

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

2008 NSF REU Summer Program

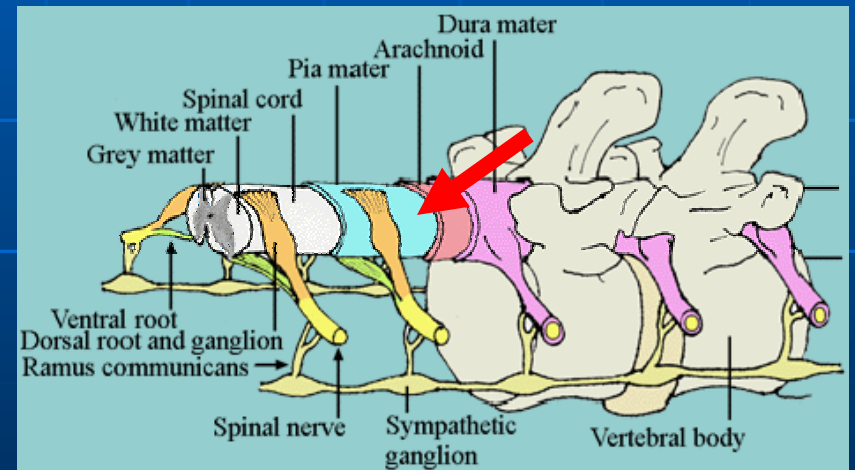
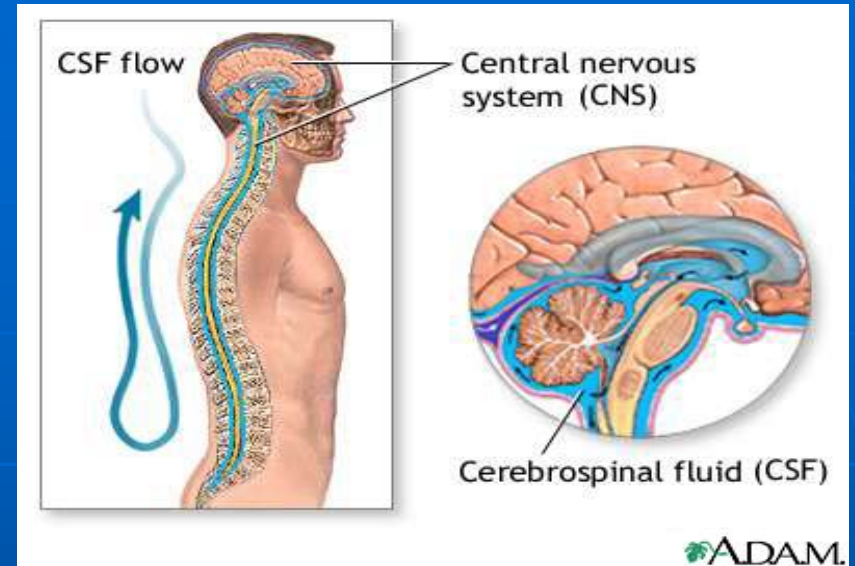
**Elizabeth LeMaster, Sang Lee, Dr. Noam Alperin
MRI Research Lab
University of Illinois at Chicago
Chicago, IL 60612**

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)

