Multiscale and Multiphase Model of the Human Liver for Description of Perfusion, Metabolism and Fat Deposition

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ABSTRACT

The human liver regulates metabolism in a complex time depending and non-linear coupled function-perfusion-mechanism. The viability of the organ could be affected by a failure in the liver structure. A common damage is the accumulation of fat in the tissue, known as a fatty liver.

In previous publications a computational model with a multicomponent/multiphasic/multiscale approach to simulate important functionalities which are directly coupled with the blood perfusion is presented, see [2-3]. Now, the growth in the liver tissue and its influence on the metabolism is examined. Furthermore, the development of the fatty liver disease which occurs of lipid inclusions and growing cells is presented.

The main functions of the liver take place at the smallest cells of the liver, the hepatocytes, which are embedded in the liver lobules. Nutrient, oxygen and other substances are transported with an anisotropic blood flow via a delicate system of capillaries, so called sinusoids. The inner structure of the lobule is highly complex due to the inhomogeneous distribution of the sinusoidal network and the complex arrangement of the hepatocytes. For a homogenization of the complex geometry we use a multiphasic mixture theory based on the Theory of Porous Media (TPM), see [1].

The intended full liver model consists of three scales, namely the organ-, lobuli hepatis- and cell-scale. Each scale is connected via energy based homogenization conditions (Hill condition). In this study we will focus on the scale bridging between the loboli hepatis (meso-) and cell-scale. The highly complex inner structure of the lobules makes it impracticable to give an accurate geometrical description in a continuum mechanical manner. Therefore, a homogenized concentration enriched biphasic mixture model is used for the meso-scale which is based on the theory of porous media [1]; see [2,3]. Regarding the processes on the cell scale in the hepatocytes a system of ordinary differential equations (ODE) for the calculation of the metabolism is included. The input for the ODE-system results from the overlying FEM meso-scale and contains information about external glucose and lactate concentrations that are solved and carried in the blood whereas the glycogen is stored stationary in the hepatocytes. In addition, the agglomeration of lipid contents has been included in the model which impacts the perfusion and metabolic equilibrium.

REFERENCES

[1] DE BOER, Reint. Theory of porous media: highlights in historical development and current state. Springer, 2002.

[2] RICKEN, T., et al. Modeling function-perfusion behavior in liver lobules including tissue, blood, glucose, lactate and glycogen by use of a coupled two-scale PDE-ODE approach. Biomechanics and modeling in mechanobiology, 2015, **14** (3), 515-536.

[3] RICKEN, Tim; DAHMEN, Uta; DIRSCH, Olaf. A biphasic model for sinusoidal liver perfusion remodeling after outflow obstruction. Biomechanics and modeling in mechanobiology, 2010, **9**.(4), 435-450.