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An MRI-Compatible Hydrodynamic Simulator of Cerebrospinal Fluid Motion in the Cervical Spine

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Purpose

Cerebrospinal fluid (CSF) dynamics are considered an important factor to help understand the pathophysiology of craniospinal disorders such as Chiari. However, at present, assessment of CSF dynamics is not a standard clinical practice as the reliability of MR protocols for CSF dynamics is unclear. A need exists for an *in vitro* experimental platform to assess the reliability of flow sensitive MR protocols for CSF dynamics detection across MRI machines and manufacturers. *In vitro* models have played an important role to help establish MR protocols for blood flow analysis and can play a similar role for CSF.

Methods

Anatomically realistic subject-specific models were created based on a 22-year old healthy volunteer and a five-year-old patient diagnosed with Chiari. The *in vitro* models were based on manual segmentation of high-resolution T2-weighted MR imaging of the cervical spine. Anatomically realistic dorsal and ventral spinal cord nerve rootlets (NR) were added manually. Models were 3D-printed by stereolithography with 50 µm layer thickness. A computer controlled pump system was used to replicate the shape of the subject specific in vivo CSF flow measured by phase-contrast MRI. Each model was then scanned by T2-weighted and four-dimensional phase contrast MRI (4D flow).

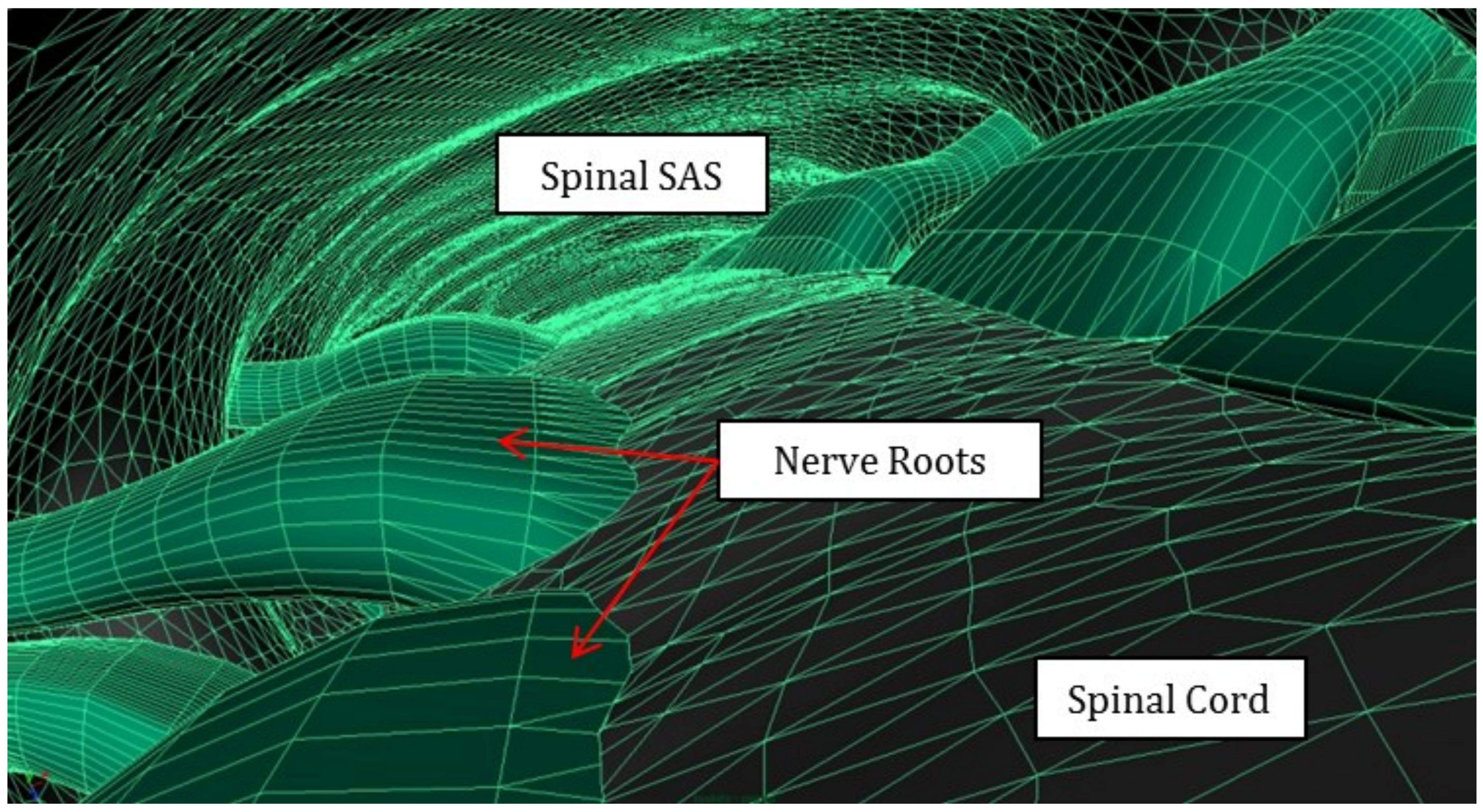
Results

Cross-sectional area, wetted perimeter and hydraulic diameter were quantified for each model. The oscillatory CSF velocity field (flow jets near NR, velocity profile shape and magnitude) had similar characteristics as previously reported in the literature found by in vivo MRI.

Conclusions

This study describes the first MRI-compatible hydrodynamic simulator of CSF motion in the cervical spine with anatomically realistic NR. CSF hydrodynamics are thought to be altered in craniospinal disorders such as Chiari I malformation. Novel MRI scanning techniques and protocols can be used to quantify CSF flow alterations in disease states. The provided *in vitro* models can be used to test the reliability of these protocols across MRI scanner manufacturers and machines.

3D visualization of the spinal cord nerve rootlets and spinal cord connection within the dorsal spinal subarachnoid space



Top: Overview of dimensions for the HV model with NR included. Bottom: 3D Printed Model (HV-NR)