Approaches for the Estimation of Cerebrospinal Fluid Pulse Wave Velocity in the Spinal Canal

Elizabeth LeMaster, Sang Lee, Dr. Noam Alperin
MRI Research Lab
University of Illinois at Chicago
Chicago, IL 60612

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Project Goals

1. Characterize the biomechanical properties of the spinal canal using cerebrospinal fluid (CSF) pulse wave velocity (PWV)
2. Investigate two approaches (e.g., sagittal vs. axial) for estimation of PWV
3. Assess the performance of several methods for identification of time delays
4. Establish reference values in a small number of healthy volunteers and patients with Arnold Chiari Malformations (ACM)
General Information about CSF

- Cerebrospinal Fluid (CSF) is a clear liquid found in the brain and spinal cord [1]

- The total volume of CSF in an adult is 80-150 ml [1]

Functions of CSF

- **Transporting** necessary molecules [1]
- **Eliminating** waste products
- **Protecting** the brain and spinal cord by acting as a shock-absorber.
- **Buoyancy**, by keeping the brain afloat the pressure at the base of the brain and spinal cord is decreased [1]

Cranio-spinal CSF pulsatile flow is driven by the beating of the heart and the flow rate of CSF varies periodically during the cardiac cycle. [2]

Definition of Pulse Wave Velocity (PWV)

- PWV describes how quickly a pulse (e.g., pressure, velocity, flow) travels from one point to another in a conduit.

\[ \text{PWV} = \frac{\text{Distance}}{\text{Time}} \]

Motivation to Investigate PWV of CSF: A Potentially Significant Parameter

- **Chiari Malformation:** the base of brain and brainstem protrude into spinal column [4]

- **Symptoms:**
  - Head and neck pain
  - Motor and sensory deficits [5]
  - Symptoms’ severity NOT correlated with severity of herniation [4]

- **Incidence:** 550-770 of every 100,000 persons [6]

Method to Determine PWV: Velocity Encoded Phase-Contrast Magnetic Resonance (PCMR) Imaging

- Contrast Differs between Fluid Flow and Stationary Tissues

- Directional: White Downward Flow & Black Upward Flow

Upper Image: Sagittal images of systole (left) and diastole (right)

Lower Image: Axial images of systole (left) and diastole (right)

“Sagittal” Approach for Estimation of PWV

PWV = Distance
Time

Distance: 10-30
Selected Points
along Upper Spinal
Canal

Time: Time Delay of
Pulse Arrival for
each of the 10-30
Selected Points

PWV scatter plot (left) results based on anatomical image (upper right) and PCMR Mid-Sagittal Image (lower right) Of Healthy Volunteer 3 (HV3)

“Axial” Approach for Estimation of PWV

CSF Flow Waveform at C2 for Healthy Volunteer 3

CSF Flow Waveform at T2 for Healthy Volunteer 3
Interpret Results – “Sagittal” & “Axial” Approaches

Conclusions:

- Average PWV
- Mid-Sagittal approach - significantly higher PWV in both healthy and CM patients

Conclusions:

- Average PWV & between levels
- PWV not uniformly distributed
- Elevated PWV upper cervical spine
- Not one number describes PWV in spinal canal
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Questions?