Mixed method vs. NURBS based continuity: two finite element approaches for Darcy and Darcy-Brinkman flow in deformable porous media including multi-scalar convection-diffusion-reaction processes

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ABSTRACT

Classical porous media are subjected to small deformations and may therefore be characterized by constant porosities. This no longer holds for applications involving large deformations since the porosity becomes non-homogeneous due to the deformation or due to flow and pore pressure. This significantly changes the mathematical description and computational treatment of the problem. In this work, we analyze the effect of porosity gradients on the finite element formulation for Darcy and Darcy-Brinkman flow in saturated two-phase porous media. We present two finite element approaches fulfilling the numerical requirements for convergence. The first approach is based on NURBS shape functions allowing higher derivatives in the weak form. The second comprises a mixed formulation with the porosity as primary solution field. Numerical examples illustrate the large potential of our methods for the analysis of porous-flow-structure-interaction with large deformations.

We additionally developed a model for coupling reactive scalar transport with deformable porous media on the macroscale, enabling efficient simulation of large-scale transport processes in biomechanics. Our objective is the modelling of cell migration and the associated biomechano-chemical processes, while treating the extracellular matrix (ECM) as a porous continuum. For this purpose, we present a model for multi-scalar transport, considering reactions among different species and between the species and the porous medium. As a result, we obtain a set of coupled, non-linear transport equations. We account for a varying porosity and its impact on the geometrical structure and mechanical behaviour of the ECM. This is of major importance for a realistic cell migration model, as the porosity can be heavily dependent on pure mechanical deformation and biochemical proteolysis, i.e. the dissolution of the porous matrix. The transport processes are driven by concentration gradients and interstitial flow and are also governed by the pore geometry, since balance of mass is explicitly affected by the porosity and macroscopic diffusivity of the porous medium. We include proteolysis effects into our model by appropriately altering the porosity of the porous medium in a stress-free reference state, thus consistently adapting the mechanical properties of the porous medium and the porous flow. By solving appropriate convection-diffusion-reaction equations within the ECM and at the cell-ECM interface, we can incorporate models for the multi-species interaction between the cell and the ECM into our approach, such as proteolysis by MMPs and focal adhesion formation due to integrins.

REFERENCES

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