

Biofilms

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Biofilms are a group of one or more **types of microorganisms** capable of developing on various surfaces. The microorganisms that can form biofilms include **bacteria, fungi, and protists**. They are held together by sugary molecular strands, collectively termed "**extracellular polymeric substances**," allowing them to develop complex, three-dimensional, attached communities that are resistant to attacks that would destroy individual cells not part of a biofilm colony. They pose a challenge to eradicate and are the cause of many **persistent infections** and **industrial fouling issues**.

About Biofilms

A biofilm is an aggregation of microorganisms such as bacteria, fungi, protozoa etc. that grow on a **surface and are enclosed** in a self-produced extracellular matrix. The biofilm matrix is composed of **extracellular polymeric substances (EPS)** which are secreted by the microorganisms and provide structural integrity and protection. Some key features:

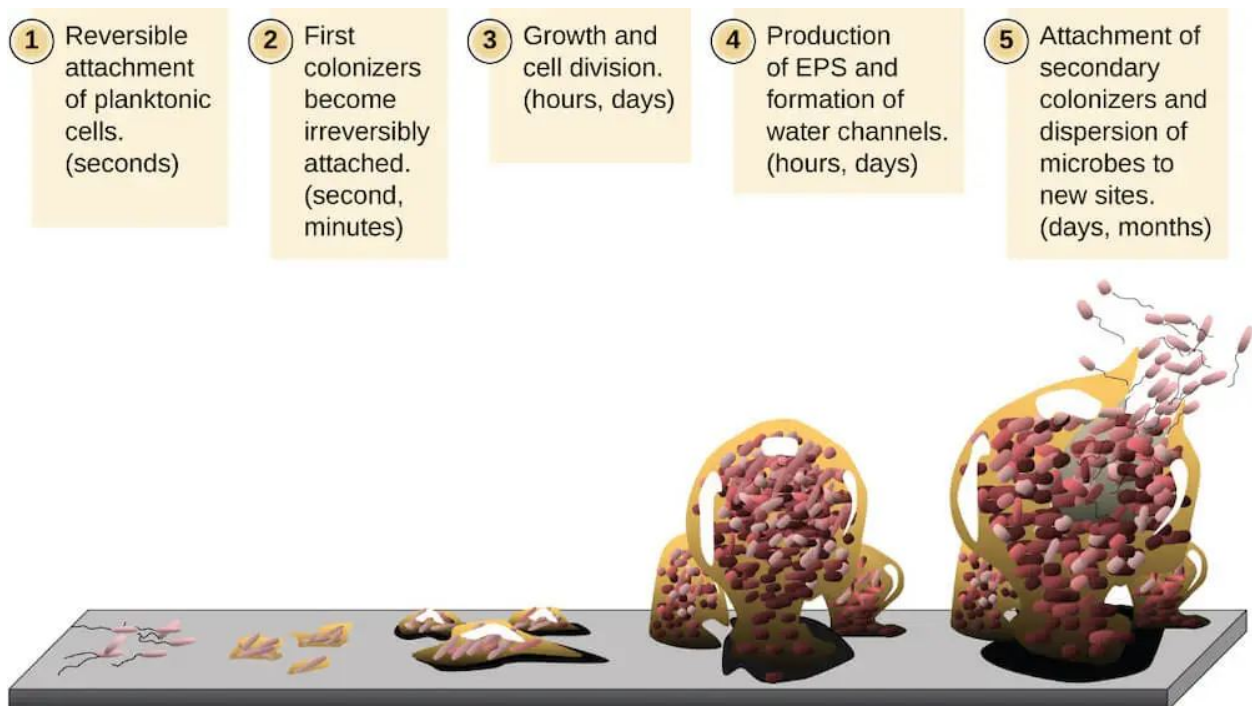
- Biofilms can form on both **biotic** and **abiotic** surfaces.
 - Common surfaces include **teeth, bones, implants**, ship hulls, pipelines, rocks etc.

- Cells are attached to the surface, but also to each other through the **EPS matrix**. This matrix acts like a glue holding the biofilm together.
- The EPS matrix is made up of **polysaccharides, proteins, nucleic acids** and **lipids**.
 - It provides structural stability and protection against environmental stresses.
- They display an altered phenotype compared to their **free-floating or planktonic counterparts**. They show increased resistance to antibiotics, disinfectants and environmental stresses.
- Biofilms can contain **single species or multiple species** living synergistically. The aggregation provides advantages like enhanced access to **nutrients** and **collective resistance mechanisms**.
- Biofilms form through a developmental process involving initial attachment, maturation, dispersal and re-attachment. Cell signalling mechanisms like **quorum sensing regulate** their development.

