

Anatomic Structure of Bacteria

External Structures

- Cell Wall
- Capsule
- Flagella
- Fimbria (Pilus)

Internal Structures

- Cytoplasmic membrane
- Mesosom
- Nucleotide
- Ribosome
- Cytoplasmic granules
- Spore
- Others (plasmids, bacteriophages, pigments, transposons, IS elements)

Cell Wall

- It is located outside the cytoplasmic membrane
- Found in all bacteria except *Mycoplasma* spp. and **L-forms**
- **Protoplasts** or **Spheroplasts** are formed when they are removed with different chemicals
- It is not necessary for the bacteria to live
- Bacteria can live without a cell wall in favorable conditions!

Cell Wall Structure in Gram Positive Bacteria

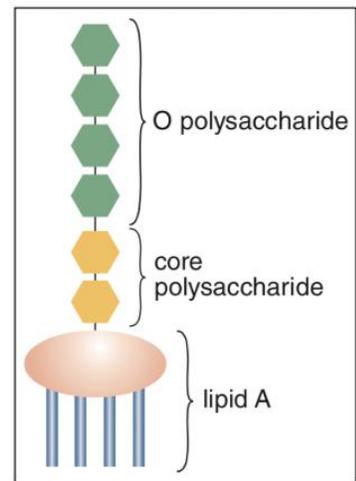
- Peptidoglycan (murein) is **40-90%**
- Peptidoglycan consists of **NAMA** (N-acetylmuramic acid) and **NAGA** (N-acetylglucosamine) molecules joined by **β -1,4-glycoside bonds**.
- NAMA molecules have short tetrapeptide chains (L-alanine, D-glutamic acid, D-lysine, D-alanine)
- Two NAMA molecules are linked by pentapeptide bonds.
- Contains **teichoic** (or teicuronic) and **lipoteichoic acid**
- The structure of teichoic acid contains carbohydrates, choline and D-alanine and **forms the antigenic structure**.
- There are two types of teichoic acid, cell wall and membrane teichoic acid.
- **Protoplasts form when peptidoglycan is removed**

Cell Wall Structure in Gram Negative Bacteria

- **More complex** than Gram-positive bacteria
- The **peptidoglycan layer is thinner (5-10%)**
- No teichoic acid
- Has **porin proteins**
- Outside the peptidoglycan layer there are layers of
 - **outer membrane**
 - **lipoprotein**
 - **lipopolysaccharide (LPS, endotoxin)**
- **Spheroplasts form when peptidoglycan is removed**

Cell Wall Structure in Gram Negative Bacteria

- The **lipopolysaccharide (LPS)** of the outer membrane is a large, complex molecule that contains **lipids** and **carbohydrates** and **consists of three components**: (1) **lipid A**, (2) a **core polysaccharide**, and (3) an **O polysaccharide**.
 - **Lipid A** is the lipid portion of the LPS and is embedded in the top layer of the outer membrane. **When Gram-negative bacteria die, they release lipid A, which functions as an endotoxin.** Lipid A is responsible for the symptoms associated with infections by Gram-negative bacteria, such as **fever, dilation of blood vessels, shock, and blood clotting.**
 - The **core polysaccharide** is attached to lipid A and **contains unusual sugars.** Its role is structural-to **provide stability.**
 - The **O polysaccharide** extends outward from the core polysaccharide and is composed of **sugar molecules.** The O polysaccharide **functions as an antigen** and is **useful for distinguishing serovars of Gram-negative bacteria.** For example, the foodborne pathogen *E. coli* **O157:H7** is distinguished from other serovars by certain laboratory tests that test for these specific antigens. **This role is comparable to that of teichoic acids in Gram-positive cells.**



Cell Wall Structure in *Mycoplasma* & Archea

- Among prokaryotes, certain types of cells have no walls or have very little wall material. These include members of the genus *Mycoplasma* and related organisms.
- Mycoplasmas are the **smallest known bacteria** that can **grow and reproduce outside living host cells**. Because of their size and because **they have no cell walls**, they **pass through most bacterial filters** and were first mistaken for viruses.
- Their plasma membranes are unique among bacteria in having lipids called **sterols**, which are thought to help protect them from lysis.
- Archaea may lack walls or may have unusual walls composed of polysaccharides and proteins but not peptidoglycan.