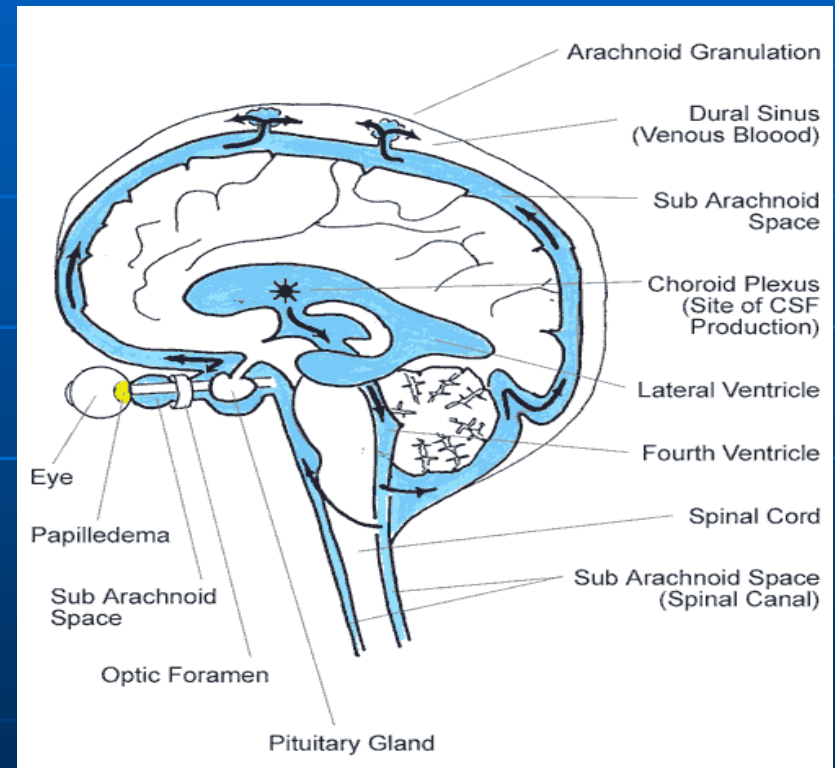
General Information about CSF

- 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]

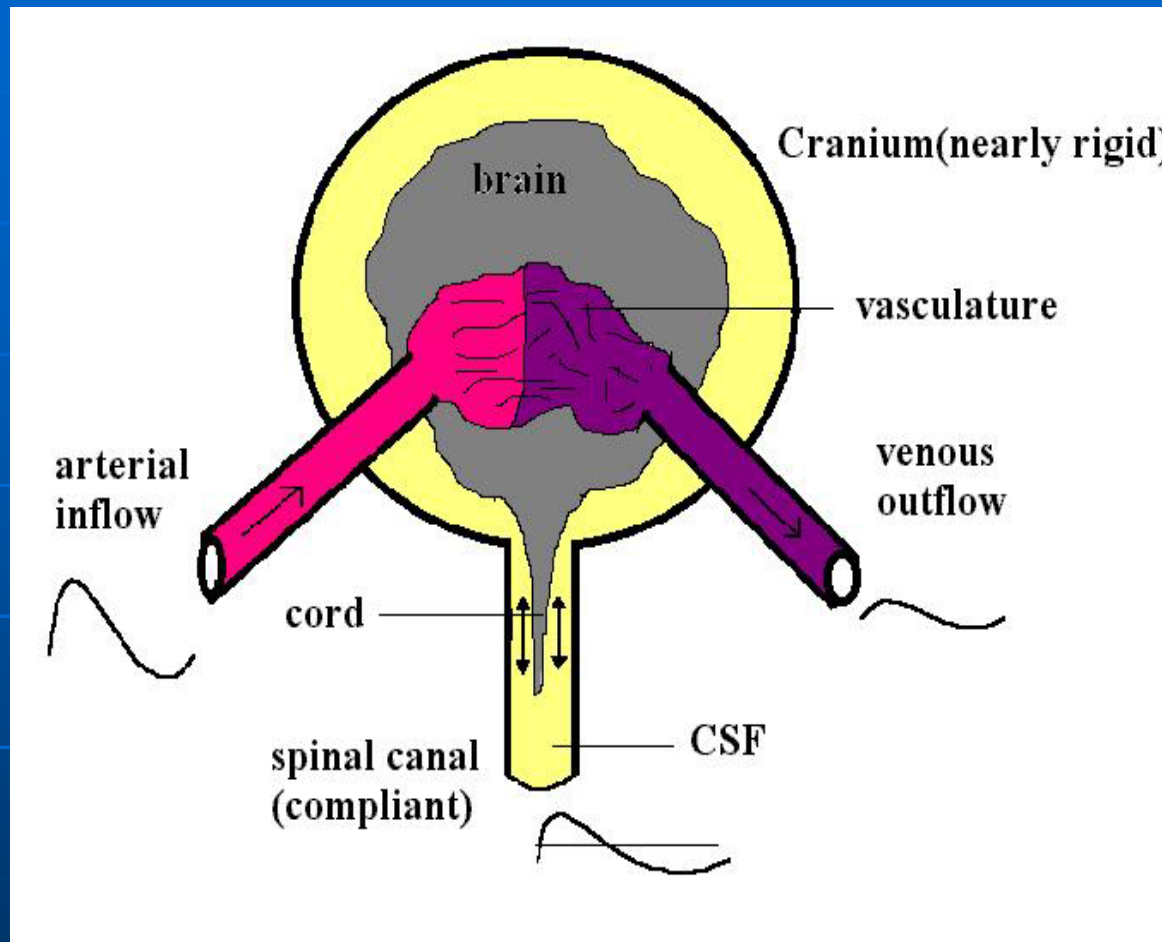


Functions of CSF

- **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]



