

Investigation of Head Response to Blast Exposure

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I. INTRODUCTION

The prevalence of blast-related mild traumatic brain injury (mTBI) in recent military conflicts, attributed in part to an increased exposure to improvised explosive devices (IEDs), requires further understanding to develop methods to mitigate the effects of primary blast exposure. Although blast injury has been studied extensively since the 1950s, many aspects of mTBI remain unclear, including the kinetic and kinematic response of the head to blast loads and the associated timeframes over which injury can occur. Exposure to a blast typically occurs over 1–10ms [1], depending on the standoff and size of explosive. It has been hypothesised that skull flexure resulting from blast exposure could increase intracranial pressures leading to injury [2]. This study aims to investigate the kinetic and kinematic response of the head using finite element (FE) models to determine the timing and magnitude of intracranial pressure and skull flexure from exposure to blast.

II. METHODS

The computational limitations present in analysing a full three-dimensional blast head model, namely the long computation time resulting from the necessary refined FE mesh, led to the development of sagittal and transverse planar models [3]. The models incorporate a fully coupled analysis with the required mesh resolution while remaining computationally feasible for parametric studies. The models comprise a single layer of solid hexahedral elements under plane strain conditions, and include all of the relevant tissues in the head, including the skin, muscle, skull, cerebrospinal fluid, and brain based on the geometry of the visible human project [4] (Fig. 1). These models were coupled to a blast loading scenario (Eulerian model) (Fig. 2) and analysed for three representative blast load cases (5 kg of C4 at 3, 3.5, and 4 m standoff distances, with overpressures of 326, 230, and 170 kPa, respectively). The models were validated using head kinematics from experimental data on Hybrid III head-forms exposed to free-field blast [5]. The models were further validated for intracranial pressure using experimental data from cadaveric heads exposed to shock tube loading [6].

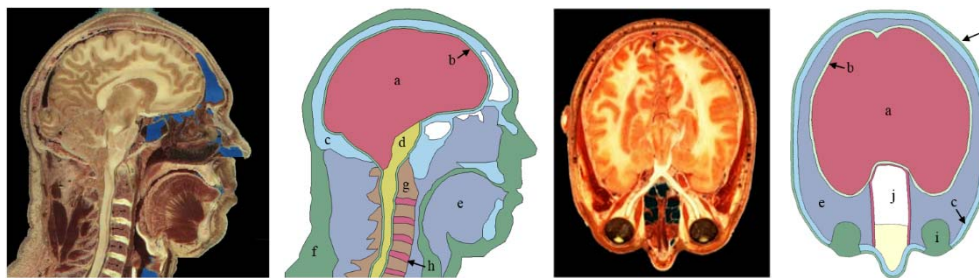


Fig. 1. The Visible Human Project image and FE head models for sagittal (*left*) and transverse (*right*) planes, showing (a) brain, (b) cerebrospinal fluid, (c) skull, (d) spinal cord, (e) muscle, (f) skin, (g) vertebrae, (h) discs, (i) eyes, and (j) sinus.

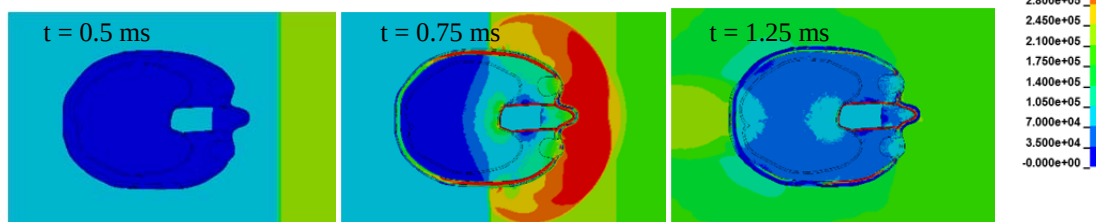


Fig. 2. Head models in air mesh with simulated 5 kg C4 at 4 m blast, with contours of pressures (Pa).