Cell Wall Structure in Acid-Fast Bacteria

- Acid-fast stain is used to identify all bacteria of the **genus *Mycobacterium*** and pathogenic species of ***Nocardia***.
- These bacteria contain **high concentrations (60%) of a hydrophobic waxy lipid (mycolic acid)** in their cell wall that **prevents the uptake of dyes, including those used in the Gram stain**. The mycolic acid forms a layer outside of a thin layer of peptidoglycan. The mycolic acid and peptidoglycan are held together by a polysaccharide.
- Acid-fast bacteria can be stained with carbolfuchsin, which penetrates bacteria more effectively when heated. The carbolfuchsin penetrates the cell wall, binds to the cytoplasm, and resists removal by washing with acid-alcohol. Acid-fast bacteria retain the red color of carbolfuchsin because it's more soluble in the cell wall's mycolic acid than in the acid-alcohol. If the mycolic acid layer is removed from the cell wall of acid-fast bacteria, they will stain Gram-positive with the Gram stain.

L Forms

- Some members of the **genus *Proteus***, as well as other genera, can lose their cell walls and swell into irregularly shaped cells called **L forms**, named for the **Lister Institute, where they were discovered**.
- They **may form spontaneously** or develop in response to **penicillin** (which inhibits cell wall formation) or **lysozyme** (which removes the cell wall).
- L forms can live and divide repeatedly or return to the walled state.

Duties of Cell Wall in Bacteria

- Protects bacteria from environmental influences
- Gives shape to bacteria
- Provides permeability and osmosis
- Plays a role in bacterial division and spore formation
- It has antigenic properties
- Plays a role in virulence
- Contains receptors in its structure (phage, antibody, bacteriocin)

