Comparison of Motion in Chiari Type I Malformation Patients Versus Healthy Controls

Nymisha Goli, YSP Student, *Acton-Boxborough Regional High School*
Henry Mai, YSP Student, *Revere High School*
Hannah Higgins, Department of Bioengineering, *Northeastern University*
Dr. Francis Loth, Departments of Bioengineering
& Mechanical and Industrial Engineering *Northeastern University*

Northeastern University College of Engineering

Northeastern University Michael B. Silevitch and Claire J. Duggan Center for STEM Education

Abstract

Chiari Type 1 Malformation is a cerebrospinal fluid (CSF) disorder that affects around 1 in 1200 people globally, which is common. It occurs when the cerebellar tonsils descend into the spinal canal by ≥5 mm, restricting cerebrospinal fluid flow. Symptoms include Valsalva-induced occipital headaches, balance issues, and brainstem and cranial nerve issues. It is unknown why some people show symptoms such as headaches, while others with tonsillar herniations are asymptomatic. Currently, there are no metrics for who will improve from current surgical procedure options, which may benefit, harm, or have no effect on patients. Our research aims to find a correlation between biomarkers and symptoms to help improve the predictability of surgical intervention. We used MATLAB to analyze and graph 25 phase PC-MRI datasets of 40 patients to find differences in the motions of CSF and spinal cord (SC) motion in Chiari and healthy patients. We conducted two-sample t-tests looking at the velocity of the CSF and the SC in patients with Chiari patients and healthy controls. When looking at velocity, for CSF we found that 3/25 phases were statistically significant, while for SC, 7/25 phases were statistically significant. The same t-test was performed for the accelerations where 8/25 CSF and 6/25 SC phases were statistically significant. Further analysis is highlighted in the Results.

Background

Our research is centered around Chiari Type 1 Malformation (Figure 1), which is an understudied cerebrospinal fluid (CSF) neurological disorder.

The brain and spinal cord (SC) are surrounded by a water-like substance called CSF. The SC (to a lower magnitude) and CSF move up and down relative to the cardiac cycle that delivers blood in and out of the brain. The imaging modality used in our study is phase-contrast MRI (PC-MRI), a type of MRI that uses magnetic pulses to track the motion of hydrogen protons in fluid and tissue. As the hydrogen atoms move, the substance moving upwards appears white and the substance moving downwards appears black, allowing the velocity of voxels (a 3D "pixel" in a scan) to be captured. The PC-MRI dataset used in this study takes 25 scans called phases over one cardiac cycle (one heartbeat) and uses signals to create a video-like scan of fluids and tissue speeding up and slowing down.

Imaging technology, including PC-MRI, has 3 views: axial (primarily used in our research – Figure 2), sagittal (Figure 2), and coronal (did not use).