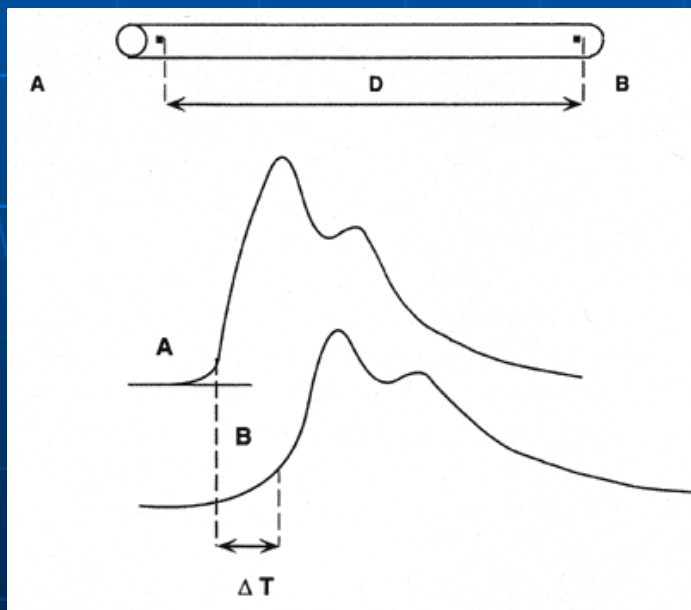
CSF Flow in the Cranio-Spinal System



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 [3]



$$\text{PWV} = \frac{\text{Distance}}{\text{Time}} \quad [3]$$

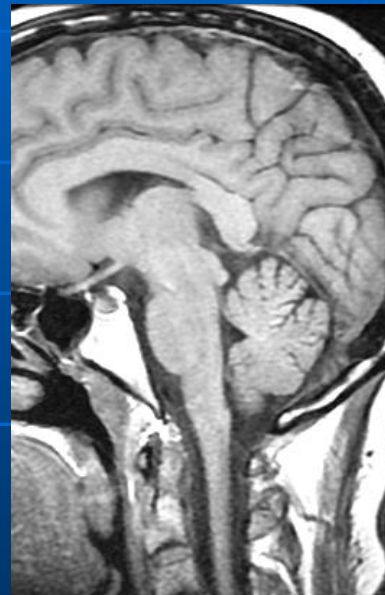
Motivation to Investigate PWV of CSF: A Potentially Significant Parameter

•**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]



Normal



Chiari Malformation

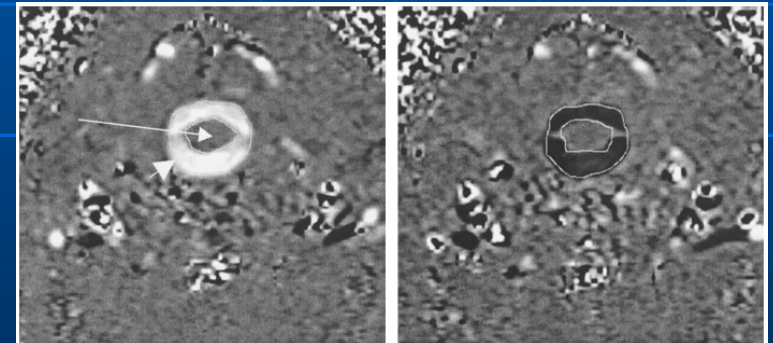
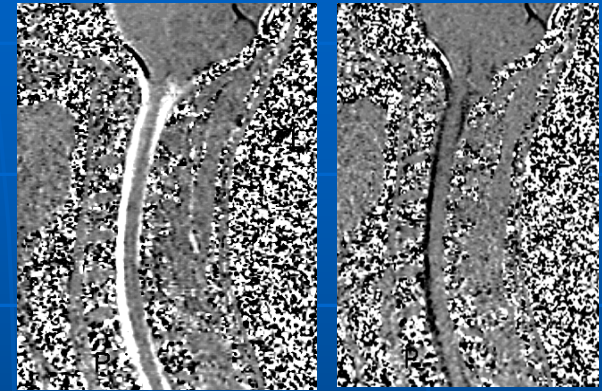
[4] Alperin N, et al. Neurosurgery Focus (2001)

[5] Sivaramakrishnan A, et al. Neurosurgery (2004) 55:1344-1351.