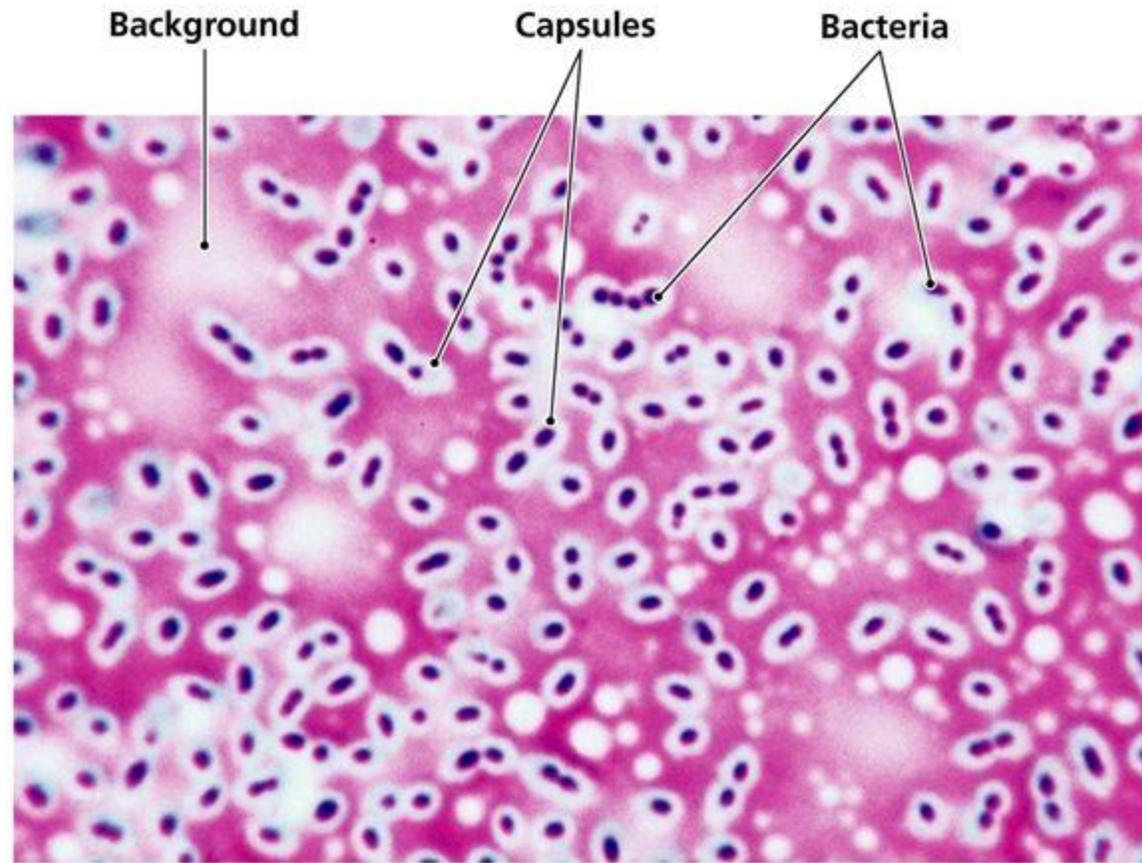
Bacterial Capsule

- It is found in some not all bacteria, outside the cell wall, with a 0.2-10 μm thickness
- It has a gelatinous, elastic, mucoid form
- They can be demonstrated by **Negative Staining** and other special staining methods (**Giemsa, Hiss**).
- Its formation varies depending on environmental conditions.
- Encapsulated bacteria form colonies with "S" and "M" forms on the media.
- Can be encoded by plasmid (*B. anthracis*)

Bacterial Capsule

- Its structure varies according to bacteria
 - Usually **polysaccharide** (such as *S. pyogenes*, *P. multocida*, *C. perfringens*)
 - Having **composed of protein** structure in some bacteria (*B. anthracis*)
 - Composed of **polysaccharide + protein** structure in others (*B. megaterium*)
- Provides bacteria different properties
- Antigenic ("**K**" **antigen**)
- Antiphagocytic
- Increases Virulence
- Provides resistance to environmental conditions

Capsule staining



LM

5 μm

Bacterial Microcapsule

- Structurally identical to the capsule
- Can only be demonstrated serologically
- Masks the **somatic (“O”) antigen**
- Related to the antigenicity (**“K” antigen**) and virulence of bacteria
- Having antigenic structures based on bacteria classification (such as *E. coli* K1,2,.....80)

Bacterial Mucoïd Substance

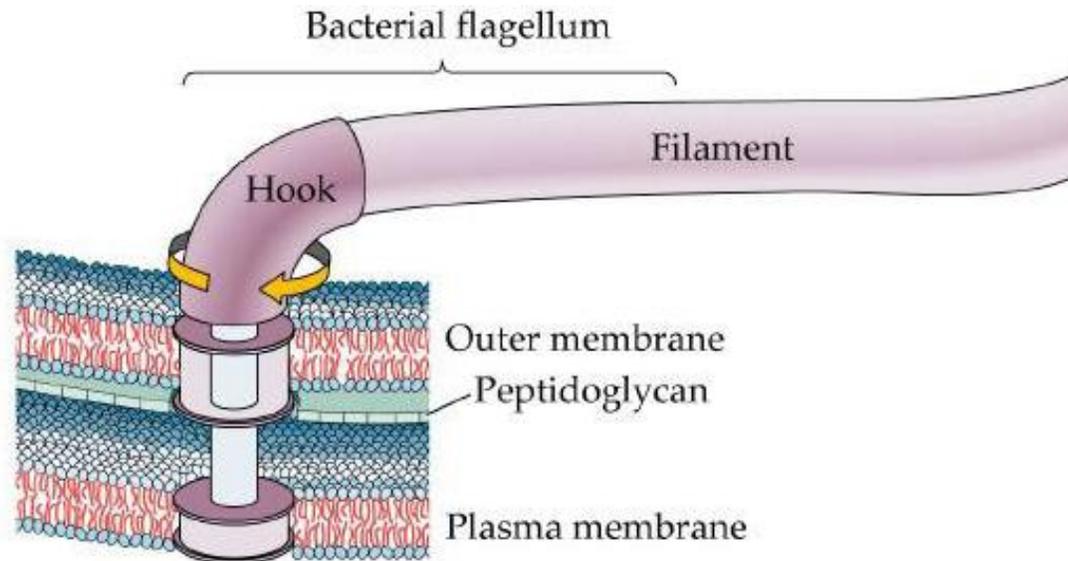
- Found in some of the bacteria (*S. salivarius*, *L. mesenteroides*).
- Capsule-like structure found outside of the cell wall
- It is an unorganized polysaccharide structure form
- Transmissible to liquid broth media
- It has weak antigenicity (hapten)

