Subject-specific computational platform of a multiporoelastic model for the simulation of cerebrospinal fluid transport

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Introduction

A breakdown in the cerebral environment is an important common cause for many diseases of old age, such as dementia. Alzheimer's disease (AD) is the most common form of dementia. There is emerging evidence suggesting that Alzheimer's disease is a vascular disorder, caused by impaired cerebral perfusion, which may be promoted by cardiovascular risk factors that are strongly influenced by lifestyle. In order to help decipher some of the underlying mechanisms of such hypotheses, it is essential to model fluid transport within the brain in a personalised manner and from first principles. Therefore, a novel in-house computational platform based on the multiple-network poroelastic theory (MPET) [1] has been developed, which can be used to conduct subject-specific mechanistic modelling of fluid transport through the perfused parenchyma tissue.

Methods

This computational platform is designed to model multi-scale spatio-temporal fluid transport between the cerebral blood, cerebrospinal fluid (CSF) and brain parenchyma. Biologically, in a porous medium representing the cerebral environment, the solid matrix represents brain parenchyma, and the four communicating fluid phases taken into account are: an arterial network, an arteriole/capillary network, a CSF/ISF network and a venous network.

The governing equations of solid and fluid phases with appropriate boundary conditions are discretised in a finite element framework and solved in an uncoupled way. This numerical model allows for the simultaneous solutions of continuity and momentum conservation equations, in four interconnected fluid networks (directional flow is defined between fluid compartments), within a deformable solid matrix (parenchyma tissue). A workflow for 3D subject-specific modelling from image segmentation to running the MPET solver is shown in Fig. 1.

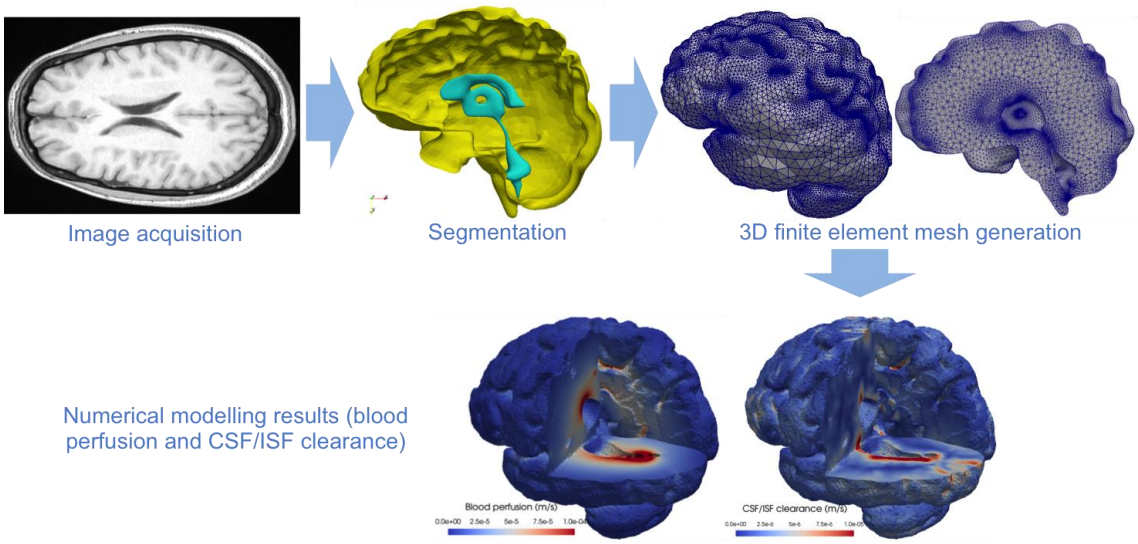

Fig. 1: Workflow of 3D subject-specific simulations using the MPET computational platform.

Results and discussion

The MPET model has been verified against classical consolidation theory, e.g. Terzaghi's and Mandel's problems. Moreover, it has also been validated using experimental data of infusion tests on mice. From an application point of view, the mesh dependence has been investigated, which provided guidance on mesh resolution in subject-specific modelling [2].

To fully explore its applicability, the MPET computational platform has been incorporated into a consolidated pipeline within the European VPH-DARE@IT project, which can provide MPET solver with subject-specific meshes and permeability tensor maps by a fully automated image-based model personalization workflow, and blood flow variability by a personalised boundary condition model. The cases simulated involved both male and female control and MCI cases. Results showed variations in clearance of CSF/ISF, elevated parenchymal tissue displacement and CSF/ISF accumulation and drainage in the MCI cases.

Acknowledgements

European Commission FP7 project VPH-DARE@IT (FP7-ICT-2011-9-601055).

References

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