SIMULATED IMPACT RESPONSE OF A 3-D PRINTED SKULL, WITH AN ELLIPSOIDAL EXCISION, USING FINITE ELEMENT ANALYSIS

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Introduction

This paper investigates methods of determining the influence of an ellipsoidal excision (14.2x11.8 mm occipital region) on the structural integrity of a human skull when exposed to impact loading. Experimental and simulation-based analyses were conducted, using 3-D printed replicas and a finite element model; both were derived from a clinical CT scan of the patient (28 YO MC, with no previous health concerns).
Previous simulation studies [1] have achieved managed to predict skull fracture locations effectively for non-excised skulls.

Methodology

The aims of this study were to:

1. determine an appropriate constraint methodology
2. the sensitivity of results to element size
3. the ability of FEA to predict the behaviour of the 3-D printed model
4. to indicate the influence of an excision in the vicinity of the impact site on stress concentrations

A 3-D model of the patient's skull was derived from CT scan data using Simpleware *ScanIP* (v7), using a flood-fill mask. This model was used to generate both a set 3-D printed replicas and a series of finite element meshes, with a range of element sizes. A second set of each was created in which the excision site in the 3-D model had been filled. The 3-D printed replicas were experimentally tested under impact loading [2] and a comparative simulation study was carried out (reported here) using *ANSYS Mechanical APDL* (v15) finite element analysis (FEA) software.
The loading was considered to be quasi-static within the FEA model, and to have been applied uniformly over the striker impact area. The load was set as equal to the peak striker force measured experimentally. Constraint was applied to the face and lower surface of the skull to reproduce use of Perma-Gel in experiment.

Results

A range of different constraint methods were investigated, and it was determined that a distributed, flexible constraint was applied to the face, with a sliding constraint on the lower surface of the skull, was suitable.
Once a suitable constraint set had been determined, stress patterns were observed to be relatively stable across the range of considered element sizes. The mesh featuring ~500,000 elements (corresponding to a refinement value of -20 within the ScanIP "FE Free" meshing algorithm) was found to be effectively equivalent to the next finer mesh (~900,000 elements), when comparing peak stresses (see Figure 1).

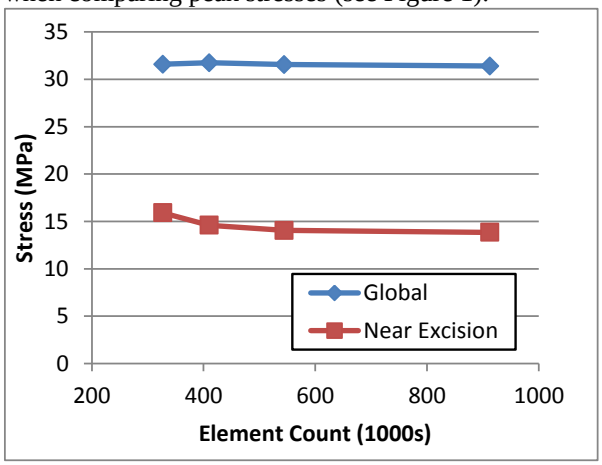


Figure 1: Peak stresses within the skull FEA model

Results from the 500,000 element FEA mesh were compared with experimental equivalents; areas of plasticity within the FEA model correlated accurately with the regions which had cracked within the printed skull, including crack initiation at the lower edge of the occipital region on the impact side (see Figure 2).

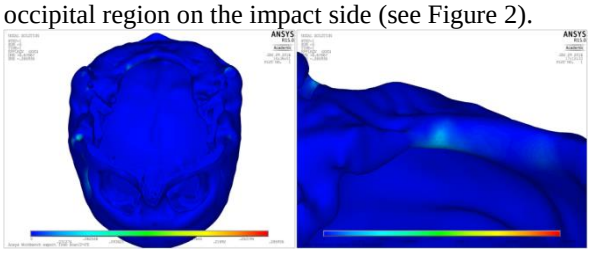


Figure 2: Plastic strains in simulated 3-D printed skull

On the lower edge of the excision site, a localised von Mises stress of ~15 MPa was observed (Figure 1), compared with ~9 MPa in the same region of the filled-hole case, indicating that the excision is a stress raiser but does not limit the strength of the skull in this case.

Conclusions

1. Distributed flexible constraint replicated Perma-Gel,
2. 500,000 elements suitable to model printed skull,
3. FEA model effective predictor of stresses,
4. Excision is a stress concentrator, but doesn't limit skull strength in the considered load case.

References

1. Asgharpour et al., JMBBM Vol 33
2. Franceskides et al., ESB2016.



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