Simula SSCP Project 5: Mechanisms of tissue perfusion under strain

May 27, 2019

Team: Henry Chukwuemeke Afambu, Leila Meyer-Hilberg, Evandro Dias Gaio
Advisors: Alexandra Diem, Alban Souche

1 Project Summary

Adequate functioning of the heart crucially relies on blood supply from the coronary vasculature to the myocardial tissue via perfusion and building computational models of perfusion can help shed light onto the effects of pathological conditions, such as the infarction of tissue. Building a computational model of cardiac perfusion gives rise to a number of challenges: Whilst the human heart is about the size of a human fist, the thousands of supplying blood vessels have diameters ranging from 10 um to 1 mm. Thus, we cannot reasonably build an accurate geometry of all perfusing blood vessels. To overcome this challenge we will use a continuum modelling, by which perfused tissue is represented as a continuous poroelastic material.

The goal of the project is to use poroelastic modelling in FEniCS to gain insights into the dynamics of tissue perfusion under strain. We will use an existing open-source implementation of a poroelastic model to build a model of cardiac perfusion in the left ventricle and validate the model using data from the literature. Finally, we will investigate the effects of pathological conditions such as infarction on myocardial blood flow patterns, or study the distribution of tracers through the tissue using a particle-tracking based method. The students will gain an understanding of using continuum modelling as a means to overcome challenges in building whole-organ simulations. The students will learn how to use the finite element method to build their model, and how to draw clinical conclusions and identify their limitations.

2 Main Objectives

Mesh generation from simple 2D geometries to more complex 2D/3D models, using Gmsh. Mathematical formulation and implementation of poroelasticity and advection-diffusion processes in FEniCS, using pre-developed code examples. Building a relevant model setup with physiological parameters from published scientific work. Numerical and physiological model validation. Drawing clinical conclusions using computational modelling and identifying its limitations.

3 Tasks

1. Generate a finite element mesh from a provided left ventricle geometry, using Gmsh.
2. Build a model of heart tissue perfusion using a poroelasticity code pacakge implemented in FEniCS.
3. Validate the model using data from the literature and describe normal flow dynamics of cardiac perfusion.
4. Choice of: a. Investigate the impact of pathologies (e.g. infarction) on flow patterns. b. Study tracer distributions through the tissue using a particle-tracking based method.

4 Recommended Pre-Reading

1. Chapelle D, et al. (2010) A poroelastic model valid in large strains with applications to perfusion in cardiac modeling. Computational Mechanics 46 (1): 91-101.

2. Cookson A, et al. (2012) A novel porous mechanical framework for modelling the interaction between coronary perfusion and myocardial mechanics. Journal of Biomechanics 45 (5): 850-855.

3. Lee J, et al (2015) Multiscale Modelling of Cardiac Perfusion in Modelling the Heart and the Circulatory System. Edited by Quarteroni A, Springer (Cham).