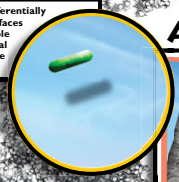
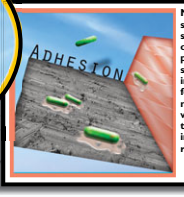
Essential biofilm concepts & phenomena

Adhesion

Bacteria preferentially attach to surfaces when favorable environmental conditions are available.



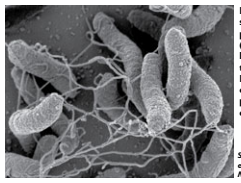


Microbes stick to surfaces. They will stick to plastic, glass, or metal—as well as plant or animal tissues. Adhesion is the initial step of biofilm formation that allows microbes to associate with each other and to establish residence in a particular environment.

The formation and development of a biofilm occurs in a predictable manner. Initially the attachment of a bacterium to a surface is tenuous and reversible. Within a matter of minutes, the bacterium becomes irreversibly attached and begins to secrete the anchoring EPS.

As bacteria begin to multiply, EPS holds cells in close proximity, which is necessary for cell-cell communication. It also allows the formation of three-dimensional structures that give the bacteria increased access to nutrients and the advantages of multicellular living.

Extracellular matrix

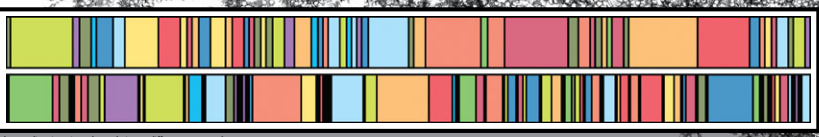


Microbes in a biofilm secrete extracellular polymeric substances (EPS) forming a sticky, hydrated gel that holds the biofilm together. EPS constituents include polysaccharides, proteins, and extracellular DNA.

SEM imaging of cells and extracellular filaments by ME Clark, MSU-CBE

Species diversity

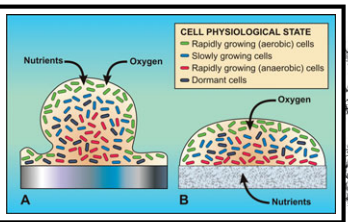
An astonishing diversity of microbial species often coexist in real-world biofilms. Hundreds of phylogenetically and metabolically distinct species have been found in environments ranging from the human mouth (dental plaque) to hot springs in Yellowstone National Park (right).



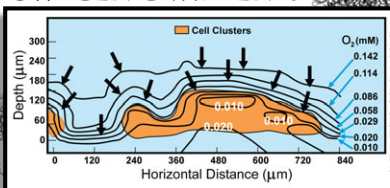
Pyrosequencing and clone library imaging reveal genus diversity using color to designate different genera and bandwidth to indicate representation in the community sampled; data imaging provided by K De León, MSU-CBE

Phenotypic heterogeneity & differentiation

Cells of a given species can occupy a wide variety of phenotypic states in the same biofilm, from rapidly growing to dormant to expressing a unique activity. Mechanisms of diversification include nutrient gradients, mutation and natural selection, and genetic regulatory switches and signaling pathways.



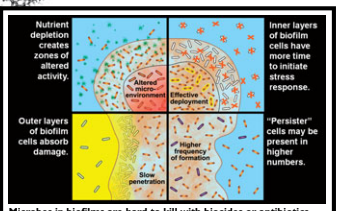
Oxygen gradients



Mature biofilms are criss-crossed by gradients in the concentrations of metabolic substrates and products. Oxygen is the foremost example. Local depletion of oxygen allows anaerobic bacteria to thrive in the depths of a biofilm bathed in aerated water.

