Construction and Testing of a 3D Printed Model of the CSF System

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Importance for Chiari patients

The current MRI measurements used to measure CSF velocity are obtained in 2D. One drawback of the 2D measurements is that they give a limited perspective of the full 3D motion of CSF in Chiari malformation patients. The aim of this project is to build a 3D model of the upper cervical spine and use the model to develop new MRI techniques to quantify CSF velocity in 3D. These MRI techniques could help medical doctors quantify the severity of Chiari malformation obstruction to CSF flow in greater detail.

Abstract

An in-vitro model of the upper cervical spine has been built using state-of-the-art 3D printing technology. This model includes the spinal cord nerve roots and has the most anatomical detail of any model of the cervical spine in the world. The next step of this work is to measure the flow field within the model by 4D PC MRI and compare the measured flow field with a 3D computational fluid dynamics (CFD) simulation based on the same geometry.

Introduction

Recent advancements in MRI flow measurement technology have enabled measurement of the three dimensional velocity encoded phase contrast MRI of the CSF flow field within the spine (4D PC MRI, Figure 1) . However, the 4D PC MRI flow measurements have not yet been quantitatively evaluated. Careful evaluation of the 4D PC MRI is needed to understand the robustness/limitations of the technique, factors that must be considered before the technology can be confidently used to quantify CSF dynamics in Chiari patients.

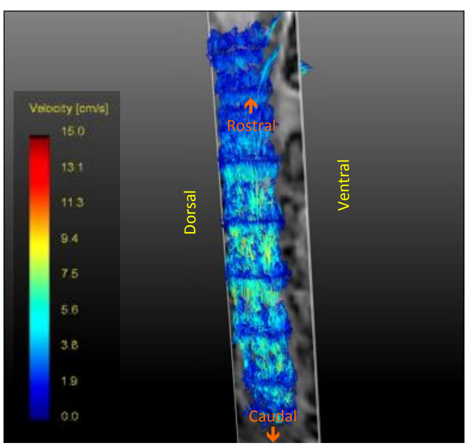

Figure 1. 4D MRI Velocity flow field for a healthy volunteer (Image courtesy of A. Bunck [1]).

Methods

Our approach is to construct in vitro models of the cervical spine with realistic anatomy and test the models with 4D PC MRI. The dura and spinal cord geometry were obtained from MRI measurements on a Chiari malformation patient and a healthy subject (Figure 2, top). Idealized spinal cord nerve roots were added to the model based on information in the literature. Extension ports were added to the model to allow flow connections (Figure 2 bottom). The model was 3D printed with a resolution of 75 µm (Figure 3).

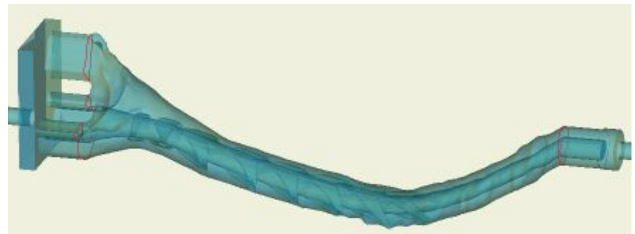

Figure 2. Computer aided design of the cervical spine used for 3D rapid-prototyping (Note: dura is shown semi-transparent to see the nerve roots).

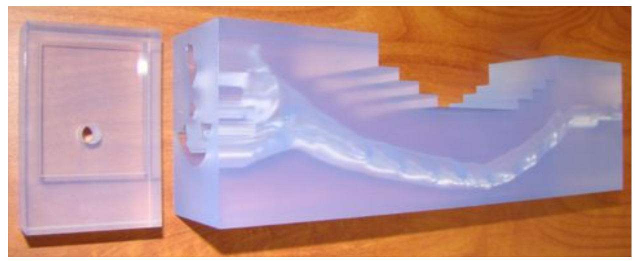

Figure 3. Final 3D printed model of the cervical spine and input adaptor (left).

Results and Discussion

A 3D model of the cervical spine was successfully constructed (Figure 3). This model provides an unprecedented level of anatomical detail by including the spinal cord nerve roots. The next steps are to: 1) obtain 4D PC MRI measurements, 2) complete a 3D CFD simulation, 3) perform laboratory bench-top tests and 4) Compare the MRI, CFD and lab tests in terms of velocity and pressure (Figure 4). We expect that the 3D CFD calculations will agree qualitatively with the 4D PC MRI flow measurements in terms of the location of fluid vortices and velocity field within the model.

Conclusion

This study will help better understand the advantages and drawbacks of 4D PC MRI and its potential as a clinical tool for assessment of Chiari malformation. It will also help understand the impact of spinal cord nerve roots on CSF dynamics.

Figure 4. Study flow chart.

References

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