QR Code for PC-MRI Video

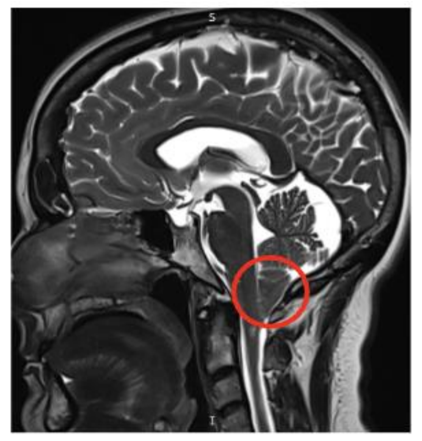

Figure 1: sagittal view of CSF crowding due to cerebellum

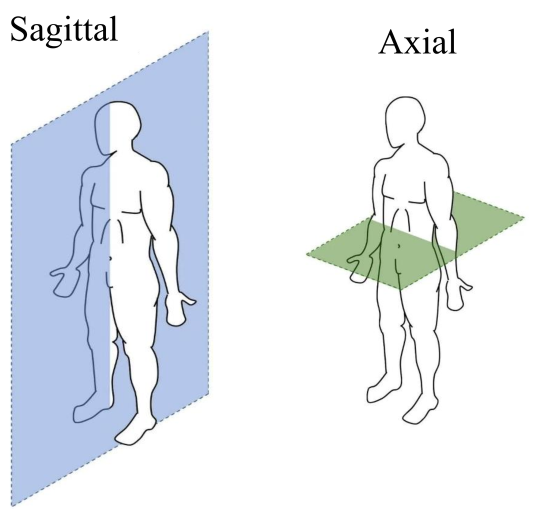

Figure 2: planes used in our study

Experimental Methods

1. PC-MRI Dataset — 30 Chiari and 10 Controls
2. MATLAB data collection — processes and obtains data from patient PC-MRI scan in the axial plane
   - Custom program allows for bulk and voxel-by-voxel selection with pop-up velocity vs phase graph to confirm whether it is CSF, SC, or unwanted noise
3. Excel and CSV — stores exported region of interest data with patient/subject ID attached
   - Voxel coordinates and within each selected voxel, there are 25 velocities over 25 phases (pictures of ROI) over a cardiac cycle
4. MATLAB data analysis — runs two-sample t-test, cross-correlation (CC), and Fast Fourier Transform (FFT) to compare the motion by phase for Chiari patients and healthy controls.

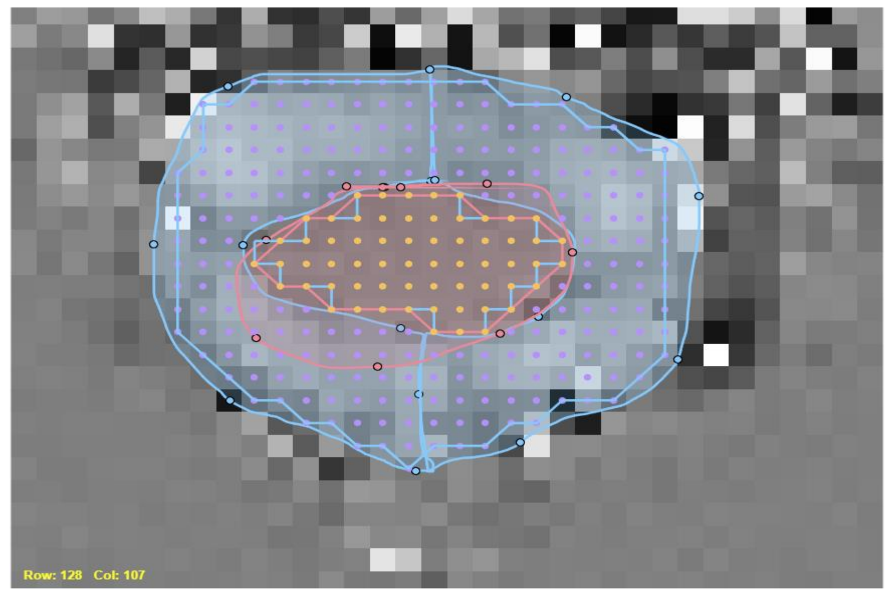

Figure 3: user interface of selection software; yellow for SC and purple for CSF

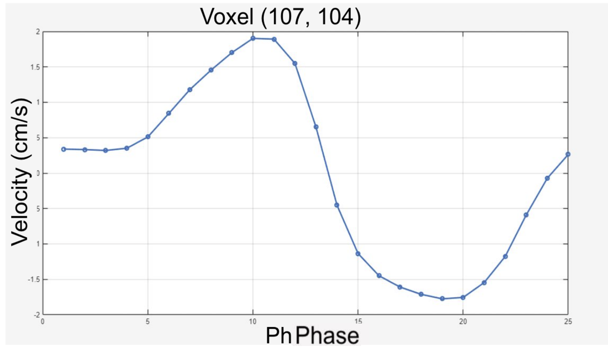

Figure 4: ideal voxel data w/o distortions

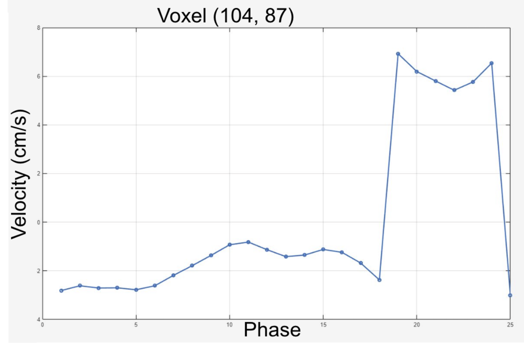

Figure 5: non-ideal voxel data w/ distortions

Results

→ For figures 6 – 9, within each phase, a 2-sample t-test was run between each mean value for Chiari vs healthy

