In vitro hydrodynamic modeling of syringomyelia

Bryn Martin, Laboratory of Hemodynamics and Cardiovascular Technology,
EPFL, Lausanne, Switzerland
Francis Loth, Department of Mechanical Engineering,
The University of Akron, United States
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Objective: It has been hypothesized that abnormal cerebrospinal fluid (CSF) pressure distribution, caused by a spinal subarachnoid space (SSS) flow blockage (stenosis), is an etiological factor contributing to various craniospinal disorders such as posttraumatic syringomyelia (PTS), Chiari malformation (CM), and hydrocephalus. However, paucity in detailed in vivo pressure data in the SSS has made theoretical explanations for craniospinal pathologies associated with SSS stenosis difficult to reconcile. Thus, the aim of this work was to investigate the SSS pressure environment using in vitro models to provide information for understanding CSF system dynamics.

Methods: The in vitro models were constructed to have anatomical similarities with syringomyelia. Model geometry and properties were based on in vivo data and incorporated pertinent elements such as a realistic CSF flow waveform, SSS stenosis, syrinx, flexible spinal cord, and flexible spinal column. Axial pressure distribution was in each model in the SSS and, if present, the syrinx. Pressure measurements were recorded under normal CSF pulsations and a simulated cough CSF pressure perturbation.

Results: Under normal CSF pulsations, the presence of a SSS stenosis caused peak-to-peak CSF pressure fluctuations to increase rostral to the SSS stenosis. The stenosis increased and dissociated SSS pressure, while axial pressure distribution in the syrinx remained uniform. The interaction of the syrinx and stenosis resulted in a diastolic valve mechanism and caudocranial tensioning of the spinal cord. Under simulated CSF cough conditions, longitudinal pressure dissociation acted to suck fluid and tissue caudocranially in the SAS with a SSS stenosis. The stenosis caused the syrinx to balloon outward at the rostral end and be compressed at the caudal end. Removal of the stenosis was found to be a key factor to reduce pressure gradients in the spinal SAS. Increasing compliance of the spinal column reduced forces acting on the spinal cord.

Conclusions: In vitro pressures were similar to in vivo measurements in the literature. The pressure wave velocities and pressure gradients were impacted by alterations in geometry, compliance, and the presence of a SSS stenosis and/or syrinx. The results highlight the importance of the CSF pulsation and material properties of the spinal cord and SSS.