[6] Meadows J, et al. J Biomech Eng (2000) 92:920-926.

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

- Contrast Differs between Fluid Flow and Stationary Tissues^[7]
- Directional: White Downward Flow & Black Upward Flow^[7]



Upper Image: Sagittal images of systole (left) and diastole (right)^[8]

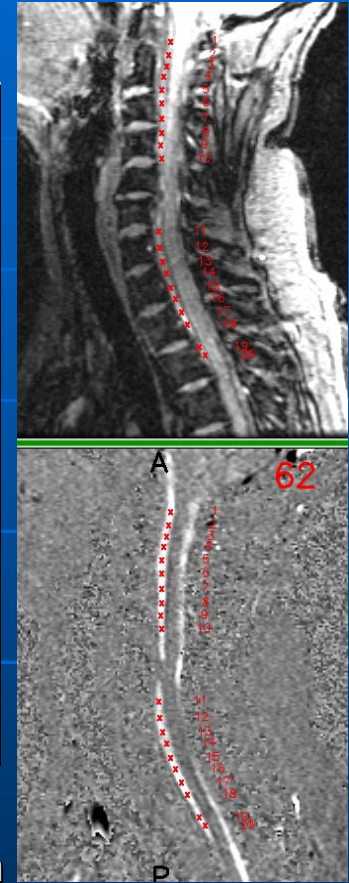
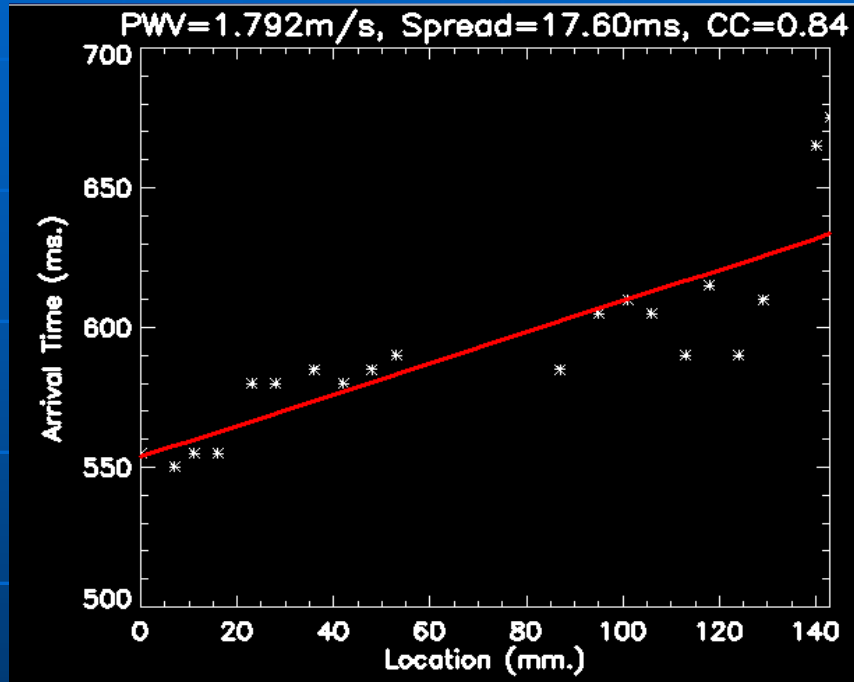
Lower Image: Axial images of systole (left) and diastole (right)^[7]