Biofilm Formation

Its formation occurs through a series of steps that involve complex biochemical signals and interactions between the microorganisms.

- **Initial attachment:** Free-floating microorganisms come into contact with a surface and attach.
- **Irreversible attachment:** The microorganisms begin to produce **extracellular polymeric substances (EPS)** and firmly attach to the surface. The production of EPS makes this attachment irreversible.
- **Early development of biofilm architecture:** The microorganisms multiply and form a layer known as a **microcolony**. The EPS matrix develops further during this stage.
- **Maturation:** It continues to develop **complexity** and **thickness**. Water channels form within the biofilm to allow nutrients and waste to circulate.
- **Dispersion:** Portions of the biofilm disperse to colonise other areas. This can occur due to environmental triggers or when the biofilm reaches a certain stage of maturity.



Functions of Biofilms

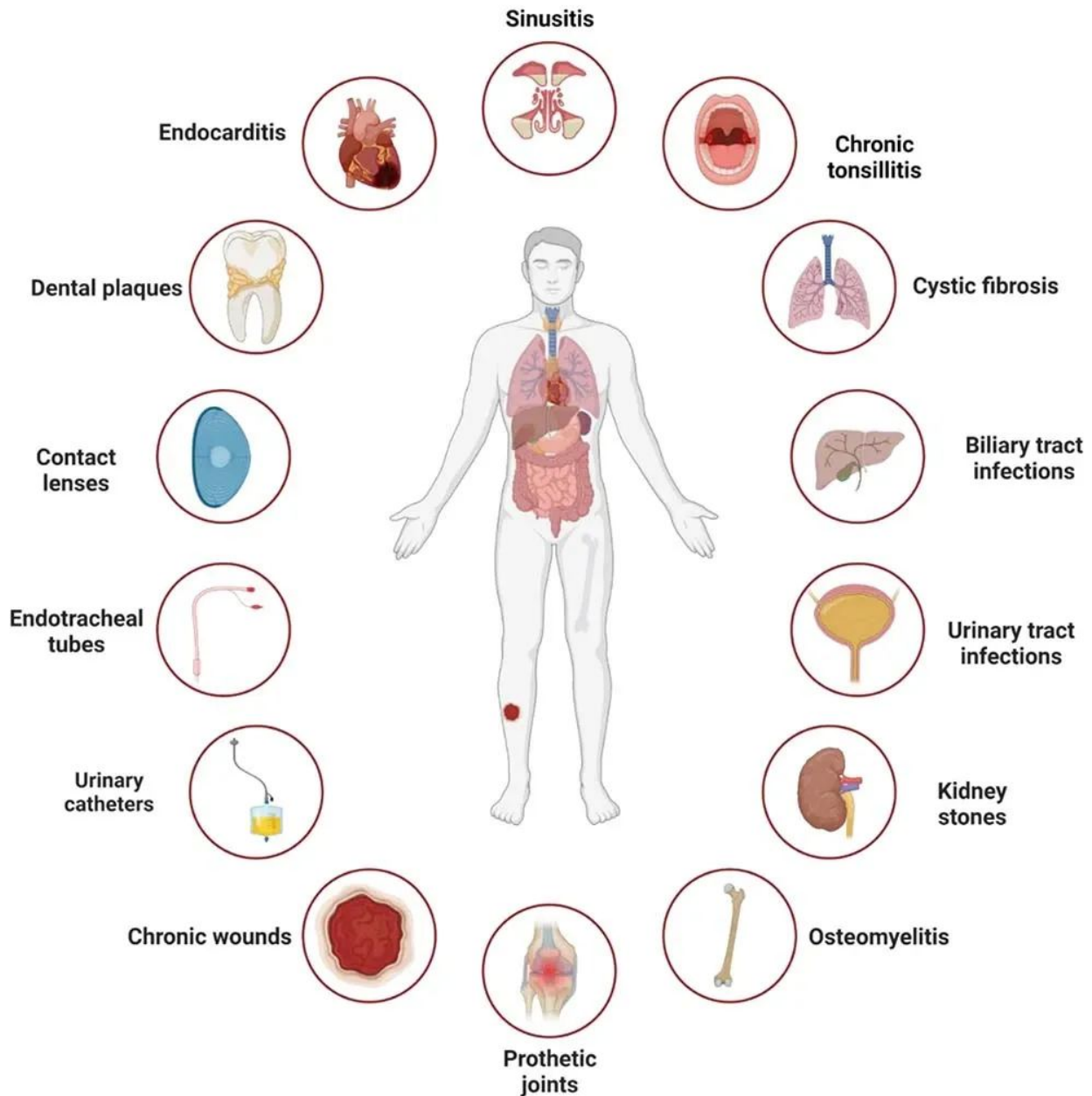
It serves several functions that promote the growth and survival of the microorganisms within them:

