Dynamics and upscaling of porous biofilms with heterogeneous rheology

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Résumé

Our focus lies on operational applications and novel numerical approaches for modeling the heterogeneous mucus biofilm in the human lungs, specifically for monitoring cystic fibrosis (CF) therapies. At an operational level, our goal is to predict the impact of a therapy on mucociliary clearance, which refers to the functional ability of respiratory mucus to move along with the surrounding cells. Conversely, non-functional mucus fails to sufficiently clear the lung wall of allergens, toxins, viruses, bacteria, and their byproducts such as DNA filaments and altered mucoïd elements.
In this biological configuration, the mucus itself acts as a porous medium composed of Newtonian periciliary fluid (PCL) and highly concentrated mucins produced by goblet cells. The interaction between mucins and PCL, facilitated by their motion within the biofilm, results in the formation of a polymerized mucus with distinct rheological properties. Among various rheological features like viscoelasticity, viscoplasticity, yield stress, and shear-thinning, we specifically focus on the latter, as it has been identified as the primary characteristic leading to non-functional mucus (4,5).

The results presented here are twofold. Firstly, we present the modeling based on the superficial velocity formulation, that we approximate numerically by a well-chosen coupling between particle methods (2), PSE schemes (1) and Stokeslets methods. The keypoint is the connexion between the equations governing the biofilm and the reactive flows involved in Digital rock Physics (DRP), as described in (3). Secondly, we use this efficient numerical method for the upscaling of the diffusion in the biofilm: the upscaled tortuosity index is practically quantified (which defines the relationship between the effective diffusion and the molecular diffusion of chemical species with respect to the local porosity). Finally, we show that these numerical results are compatible with clinical resume of the patients whose sputum rheology has been characterized (5).

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*Intervenant

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