The Applicability of a Meshless Cerebrospinal Fluid in Traumatic Brain Injury Head Models

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Objective

Our aim is to determine the accuracy of a mesh-free method, Smoothed Particle Hydrodynamics (SPH), for modeling the biomechanics of cerebrospinal fluid (CSF) during impact loading of the head.

Introduction

The interaction between the brain and the skull during impact head loading is a key to the prediction of traumatic brain injury. Reducing the complex and highly variable structures which populate the skull-brain interface down to a simplified definition has been done in previous work, through using Lagrangian elements and defining contact between the boundaries as slip or tied. However, the CSF layer can undergo larger distortions, which renders Lagrangian elements inaccurate. Recently the arbitrary Lagrangian-Eulerian approach has been used to model CSF, but this work is limited to simple brain and CSF geometries. As computational power increases so does the ability to generate models with a greater level of detail; structures such as sulci, gyri, and vasculature can be included for the prediction of pathologies such as chronic traumatic encephalopathy and subdural hematoma. Here we test whether a mesh-free method, SPH, can accurately predict brain/skull relative displacement during head impacts.

Method

A 2D parasagittal slice of the brain, which includes skull, dura, tentorium, grey matter, white matter, brain stem and CSF, is created from a previously validated 3D model of the head and verified anatomically through comparison to MRI scans of the subject (Figure 1a and b). Two 2D models are created; one using Lagrangian solid elements for all tissues (Figure 1c), and the second identical except the CSF is represented as SPH particles (Figure 1d). In the second model, the effects of the SPH formulation, particle distance, smoothing length and material model on the brain/skull relative displacement are investigated.

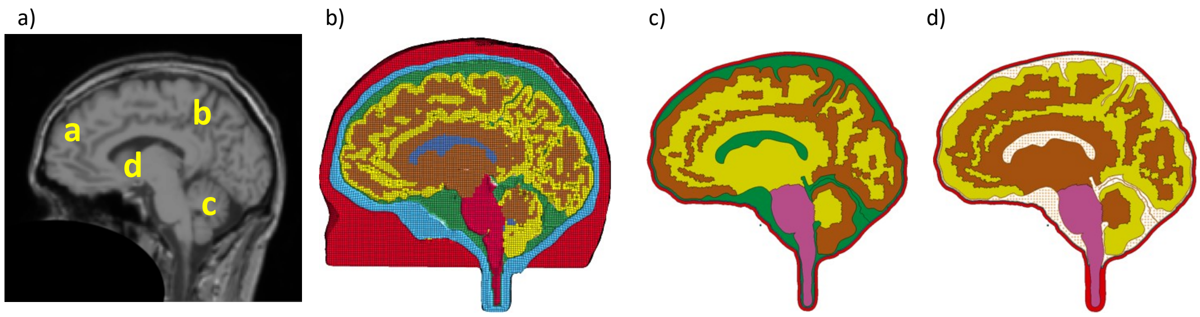

Figure 1: a – T1 MRI scan of parasagittal plane taken from subjec with lables showing the four locations in the brain investigated, b – Parasagittal slice of brain model used as basis for creation of this study's model, c – Solid element model (mesh not shown) created in this study, d – Example hybrid solid element (mesh not shown) and SPH model created in this study

The models were used to predict in vivo relative displacement data of the brain to the skull. Velocities, calculated from in vivo displacement data, were prescribed for the skull, and the relative brain displacements in the frontal, parietal and temporal lobes, and cerebellum, were compared to in vivo data.

RESULTS

The mesh-free method is found to produce relative brain displacements which predict similar levels of magnitude to the in vivo data (Figure 2), where the Lagrangian mesh typically under predicts magnitude of displacement (Figure 3). The choice of formulation has minimal effect and produces one of two general outcomes (figure 2), and smoothing length and particle distance do not converge as expected, however the ideal values for this model were deduced to be around 1.5mm for smoothing length and 0.7mm for particle distance.

CONCLUSION

This study shows that the SPH mesh-free approach to modelling the CSF can significantly improve the prediction of brain/skull relative displacement over the commonly used finite elements. Future work should focus on extending this approach to 3D models, which incorporate detailed anatomy of tissues and should provider a greater level of biomechanical accuracy. This work can potentially help us improve our understanding of biomechanics of vascular injury, contusions and neurodegenerative disease, chronic traumatic encephalopathy.

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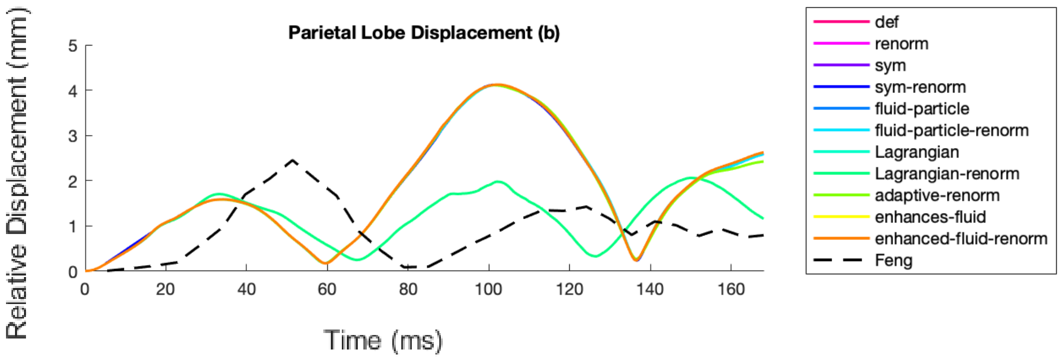

Figure 2: Comparison of different SPH formulations (solid, coloured lines) to displacement data from literature (black, dotted line) of the parietal lobe (b)

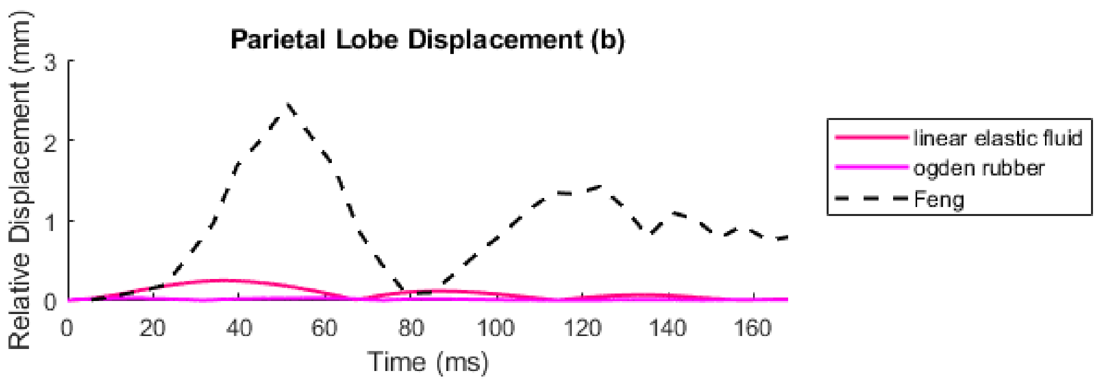

Figure 3: Solid element, Lagrangian mesh model using Fluid elastic and Ogden rubber material models. Data from Literature is shown as a blue corridor of the parietal lobe (b)