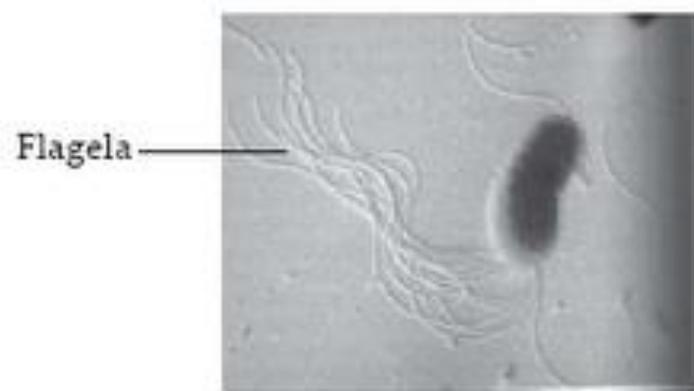
Bacterial Flagella

- **Organel of motility** in bacteria and found in some bacteria
- Longer and thinner than bacteria
- Their location and number differ according to bacteria.
- They can be demonstrated by special staining methods (**Leifson, Kodaka**)
- There are differences in their number and structure depending on environmental conditions.
- It is in protein structure and is called “**flagellin**”
- Flagella have antigenic (“**H**” **antigen**) feature
- The structure of flagella differs in Gram-positive and Gram-negative bacteria.
- Flagella can be removed by mechanical and chemical means.
- Flagella originate from basal granule (blepharoplast)

Structure of Flagella in Bacteria

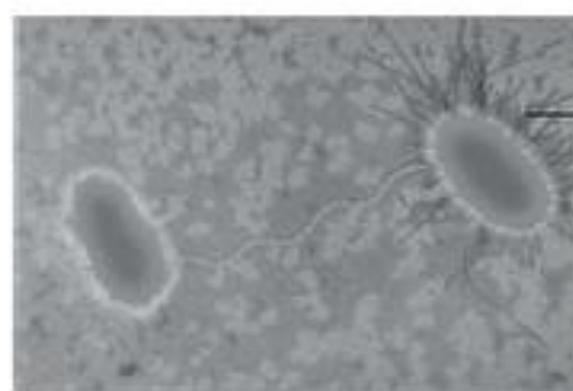
- Flagella is composed of three structural parts
 - Basal body
 - Hook
 - Filament





(a)

(s)



(b)

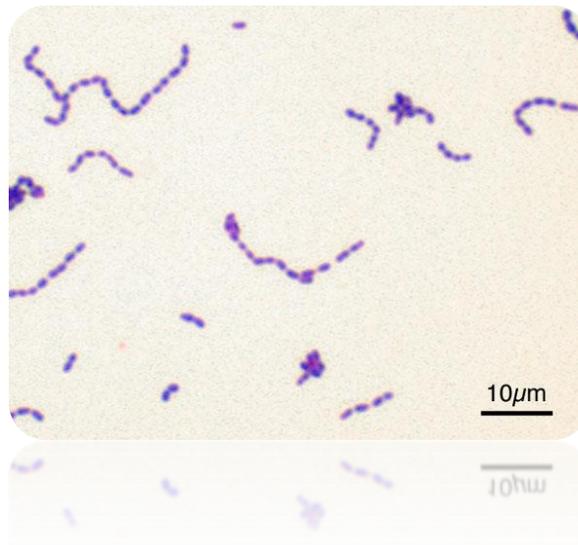
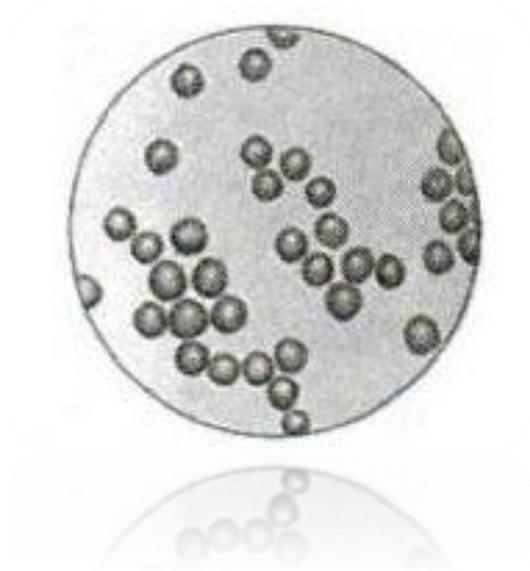
(p)

