Fluid Structure Interaction Model Analysis of Cerebrospinal Fluid in Patients with Continuous - Flow Left Ventricular Assist Devices

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Objective

CSF circulation includes directed and pulsatile flow throughout the cerebral ventricular system as well as the brain and spinal subarachnoid spaces, cisterns, and sulci. Novel research insights have proven that the traditional physiology of CSF circulation is more complex than previously understood by describing the role of lymphatic pathways for drainage of CSF along astrocytes and their aquaporins and the overall fluid exchange between CSF and interstitial spaces. We have to improve our understanding as it may have clinical relevance to understand neurodegenerative and immunological diseases of the brain and spinal cord. Our study aims to utilize a computation Fluid Structure Interaction (FSI) model to characterize behavior of CSF pressure and flow in patients with continuous - flow left ventricular assist device where arterial pulsatility is greatly diminished or absent.

Methods

- We used modified principles of Raymond’s (1:2) dimensional model to simulate cisternal segments within the brain and spinal cord and couple the cardiovascular system with the cerebrospinal fluid system using computational fluid dynamic. (Figures A – C)

- We constructed the CSF motion and fluid dynamic simulation for our Fluid Structure Interaction model using the same approach, as described by Gupta et al., 2010. We modeled the pulse wave propagation for our model using the equations and calculations depicted below and, incorporated the boundary condition values based on their MRI studies. For our model we established low pulse wave to represent patients with continuous flow left ventricular assist device. (Figures D – F)

Results

- Figure A-B: Schematic representation of arterial tree based on Raymond et al. model within ventricular venous system (figures adopted from Martin et al., 2012).

- Figure C-D: Schematic computational diagram of Compute Circle of Willis.

- Figure E-F: Measured Pulse Wave Propagation of pressure and velocity through cisternal arteries at various locations using boundary conditions with diminished pulse to represent continuous flow left ventricular assist device patient.

- Figure G: Schematic representation of CSF circulation system, with some boundary conditions depicted in red is a histological gradient. Figure H: Low pulse-computational simulation of CSF at first ventricle and anumrutho, showing well-established convective separation of pressure and velocity profiles for pressure and velocity.(Note: Due to time constraints, these results are not fully detailed.)

- Figure J: Velocity and pressure profiles in the longitudinal direction of low pulse CSF simulations at the boundaries obtained at the third ventricle.

Future Directions

- Utilize invivo data from our institutional phase contrast MRI as boundary conditions for our Fluid Structure Interaction model. Based on our assumptions above, coordinate patient specific computational fluid dynamic simulations for 1D, 2D, and 3D simulations. Extend our FSI model to further understand the modified view of CSF flow which includes bi-directional fluid exchange with the extracellular space, perivascular flow, and lymphatic drainage. Construct computational model of mechanical behavior of the CSF system using 3D printing technology and couple cardiovascular pulse flow with a continuous flow left ventricular assist device in vitro.

- Continuous testing of patients with Continuous - Flow Left Ventricular Assist Device at our institution.

References


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