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FINITE ELEMENT MODEL OF HUMAN SKULL FOR INVESTIGATION OF EXTREME STRESS STATE

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Summary: *The article reports on development of finite element models of human skull used in investigation of extreme stress state during a traffic accident. The procedures used in the development of the geometry of the skull from the series of computer tomography scans are shortly described and simplified FE-models presented. The finite element models will be used for evaluation of parameters that are necessary for protective helmet design.*

1 Introduction

Head injuries resulting from traffic accidents are one of the major causes of death and disability. It is very difficult to study the injury mechanisms of the human skull experimentally not only due to the ethical reasons, but also due to the large number of impact conditions involved. It is by far easier to study the injury mechanism of the human skull through finite element simulations. There is a number of papers describing the use of finite element model of human skull in connection with investigation of the impact response of a protective helmet, e.g. [A. Gilchrist and N. J. Mills, 1994], but those models are usually very simple and do not reflect the true geometry of human skull. The FE model of the human skull described in this paper is very detailed and based on data obtained from computer tomography scans. The model will be used in protective helmet design and its simplified version in a study of neck injury mechanisms later on.

The design of a protective helmet usually incorporates four main elements and many different materials, that combined, provide a unique form of protection. From the mechanical point of view the most important part of the helmet is the outer casing, which is the primary defense against the initial impact. Inside of the casing there is a crushable liner that is made of an energy absorbing material. One of the objectives of the study is the investigation of the protective influence of the outer casing and the foam liner on the stress distribution in the human skull after an impact during a traffic accident. The geometry of the human skull is based

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on a series of computer tomography scans of resolution 512x512 pixels taken in 1 mm slices. Material model for the trabecular bone is nonlinear elastic and inhomogeneous with material properties varying accordingly to the apparent density of the bone density obtained from the CT-scan data. This model is used in conjunction with different designs of protective helmets and provides for the evaluation of contact stress field as well as for evaluation of the influence parameters of protective helmet design.

2 Methods

For the construction of the skull geometry a standard procedure including a semi-automatic tissue segmentation is used. The aim of image segmentation is to identify some physical property of the tissue of interest. Before the specified tissue can be reconstructed its boundaries must be identified. For the segmentation purposes we use traditional intensity based segmentation relying on the fact, that pixels representing the same tissue are clustered around a mean characteristic value. A thresholding procedure combined with repetitive application of Gaussian filter is used combined with removal of islands (removing regions of tissue smaller then specified value), semi-automated removal of misclassified tissue, etc. This procedure is fully automatic, but for segmentation of such a geometrically complex object as a human skull a manual correction of several slices must be applied.

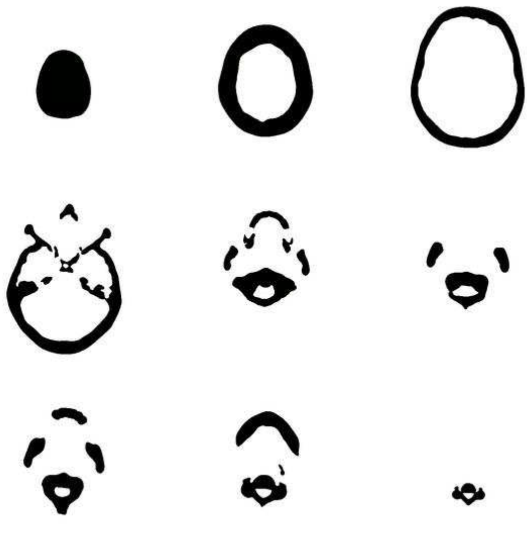

Figure 1: Segmentation process of the human skull tissue (selected slices)

After the skull tissue is segmented a surface reconstruction using a generalized marching cubes algorithm (MCA) is used to identify the inner and outer surface describing the skull. The MCA was first published in [W.E. Lorensen and H.E. Cline, 1987] and utilize the "divide and conquer" technique to determine the surface of an organ. The algorithm can be explained in two steps: in the first one the algorithm detects the surface based on a user-defined value of apparent density (corresponding to the density of the organ to be reconstructed) and the triangle mesh representing the surface is created. In the second step we need to calculate the normals to each of the triangles to be able to determine what is the inner and outer space of the organ. Since the MCA produces very large number of triangles describing the surface a decimating algorithm [W.J. Schroeder and J.A. Zarge, 1992] follows. After the reduction of the triangles, we apply smoothing of the surface and fill the volume with tetrahedral finite elements.

3 Results and conclusions

A finite element model of human skull has been built using a data from computer tomography scans. The model will be used in numerical modeling of head impact during traffic accidents. Once validated, the finite element model can help to describe possible injury mechanisms and to quantify design parameters of protective helmet related to a specific impact event.

