3D CFD Quantification of CSF Movement in Chiari Patients by 4D PC MRI

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Importance for Chiari patients

In this project, our team has developed and tested a novel MRI based technique to measure the complex 3D motion of CSF in Chiari malformation. Our results show new information about the 3D CSF flow field that have never before been seen. We expect this MRI technique to help medical doctors understand underlying hydrodynamic factors that could contribute to Chiari pathophysiology.

Introduction

The underlying physiological importance of the pulsatile movement of CSF around the brain and spinal cord is not known. One of the major barriers to understanding CSF physiology is the limited information that can be obtained from the current phase contrast MRI (pc MRI) measurements that are used clinically. These measurements are limited to a single measurement plane and measure velocity in a single direction; thus they do not allow for analysis of complex 3D CSF flow patterns that can be present in Chiari I Malformation (CMI).

Recent progress in MRI sequence development has led to a novel 4D pc MRI technique that can measure blood movement in 3D (e.g. in the heart and aorta to help diagnose cardiovascular problems). In this project, our aim was to adapt the 4D pc MRI sequence to measure CSF movement in Chiari patients.

Methods

The 4D pc MRI technique was adapted and then used to obtain CSF flow in three healthy volunteers and four Chiari patients (Figure 1). To better understand the 4D pc MRI measurements, computational fluid dynamics (CFD) simulations were carried out for each volunteer and patient with subject specific geometry and flow input. The 4D pc MRI and CFD simulations were then compared in terms of 1) peak velocities and 2) velocity profiles (Figure 2 for study workflow diagram). The purpose of the comparison was to determine if the CFD simulation was done with enough detail to mimic in vivo CSF dynamics, an approach sometimes called "reverse engineering".

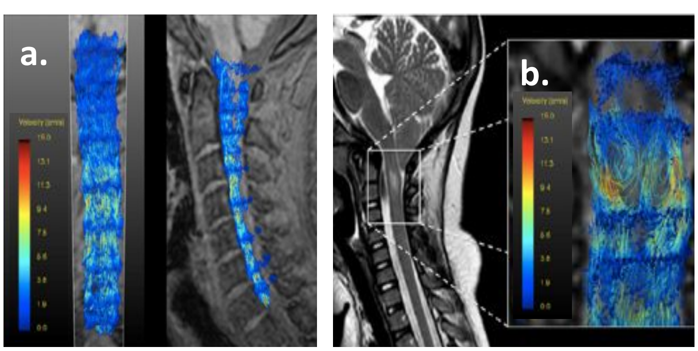

Figure 1. 3D CSF flow pattern measured by 4D pc MRI at systole in a healthy volunteer (a) and a Chiari patient (b) [1]. Note the complex CSF flow patterns near the base of the brain in the Chiari patient just below the level of the tonsils. Also, note the elevated CSF flow velocities on the anterior side of the spinal cord in the healthy subject.

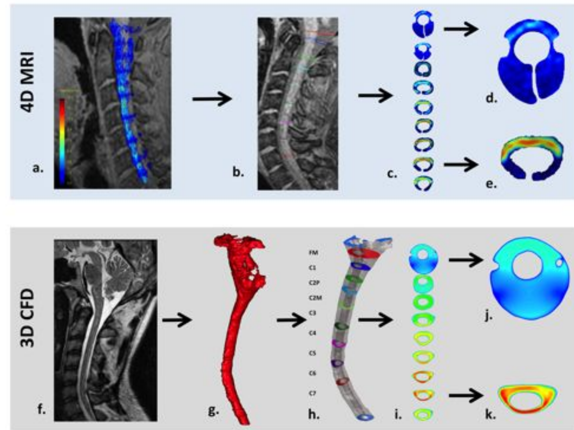

Figure 2. Study methodology diagram. 4D pc MRI measurement (a) and flow quantification (b,c,d & e). 3D CFD simulation: MRI measurement of geometry (f), 3D reconstruction of geometry (g), CFD simulation (h) and measurement plane comparison (i, j & k) [2].

Results

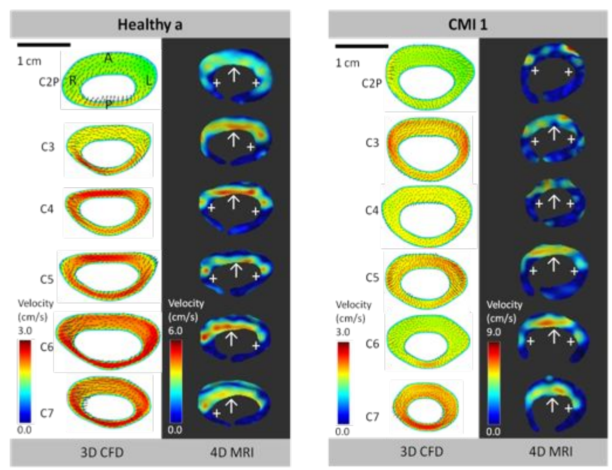

Figure 4. a) Peak CSF velocities b) Velocity profiles for a healthy subject and CMI patient. ↑ highlights the elevated anterior CSF flow velocities in comparison to the posterior that were observed by the 4D MRI. + indicate locations where the nerve roots appear to be slowing CSF motion [2].

Conclusions

1. 4D pc MRI was successful to quantify complex CSF flow dynamics in Chiari patients
2. Peak CSF velocities were greater in 4D pc MRI than CFD
3. Anterior CSF flow was dominant in 4D pc MRI measurements but not in the CFD simulations
4. The differences in the 4D pc MRI vs. CFD results suggest that small anatomical structures in the CSF flow field have an important impact on CSF dynamics.

References

1. Bunck et al., 2011, "Magnetic Resonance 4d Flow Characteristics of Cerebrospinal Fluid at the Craniocervical Junction and the Cervical Spinal Canal," E Radiology
2. Yiallourou TI, Odier C, Heinzer R, Hirt L, Martin BA, Stergiopulos N, Haba-Rubio J (2012) The effect of continuous positive airway pressure on total cerebral blood flow in healthy awake volunteers. Sleep Breath.

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