BIOMECHANICAL ASPECTS OF BRAIN TISSUE DYSFUNCTIONS

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1. Introduction

According to the World Health Organization (WHO) traumatic brain injury (TBI) constitutes a major public health issue all over the world [1]. Traumatic brain injury resulting from vehicular collisions, contact sports, or battlefield operations can have devastating consequences. Traumatic brain injury occurs when local mechanical load exceeds certain tolerance levels for brain tissue. Intracranial brain deformation caused by rapid angular acceleration or blunt impact to the head during injurious events is responsible for traumatic brain injuries, which are a leading cause of death or disability. TBI involves acute subdural hematoma, brain contusion and diffuse axonal injury. A proper biomechanical understanding of the mechanisms of traumatic brain injury challenges many published and testified assumptions regarding TBI. Understanding how these loading/kinematic conditions applied to the organ boundary translate into local stress–strain states within the tissue continuum is challenging, because the brain is, from a biomechanical perspective, a highly complex organ housing multiple “substructures”, e.g. brainstem, cerebellum, thalamus, cerebral cortex, corpus callosum, associated with somewhat distinct mechanical properties [2]. It is worth noting that the best solution is offered by human in vivo studies, but for obvious reasons they are prohibited. Another solution is to use physical models, however the selection of mechanical properties of materials poses a considerable problem, since biological tissues are involved. Analytical models also offer a useful solution, however the difficulty lies in the fact that not all self-adjoint problems can be described by local and global formulas. Therefore, at present one of the most effective ways of identifying the response of brain structures to loading is numerical modelling. In particular, the Finite Element Method designed for models of irregular geometry, composite materials and complex loading as well as complex boundary conditions is now the preferred method for studying head injuries [3].

In the present study, the authors have undertaken to develop numerical models which contain detailed geometric descriptions of anatomical features of the human brain tissues, in order to investigate internal dynamic responses to multiple loading condition. In particular, the numerical study was an attempt to analyse changes in the parameters and mechanical characteristics of brain structures in rapid overload conditions that result from combat operations.

2. Material and methods

In the study, brain structures were identified on the basis of DICOM images obtained from computed tomography (CT). DICOM files were imported to the Mimics software in which a 3D model was obtained. The mesh was generated in ANSYS and imported to LS-DYNA software. The model consisted of a skull, meninges, falx, tentorium, superior sagittal sinus, cerebrospinal fluid (CSF), nerve tissue and blood vessels divided into regions: frontal, parietal and occipital (Figure 1). Mechanical properties of brain structures were obtained from experimental studies. The boundary conditions were obtained from real combat conditions in Afghanistan and car accidents.

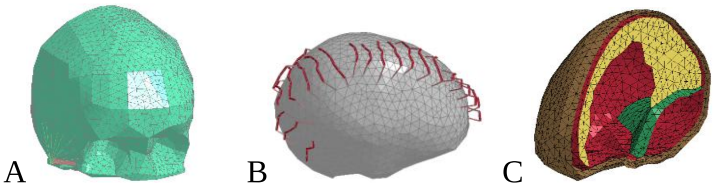

Figure 1. The global models. A- skull, B - the brain of the venous system, C - falx cerebri and tentorium cerebelli, D - cross-sectional view

3. Results

As a result of the numerical analysis, critical values of strain, stress, displacement and energy have been obtained. The following analysis showed a high level of diversity in the properties of the different regions of the brain. Figure 2 shows exemplary characteristics of the changes in total energy over time for different blood vessels of the brain as a result of head trauma.

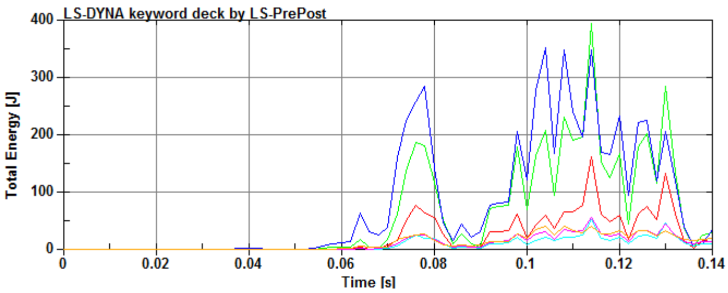

Figure 2. Total energy [J] change over time [s] for different vessels, located in different regions of the brain

4. Conclusion

A finite element (FE) model of the human head has been developed. The reliability of this model depends on an appropriate level of structural detail and accurate representation of the material behavior simulations. The present model assumed the isotropic, homogenerous and hyperviscoelastic material properties for brain tissue. During the impact, the principal strain on the cortical surface of the brain is high. Gradually, high shear stresses are concentrated at the white matter, corpus callosum and brain stem. As expected, with an increase of the shockwave, the maximum averaged shear strains will increase and decrease, respectively. Mechanically induced brain deformation at a particular region, or site, as a consequence of applied loading, may determine a particular type of brain injury.

5. References

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