

Marshall K C, Stout R & Mitchell R. Mechanism of the initial events in the sorption of marine bacteria to surfaces. *J. Gen. Microbiol.* 68:337-48, 1971. [Laboratory of Applied Microbiology, Harvard University, Cambridge, MA]

This paper described the process of bacterial adhesion in terms of an instantaneous reversible phase and a time-dependent irreversible phase. The reversible attraction of bacteria to a surface depended on the concentration and valency of the suspending electrolyte, and this phase was interpreted in terms of the balance between electrical double layer repulsion and van der Waals attraction energies. It was indicated that bacteria adhered irreversibly by means of polymer bridging between the cell and the substratum. [The SC® indicates that this paper has been cited in more than 290 publications.]

## Adhesion of Marine Bacteria

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In 1969-1970 when on sabbatical leave from the University of Tasmania, I was invited by my friend Ralph Mitchell at Harvard University to participate in a study of primary film formation on surfaces supported by the Office of Naval Research. I had previous experience in the application of colloid chemistry to bacteria,<sup>1,2</sup> leading Ralph to suggest that I look at possible mechanisms whereby bacteria adhere to surfaces in marine environments. Despite an extensive literature on interactions between bacteria and surfaces,<sup>2</sup> Zobell<sup>3</sup> had been the only person to seriously consider the processes involved and, on the basis of his observations, had suggested that adhesion was a time-dependent process and that extracellular adhesives may be synthesized during the delay period. W. A. Corpe<sup>4</sup> had isolated extracellular polymer from a marine bacterium and found that the isolated polymer enhanced bacterial attachment.

Ruby Stout and I began isolating adhesive marine bacteria and recording their behavior

at a glass-water interface by means of a movie camera mounted on an oil immersion, phase contrast microscope. Over short time periods, nonmotile cells showed obvious Brownian motion, whereas motile cells rotated in various modes and many were able to detach from the surface. Both types of cells could be washed from the surface, and this form of attraction to the surface was termed reversible adhesion. A technique was developed to determine the effects of electrolyte concentration and valency on the attraction or repulsion of nonmotile bacteria to a glass-water interface, and the results were interpreted in terms of the DLVO colloid stability theory with the help of Leonard Weiss and Jim P. Hartos,<sup>5</sup> Roswell Park Memorial Institute, Buffalo, New York.

The time-dependent irreversible adhesion of *Pseudomonas* R3 was stimulated by small amounts of glucose (7mg<sup>-1</sup>), but inhibited by larger amounts of this substrate. Firm adhesion and cell growth were inhibited when the divalent cations, Ca<sup>2+</sup> and Mg<sup>2+</sup>, were eliminated from the suspending medium. These results suggested a role for cell metabolism in the adhesion process and the possibility of divalent cation involvement with extracellular polymers. Electron microscopy revealed the presence of such extracellular polymers and of polymer "footprints" remaining when adherent cells were removed by a shear force. It was postulated that the polymer chains could overcome repulsion effects near the surface and provide a bridge between the cells and the substratum surface. Interestingly, the exact mechanism of polymer bridging to both hydrophilic and hydrophobic surfaces remains to be explained. We also demonstrated that the adhesion of bacteria from natural sources was a selective process. Many bacteria were initially attracted to a surface, but it was mainly small rods that first adhered irreversibly followed by a sequence of other types.<sup>6</sup>

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3. Zobell C E. The effects of solid surfaces upon bacterial activity. *J. Bacteriol.* 46:39-59, 1943. (Cited 310 times since 1945.)
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5. Weiss L. & Harlos J P. Short term interactions between cell surfaces. *Prog. Surf. Sci.* 1:355-405, 1972.
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