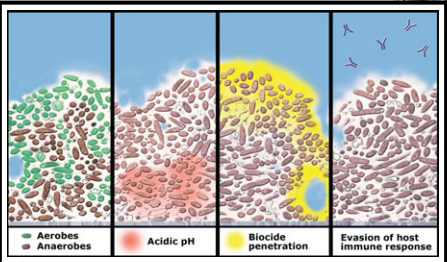
Plot of microsensor-detected gradients of dissolved oxygen in a biofilm: D de Beer, P Stoodley, Z Lewandowski, MSU-CBE

Antimicrobial tolerance



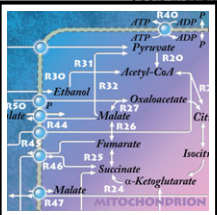
Microbes in biofilms are hard to kill with biocides or antibiotics. Protective mechanisms include poor penetration of reactive agents, non-growing cells whose inactivity makes them less vulnerable, and implementation of adaptive responses.

Diffusion limitation



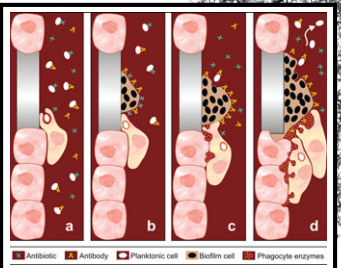
Diffusion is the predominant solute transport process within biofilm cell clusters and is often rate limiting. Many biofilm phenomena (e.g., oxygen gradients, antimicrobial tolerance, species diversity) can be explained in part by reaction-diffusion interactions.

Genetic & biochemical bases



The activities and interactions of microorganisms in biofilms have specific genetic and biochemical bases. Analyses of mutants, gene expression patterns, and quorum sensing pathways linked to conditions of an organism's microenvironment reveal complex spatial and temporal changes in the biological activities of microorganisms in a biofilm.

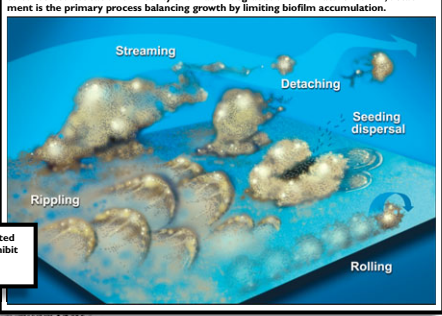
Persistent infection



Biofilms that form on implanted devices or damaged tissue establish slow-moving but difficult to resolve infections. Periodontitis, cystic fibrosis pneumonia, and catheter-associated infections are examples. *See reference #17.*

Detachment & dispersal

The release of biofilm-associated microbes into the fluid surrounding the biofilm is a natural phenomenon. It can occur by multiple pathways, from hydrodynamic shearing to concerted activation of motility and matrix degradation. In a mature biofilm, detachment is the primary process balancing growth by limiting biofilm accumulation.



Viscoelasticity

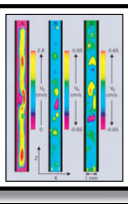
Biofilms stretch, deform, and oscillate when subjected to an applied force, such as flowing water. They exhibit a combination of elastic and viscous behavior that makes them resilient to physical challenges.

Mineral transformations

The metabolic activity and extracellular matrix polymers of a biofilm can facilitate the precipitation or dissolution of a mineral phase. Algal biofilms raise pH and produce CO_2, sometimes resulting in deposition of calcium carbonate. Dental plaque lowers pH, which may result in dental caries.

Calcite crystal stereo microscope image by L Schultz, MSU-CBE

Hydrodynamics



Biofilms interact with the flowing fluid around them. In many industrial and household systems this results in fouling that reduces the performance of piping or equipment (left). Nuclear Magnetic Resonance imaging can help us visualize the interactions of biofilms and water in conduits (right).

Photograph by C Abernathy; NMR imaging by E Gjersing, #23.

MONTANA STATE UNIVERSITY
College of Engineering

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Adhesion

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12. Stewart PS, "Diffusion in biofilms," *J Bacteriol*, 2003; 185(5):1485–1491.

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Biofilm conceptual graphics by P Dirckx, MSU-CBE