INVESTIGATIONS INTO FINITE ELEMENT MODELLING ASPECTS OF THE HUMAN HEAD.

Timothy J. Horgan Michael D. Gilchrist*

Department of Mechanical Engineering, University College Dublin, Dublin 4, Ireland

* Corresponding Author

KEYWORDS

Brains, biomechanics, pressure, finite element method, three dimensional.

INTRODUCTION

THE HEAD IS one of the most frequently injured body regions and neurotrauma constitutes one of the major causes of accidental fatalities. In order to investigate the mechanisms of injury a three-dimensional finite element (3DFE) representation of the human head complex has been constructed for simulating the transient occurrence of simple pedestrian accidents.

A set of Computed Tomography and Magnetic Resonance Imaging data files has been determined and are available through the Visible Human Database (NIH, 2002). A polygonal representation of the skull was constructed and from this the finite element model was formed. Contours were extracted from the polygonal model and then sections were carefully chosen (Fig. 1) across these contours in order for the model to have good hexahedral element quality and ease of mesh generation. A number of variations of the model were created. The model was skewed in such a way so as to represent the same size head as that used in Nahum's experiment (1977). The resulting model was validated against the cadaver tests of Nahum, with good agreement being found for pressure response. A parametric High/Low study was performed, which consisted of 16 tests, to investigate the effect of the bulk and shear modulus of the brain and cerebrospinal fluid (CSF). The range of values for the bulk modulus and shear modulus of the brain chosen were 200MPa-20GPa and 20kPa-500kPa respectively, with 0.25MPa-2.5GPa and 0.5kPa-50kPa for the CSF. The influence of different mesh densities on the models and the use of different element formulations to model the skull were also investigated. Mesh densities were varied from approximately 9,000 elements to 60,000 elements overall, limited only by computing resources. The skull was modelled as (a) a layered brick element skull, with the middle two bricks assigned to be trabecular bone, (b) a composite shell element skull (with and without a defined variance of thickness) and (c) as a 'shell-brick' element type skull where the shell elements were cortical bone and the brick elements were trabecular bone.

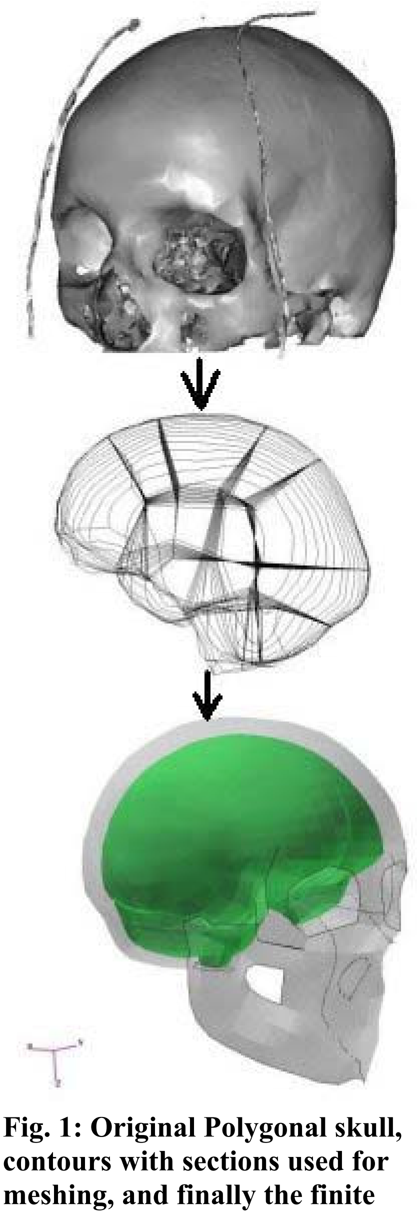

Fig. 1: Original Polygonal skull, contours with sections used for meshing, and finally the finite element model with brain visible.

RESULTS

It was found that the short-term shear modulus of the neural tissue had the biggest effect on intracranial frontal pressure, and on the model's Von-Mises response (Table 1). The bulk modulus of the fluid had a significant effect on the contre-coup pressure when the CSF was modelled using a coupled node definition. Table 1 reports the change in the pressure response for the frontal and contre-coup positions and the change in Von-Mises response at the corpus callosum. The percentages refer to the 'effect' of changing the values based on the Taguchi method. Further information can be found from Horgan and Gilchrist (2003).

Case	Range of Largest Effecting Modulus (MPa)	Effect on Frontal Pressure	Effect on Contre-Coup Pressure	Effect on Von-Mises Stress
Brain	Shear: 0.02 – 0.5	13%	12%	86%
CSF	Bulk: 0.25 – 2500	12%	16%	69%

Table 1: Significance of different constitutive properties in a high/low parametric study.

Following this, investigations were conducted on the natural frequency of the skull when mapped with different thicknesses. It was of interest to know the influence of the skull resonant frequencies since these are important in short duration impacts. Consequently, a method was developed to map the thicknesses to the model. The analyses were carried out on two different skull shapes (the first being that of the visible male, the information for the second from Van Lierde and Vander Sloten (2002)).using the composite shell skull element formulation (facial bone excluded) using two sets of skull properties. Initial results suggest that changing the thickness pattern on an existing skull shape influences the frequency response more than changing the shape itself. For example, for the first property set for the cortical and cancellous bone, the first mode achieved for three different thickness mappings was 2284Hz, 1064Hz and 1624Hz respectively, while for the same mappings on a different shape these became 2015Hz, 1156Hz and 1750Hz.

DISCUSSION

By simulating identical impact scenarios with a range of different finite element model properties it has been possible to investigate their influence on intracranial pressure. We can conclude that careful modelling of the CSF and brain is necessary if the correct intracranial pressure distribution is to be predicted, and so further forms of validation are required to improve the finite element models' injury prediction capabilities. Furthermore, if the physical dimensions of the particular human head being modelled are known, the finite element model should be scaled to these dimensions. We have also shown that the shape and thickness by which the skull model is constructed will affect the frequency response. This could have implications on modelling very short duration impact cases.

REFERENCES

1. Horgan, T.J. and Gilchrist, M.D. The creation of three-dimensional finite element models for simulating head impact biomechanics. In Press, *International Journal of Crashworthiness, 2003*.
2. Nahum, A.M., Smith, R.W. and Ward, C.C. Intracranial pressure dynamics during head impact. In *Proc. Of the 21st Stapp Car Crash Conf.*, SAE paper no. 770922, 1977.
3. National Institutes of Health (NIH) U.S. National Library of Medicine. Department of health and human services. Visible Human Database www.nlm.nih.gov/research/visible/visible human.html, 2002.
4. Van Lierde, C. and Vander Sloten, J., Private Correspondence, Catholic University of Leuven, 2002.