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Large-scale simulation of the human cranial arterial tree: utility in hydrocephalus

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Background

Recent work in hydrocephalus modelling has drawn attention to the potential role of disruption of a pulsation absorber mechanism in the intracranial compartment. Therefore, characterization of cerebral hemodynamics is essential for understanding complex intracranial dynamics under normal and diseased conditions, diagnosing and treating patients suffering from hydrocephalus, and designing medical devices. To this end, we have developed a procedure for generating physiologically accurate models of the cerebral hemodynamics by coupling clinical data and the multiscale modelling approach.

Materials and methods

Our strategy for the cranial arterial tree modelling is to include *all* arteries that can be accurately imaged using conventional medical imaging techniques, such as Magnetic-Resonance Angiography (MRA) and Computed Tomography (CT) in the computational domain. The "sub-pixel" dynamics described by microvascular network act as "closure" to the large-scale arterial dynamics. Patient-specific anatomical models are constructed from high resolution MRA and CT images covering the volume of interest. Due to the geometric complexity of the cranial arterial system, we employ high-order spectral/hp element methods for solving the governing flow equations. *Highly scalable parallel implementation* allows the dramatic reduction of overall computation time of the 3D large-scale simulations. In our models *we account for the cerebral autoregulation mechanism* by prescribing a scalable and efficient type of pressure boundary condition applicable to flow domains with multiple outlets. This method allows us to impose accurately and in a straight-forward manner in-vivo measured flow rates at terminal outlets. Measuring the flow rate, unlike measuring the pressure, is a straightforward procedure that is performed using non-invasive techniques. Two such techniques that we employ are Transcranial Doppler Ultrasound (TCD) and Phase-contrast MRI. Volumetric flow rates are obtained by integration of the velocities throughout a lumen cross-sectional area defined by its boundary.

Results

Consistent with previous findings, our 3D simulations of human intracranial dynamics predict cerebral hypoperfusion and elevated resistivity and pulsatility indices in patients with hydrocephalus. Our models can be utilized to predict the hemodynamic effects and outcomes of clinical interventions such as shunting and endoscopic third ventriculostomy. In developing a model of this complexity, validation is critical. The numerical results are consistent with observed data obtained from dog and human measurements.

Conclusion

Human intracranial dynamics models are powerful research tools to enhance the understanding of pathophysiological mechanisms in hydrocephalus and provide realistic parameters for comparing patients with normal controls.