Characterization of Spinal Canal Hydrodynamics and Compliance Using Bond Graph Technique and CSF flow Measurements by MRI

N. Yallapragada[1], N. Alperin[1]

[1]University of Illinois at Chicago, Chicago, IL, United States

Introduction: A noninvasive method for a patient-specific characterization of the spinal canal hydrodynamic properties is presented. The spinal canal contributes to the overall compliance of the craniospinal compartment. Thus it plays an important role in regulating craniospinal hydrodynamics and intracranial pressure. Limited information is available concerning the spinal canal compliance, its dynamics, and its distribution along the spinal canal, in the healthy and the diseased states, as current methods require injection of fluid into the spinal canal cerebrospinal fluid (CSF) spaces and thus are associated with risk and morbidity. The proposed method estimates the spinal canal compliance from MRI-based measurements of the oscillatory CSF flow and thus is noninvasive.

Methods: Measurements were obtained from 4 healthy volunteers using a 1.5T scanner (GE Medical system, Milwaukee). Retrospectively gated cine phase-contrast MRI technique with velocity encoding between 3cm/sec (lumbar region) and 7cm/sec (cervical spine) was employed to quantify the oscillating CSF volumetric flow at 6-8 locations along the spinal canal. Bond Graph modeling [1] of the spinal canal hydrodynamics provides the differential equations governing CSF flow in a compliant conduit. The model accounts for energy storage and dissipation processes associated with compliance and inertia, and resistance, respectively. The distributed compliances in the spinal canal are lumped into finite number of sub segments to obtain a state-determined system. Flow dynamics satisfying the differential equations are then compared iteratively with actual flow measurements to yield compliance, resistance and inertia. Validation is obtained by comparing the overall compliance of a large segment of the spinal canal to the sum of its several sub-segments calculated independently. Derived parameters were further validated by comparison of the predicted and measured CSF flow waveforms at intermediate locations.

Results: The compliance of the spinal canal ranged from 0.0125 mL/Pa to 0.34 mL/Pa. The middle and the lower segments of the spinal canal contributed the majority of the spinal canal compliance. Good agreement (within 15%) was found between the overall compliance of a large segment and the sum of its several sub-segments calculated independently. Images and CSF flow waveforms obtained for one of the subjects are shown in Figure 1 and 2.

Conclusions: A noninvasive means for characterization of the spinal canal hydrodynamic state has been developed. The method may improve our understanding of the role of the spinal canal in regulating the complex dynamics associated with the craniospinal system**.** The new method is safe and thus can be used to study the healthy and the diseased states. The proposed method could become a practical diagnostic tool since a patient-specific characterization of the spinal canal hydrodynamics is computed in few minutes.

Reference: 1**.** DC. Karnopp, et al. *System Dynamics: Modeling and Simulation of Mechatronic Systems IIIrd Ed*., John Wiley and Sons, Inc., New York, 2000.

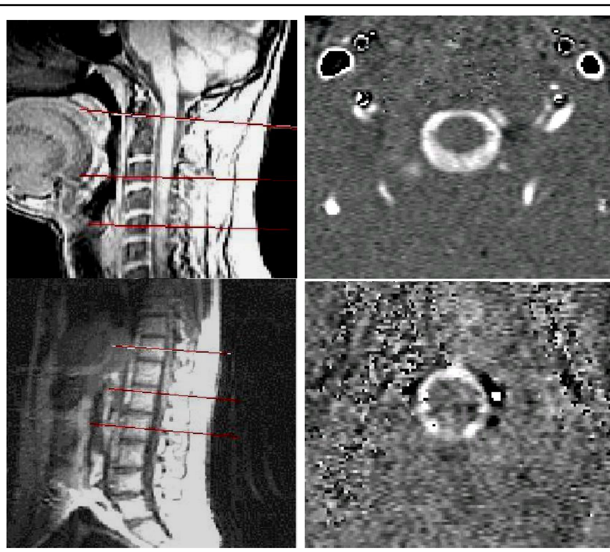

Figure 1. Left: Sagittal T1W images showing the locations of the CSF flow measurements. Right: Phase-Contrast images from cervical (upper) and lumbar (lower) locations.

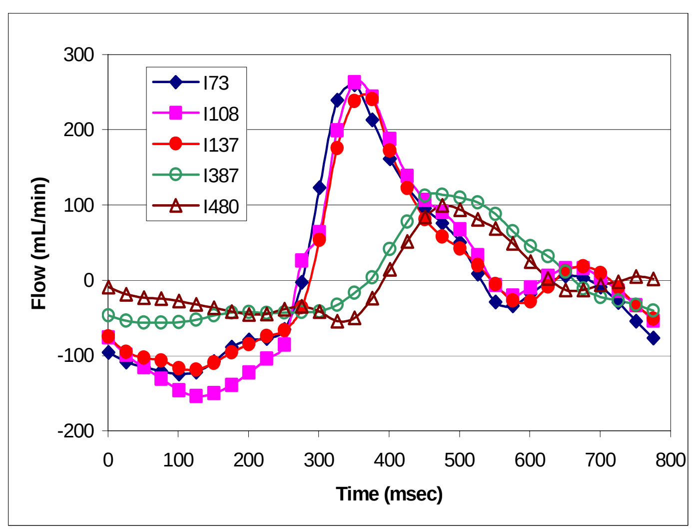

Figure 2 Measured CSF volumetric flow waveforms from cervical and lumbar locations used to calculate the compliance distribution along the spinal canal.