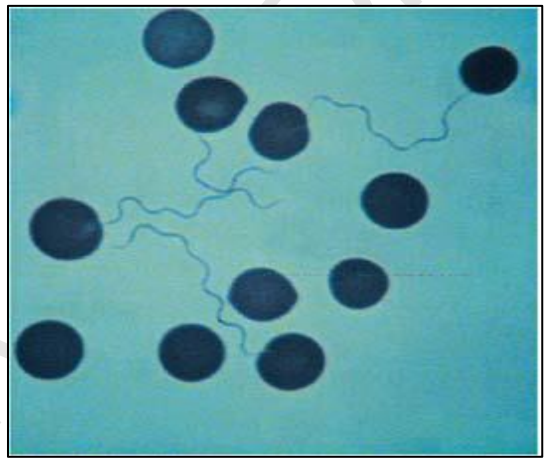
Bacteria differ from other single-cell microorganisms in both their cell structure and size, which varies from 0.3–5 µm. Magnifications of 500–1000X—close to the resolution limits of light microscopy—are required to obtain useful images of bacteria. Another problem is that the structures of objects the size of bacteria offers little visual contrast. Techniques like phase contrast and dark field microscopy, both of which allow for live cell observation, are used to overcome this difficulty. Chemical-staining techniques are also used, but the prepared specimens are dead. Bacteria have three basic forms: cocci, straight rods, and curved or spiral rods.



Cocci are spherical bacteria. Those found in grapelike clusters as in this picture are staphylococci (Scanning electron microscopy (SEM)).



The straight rod bacteria with rounded ends Shown here are coli bacteria (SEM).



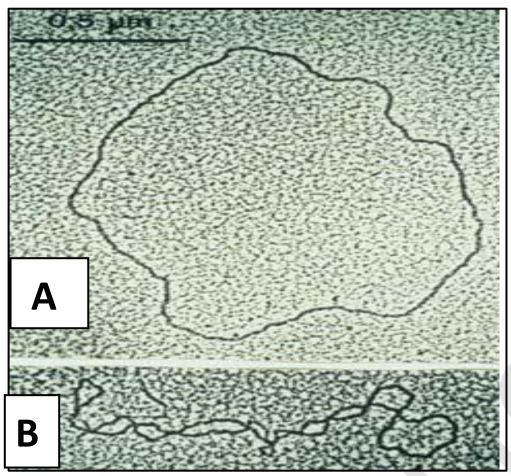
Spirilla, in this case borrelia are spiral bacteria (light microscopy (LM), Giemsa stain).

The Structures of Bacterial cell

The Nucleoid and plasmids

The prokaryote **Nucleoid** (the equivalent of the eukaryotic Nucleus) consists of a very thin, long, circular DNA molecular double strand that is not surrounded by a membrane and localized in the cytoplasm. In *E. coli* (and probably in all bacteria), it takes the form of a single circular molecule of DNA. The genome of *E. coli* comprises 4.63 X10^6 base pairs (bp) that code for 4288 different proteins. The genomic sequence of many bacteria is known. The **plasmids** are nonessential genetic structures. These circular, twisted DNA molecules are 100–1000X smaller than the nucleoid genome structure and reproduce autonomously .The plasmids of human pathogen bacteria often bear important genes determining the phenotype of their cells (resistance genes, virulence genes).

The nucleoid (nucleus equivalent) of bacteria consists of a tangled circular DNA molecule without a nuclear membrane.
Transmission electron microscopy (TEM) image of staphylococci



A) Open circular form (OC). The result of a rupture in one of the two nucleic acid strands. B) Twisted (CCC = covalently closed circular), native form (TEM image).

Cytoplasm

The cytoplasm contains a large number of **solute** (low- and high-molecularweight) **substances**, **RNA** and **ribosomes** (approximately 20 000 per cell). Bacteria have 70S ribosomes comprising 30S and 50S subunits. Bacterial ribosomes function as the organelles for protein synthesis. The cytoplasm is also frequently used to store reserve substances (glycogen depots, polymerized metaphosphates, lipids).

The Cytoplasmic Membrane

This elementary membrane, also known as the **plasma membrane**, is a 40–80 A ˚-thick semipermeable membrane. It is basically a double layer of phospholipids with numerous proteins integrated into its structure. The most important of these membrane proteins are permeases, enzymes for the biosynthesis of the cellwall, transfer proteins for secretion of extracellular proteins, sensor or signal proteins, and respiratory chain enzymes. In electron microscopic images of Gram-positive bacteria, the **mesosomes** appear as structures bound to the membrane. How they function and what role they play remain to be clarified.

Cell Wall

The tasks of the complex bacterial cellwall are to protect the protoplasts from external noxae, to withstand and maintain the osmotic pressure gradient between the cell interior and the extracellular environment (with internal pressures as high as 500–2000 kPa), to give the cell its outer form and to facilitate communication with its surroundings.