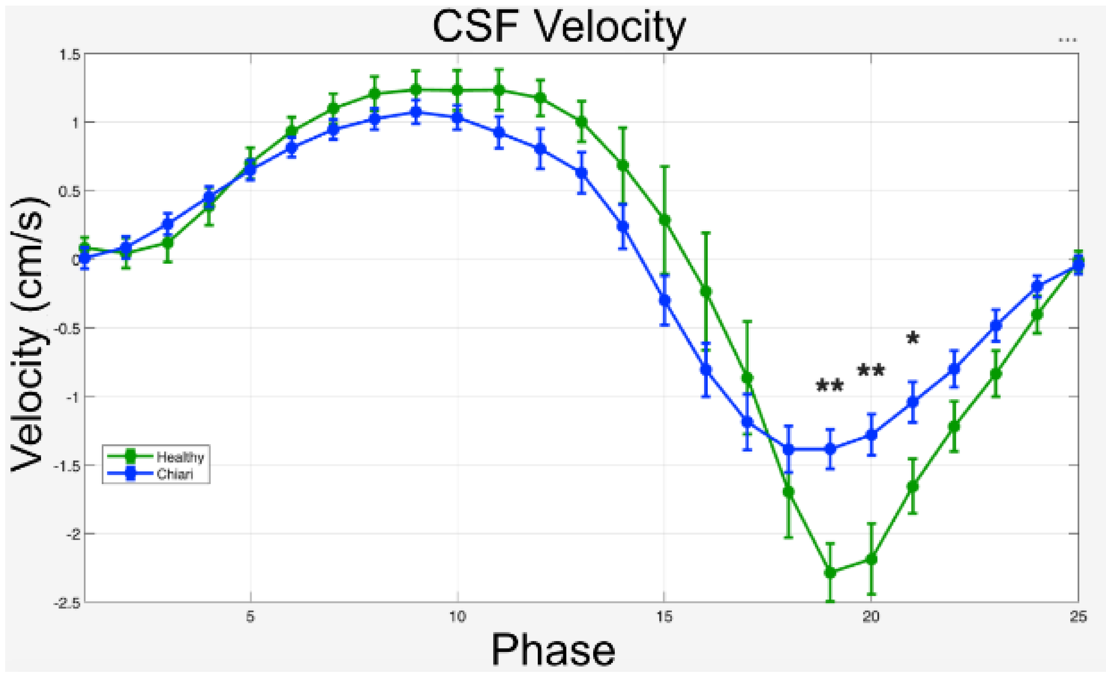

Figure 6: CSF velocity vs phase for Chiari vs healthy; 1 star $p \leq 0.05$ 2 stars $p \leq 0.01$ 3 stars $p \leq 0.001$

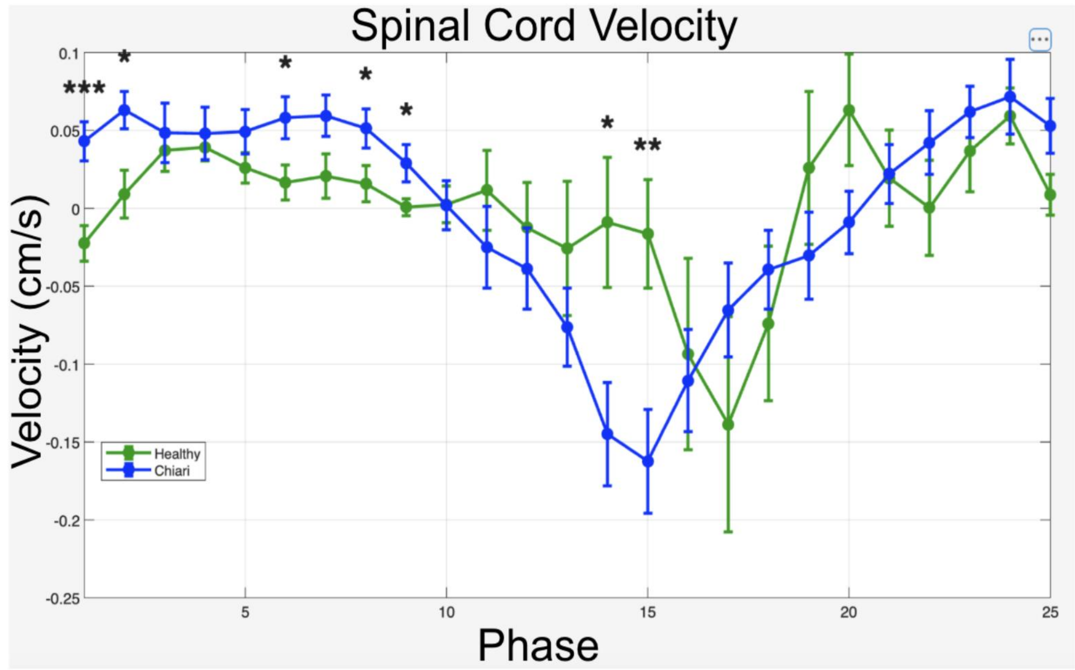

Figure 7: SC velocity vs phase for Chiari vs healthy; 1 star $p \leq 0.05$ 2 stars $p \leq 0.01$ 3 stars $p \leq 0.001$

