A coupled multi-compartment model of blood and oxygen transport in the human cerebral cortex

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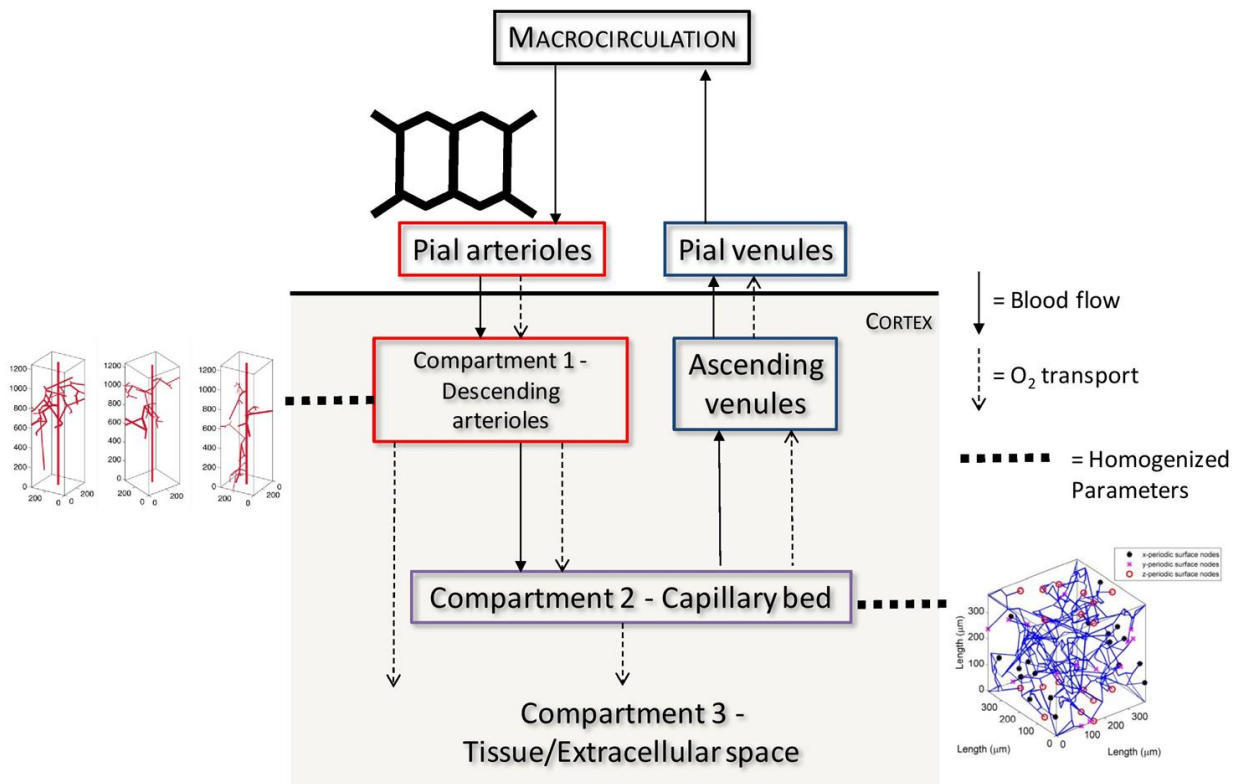[1]*Department of Biomedical Engineering, University of Oxford, UK*

Objectives

Developing full brain models of the vasculature in the brain is currently unfeasible due to the extremely large number of microvessels in the human brain. However, compartmental level modelling of the microvasculature, as previously adopted in the heart and liver and more recently demonstrated in the human brain capillary bed, allows us to move towards full brain models of the vasculature. The aim of this work is thus to generate full human brain compartmental models of coupled oxygen and blood transport in the microvasculature as part of the INSIST (In-silico trials for treatment of acute ischaemic stroke) project. The broader aim of this project is to develop full human brain statistical computational models of blood and oxygen transport in order to simulate in-silico thrombectomy clinical trials.

Methods

Homogenization methods are used to upscale the penetrating arterioles (compartment 1), the capillary bed (compartment 2), and the tissue (compartment 3), as outlined in the figure. These upscaled equations have averaged parameters that capture the micro-scale variations in geometry that affect the flow and oxygen transport and that allow us to characterise the overall microvasculature as a continuum. These parameters are derived from statistical models of the capillary bed and penetrating arterioles. Once the micro-scale dependent parameters are determined, the macro-scale equations are then used to compartmentally model an idealised human cerebral cortex where a hexagonal pial geometry acts as a flow and oxygen source for the arteriolar compartment, which in turn acts as a source for the tissue and capillary compartments, and the capillary compartment acts as a further source for the tissue compartment which metabolises the oxygen. The pial vasculature is coupled via an ODE/PDE model to the microvascular compartments, with the microvascular compartments coupled via coupling coefficients derived from voxel-sized microvascular models.

Results

The homogenization of the flow in the capillary and arteriolar beds results in a Darcy flow problem with an isotropic permeability and an anisotropic permeability respectively. The oxygen transport problems result in an averaged mass transport problem with the parameter of interest being the surface area to volume ratio of the microvasculature. All parameters converge (the capillaries at a length scale of approximately 350 microns and the descending arterioles at a length scale of approximately a few mm), allowing us to model accurately full-brain simulations of coupled blood and oxygen transport in this framework.

Conclusions

The novel multi-compartment, multi-scale solver of coupled blood and oxygen transport in the human microvasculature developed here can be used on real brain mesh simulations of the human brain (derived from MRI or otherwise). The statistical nature of the microvascular model means that patient specific geometries of the large vasculature can then be superimposed over the model presented here allowing for the development of in-silico full brain modelling. This will then be used to develop computational thrombectomy trials on in-silico subjects.

References
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