Numerical simulation of liver perfusion from CT scans to FE model

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Introduction

Patient specific numerical modelling of a human liver involves:
▶ identification of larger vascular structures and hepatic parenchyma from computed tomography (CT) or magnetic resonance (MR) data
▶ generation of a finite element (FE) mesh and vascular trees
▶ numerical simulations of liver perfusion using different mathematical models of blood flow at different spatial scales

Volumetric model of liver parenchyma

DICOM2FEM: application for semi-automatic segmentation and generation of finite element meshes from CT scans
▶ DICOM files handled by pydicom library
▶ user interface build up using PyQt
▶ visualization and data storage: PyVTK
▶ segmentation of liver parenchyma based on the Graph-Cut method

Geometric model of vascular structures

Reconstruction of vascular trees:
▶ requires perfusion CT examinations - a contrast fluid injected into the blood system
▶ a voxel-based representation of the detected vascular structures transformed into a graph representation
▶ a complicated task with uncertain results → missing parts of the vascular trees generated artificially
Generation of artificial vascular trees:
▶ constructive optimization method based on minimization of intravascular blood volume and energy lost to friction
▶ iterative process including smoothing, merging and splitting of the tree

Mathematical model of liver perfusion

Numerical modelling of blood flow through the human liver:
▶ branching vessels with diameters above 2 mm described by a simple 1D model based on the Bernoulli equation with friction losses → system of non-linear algebraic equations solved by the Newton method
▶ blood flow at lower hierarchies modelled as parallel flows in a 3D porous media governed by the Darcy equation extended for multiple compartments
▶ compartments - spatially co-existing domains reflecting a certain hierarchy of tissue vascularity, compartments are coupled together and communicate with the 1D flow model through sources and sinks
▶ multicompartiment Darcy flow model implemented in SfePy (Simple Finite Elements in Python) and solved by the standard finite element method
▶ modelling of contrast fluid transport through the hepatic tissue
▶ simulation of a dynamic perfusion test → possibility to compare numerical results with real perfusion data
▶ numerically solved using an upwind cell-centered finite volume scheme and the two-stage Runge-Kutta method

Numerical results

Saturation in the portal, filtration (inter) and hepatic systems and the corresponding distribution of the total concentration in the transverse section (like in CT scans).

References


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