- **Protection:** The EPS matrix provides a physical barrier against environmental threats like **desiccation, UV exposure, pH changes, salinity, metal toxicity and predation.**
- **Nutrient access:** The biofilm structure with water channels allows efficient circulation of nutrients to cells deep within the matrix.
- **Cellular communication:** The proximity of the cells within a biofilm allows for ease of cellular communication through signal molecules.
 - This can enhance the survival and growth of the microorganisms.
- **Collective antimicrobial resistance:** It displays up to **1000 times** greater antibiotic resistance than planktonic cells.
 - The EPS matrix limits antibiotic penetration. Also, slow growth in biofilms contributes to resistance.
- **Gene transfer:** High cell density and EPS matrix aids horizontal gene transfer through **plasmids** and **transposons.**
 - This facilitates the acquisition of new traits like **antimicrobial resistance.**

Biofilms in Disease

Many recalcitrant bacterial infections are attributed to biofilms. Its formation is a key virulence factor for many pathogens.

- **Dental plaque:** Plaque is a classic example of a natural **multispecies biofilm.** It is responsible for **dental cavities** and **periodontal disease.**
- **Urinary tract infections (UTI):** The most common cause of catheter-associated UTIs is biofilm formation by **Uropathogens** like ***E. coli*** on the catheter surface. This leads to chronic and resistant infections.
- **Cystic fibrosis pneumonia:** Chronic lung infections due to biofilm formation by *Pseudomonas aeruginosa* and *Burkholderia cepacia* complex are the primary cause of **morbidity** and **mortality** in **cystic fibrosis** patients.
- **Medical device infections:** Biofilms readily form on the surfaces of medical devices like catheters, cardiac implants, contact lenses etc.
 - This can lead to life-threatening infections like **'ESKAPE' pathogens.**
- **Endocarditis:** Biofilms formed by **viridans group** streptococci and *Staphylococcus aureus* on heart valves can cause infective endocarditis.
 - **Chronic inflammation** and **echocardiographic** changes may necessitate valve replacement surgery.
- **Otitis media: Middle ear infections** caused by non-typeable *Haemophilus influenzae* and *Streptococcus pneumoniae* biofilms are persistent and resistant to antibiotics due to poor penetration.
- **Chronic wounds:** Biofilms formed by mixed species including *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *anaerobes* impair the healing of **chronic ulcers** and **diabetic foot infections.** This can lead to **limb amputation.**

