Computational Analysis of White Matter Response to Rear and Lateral Impacts

Mazdak Ghajari, David J. Sharp*

I. INTRODUCTION

Traumatic Brain Injury (TBI) is often caused by inertial loading, which leads to excessive brain deformation and damage to nerve cells and fibres (axons). Computational models of the human head can provide useful information about the mechanical behaviour of the brain during loading. These are usually developed by using medical images and contain details about some aspects of brain anatomy. Previous models have not fully incorporated information about organisation of white matter tracts, however, which is a key factor in determining the effect of inertial loading on axonal integrity. An advanced MRI technique, diffusion MRI (dMRI), allows the structure of white matter tracts to be mapped and also provides a method of quantifying their damage after TBI [1]. A few researchers have incorporated the information provided by dMRI into their Finite Element (FE) head models in order to estimate white matter injury [2-4]. However, their models are either two-dimensional or the discretisation is too coarse, which affects their ability to make predictions for individual white matter tracts.

Here we present a new methodology, based on using a finely discretised three-dimensional FE model of the human head and image-processing techniques, for determining mechanical response of 23 white matter tracts to head loading, and use the approach to compare the effects of rear and lateral head impacts on the brain.

II. METHODS

Computational Modelling

An FE model of the human head was developed in LS-DYNA format from the T1-weighted images of a healthy male subject (age 34). The brain, skull and scalp were extracted and segmented using the Brain Extraction Tool from the FMRIB Software Library [5] and the Segmentation Tool of the Freesurfer software [6]. The images were combined to build a head image, which was converted to an FE mesh of 1.5 mm hexahedral elements (Fig. 1, *left*). The jagged edges of the mesh were smoothed, and the inner and outer skull layers, the *pia mater* and the flax and tentorium were added to the FE model. The Ogden hyperelastic model combined with a linear viscoelastic model was used for the brain. Continuum damage mechanics models were used for the skull layers. The other parts were elastic. Material properties were obtained from literature.

Diffusion weighted images of the same subject were processed using the Bedpostx Tool [7] from the FMRIB Software Library. The map of fibre directions was used to determine computationally predicted mechanical parameters along the fibres. Falls onto a rigid surface at an impact velocity of 5.3 m/s, resulting in impacts to the rear and left sides, were simulated. The displacements and velocities of the brain nodes, recorded for 15 ms, were post-processed to determine for each element the peak stretch along the fibre direction (axial stretch). The results were written in the NIfTI medical image format. The images were "skeletonized" as described in [1] (Fig. 1, *right*). Then, the John Hopkins University White Matter Tractography Atlas was used to determine the mean axial stretch in the central points of 23 white matter tracts.

III. INITIAL FINDINGS

A horizontal view of the skeletonized axial stretch map for the rear impact is shown in Fig. 1 (*right*). The yellow (lighter) colour indicates regions with higher axial stretch. In Fig. 2, the mean axial stretch of the white matter tracts is compared between the rear and lateral impacts. As can be seen, the simulation predicts higher axial stretch in all tracts for the lateral impact with larger axial stretches in the right hemisphere.

* M. Ghajari is a research fellow in Biomechanics and Mitigation of Traumatic Brain Injury in Department of Aeronautics (tel: +442075945140, e-mail: m.ghajari@imperial.ac.uk) and D. J. Sharp is a Professor of Neurology in Department of Medicine, both at Imperial College London.

IV. DISCUSSION

The simulation results suggest that the brain is more vulnerable to lateral impacts, consistent with the findings of previous experimental and computational studies [8-9]. The computational predictions are presented as 3D images with a resolution comparable with that of diffusion images. This enables direct comparisons with images of diffusion markers of white matter injury, e.g. fractional anisotropy, in order to further establish the mechanisms of white matter injury and their relation with the cognitive outcome after TBI.

