

Ellwood D C & Tempest D W. Effects of environment on bacterial wall content and composition. *Advan. Microb. Physiol.* 7:83-117, 1972.
[Microbiological Research Establishment, Porton, Salisbury, Wiltshire, England]

Gram-positive bacteria when grown in Mg^{2+} -limited media contained the maximum amount of teichoic acid in their bacterial walls. However, when grown under PO_4^{3-} -limited conditions, teichoic acid was absent and teichuronic acid was found. The kinetics of the change showed that wall turnover had occurred. [The SCI® indicates that this paper has been cited in over 155 publications.]

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The Microbiological Research Establishment at Porton Down—and more particularly its Biochemistry Section led by Denis Herbert—was an exciting place in which to work in the later 1960s and early 1970s. Encouraged, as we then were, to pursue fundamental microbiological research, and freed from the constraints of funding agencies and their "peer review" procedures, we could unashamedly engage in "blue skies" research. Those were indeed halcyon days, fondly remembered but, I fear, gone forever!

At that time, Dave Tempest was engaged in quantifying and correlating the cellular contents of cations (K^+ and Mg^{2+}) and anions (principally PO_4^{3-}) in bacteria and had observed a marked difference between Gram-positive and Gram-negative bacteria in their requirements for K^+ and PO_4^{3-} . Assuming that the additional phosphate present in Gram-positive bacteria was polyphosphate, he grew these organisms in a phosphate-limited chemostat culture and was rather disappointed to find that, whereas the cellular phosphate content decreased markedly (to a value similar to that found in Gram-negative bacteria), the cellular K^+ content remained high.

At the same time, I was studying the surface structures of bacterial cells, and it was clear to me that the additional phosphate present in Gram-positive bacteria, as compared with Gram-negative organisms, was most probably due to teichoic acid and not to polyphosphate. But if this was the case, then it was equally apparent that organisms growing in phosphate-limited chemostat culture must have walls that were either devoid of teichoic acid or else possessed grossly diminished amounts of this polymer.

This was a lead that obviously was worth following, and it was soon established that, whereas *Bacillus subtilis* var. *niger* (a representative Gram-positive bacillus) had walls that were rich in teichoic acid when grown under a variety of conditions, this polymer could not be detected in the walls of organisms grown in phosphate-limited chemostat culture. Bearing in mind the fact that teichoic acid is an integral part of the wall structure, this was a most surprising finding, but equally surprising was the additional observation that teichoic acid had been replaced quantitatively by another anionic polymer that lacked phosphate. This alternative polymer was isolated and shown to be teichuronic acid—a compound that was known to be present in variable amounts in the walls of bacilli.

Kinetic studies of organisms growing in chemostat culture soon revealed that this dramatic change in wall composition was a phenotypic response and was not due to mutant selection. Indeed, the rapidity with which wall composition changed following a switch from magnesium-limited growth conditions to conditions of phosphate limitation, and *vice versa*, indicated a high rate of wall turnover in the growing cells. Thus, the idea of the bacterial wall acting as a dynamic organelle was born. However, times were changing, and, because we were not in a position to mount a major attack on the physiology of microbial surface structures, we decided to write a general review article in *Advances in Microbial Physiology* as a means of indicating the breadth and potential of this field of study. This review was written to bring together all the results we obtained when the effects of changing growth conditions on bacterial surfaces were first examined. Thus, it is a useful start point for subsequent work in this area.

[For more recent reviews, see references 1, 2, and 3.]

1. Archibald A R. Phage-receptors in Gram-positive bacteria. (Randall L L & Philipson L, eds.) *Virus receptors. Volume 1. Bacterial viruses*. London: Chapman and Hall, 1980.
2. Tempest D W, Neijssel O M & Zevenboom W. Properties and performance of microorganisms in laboratory culture; their relevance to growth in natural ecosystems. (Slater J H, Whittenbury R & Wimpenny J W T, eds.) *Microbes in their natural environments*. Cambridge, England: Cambridge University Press, 1983. p. 119-52.
3. Robinson A, Gorringe A R & Keevil C W. Expression of virulence determinants in *Bordetella pertussis* and *Neisseria gonorrhoeae*. (Dean A C R, Ellwood D C & Evans C G T, eds.) *Continuous culture 8: biotechnology, medicine and the environment*. Chichester: Ellis Horwood, 1984. p. 22-37.