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INVESTIGATION OF A LOCAL ABSORPTION ENERGY CRITERION FOR SKULL IMPACTS THROUGH SUBJECT SPECIFIC FINITE ELEMENT HEAD MODELING

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Introduction

Head injury is recognized as the leading cause of mortality and morbidity in children and young adults [1, 2]. 15% of deaths of children aged between 1 and 15 years are caused by head injuries [3]. It is the most frequent cause of death in the paediatric population, up to 80% of all trauma related deaths each year [4]. These surveys stimulate the need for research to determine the cause and to develop improved protective headgear.

Over the past decades, mechanics and characteristics of skull fracture have been studied [5, 6, 7]. A skull fracture occurs when contact load exceeds a certain threshold of the skull. Computational modeling of head impacts is an efficient tool to study subject specific variations and the mechanisms of skull fracture. Yoganandan *et al.* postulate that the energy absorbed by the skull before it fractures likely represents the best predictor for skull fracture, by incorporating impact as well as structural characteristics [5]. Sahoo *et al.* uses the strain energy of the skull bone to predict the skull fracture [8].

By encompassing impact information as well as structural characteristics, the energy criterion has the potential to accurately predict skull fracture [9]. Previous results at our research group investigated the existence of an energy failure criterion with a double pendulum set-up in a series of intact cadaver heads [9, 10]. For frontal impacts the existence of an energy failure level of 22-24J is suggested [10], for temporal dynamic loading conditions 5-15J [9]. Monea *et al.* concluded that energy criteria for impacts are location dependent. The interest of this study is to gain insight in the local absorbed energy of an impact by the skull.

Materials and methods

CT-scans of each subject are obtained before and after the impact experiment and segmented in Mimics^{TM} (Materialise, Leuven, Belgium) to create a mask of the skull. A 3D object is calculated from the mask and exported to 3-Matic^{TM} (Materialise, Leuven, Belgium) where the mean thickness of the impact site is measured. To calculate the local bone density, Hounsfield Units at the impact site were compared to Hounsfield Units of the European Spine Phantom with known bone mineral densities. A statistical relationship between the absorbed energy and the thickness and density of the skull at the impact site are investigated.

Secondly, a simplified model of the experiments is developed in Abaqus (SIMULIA) consisting of an impactor with an identical geometry as the one used in the experiments and a hollow sphere, resembling the skull. To investigate the influence of the skull thickness at impact site, a variable wall thickness of the hollow sphere is used. The strain energy density at the site of impact in the simplified model can be compared with the average absorbed energy per volume of the impact site. Volume of the impact site is calculated as the thickness of the skull at impact site multiplied with the circular area of the cylindrical impactor that hits the skull during the experiments.

Results

Spearman correlation coefficients show that there is a statistically significant positive relationship between the absorbed energy and the local density of the skull at the impact site, the coefficient is 0.48. While the Spearman correlation coefficient between the local skull thickness at the impact site and the absorbed energy is 0.39, it is not statistically significant. There exists a statistically significant positive relationship between the fracture force and the local skull thickness, Spearman correlation coefficient = 0.56 [9].

Results of the Abaqus (SIMULIA) simulation for an impact velocity of 5 m/s give a maximum strain energy density ranging from 0.15 mJ/mm^3 for a wall thickness of 6 mm to 1.19 mJ/mm^3 for a wall thickness of 3 mm. The absorbed energy per volume of the impact site for impacts of an impact velocity of 5 m/s ranges from 0.84 mJ/mm^3 to 2.22 mJ/mm^3. These results correlate well to the experimentally obtained values.

Discussion and future work

The statistical analysis combined with the results of the simplified finite element model indicate the dependence of the absorbed energy on local geometrical features and the local bone density. Future work will include the development of a subject specific finite element model of the experimental set-up in Abaqus (SIMULIA) to investigate the influence of the local geometrical characteristics on the energy criterion. Experimental results will be compared to the outcome of the finite element head model of the subject, ultimately leading to a fracture criterion based on strain energy density.

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