Location of Flagella in Bacteria

- **Atrichous Flagellum**
- **Monotrichous** (monopolar) Flagellum
- **Polytrichous** (multitrichous) Flagella
 - *Amfitric (bipolar politrichous)*
 - *Lophotrichous (monopolar or bipolar politrichous)*
 - *Peritrichous*
 - *Monolateral*

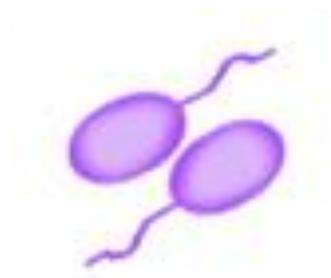
1) Atrichous Flagellum

- **Bacteria lacking Flagella (non-motile bacteria)**
- ***S. Pullorum*, *S. Gallinarum*, *B. anthracis*, *Brucella* spp., *Staphylococcus* spp., *Streptococcus* spp.**



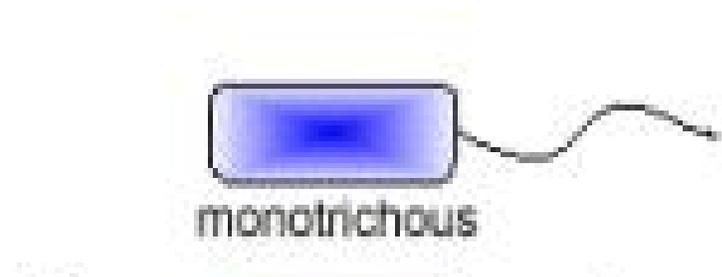
2) Monotrichous (Monopolar) Flagellum

- Single Flagellum located at one end of bacteria (*V. metchnikovii*, *C. fetus*)



Monotrik

Monotrik



monotrichous

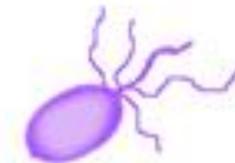
3) Politric (multitrichous) Flagella

1. Amfitrichous (bipolar politrichous)
Vibrio spp., *Spirillum* spp.



2. Lophotrichous (monopolar vey a bipolar politrik)

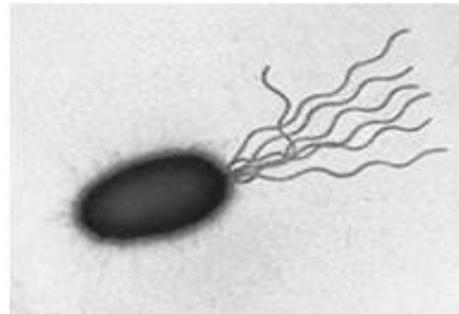
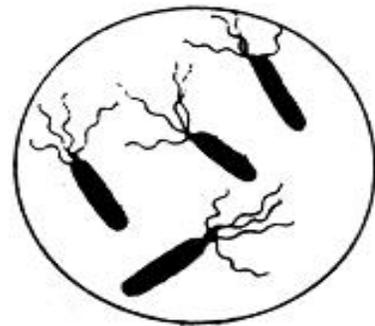
Ex. *P. aeruginosa*



