Investigation of CSF Volumetric Response and Skull Flexure Effect on Blast Induced Traumatic Brain Injury

Xiancheng Yu, David J. Sharp, Mazdak Ghajari

I. INTRODUCTION

Mechanisms of blast-induced traumatic brain injury (bTBI), particularly the role of primary pressure wave, are still not fully understood. Recent neuropathological analyses of brain tissue from post-mortem cases of bTBI indicate that the brain tissue close to ventricles sustains damage [1]. This damage is likely to be produced by large loadings concentrated at the boundary of the brain and ventricles. Two possible explanations for this location of injury are CSF cut-off pressure effect and skull flexure effect. The brain tissue and CSF have a very similar volumetric response under positive pressure, but CSF can only bear negative pressures up to its vapour pressure (-100 kPa), which usually refers to cut-off pressure [2]. CSF cut-off pressure can create a discontinuous pressure distribution, which may lead to strain concentration at its boundary with brain. Blast pressure wave can also generate skull flexure, causing brain deformations. Here we investigate whether CSF cut-off pressure and/or skull flexure can produce large strain and strain rate concentrations at the CSF/brain interface.

II. METHODS

To test this hypothesis, we developed a 2D human head FE model of bTBI (Fig. 1), composed of skin, skull, CSF, brain and ventricles. The skin and skull were modelled by linear elastic models and the brain was modelled using a viscoelastic material model. To model CSF volumetric response under negative pressure, a cut-off pressure was defined in the material model. If the pressure drops below the cut-off value, it is reset to that value. The CSF cut-off pressure effect was investigated by comparing brain deformation of CSF material models with and without cut-off pressure. The effect of skull flexure was studied by increasing skull stiffness. We simulated detonation of a TNT charge, generating a 12.5 bar incident pressure (Fig. 1).

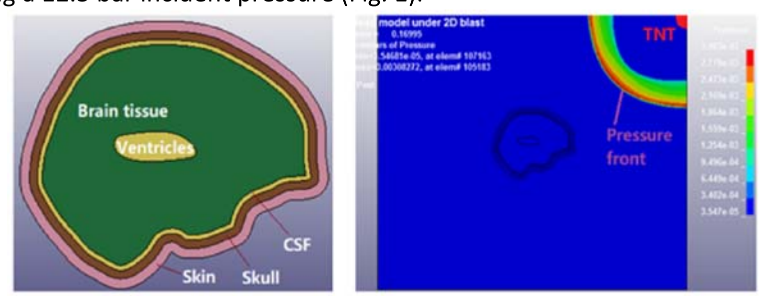

Fig. 1. 2D human head FE model and blast loading generation. (In all simulations, the positive phase duration of the blast wave is 0.2 m/s and the incident overpressure are 12.5 bar.)

III. INITIAL FINDINGS

Figure 2 shows that CSF cut-off pressure leads to strain discontinuity at the CSF/brain interface and elevated strain levels in brain. Similar effects can be seen for strain rate distribution (Fig. 3), though the discontinuity is not as pronounced as for strain distribution. Fig. 4(a) shows that increasing skull stiffness reduces the strain level within cranium, but it does not have a significant effect on strain distribution, as shown in Fig. 4(b), which has a lower limit for strain contour. Interestingly, increasing skull stiffness did not have a significant influence on the level and distribution of strain rate (Fig. 5).

X. Yu (e-mail: x.y16@imperial.ac.uk; tel: +44 07497225458) is a PhD student and M. Ghajari is a lecturer in computational biomechanics, both at the Dyson School of Design Engineering, Imperial College London. D. J. Sharp is a professor in Neurology at the Department of Medicine, Imperial College London.

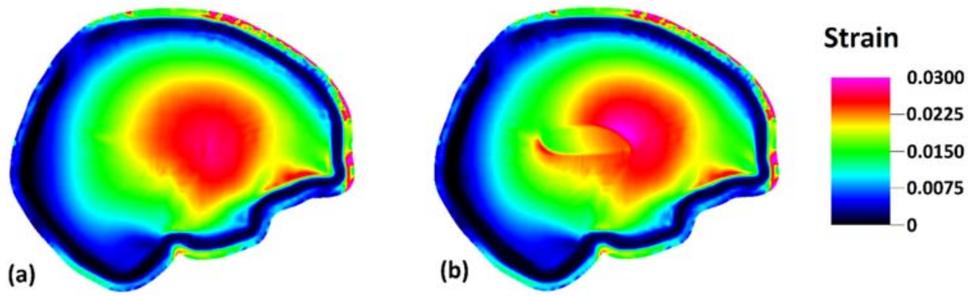

Fig. 2. Strain distribution of brain, using CSF models (a) without cut-off pressure and (b) with cut-off pressure.

