Patient-Specific Multicompartment Darcy Flow Model: Effect of Heterogeneity and Anisotropy in Porous Parameters

Namshad Thekkethil, Hao Gao, Nicholas A. Hill, Xiaoyu Luo
University of Glasgow, School of Mathematics and Statistics

Abstract:
Myocardial perfusion plays a crucial role in cardiac function, and disruptions in blood flow can contribute to severe cardiovascular diseases. However, modelling perfusion with sufficient physiological detail remains challenging, as traditional homogeneous approaches fail to capture the complex heterogeneity of vascular networks. In this study, we present a novel computational framework for modelling myocardial perfusion using a multi-compartment poroelastic Darcy flow model. This approach incorporates anisotropic and heterogeneous perfusion parameters derived from realistic vascular data.
Through numerical simulations, we compare our proposed framework to conventional homogeneous models and validate it against Poiseuille flow results. Our findings highlight that the heterogeneous anisotropic model significantly improves the accuracy of pore pressure predictions, particularly in capturing spatial variations in permeability from large vessels to microvessels. Additionally, we investigate the impact of compartmentalisation on model accuracy, demonstrating that a three-compartment structure optimally balances computational efficiency and physiological realism.
The model's ability to simulate patient-specific conditions, such as vessel occlusions, further underscores its potential for clinical applications. Our results indicate that under pathological conditions, the discrepancy between homogeneous and heterogeneous models becomes more pronounced, emphasizing the need for detailed vascular reparametrisation in perfusion simulations.
This work represents an advancement in computational modelling for myocardial perfusion, bridging the gap between traditional porous media approaches and high-resolution vascular data. Future extensions of this framework will incorporate unsteady effects, wave dynamics, and external forces to further enhance its applicability in patient-specific simulations.