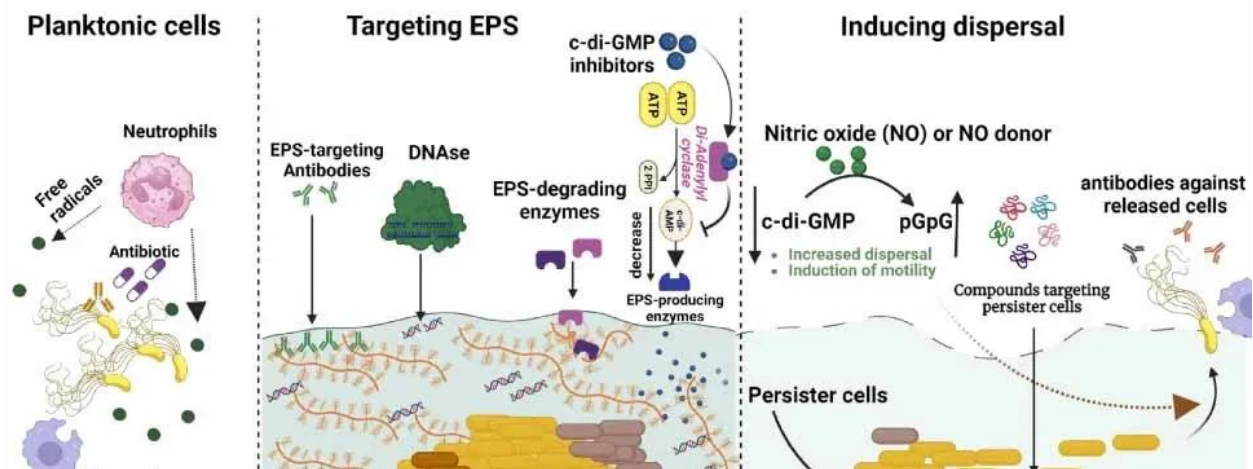


Diagnosis of Biofilms

Diagnosis of biofilm infections is challenging due to the lack of sensitive and specific tests. Some methods include:

- **Microscopy:** This involves the use of microscopes to visually inspect samples for the presence of biofilms.
 - Techniques such as **scanning electron microscopy (SEM)** and **confocal laser scanning microscopy (CLSM)** can provide detailed images of biofilms and allow for the study of their structure.
- **Culture:** These techniques involve growing the microorganisms in a laboratory setting.
 - Quantitative culture showing bacterial counts **>10³-10⁴ CFU/g or mL** from superficial swabs indicates biofilm.
 - However, they are difficult to culture due to slow growth.
- **Molecular techniques:** These techniques involve the analysis of the genetic material of the microorganisms.
 - Polymerase chain reaction (PCR) and other genetic analysis tools can be used to identify the specific types of microorganisms present.

- **Antibiotic susceptibility:** Increased antimicrobial tolerance is suggestive of a biofilm phenotype.
 - Minimum inhibitory concentration determination can differentiate **planktonic** and **biofilm bacteria**.
- **Biofilm reactor models:** Experimental systems like the **Calgary biofilm** device allow the quantification of biofilms on various surfaces and test antibiotic susceptibilities. However, these are not used for clinical diagnosis.



Biofilms in Water Systems

Issue	Control Strategy
Contamination and pathogens	- Disinfectants, UV, anti-fouling coatings
Corrosion and leaks	- Smooth pipe materials, corrosion inhibitors
Flow reduction	- Pigging, flushing, thermal shock
Regrowth prevention	- Alternating disinfectants, silver ionization

Biofilms in Wastewater Treatment

They are an integral part of wastewater treatment systems:

Role	Problem	Control
Degrade organics in filters and reactors	- Sloughing causes clogging	- Mechanical cleaning
Aid flocculation in activated sludge	- Filamentous bulking	- Reduce Food to Micro-organism Ratio (F: M) ratio
Perform membrane biodegradation	- Severe membrane biofouling	- Catalytic cleaners, disinfectant rotation
Produce methane in digesters	- Pipe/tank corrosion	- Aeration, mixing

Biofilms in the Environment

Biofilms play a significant role in the environment. They exist in various natural settings such as lakes, rivers, soil, rocks, aquatic plants, sediments, and wetlands.

- **Water bodies:** It grows on submerged rocks and sediments. They help purify water by metabolising **nutrients, pollutants** and **pathogens**. However, excess growth can clog water pipes and conduits.
- **Soil:** The **rhizosphere** around plant roots is coated with biofilms that protect plants, improve soil structure and promote **mineralisation**.
- **Animals:** **Gut** and **skin microbiome** biofilms in animals promote immunity and inhibit pathogens. Dental/intestinal biofilms also cause disease.
- **Ships: Biofouling** by marine bacteria and algae increases hydrodynamic drag. This reduces speed and fuel efficiency.
 - Antifouling paints contain biocides to kill biofilms.
- **Food industry:** It helps produce fermented foods like **cheese, yogurt** and **vinegar**. But they also cause food spoilage and transmission of foodborne pathogens.
- **Fossil fuels:** Microbial biofilms contribute to **microbial-enhanced oil recovery** by increasing oil detachment and flow.
 - But they also cause corrosion in **oil reservoirs** and **pipelines**.
- **Bio-remediation:** It helps purify contaminated wastewater and soils through biodegradation of pollutants. But can also clog remediation systems.
- **Bio-corrosion: Sulfate-reducing bacteria** biofilms corrode metals like **iron, steel and concrete** by generating **hydrogen sulfide**. This causes structural damage.

Thus, biofilms have diverse impacts on the environment. Careful control is needed to maximise beneficial effects while minimising the detrimental effects of biofilms in different environmental niches.

Source: <https://vajiramandravi.com/upsc-exam/biofilms/>

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