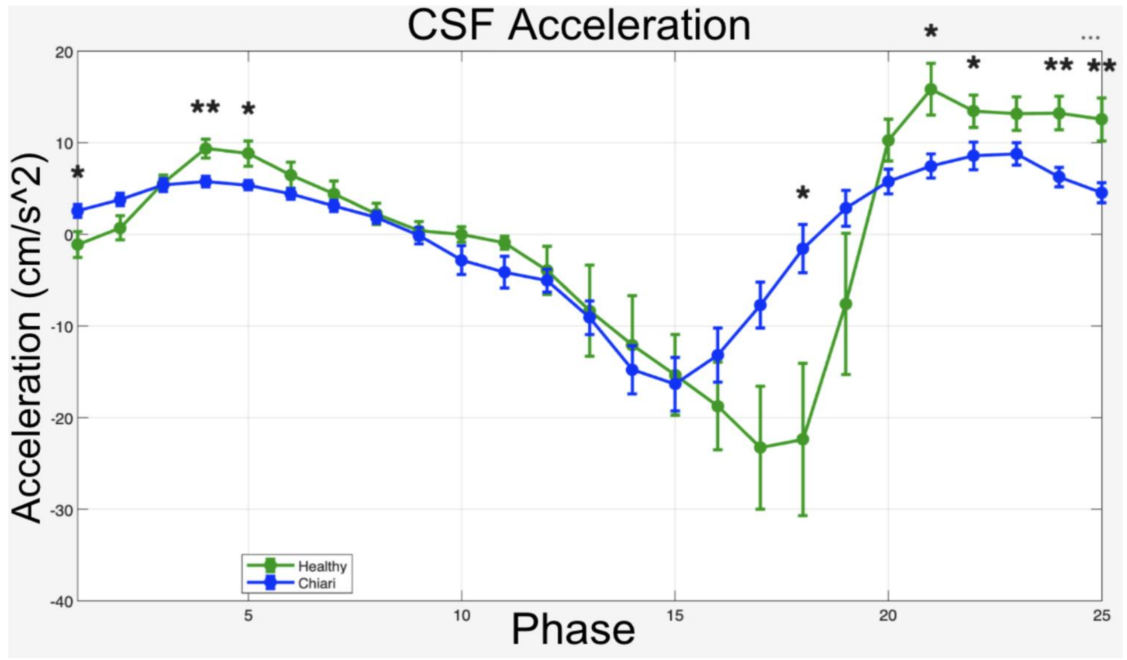

Figure 8: CSF velocity vs phase for Chiari vs healthy; 1 star $p \leq 0.05$ 2 stars $p \leq 0.01$ 3 stars $p \leq 0.001$

