Environmental Influences on Biofilm Development

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Abstract Bacterial biofilms are found under diverse environmental conditions, from sheltered and specialized environments found within mammalian hosts to the extremes of biological survival. The process of forming a biofilm and the eventual return of cells to the planktonic state involve the coordination of vast amounts of genetic information. Nevertheless, the prevailing evidence suggests that the overall progression of this cycle within a given species or strain of bacteria responds to environmental conditions via a finite number of key regulatory factors and pathways, which affect enzymatic and structural elements that are needed for biofilm formation and dispersal. Among the conditions that affect biofilm development are temperature, pH, O₂ levels, hydrodynamics, osmolarity, the presence of specific ions, nutrients, and factors derived from the biotic environment. The integration of these influences ultimately determines the pattern of behavior of a given bacterium with respect to biofilm development. This chapter will present examples of how environmental conditions affect biofilm development, most of which come from studies of species that have mammalian hosts.
1 Introduction

In the past decade, substantial advances in the understanding of the genetic and physiological bases of biofilm formation have been made. Dramatic differences in gene expression patterns exist between planktonic and sessile cells, and indeed even between different stages of biofilm development (e.g., Sauer et al. 2003). Nevertheless, the environmental and genetic factors that promote the transition from planktonic to sessile communities are only beginning to be understood in a few model organisms (reviewed by Stanley and Lazazzera 2004). It is clear that different species and even strains of bacteria can exhibit unique patterns of response to the environment. What environmental conditions predispose various species of bacteria to initiate a given biofilm? How are the molecular genetic, biochemical, and structural elements that mediate biofilm development regulated in response to environmental conditions? The following sections describe some of the environmental influences on biofilm development in the context of the molecular genetics and biochemistry of the biofilm development cycle (Fig. 1).

![Fig. 1 A model for biofilm development. Planktonic cells (1) use motility to approach and swim on a surface (2). Upon interacting with the substratum by a pole, cells can become reversibly attached, which may allow for sampling of the environment before committing to a sessile lifestyle (3). Next, cells become laterally attached to the surface, involving adhesins such as PGA or LapA (4). During this time, the attachment of cells begins to create a two-dimensional biofilm, which in E. coli, exhibits distinct periodicity in cellular distribution (5). The biofilm grows in thickness as more cells are incorporated into its structure. Extracellular polysaccharides and other substances are produced, resulting in more firmly attached cells within an extracellular matrix. The architecture of the biofilm may be modified by production of surfactant and release of attached cells (6). In response to environmental or physiological clues, cells may be released from the matrix and return to a planktonic state, thus completing the developmental cycle (7). The entire process of biofilm development is dynamic and is influenced by numerous environmental factors](image-url)