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Cell-scale haemodynamics and transport in canonical disordered porous media: numerical simulation and microfluidic experiments

Monday, 31 May 2021 10:25 (15 minutes)

Key words: porous media, haemodynamics, heterogeneity, modelling, microfluidics

Introduction
While extensive research has been devoted to fluid flows through porous media with comprehensive theories established ranging from pore-scale to field-scale (single-phase or multiphase, inertial or non-inertial, Newtonian or non-Newtonian, Darcy or non-Darcy), the underlying mechanisms for the flow and transport of blood and nutrients in biological organs/tissues such as the highly porous human placenta are still unclear [1]. As the size of flow channels within these systems becomes comparable with that of a red blood cell (RBC, about 8 μm in diameter), the particulate character of blood gives rise to complex nonlinearity by introducing spatiotemporal heterogeneities that require microscopic interrogation. In this work, we aim to characterise the microscopic blood flow within canonical porous media consisting of disordered pillar arrays. Both flow simulations at the microscale and corroborating experiments in a microfluidic analogue will be presented.

Methods
The porous media models are constructed by introducing different levels of disorder to regular obstacle arrays arranged on a square grid. Using the lattice Boltzmann and immersed boundary methods [2, 3], we simulate blood flow through the disordered geometry as a suspension of deformable RBCs in plasma. The volume fraction of RBCs (known as haematocrit) simulated is in the range of 20%-30%. In parallel with the numerical model, a microfluidic analogue with equivalent conditions (e.g. confinement ratio and capillary number) is designed and fabricated, in which flow experiments are performed with monodisperse capsules (about 250 μm in diameter) that imitate the properties of RBCs.

Results
Our results show an intricate interplay of structural disorder, rheological uncertainty, and time-dependent effects on the localisation of RBCs within a porous medium, which is highly heterogeneous presenting preferential paths subject to the "channelling effect"[4, 5] as well as emerging cell occlusion. We report for the first time the effect of incremental disorder within the porous media on the overall hydrodynamic resistance of the cellular blood flowing through, which markedly increases as the level of disorder introduced into the system, whereas in the Newtonian counterpart (for which only plasma is infused) a larger degree of disorder has a much weaker effect.

Discussion
The role of RBCs in the intervillous space within the human placenta is multifold. On the one hand, the RBCs facilitate the transport of oxygen, CO2 and other solutes. On the other hand, RBCs'localisation can significantly affect the flow patterns in the porous media, which are not well-captured by Darcy's law. Thus, more generalised constitutive relationships need to be derived based on cross-validation of simulations and experiments to bridge microscopic characterisation and organ-level modelling.

Time Block Preference

Time Block B (14:00-17:00 CET)

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