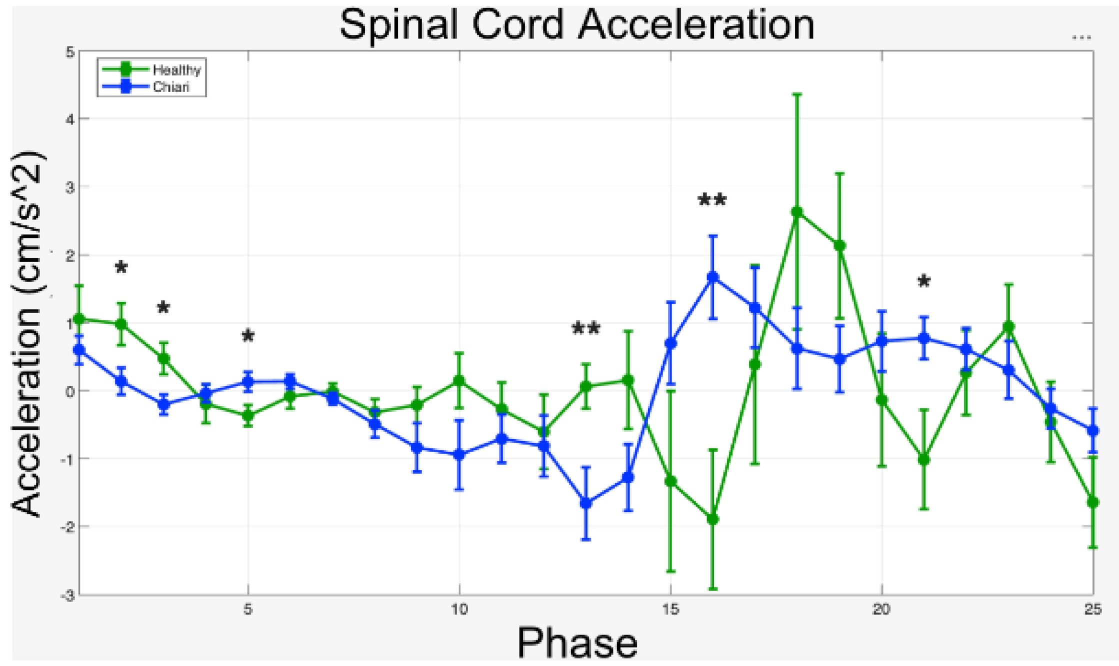

Figure 9: SC velocity vs phase for Chiari vs healthy; 1 star $p \leq 0.05$ 2 stars $p \leq 0.01$ 3 stars $p \leq 0.001$

Conclusion and Future Steps

Significant differences were observed at and around the downward peaks of both velocity and acceleration for the CSF and SC between the Chiari patients and healthy controls. We were able to collect and analyze data, which adds to small number of existing velocity waveform analyses of Chiari Type I Malformation.

Healthy controls had a higher magnitude in velocity extremas than Chiari patients, which were shown to be statistically different. CC and FFT showed no statistical difference.

Future research could investigate the other spinal landmarks instead of the lower C2 level, measurements other than motion, tools to better eliminate distorted data, and differences in subpopulations such as females versus males or pre-surgery versus post-surgery.

References

Clarke, E. C., Stoodley, M. A., & Bilston, L. E. (2013). Changes in temporal flow characteristics of CSF in Chiari malformation Type I with and without syringomyelia: implications for theory of syrinx development. *Journal of neurosurgery*, *118*(5), 1135–1140. https://doi.org/10.3171/2013.2.JNS12759

Eppelheimer, M. S., Nwotchouang, B. S. T., Heidari Pahlavian, S., Barrow, J. W., Barrow, D. L., Amini, R., Allen, P. A., Loth, F., & Oshinski, J. N. (2021). Cerebellar and Brainstem Displacement Measured with DENSE MRI in Chiari Malformation Following Posterior Fossa Decompression Surgery. *Radiology*, *301*(1), 187–194. https://doi.org/10.1148/radiol.2021203036

Labuda, R., Nwotchouang, B. S. T., Ibrahimy, A., Allen, P. A., Oshinski, J. N., Klinge, P., & Loth, F. (2022). A new hypothesis for the pathophysiology of symptomatic adult Chiari malformation Type I. Medical hypotheses, 158, 110740. https://doi.org/10.1016/j.mehy.2021.110740

Nwotchouang, B. S. T., Eppelheimer, M. S., Bishop, P., Biswas, D., Andronowski, J. M., Bapuraj, J. R., Frim, D., Labuda, R., Amini, R., & Loth, F. (2019). Three-Dimensional CT Morphometric Image Analysis of the Clivus and Sphenoid Sinus in Chiari Malformation Type I. *Annals of biomedical engineering*, *47*(11), 2284–2295. https://doi.org/10.1007/s10439-019-02301-5

Yildiz, S., Thyagaraj, S., Jin, N., Zhong, X., Heidari Pahlavian, S., Martin, B. A., Loth, F., Oshinski, J., & Sabra, K. G. (2017). Quantifying the influence of respiration and cardiac pulsations on cerebrospinal fluid dynamics using real-time phase-contrast MRI. Journal of magnetic resonance imaging : JMRI, 46(2), 431–439. https://doi.org/10.1002/jmri.25591

Acknowledgements

Chiari Neurobiomechanics Research Laboratory
Hannah Higgins, PhD Student, Bioengineering
Francis Loth, PhD, Prof. of Bioengineering, Prof. of Mechanical and Industrial Engineering
Center for STEM Education
Claire Duggan, Executive Director
Jennifer Love, Associate Director
Ahmed Othman & Kenneth Santizo Carbajal & Frances Corcell, YSP Coordinators
Nicolas Fuchs, Program Manager
Mary Howley, Administrative Officer

Young Scholars Program at Northeastern University
Claire Duggan, Program Director

This work was supported by the National Science Foundation