Computational fluid dynamics applied to Chiari Malformation

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Importance for Chiari patients

Objective diagnosis of Chiari malformation is challenging. In particular, it is difficult to diagnosed Chiari with mild herniation. In this project we use computational fluid dynamics (CFD) to help identify new objective measurements that could be used to help diagnose Chiari severity.

Abstract

This study investigates the use of longitudinal impedance (LI) as a means to quantify the severity of Type I Chiari Malformation (CMI). LI was computed from image-based CFD models of the cervical spine for 22 CMI patients and 10 healthy volunteers. LI was compared with the cerebellar tonsil herniation (CTH). Results showed that both LI and CTH differentiated CMI patients from healthy volunteers. Further analysis is needed to determine if it is possible to differentiate symptomatic and asymptomatic patients.

Introduction

CMI is classically characterized by tonsillar herniation ≥5 mm below the foramen magnum (FM) [1]. However, it has been shown that CTH does not always correlate with symptom severity [2]. Thus, another measurement to quantify disease severity may be useful. One potential measurement is LI, or the impedance to pulsatile flow in a fluid conduit, which is a function of conduit geometry. Due to the importance of conduit geometry in CMI, we hypothesized that LI would help stratify healthy subjects from asymptomatic and symptomatic CMI patients and would correlate with CTH.

Methods

Twenty two CMI patients were selected for the study. The inclusion criterion was CTH ≥5 mm beyond the FM into the cervical spinal canal. Patients were further classified as symptomatic or asymptomatic based on the presence or absence of sufficient neurological symptoms to warrant corrective surgery. Patients were compared with a group of ten healthy volunteers with no history of neurological disorder or spinal trauma. CTH for all subjects was measured independently by two neurosurgeons, neither of whom made the original diagnoses. Geometric models of the cervical spine between the FM and C2 level were reconstructed from high-resolution MRI (Figure 1).

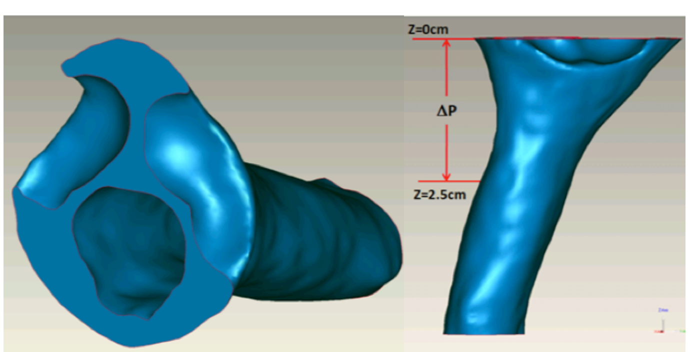

Figure 1. Example of a cervical spine geometry model and length over which pressure drop was calculated for impedance analysis.

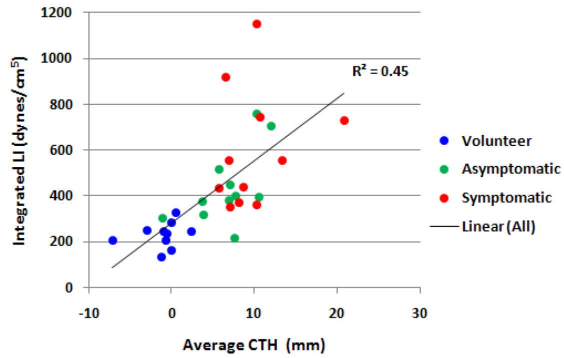

Figure 2. Integrated LI as a function of average CTH depth.

Subject specific CSF flow waveforms were obtained at the C2 level of the spine and used for the CFD simulation of each case. Pressure drop and flow were used from each case to calculate an integrated LI (ILI) modulus. ILI and CTH were then compared statistically.

Results

Figure 2 shows the relationship between ILI and CTH. In low impedance cases, ILI showed a strong linear correlation with CTH. However, at greater LI, the linear correlation was much weaker. Mean values of CTH depth and ILI for both the symptomatic and asymptomatic CMI patient groups were significantly different from healthy volunteers ($p<0.001$ for all tests). The test failed to find a statistical difference between CMI patient groups for either parameter (Table 1). The lack of a statistical difference may have been the result of two factors: (1) Large differences in the CTH depth measurements made by the two neurosurgeons; (2) Standard deviation in ILI for cases with CTH greater than 5 mm was 285% greater than in those with lesser herniations.

Table 1. Mean CTH and integrated LI for each subject group

	Symptomatic	Asymptomatic	Volunteer
Average CTH (mm)	9.9 (SD 4.3)	6.8 (SD 3.7)	-1.0 (SD 2.5)
Integrated LI (dynes/cm^5)	600 (SD 259)	438 (SD 164)	229 (SD 56)

Conclusions

LI appears to be a useful parameter in quantifying geometric differences between CMI patients and healthy volunteers. However, it appears to vary greatly for herniations larger than 5 mm and the relationship between integrated LI and CTH is less clear. A larger and more controlled study population is needed to fully understand the clinical relevance, if any, of LI.

References

1. Milhorat, T.H., et al. Neurosurgery, 1999. 44(5): p. 1005-17.
2. Meadows, J., et al. J Neurosurg, 2000. 92(6): p.920-6.