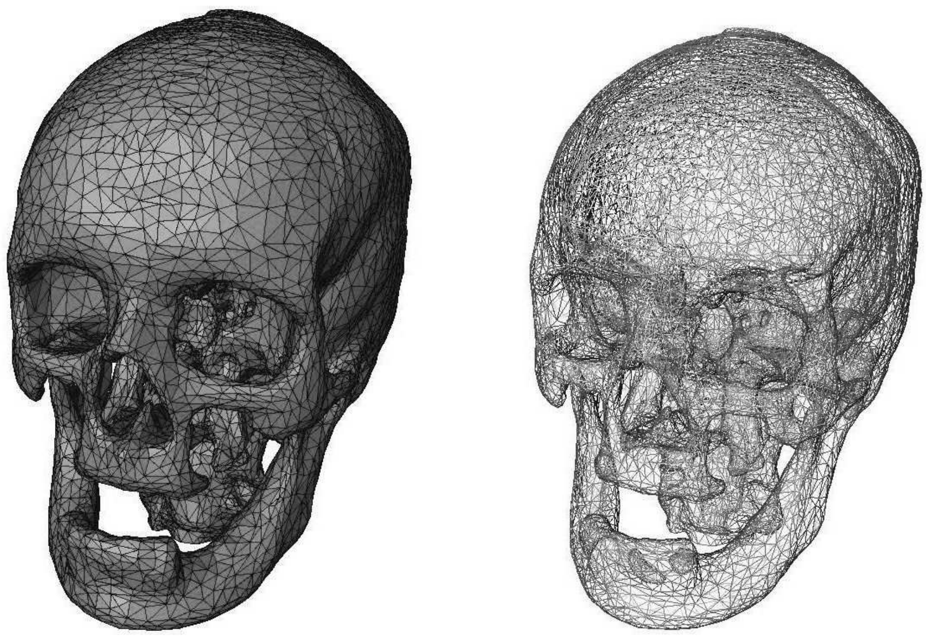

Figure 2: FE model of the human skull

The next step is to develop several simplified models of the skull based on the same computer tomography data and to reconstruct the human brain from a series of respective slices obtained from Magnetic Resonance Imaging. These simplified models will be used in determination of the influence of the head impact on stress distribution in the brain tissue. The ability of these simplifications are demonstrated in Fig. 3.

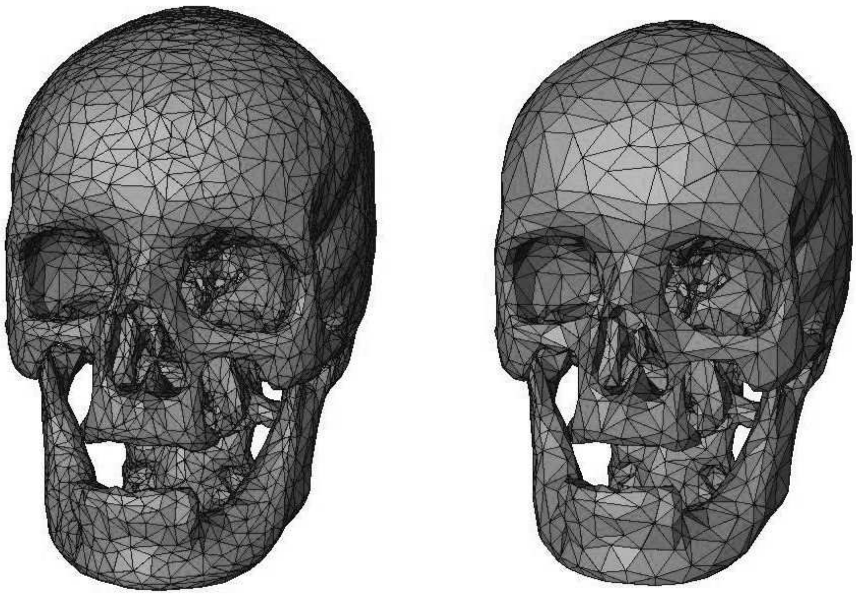

Figure 3: Simplified versions of the same FE model

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References

A. Gilchrist and N. J. Mills (1994). Modelling of the impact responce of motorcycle helmets. *International journal of Impact Engineering*, (15):201–218.

W.E. Lorensen and H.E. Cline (1987). Marching Cubes: A High Resolution 3D Surface Construction Algorithm. *Computer Graphics*, 21(2):155–168.

W.J. Schroeder and J.A. Zarge (1992). Decimation of Triangle Meshes. *Computer Graphics*, 26(2):65–70.