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Neural Tissue Motion Impacts CSF Dynamics at the Cervical Medullary Junction: A Patient-Specific Moving-Boundary Computational Model

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Purpose

Since the discovery of cerebrospinal fluid (CSF) in 1741 by Emanuel Swedenborg, the importance of CSF dynamics at the cervical-medullary junction (CMJ) has been investigated to help understand pathological states such as Chiari. The goal of the present study was to investigate the importance of the central nervous system (CNS) tissue motion on CSF dynamics using a patient-specific moving-boundary computational fluid dynamics (CFD) model of the CMJ of a CM patient.

Methods

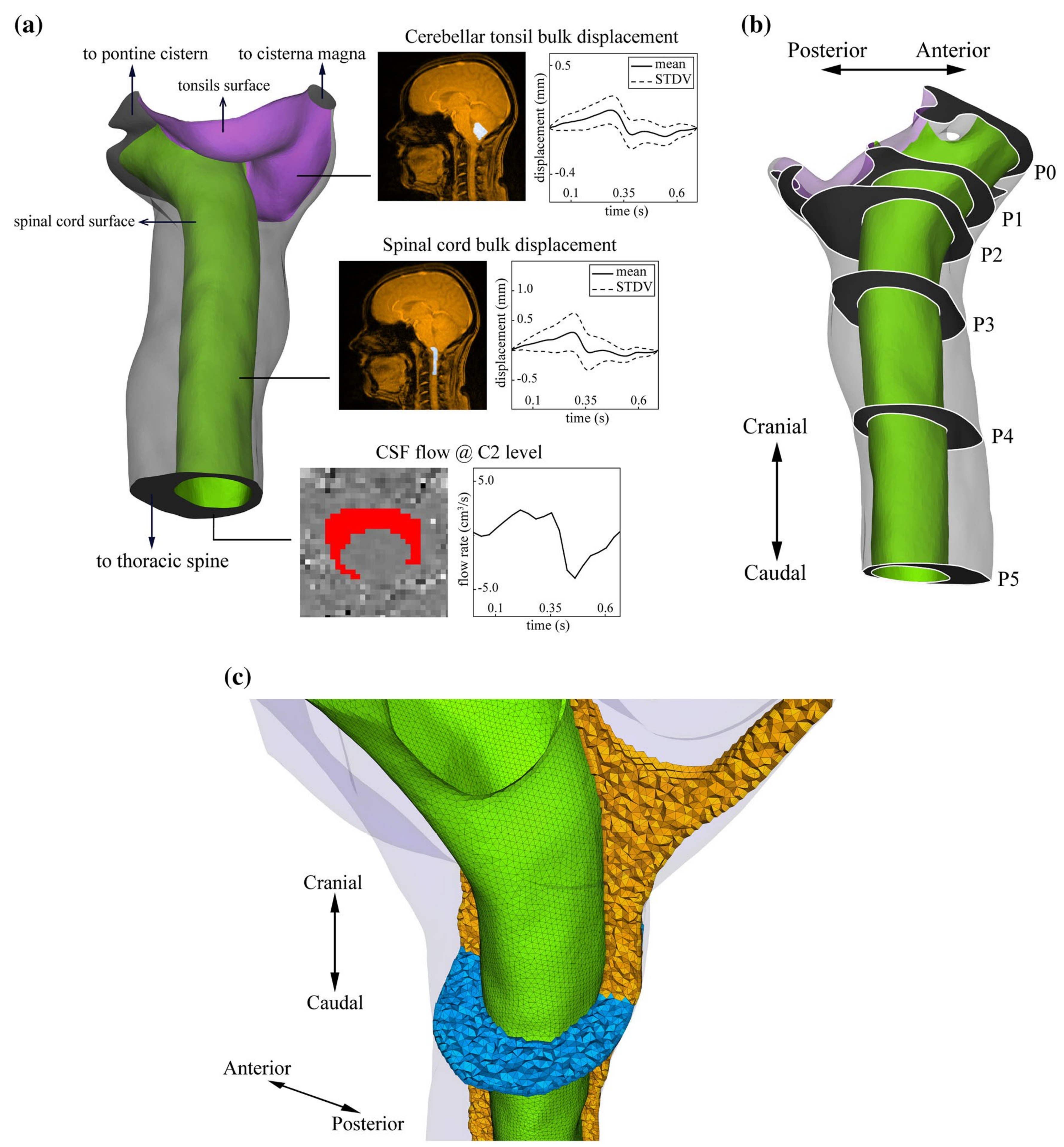
The impact of CNS tissue motion on CSF dynamics was assessed using a moving-boundary CFD model of the CMJ. The cerebellar tonsils and spinal cord were modeled as rigid surfaces moving in the caudocranial direction over the cardiac cycle. The CFD boundary conditions were based on *in vivo* MR imaging of a 35-year old female Chiari malformation patient with ~150–300 µm motion of the cerebellar tonsils and spinal cord, respectively.

Results

Results showed that tissue motion increased CSF pressure dissociation across the CMJ and peak velocities up to 120 and 60%, respectively. Alterations in CSF dynamics were most pronounced near the CMJ and during peak tonsillar velocity. These results show a small CNS tissue motion at the CMJ can alter CSF dynamics for a portion of the cardiac cycle and demonstrate the utility of CFD modeling coupled with MR imaging to help understand CSF dynamics.

Conclusions

A patient-specific moving-boundary CFD study was completed to understand how CNS tissue motion can alter CSF dynamics near the CMJ. The results showed that a small degree of CNS tissue motion (tonsillar displacement ~150 µm) can have an important impact on CSF dynamics at the CMJ. The impact of CNS tissue motion was more pronounced near the foramen magnum where the CMJ space was restricted by tonsillar descent. At this location, the CSF dynamics were most altered when peak tonsillar velocity occurred and not at peak tissue displacement, when the sub-arachnoid space had the smallest volume.



(a) Rendering of the reconstructed geometry of the upper cervical subarachnoid space (spinal cord and cerebellar tonsil are shown in green and purple respectively). Insets show the mask selections (white regions in MRI images) and the resulting waveforms used to obtain boundary conditions for the moving walls and velocity inlet.

(b) Axial planes along the geometry used to compare the results obtained from various computational models.

(c) Computational grid used for CFD simulations. Spinal cord surface mesh is shown in green. The volumetric mesh in the mid-sagittal and axial planes are shown in orange and blue, respectively.