“Sagittal” Approach for Estimation of PWV [8]

$$\text{PWV} = \frac{\text{Distance}}{\text{Time}}$$

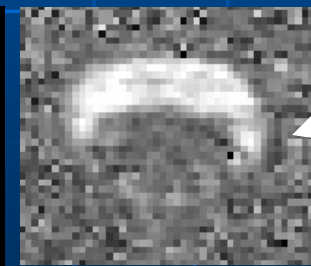
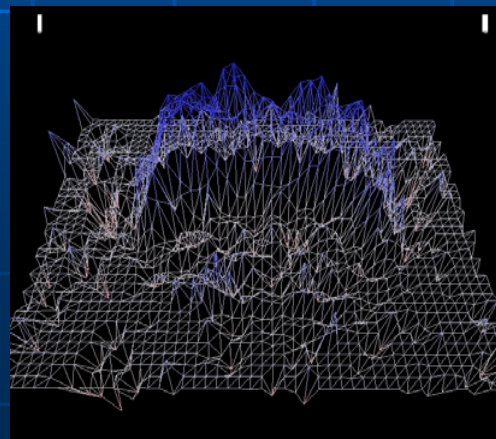
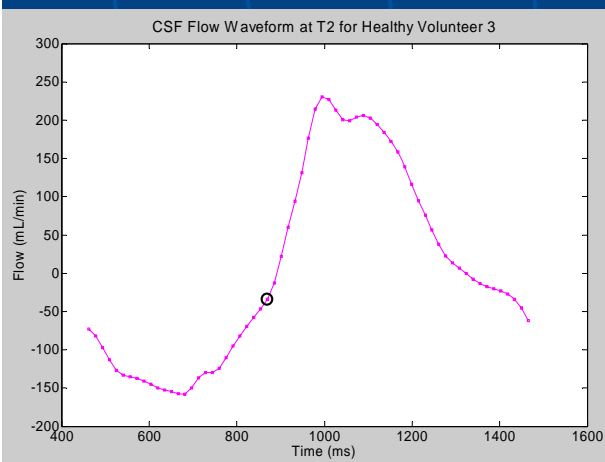
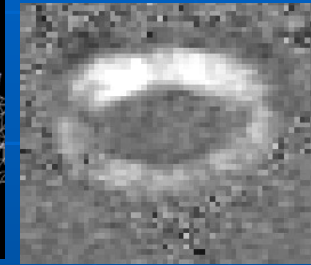
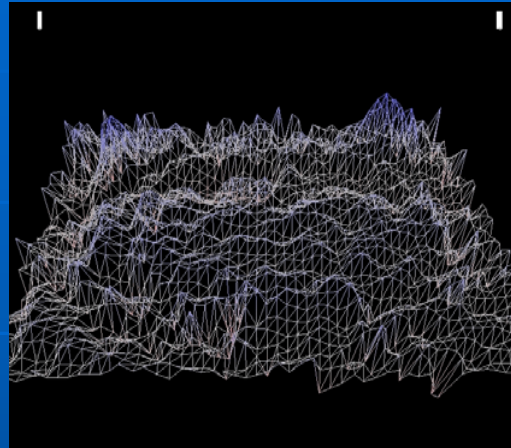
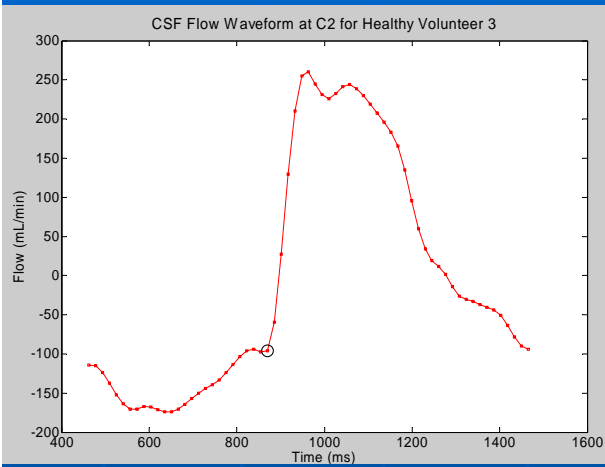
Distance: 10-30 Selected Points along Upper Spinal Canal

