A Multiphysics Approach to Modeling Early Atherosclerosis Progression

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ABSTRACT

The analysis of couple problems such as fluid-structure interaction (FSI) and coupled convection-diffusion-reaction equations are a field of intensive studies and can be utilized to model and study hemodynamics, cardiovascular mechanics and disease progression such as atherosclerosis. In this context, the challenge is the coupling of an incompressible flow with a deformable structure undergoing large deformations, where in the scalar transport the migration of key species into the structure is of special interest. Migrated species react and constitute mechanobiological remodelling, change of material behaviour and finally the development of a stenosis. The underlying bio-chemical and mechanical connections in atherosclerosis are not yet fully understood and hence addressed in an interdisciplinary research project.

In this contribution, we present a sequentially staggered FSI-convection-diffusion-reaction model approach coupling a monolithic FSI solver with a monolithically coupled set of convection-diffusion-reaction equations [1, 2]. Since the influence of the scalar fields to the FSI mechanics problem is assumed to be on a very large time scale, the overall coupled system is sufficiently addresses by a sequentially staggered scheme. The two scalar fields reside in the fluid and structure domains, where the scalar field on the fluid domain is transported with the fluid flow and the other is diffusive and bio-chemical reactive. Their interface is modelled as a semi-permeable membrane where the transport is diffusion driven. The permeability of the membrane therein is shear stress dependent and allows for strong regional differences in permeability of scalars through the interface. A resulting reactant in the structure domain scalar field finally influences mechanical properties of the structure and induces a slowly advancing volumetric growth [3] and remodelling [4], leading to a narrowing of the fluid domain and hence to a change of the fluid flow and formation of a stenosis.

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