Lopotrik

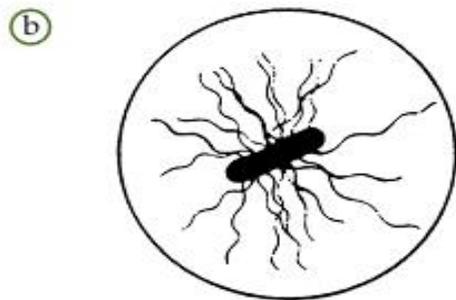
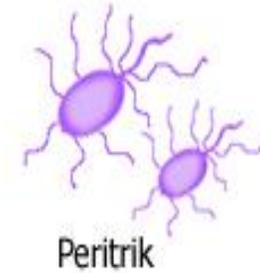
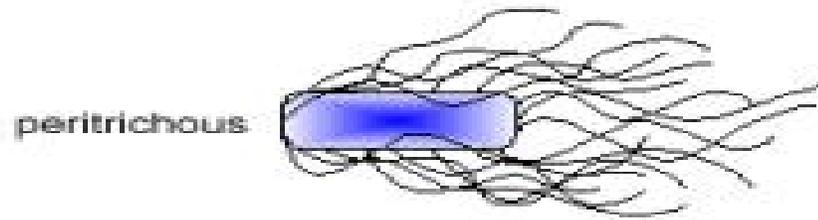
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3. Peritrichous Flagella

- Flagella is located all around the bacteria. Ex.
- *E. coli*, *Salmonella* spp., *Proteus* spp., *Pseudomonas* spp.

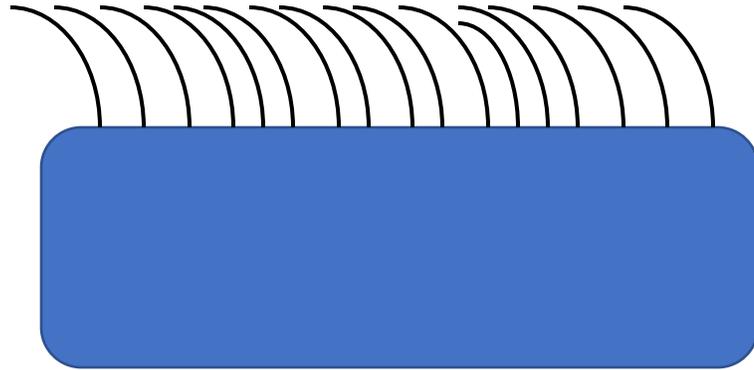


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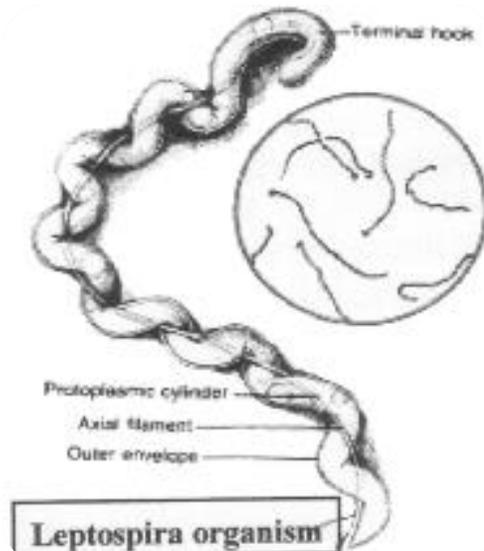
4. Monolateral Flagella

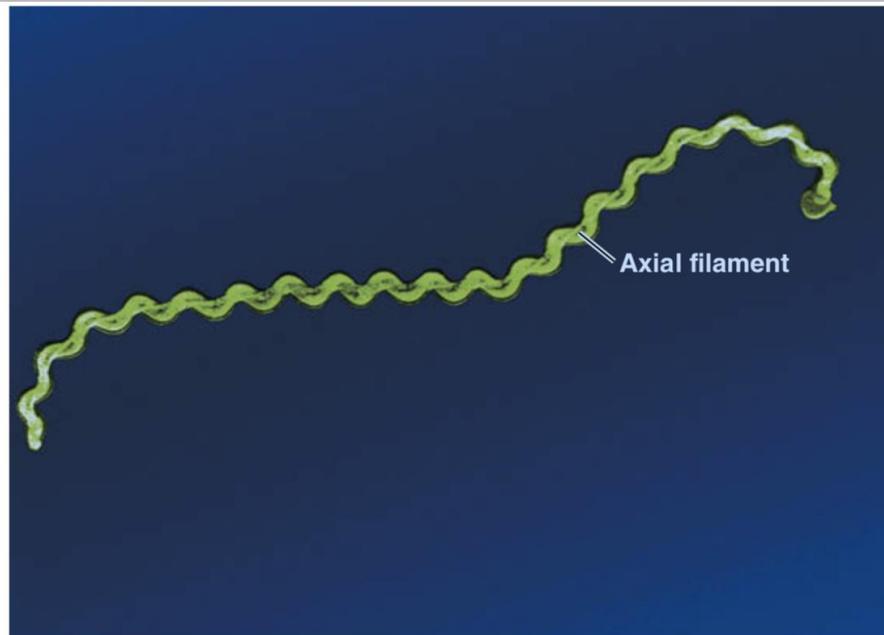
Flagella located on one side of bacteria (*Selenomas ruminantium*)



