CONTRAST AGENT TRANSPORT IN A POROELASTIC MODEL OF MYOCARDIAL PERFUSION

Tao Zhang (1), Katharine Fraser (1), Harinderjit Gill (1), Andrew Cookson(1)

1. Dept. of Mechanical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, UK

Introduction

With more than 80,000 deaths per year due to coronary heart disease in the UK and an associated cost of treatment estimated at £1.8 billion [1]. One promising technique for the early diagnosis of coronary disease is contrast enhanced magnetic resonance (MR) perfusion imaging. In this diagnostic approach a contrast agent (CA), typically gadolinium-based, is injected into the patient and MR images measure its progress through the coronary circulation. This CA transport distinguishes between the areas of myocardial tissue receiving blood and those which are not. In this study we introduce a novel computational model of MR coronary perfusion imaging to provide a platform for optimising this imaging technique across a range of imaging and physiological parameters.

Methods

Darcy's law along with the continuity equation is derived to describe the blood flow in a poroelastic medium. And these equations are coupled with the poroelastic equation which characterising the deformation of myocardium. Its constitutive law is hyperelastic and taken into account three factors: the elastic behaviour of the skeleton, the change in free energy due to the incoming fluid and a barrier preventing the fluid porosity from becoming negative. Moreover, the transport of a freely diffusive CA is characterised through advection-diffusion equation. Finally, an Arbitrary Lagrangian Eulerian (ALE) formulation is applied to the resulting coupled system of reaction-advection-diffusion equations in this deforming poroelastic medium. The system of equations is solved by the Finite Element Method (FEM), implemented in FEniCS. An iterative approach is used to loop through the deformation of myocardium and blood flow rate until converged. Due to the large computational cost, HPC cluster is used.

Results

The schematic graph illustrates the configuration in Figure 1. A geometrically simplified cuboid model characterises coronary flow and cardiac mechanics. The coronary vessels are represented by three source terms of Gaussian functions. The middle source term can be removed to simulate the effect of a severe coronary stenosis. The drainage of blood fluid out of the capillaries and into the venous system is represented as a uniformly-distributed pressure-dependent sink term such that the term is only active when the pore pressure is greater than the venous pressure. Assuming the body force and acceleration of the solid is zero and the boundary condition on the left side is set to zero displacement in longitudinal x direction. A sample point near the middle source is chosen to illustrate the CA transport. When the middle term is switched on, the concentration goes up quickly and then it is washed out into venous sink term and gradually diffuses into tissue. While the middle term is off, the concentration increases slowly (See Figure 2).

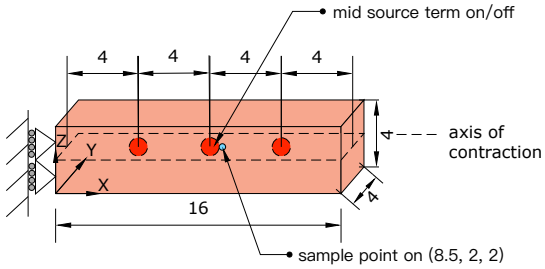

Figure 1: Schematic showing the arrangement of three source terms evenly placed in the longitudinal direction of a poroelastic cuboid. The middle source term can be turned off to simulate the effect of a severe coronary stenosis.

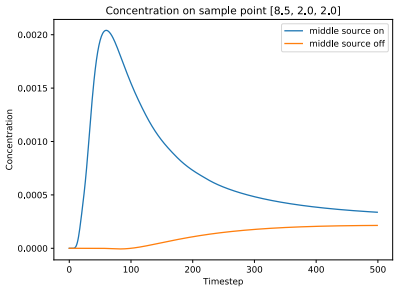

Figure 2. Concentration plot on the sample point (8.5,2.0,2.0) when the middle source term is turn on/off.

Discussion

The results demonstrate that the transport of CA in myocardial perfusion can be modelled by using poromechanics theory coupled with advection-diffusion equation in Lagrangian frame. The effect of a severe coronary stenosis can be simulated. The model will be developed for application to realistic ventricular geometries in the future.

References

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