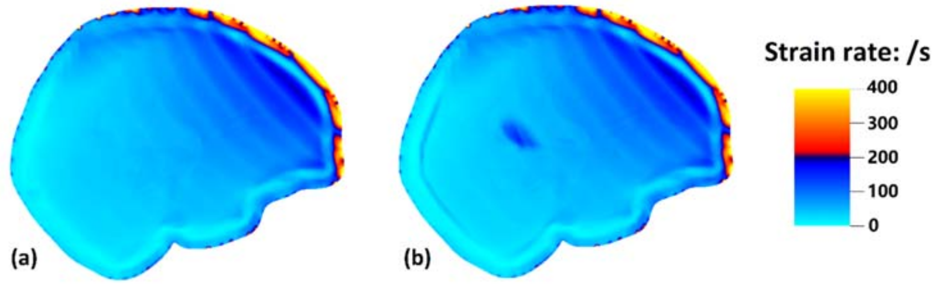

Fig. 3. Strain rate distribution of brain, using CSF models (a) without cut-off pressure and (b) with cut-off pressure.

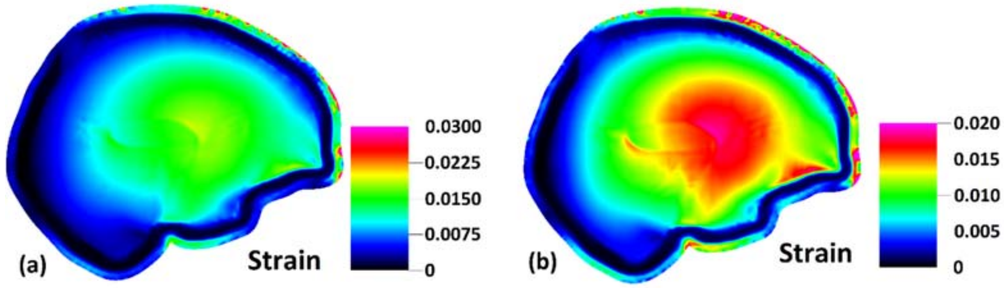

Fig. 4. Strain distribution of brain with a five times stiffer skull (a) strain contour range: 0–0.03 and (b) strain contour range: 0–0.02.

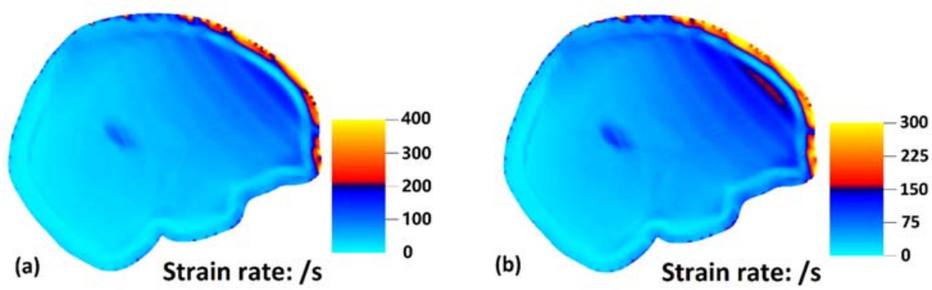

Fig. 5. Strain rate distribution with a five times stiffer skull (a) strain rate contour range: 0–400 /s and (b) strain rate contour range: 0–300 /s

IV. DISCUSSION

In this study we used a 2D brain model, an approach adopted in previous work [3], which is one of its limitations. We will extend the work by using 3D models. Our results suggest that blast pressure wave can cause CSF pressure dropping to cut-off pressure, which leads to strain concentration in the brain near ventricles, and that skull flexure increases the level of strain. These results may have implications for novel ways to better prevent bTBI.

V. REFERENCES

[1] Shively, S., *et al.*, *Lancet Neurology*, 2016.
[2] Goeller, J., *et al.*, *J Neurotrauma*, 2012.
[3] Panzer, M. B., *et al.*, *Ann of Biomed Eng*, 2012.