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MULTISCALE AND MULTIPHASE SIMULATION OF FUNCTION-PERFUSION PROCESSES IN THE HUMAN LIVER

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Summary: As the key organ for metabolic processes in the human body, the human liver is responsible for essential processes like fat storage or the detoxification. Some liver diseases can trigger growth processes in the liver, disrupting important hepatic function-perfusion processes. With an increased intake of free fatty acids, a non-alcoholic fatty liver disease (NAFLD) develops causing tissue growth with a negative impact on the hepatic functions. NAFLD can lead to hepatic carcinoma, causing a growing tumor and influencing the blood perfusion as well as the metabolic processes. In addition, surgical interventions such as portal vein ligation (PVL) or resection as well as donor organ removal and associated ischemia-reperfusion injury (IRI), may affect liver function and perfusion [1]. To better understand the interplay between hepatic perfusion, metabolism and tissue in the hierarchically organized liver structure, we have developed a multicomponent, poro-elastic multiphasic and multiscale function-perfusion model, cf. [2,3], using a multicomponent mixture theory based on the Theory of Porous Media (TPM, see [4]). The multiscale approach considers the different functional units of the liver, the so-called liver lobules, with an anisotropic blood flow via the sinusoids (slender capillaries between the periportal field and the central vein), and the hepatocytes, where the biochemical metabolic reactions take place. On the lobular scale, we consider a tetra-phasic body, composed of a porous solid structure representing healthy tissue, a liquid phase describing the blood, and two solid phases with the ability of growth and depletion representing the fat tissue and the tumor tissue. The phases consist of a carrier phase, called solvent, and solutes, representing microscopic components, e.g. nutrients, dissolved in the solvent. To describe the influences of the resulting tissue growth, the model is enhanced by a kinematic growth approach using a multiplicative split of the deformation gradient into an elastic and a growth part, dependent on the fat accumulation and tumor development. To describe the metabolic processes as well as the production, utilization and storage of the metabolites on the cellular scale, a bi-scale PDE-ODE approach with embedded coupled ordinary differential equations (ODE) is used.
In order to represent realistic conditions of the liver, experimentally or clinically obtained data such as changes in perfusion, material parameters or tissue morphology and geometry are integrated as initial boundary conditions or used for parametrization and validation [5]. Data integration approaches like machine learning techniques are developed for the identification, processing and integration of data. Here, a workflow is designed that directly prepares the model for clinical application by (semi-)automatically processing the data, considering uncertainties, and reducing computation time.

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