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A 1-D coupled hydrodynamic model of the cardiovascular tree and cerebrospinal fluid system

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Hemodynamical factors such as pressure, perfusion flow, local shear stress and pulsatility in both pressure and flow play an important role in the genesis, progression and treatment efficiency of various forms of cerebrovascular disease. While the mechanism are different, the dynamics of flow in the cerebrospinal fluid (CSF) system appear to be important in a number of CSF-related diseases, such as hydrocephalus, spina bifida, and Chiari malformation, to name a few. Research and clinical evidence have demonstrated a coupling between arterial flow and the CSF system, and the interaction between the two fluid systems is considered key in understanding the physiopathology of cerebrovascular and craniospinal diseases.

We have developed a 1-D hydrodynamic model which couples the cardiovascular tree with the CSF system through the cerebrovascular network. The governing equations for the cardiovascular tree and spinal subarachnoid space (SSS) model consider the flow conduit(s) to be straight long tapered segments having nonlinear and viscoelastic wall behavior. The 1-D continuity and momentum equations are obtained by integrating continuity and longitudinal momentum equations of the Navier-Stokes equations. Peripheral arterial segments and the lumbar SSS were terminated with a three element Windkessel model. In the case of arterial bifurcations, continuity of pressure and flow was

imposed, thus neglecting any minor pressure losses occurring in the vicinity of the bifurcation. Wave reflection due to impedance mismatch at arterial bifurcations was taken into account.

The model functions as follows. An aortic flow or pressure wave is input to the cardiovascular tree and flow and pressure in all segments are determined. The total arterial cerebral blood flow (CBF) pulsation is calculated as the sum of flow in the left and right internal carotid and vertebral arteries. A transfer function relating the CBF to CSF pulsations, based on data in the literature, is used to calculate the CSF flow pulsation at the craniospinal junction based on the CBF pulsation calculated from the cardiovascular tree. The CSF flow pulsation at the craniospinal junction is input to a 1-D SSS model with diameter and nonlinear compliance based on in vivo measurements. SSS flow and pressure are determined.

The calculated flow, pressure, and wave propagation velocity in the SSS and cardiovascular tree are similar to in vivo measurements. Phase relationship between the SSS and spinal artery pressure are sensitive to the properties of the SSS and cardiovascular tree such as compliance and geometry. The 1-D coupled hydrodynamic model of the cardiovascular and CSF system addresses a significant gap in prior models of the cardiovascular and CSF system and has the potential to provide a tool for interpretation of bedside tests related to cerebral perfusion and CSF system function.