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

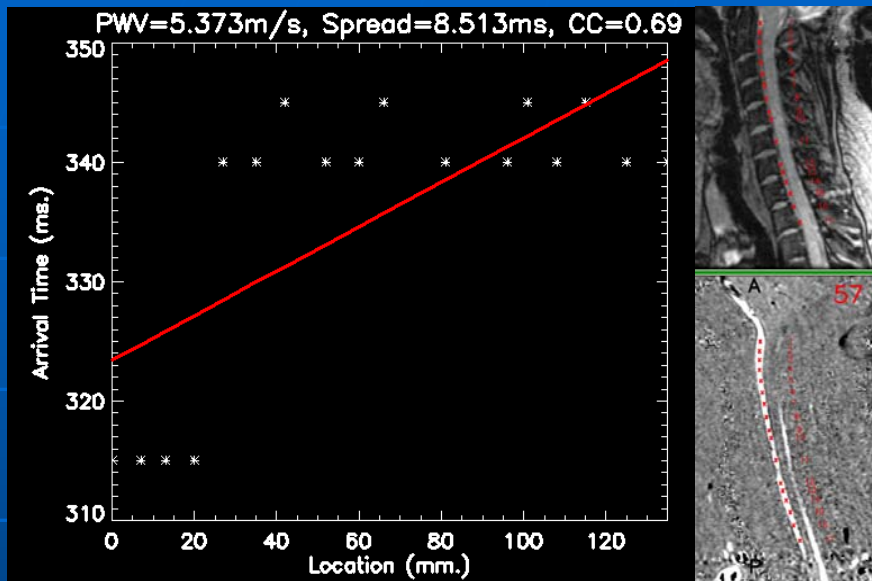


PWV scatter plot (left) results based on anatomical image (upper right) and PCMR Mid-Sagittal Image (lower right) Of Healthy Volunteer 3 (HV3)

“Axial” Approach for Estimation of PWV

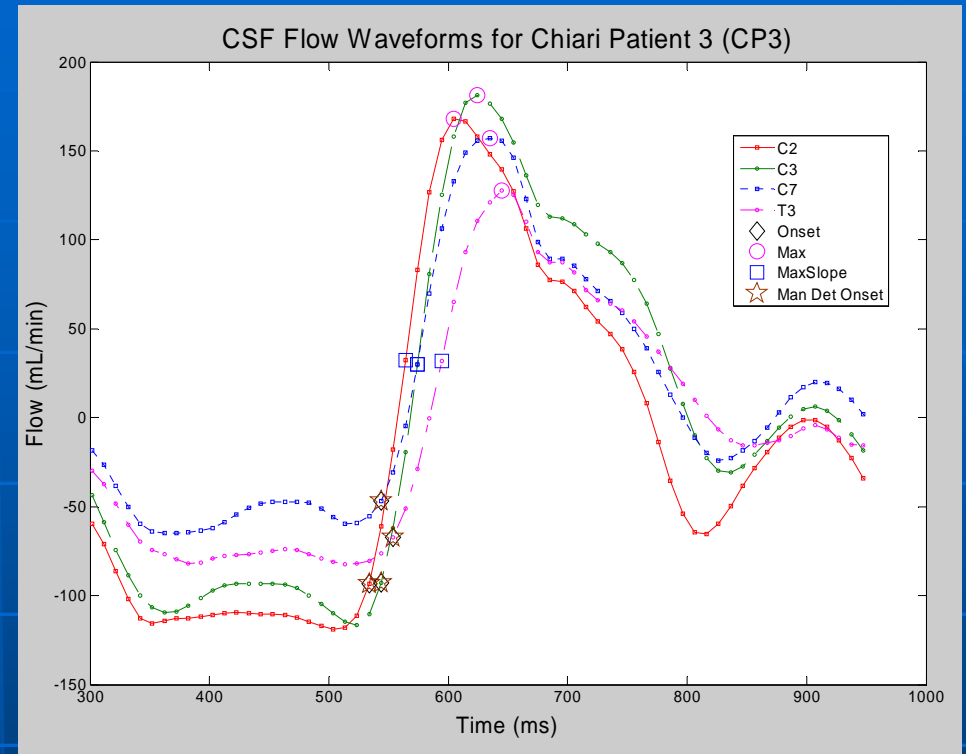


Interpret Results – “Sagittal” & “Axial” Approaches



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

Acknowledgements

- National Science Foundation (NSF) and Department of Defense (DoD) [Grant #NSF-EEC 0755115]
- Dr. C. Takoudis, Director REU
- Dr. G. Jursich, Co-Director REU
- Dr. N. Alperin, Head of MRI Research Lab
- Sang Lee, MRI Research Lab
- Manish Singh, Graduate Student

Questions?