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III. INITIAL FINDINGS

The response of the head can be described in three phases, corresponding to different timeframes [7]. First, an approaching pressure wave will interact with the head, resulting in a reflected and transmitted wave. The models in this study predict reflected pressures in the range of 3–4 times the incident pressure in agreement with the expected range of 2–8 [1]. A portion of the incident wave is transmitted directly through the skull and into the brain tissue, resulting in high positive pressures in the anterior portions of the brain for frontal blast exposure (270–750 kPa peak pressure, occurring in the first 15 μ s after impact for the load cases considered). In the second phase of the response, the pressure wave, upon reaching the free surface of the skull, is reflected back into the brain in a tensile manner, resulting in relatively large negative (tensile) pressures in the posterior regions of the brain, ranging from -90 to -311 kPa for the cases considered, occurring at approximately 20–30 μ s after impact. The pressure waves in the brain dissipate approximately 1 ms after impact. Finally, longer duration response, such as bulk movement of the head, occurs in the third phase of response.

Skull flexure, which has been hypothesised as a potential mechanism of loading, is observed in the models. The sagittal and transverse models report maximum relative difference between the frontal and occipital bones of 0.075–0.231 mm and 0.346–0.826 mm respectively for the load cases. These values are likely over-predicted in these planar models, which do not incorporate the three-dimensional aspects of the skull.

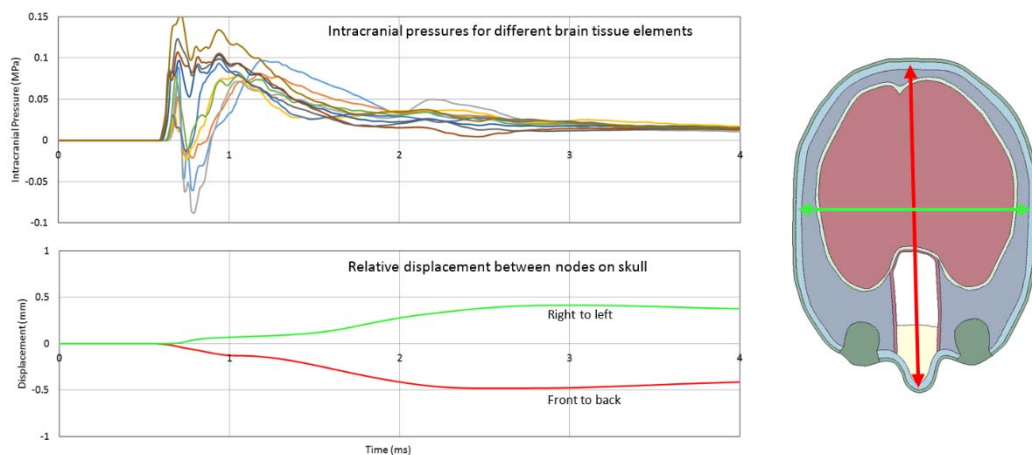


Fig. 3. Intracranial pressure history and relative displacement of skull nodes (skull flexure) in the transverse model for the 5 kg of C4 at 4 m load case.

IV. DISCUSSION

The models were able to accurately predict head kinematics resulting from primary blast effects. Since the blast pressure wave is well approximated as a planar wave, the resulting head acceleration is primarily linear, as shown in previous studies utilising full body models in blast.

Although skull flexure is observed in the sagittal and transverse models as a structural response to the applied blast load, it occurs later in time (>1 ms post-impact) compared to the initial wave (0–1 ms post-impact). The predicted ICP at maximum skull flexure is much lower compared to the direct transmission of the pressure wave through the head (Fig. 3). However, these models are mainly concerned with primary blast, which occurs over the first few milliseconds, so the contribution of skull flexure during longer timeframes may become more important and has not yet been investigated. Future studies will include an investigation of blast exposure from alternate directions and complex blast environments, including enclosed spaces.

V. REFERENCES

- [1] Schmitt, K., et al. *Trauma Biomechanics*, 2013. [2] Bolander, R., et al. *Ann Biomed Eng*, 2011. [3] Singh, D., et al. *Int J Num Meth Biomed Eng*, 2013. [4] Spitzer, V., et al. *J Am Med Info Assoc*, 1996. [5] Lockhart, P., et al. *J Trauma*, 2011. [6] Bir, C. *US Army Med Research*, 2011. [7] Cronin D, *PASS 2008*.

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