MULTISCALE MODELLING OF THE HUMAN HEPATIC PERFUSION

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Introduction

Hepatic perfusion plays a crucial role in many liver-related research areas (e.g. transplantation). However, liver perfusion remains relatively poorly understood. It is thus essential to clarify the hepatic angioarchitecture and hemodynamics. Therefore, we present a multiscale modeling approach for the human hepatic circulation, based on detailed 3D images from the hepatic macro- to microcirculation.

Methods

Vascular corrosion casting was applied to a human liver by simultaneous injection of resin (Batson's^{TM} #17) in the hepatic artery (HA) and portal vein (PV) until resin emerged from the hepatic veins (HV). The liver macrovasculature was imaged by a high resolution (110 µm) in globo micro-CT scan. Consecutively, a mesovascular sample and a micro-vascular sample (± 0.134 mm³) were dissected from the cast and scanned at higher resolutions (71 µm and 2.6 µm, respectively). Image processing allowed 3D reconstructions up to the terminal microcirculatory level (Fig. 1). These data were used to quantify branching topology and geometrical vessel features. Various models (electrical analog models and 3D computational fluid dynamic (CFD) models) were used to simulate hepatic hemodynamics.

Results and discussion

Vascular analysis of the macrocirculation resulted in the quantification of 5-6 blood vessel generations, previously used to build an electrical analog model of hepatic perfusion [Debbaut, 2011]. In addition, the mesocirculation sample allowed assessing geometrical features up to 13 generations: radii ranging from 13.2 to 0.08 mm, lengths from 74.4 to 0.74 mm. Exponential relations ($y=a\cdot exp(bN)$; y=geometrical feature, N=generation number) were fitted to the data, relating generation number to radius, length and number of vessels. For the HA/PV/HV radii [mm], a was 4.22/10.26/13.52 and b was -0.31/-0.37/-0.48, respectively.

The terminal microcirculation sample showed a complex network of interconnected and intertwined sinusoids (5-10 µm diameters), and the mean sinusoidal porosity was 14.3% ± 2.8%. Microcirculatory CFD simulations revealed anisotropic permeability characteristics within the liver lobules (higher permeability parallel to the central vein; lower permeability in radial or circumferential directions) [Debbaut, 2012].

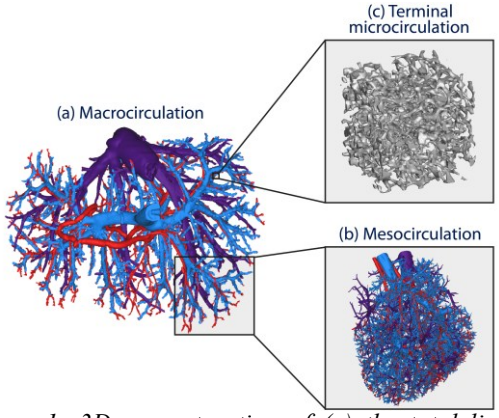

Figure 1: 3D reconstruction of (a) the total liver macrocirculation (110 µm resolution), (b) the mesocirculation sample (71 µm resolution) and (c) a terminal microcirculation subsample (2.6 µm resolution).

In conclusion, unique anatomical and morphological data on the hepatic macro- and microcirculation were obtained. These data allowed designing novel multiscale models, which might be helpful to better understand liver perfusion. This approach is applicable to study normal and pathological liver perfusion, as well as other organs, such as the kidney.

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References

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