Title : Simulating biofilm detachment effectively using the Immersed Boundary(IB) method

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Bacterial biofilms are microbes growing on wetted interfaces in aqueous environments. They form when the planktonic bacterial cells in the overlying fluid attach themselves to the surface and start producing an extracellular polymeric substance (EPS) inside which the growing bacteria cells remain embedded. The EPS network has been shown to provide mechanical and chemical protection to the cells growing within the biofilm from the physio-chemical conditions (PH, temperature, fluid flow -creeping to turbulent flow, antibiotics) present outside in the overlying fluid. Mathematical modeling of growth of bacteria cells inside the biofilm and their removal (detachment) is a growing area of research motivated by the contrasting roles biofilms play in different applications; as useful agents in waste water treatment, and as an hindrance in health and food processing environments. Simulating flow induced deformation and detachment (cells breaking away when the EPS network is mechanically broken) of biofilms effectively and efficiently is vital to understand their mechanical stability. In healthcare settings, detachment of cells from the biofilm before being treated by antibiotics can spread the biofilm related infection when these cells reattach elsewhere, while in waste water reactor, the excessive detachment can cause washout of the biofilm from the reactor affecting its performance.

In our work, we have used an Immersed Boundary (IB) method originally developed by Peskin to study flow-induced deformation and detachment of a biofilm colony. We represent the biofilm continuum by a network of Hookean springs and initiate detachment when the strain along a spring exceeds a critical value. This treatment although straightforward to implement inside a simulation code is ad hoc as the strain along a spring is not a true measure of strain in the continuum. Moreover, no clear guideline is available on how to choose this critical spring strain parameter to match a given set of measured biofilm mechanical properties. In our work, we introduced an effective and novel detachment criterion which is based on the concept of an averaged equivalent continuum stress tensor defined at each IB point in the biofilm which is then used to determine a corresponding von Mises yield stress; wherever this yield stress exceeds a given critical threshold the connections to that node are severed, thereby signalling the onset of a detachment event. Our detachment strategy based on equivalent continuum stresses provides a unified and consistent IB framework that handles both sloughing and erosion modes of biofilm detachment, and is consistent with strategies employed in many other continuum based biofilm models.