On a Two-Scale Function-Perfusion Model for Fatty Liver

Tim Ricken*, Daniel Werner* Hermann Georg Holzhütter‡, Matthias König‡, Uta Dahmen†, and Olaf Dirsch§

* Chair of Mechanics - Structural Analysis – Dynamics, TU Dortmund University
‡ Conputational Systems Biochemistry Group, Charité Berlin
† Department of General, Visceral and Transplantation Surgery, University Hospital Jena
§ Institute of Pathology, University Hospital Jena

ABSTRACT

INTRODUCTION: Biological tissues are characterized by their unique functionality due to their biological and biochemical specialization and complex structure. Regarding the biochemical activity the liver is one of the most complex organs in the human body acting as the central organ in terms of metabolism. The main functions of the liver are the production and secretion of proteins, breakdown of hormones and toxins and storing of high-energy substances such as glucose. The metabolism takes place in the liver cells, the hepatocytes, which are arranged in hexagonal functional segments, the liver lobules. The liver consists of more than one million liver lobules. In each corner of each hexagonal lobule a portal triad is located. Within this portal triad a bile duct gathers and drains bile, which is produced in the hepatocytes, an artery ensures the supply of oxygen enriched blood and a portal vein delivers nutrient-rich blood from the digestive organs. In the center of each lobule the central vein drains the blood coming from the portal triad. On its path from the portal triads to the central vein blood is guided through columns of hepatocytes, the so called sinusoids. The inhomogeneous distribution of the sinusoidal network leads to an anisotropic blood flow in the liver lobules.

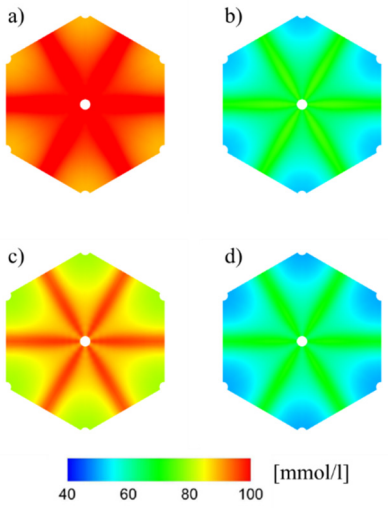

Figure 1: Corresponding contour plot for glycogen storage in liver lobules at different time steps. a) 12 hours, b) 24 hours, c) 36 hours, d) 48 hours [3].

METHODS: 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.

DISCUSSION: This study showed a first approach for a coupled finite element simulation capturing a homogenized mixture model with an embedded 0D-ODE coupled metabolism model. The simulation results deliver information about insights into the development of liver functionality. In future works, the main focus of the project is the investigation of the question how a disease caused disorder of the perfusion will influence the functionality of the liver.

REFERENCES

[1] de Boer, R.: Theory of Porous Media – highlights in the historical development and current state; Springer-Verlag, 2000
[2] Ricken, T. et al., Biomech. Model. Mechanobiol. 9, 435-450, 2010
[3] Ricken, T. et al., Biomech. Model. Mechanobiol. DOI 10.1007/s10237-014-0619-z, 2014