Axial Filament

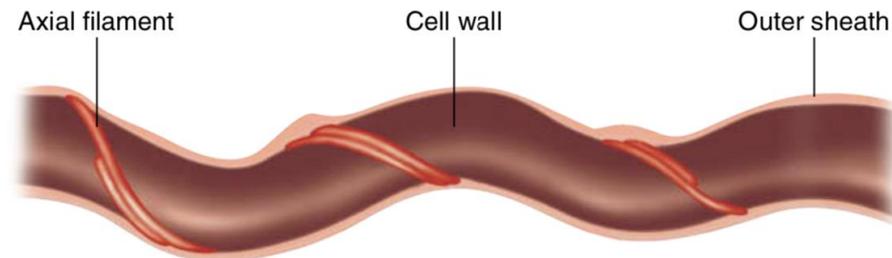
- Found in **Spirocheta** (Spirochetes)
- It is different from flagella and consists of 2-8 filaments and the sheath that surrounds them.
- Located between the outer membrane and the cytoplasmic membrane





(a) A photomicrograph of the spirochete *Leptospira*, showing an axial filament

SEM 5 μm



(b) A diagram of axial filaments wrapping around part of a spirochete

Figure 4.10 Axial filaments.

Bacterial Motility

- Flagella
- Axial filament
- Sliding Movement
- Passive movement (Brownian movement)

Methods for Investigation of Bacterial Motility

- Investigation In-between Slide&Coverslip
- Hanging Drop Method
- Investigation Under Dark Field Microscope
- Motility in Semi-Solid Media
- Flagella Staining
- Investigation Under Electron Microscopy

Bacterial Fimbriae (Pilus/Pili)

- Different from flagella, short, straight, thin and numerous
- Originates from the cytoplasmic membrane
- Can be found in Gram-positive and Gram-negative bacteria
- Can be found in motile and immobile bacteria
- They are not related with bacterial motility
- Environmental conditions are effective in its formation
- The antigens in the protein structure of the pili are called "**pilin**".

Bacterial Fimbriae (Pilus/Pili)

- Fimbriae are divided into **normal** and **sex** fimbriae.
- Sex fimbriae are thicker and longer; they are also called "**F-pilus** or **sex pilus**"
- The middle of the sex pili are hollow in the form of channels and take part in the transfer of genetic material (conjugation) from one bacterium to another.
- There are no channels in the middle of normal pili and they take part in cell adhesion (adhesion).
- Antifimbrial serums and some carbohydrates (mannose) prevent fimbriae from attaching to cells
- Can be encoded by plasmids (***E. coli* K88, K99**)

Function of Fimbriae in Bacteria

- Binding to erythrocytes (**Hemagglutination**)
- Attachment to cells (**Adhesion**)
- Enterotoxigenic *E. coli* (**ETEC**), Uropathogenic *E. coli* (**UPEC**)
- Binding to latex (**Agglutination**)
- Antigenicity
- Virulence
- Conjugation (F-pilus)
- Receptor for some phages

Types of Fimbriae in Bacteria

- **Type-1** agglutinates erythrocytes, mannose sensitive
- **Type-2** does not agglutinate erythrocytes
- **Type-3** agglutinates erythrocytes when treated with tannic acid
- **Type-4** agglutinates erythrocytes, mannose resistant
- **Other**, agglutinates erythrocytes, mannose sensitive

References

1. Quinn PJ, Markey BK, Leonard FC, FitzPatrick ES, & Fanning S (2011). *Veterinary Microbiology and Microbial Disease*. 2nd Ed., Wiley-Blackwell.
2. Tortora GJ, Funke BR, Case CL (2019). *Microbiology, An Introduction*. 13rd Edition, Pearson Education Inc.