- **Peptidoglycan (syn. murein).** The most important structural element of the wall is peptidoglycan, a netlike polymer material surrounding the entire cell (sacculus). It is made up of polysaccharide chains crosslinked by peptides.
- **The cell wall of Gram-positive bacteria .** The murein sacculus may consist of as many as 40 layers (15–80 nm thick) and account for as much as 30% of the dry mass of the cell wall. The membrane lipoteichoic acids are anchored in the cytoplasmic membrane, whereas the cell wall teichoic acids are covalently coupled to the murein. The physiological role of the teichoic acids is not known in detail; possibly they regulate the activity of the autolysins that steer growth and transverse fission processes in the cell.
- **The cell wall of Gram-negative bacteria.** Here, the murein is only about 2 nm thick and contributes up to 10% of the dry cell wall mass. The outer membrane is the salient structural element. It contains numerous proteins (50% by mass) as well as the medically critical lipopolysaccharide.

➢ **Outer membrane proteins**

— **OmpA** (outer membrane protein A) and the murein lipoprotein form a
bond between outer membrane and murein.

— **Porins**, proteins that form pores in the outer membrane, allow passage of hydrophilic, low-molecular-weight substances into the **periplasmic space**.

— **Outer membrane-associated proteins** constitute specific structures that enable bacteria to attach to host cell receptors.

— **A number of Omps are transport proteins.** Examples include the LamB proteins for maltose transport and FepA for transport of the siderophore ferric (Fe3+) enterochelin in *E. coli* .

- <u>**Lipopolysaccharide (LPS)**</u>.
  This molecular complex, also known as **endotoxin**, is comprised of the **lipoid A**, the **core polysaccharide**, and the **O-specific polysaccharide chain**.
  — **Lipoid A** is responsible for the toxic effect.
  — The **O-specific polysaccharide** chain is the so-called **O antigen.**

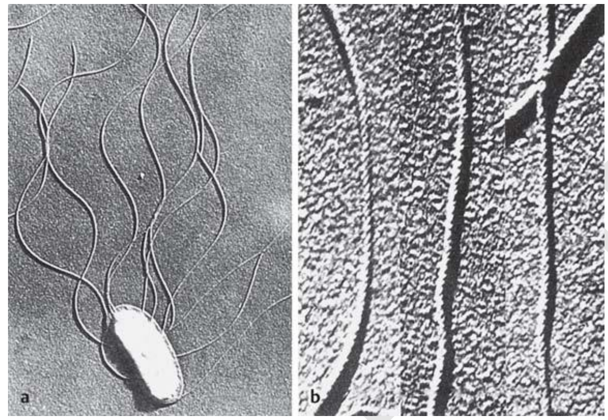
L-forms (L = Lister Institute). The L-forms are bacteria with murein defects, e.g., resulting from the effects of betalactam antibiotics. L-forms are highly unstable when subjected to osmotic influences.

Capsule

Many pathogenic bacteria make use of extracellular enzymes to synthesize a polymer that forms a layer around the cell: the capsule. The capsule protects bacterial cells from phagocytosis. The capsule of most bacteria consists of a polysaccharide. The bacteria of a single species can be classified in different capsular serovars (or serotypes) based on the fine chemical structure of this polysaccharide.

Flagella

Flagella give bacteria the ability to move about actively. The flagella (singular flagellum) are made up of a class of linear proteins called flagellins. Flagellated bacteria display various flagellar arrangements ranging from monotrichous (polar flagellum; e.g., *Vibrio coma*), lophotrichous (bundle of flagella at one end of the cell; e.g., *Spirillum volutans*), to peritrichous (several flagella distributed around the cell; e.g., *Escherichia coli*) .Together with the O antigens, they are used to classify bacteria in serovars.



a Flagellated bacterial cell (SEM, 13 000!). b Helical structure of bacterial flagella (SEM, 77 000X).

Attachment Pili (Fimbriae), Conjugation Pili

Many Gram-negative bacteria possess thin microfibrils made of proteins (0.1–1.5 nm thick, 4–8 nm long), the attachment pili. They are anchored in the outer membrane of the cell wall and extend radially from the surface. Using these structures, bacteria are capable of specific attachment to host cell receptors (ligand—receptor, key—keyhole). The conjugation pili (syn. sex pili) in Gram-negative bacteria are required for the process of conjugation and thus for transfer of conjugative plasmids.

Biofilm

A bacterial biofilm is a structured community of bacterial cells embedded in a self-produced polymer matrix and attached to either an inert surface or living tissue. Such films can develop considerable thickness (mm) . Foreign body infections are caused by bacteria that form a biofilm on inert surfaces. The bacteria located deep within such a biofilm structure are effectively isolated from immune system cells, antibodies, and antibiotics. The polymers they secrete are frequently glycosides, from which the term glycocalyx (glycoside cup) for the matrix is derived.

Bacterial Spores

Bacterial spores (endospores) are purely dormant life forms. Their development from bacterial cells in a “vegetative” state does not involve assimilation of additional external nutrients. They are spherical to oval in shape and are characterized by a thick spore wall & a high level of resistance to chemical & physical noxae. Among human pathogen bacteria, only the genera Clostridium and Bacillus produce spores. The heat resistance of these spores is their most important quality from a medical point of view, since heat sterilization procedures require very high temperatures to kill them effectively.