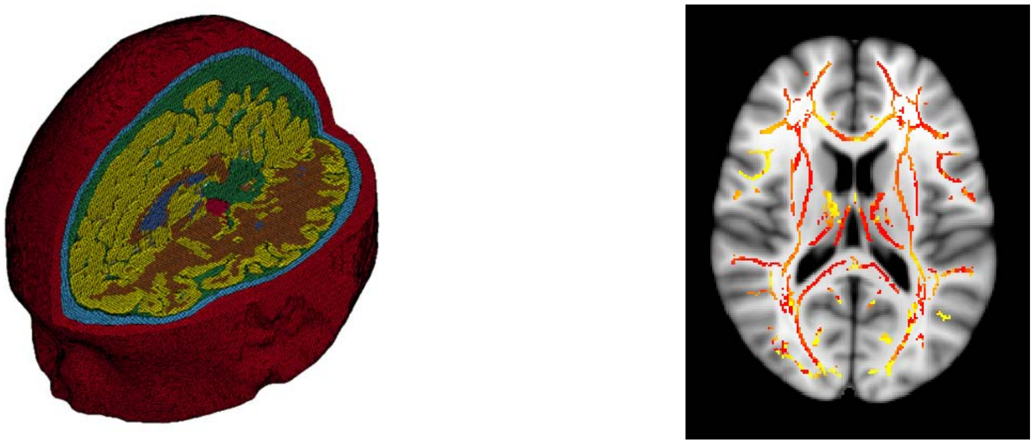

Fig. 1. The FE human head model (*left*) and a skeletonized axial stretch image (*right*).

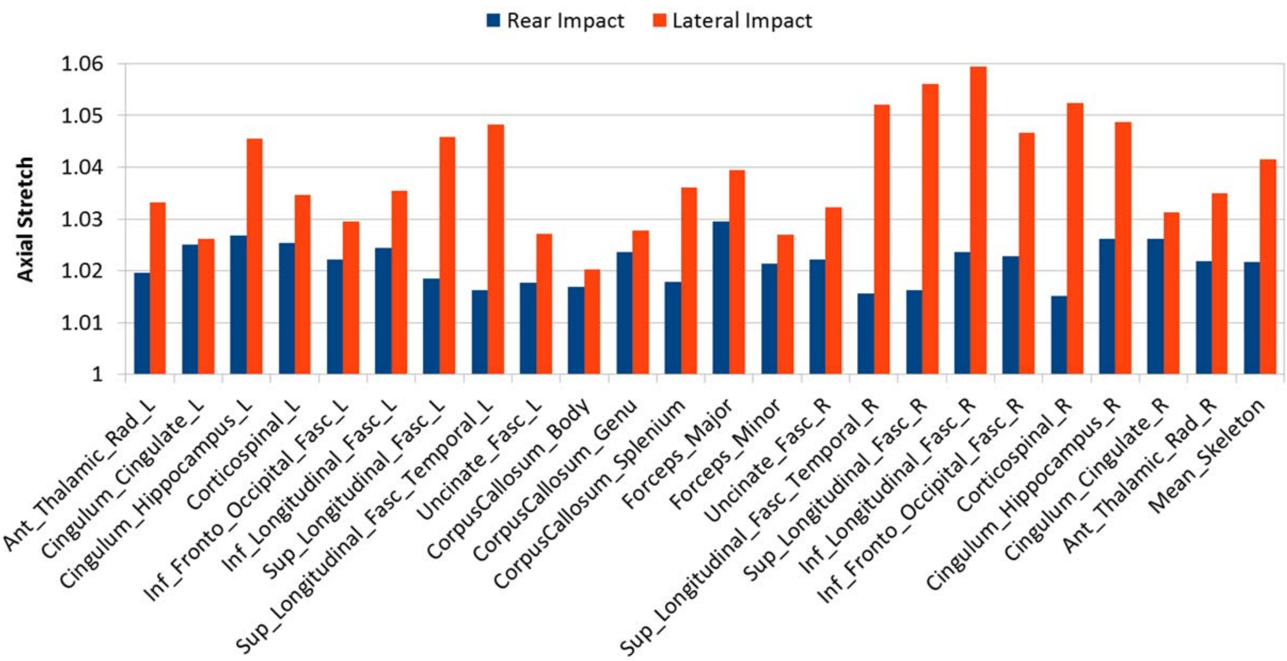

Fig. 2. Comparison of the mean axial stretch of the tracts between rear and lateral impacts.

V. REFERENCES

[1] Kinnunen, K. M., et al. *Brain*, 2011.
[2] Colgan, N. C., et al. *Prog Biophys Mod Biol*, 2010.
[3] Chatelin, S., et al. *J MechBehav Biomed Mater*, 2011.
[4] Wright, R. M., et al. *J Neurotrauma*, 2013.
[5] Smith, S. M. *Hum Brain Mapp*, 2002; Smith, S. M., et al. *Neuroimage*, 2004.
[6] Fischl, B. D. H., et al. *Neuroimage*, 2004.
[7] Behrens, T. E. J. et al. *Neuroimage*, 2007.
[8] Hodgson, V. R. et al. *Stapp Car Crash J*, 1983.
[9] Zhang, L., et al. *J Neurotrauma*, 2001.