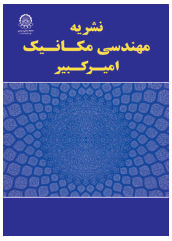

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Brain Trauma in Vehicle Side Crash; Developing a Computational Model for Diffuse Axonal and Subdural Hematoma Injuries

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ABSTRACT: Based on complicated modelling problems of head trauma, a finite element model of the human head has been developed in order to evaluate different types of brain damage. 233 sections Magnetic Resonance Images of the head of a 42 years old man were prepared. The geometric models of Skull, Meninges and brain were extracted. Mechanical properties related to tissues of the skull, meninges and brain membrane are applied. Obtained results from simulation correlated well with experimental results. After ensuring the validity of the model, data acceleration in the head recording from side impact test was applied to the model. The simulation results showed that the rotational acceleration, due to high strain rate in the brain and increased pressure in meninges, is responsible for rupturing arteries and veins. However, linear acceleration alone does not lead to severe damages in the brain. Developing a new computational model for these injuries evaluation including side crash case, have not been considered in previous studies. So, considering this problem in addition to developing an accurate and efficient FEM head model could be supposing the considerable innovation of this study.

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1- Introduction

Direct impact and sudden acceleration are major sources of death and disability as the result of transportation collisions, falls, assaults, military, and sports accidents. On the other hand, the human brain is the most important organ in severe damage due to the rupture of blood vessels and damage to brain tissue, causing long-term unconsciousness and even death. Today, traffic accidents are statistically ranked first among the events. In the US, there are about 1.4 million people who sustained TBI each year and it was estimated that one-fifth of the hospitalized persons cannot return to work [1]. The major causes of death in accidents are due to the brain damage. Simulating and analyzing the dynamic response under impact and sudden acceleration is the only way to predict the severity of the brain injury. Traumatic Brain Injury Biomechanics connects physical processes associated with traumatic brain injury to the physiological pathology of brain tissue.

2- Materials and Models

2- 1- Image processing and extracting initial geometric modeling

Geometric modeling to include the skull, brain and meningeal membrane, is a phased and orderly process. These steps include preparing the MRI images, building initial parts using image processing method in MIMICS17 software, surface editing in 3Matic software and preparing CAD models, and finally assembly process. The first step to build head geometric model is preparing CT or MRI medical images of the head. High resolution of the medical images makes it possible to detect boundaries between tissues. Also, the number of images affects the accuracy of the measurements. At this point, the prepared medical images were imported to the MIMICS17 medical image processing software in DCM format. Fig. 1 shows MRI images in three orthogonal views in the workspace of MIMICS17. After identifying MRI images by MIMICS17 software, the initial CAD models of the skull bone and brain tissue were extracted.

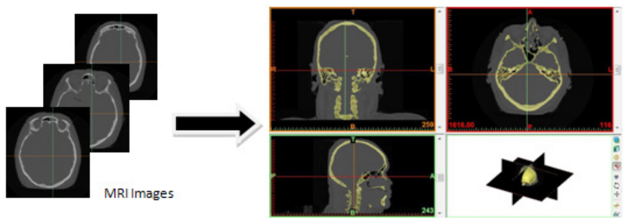

Figure 1. MRI images in three orthogonal views

The CAD model of the skull and brain has many holes and unevenness on their inner and outer surfaces. In order to smooth the surface roughness, 3Matic software was used. After final editing operation in 3Matic software, each model of skull and brain was saved using STEP format. The final models of the skull, meningeal membrane, and brain were shown in Fig. 2. Assembly operation is the final step of geometric modeling.

2- 2- Model Preparing for Dynamic Analysis

The final geometrical model of a human head was imported to ABAQUS6.14 finite element solver software in order

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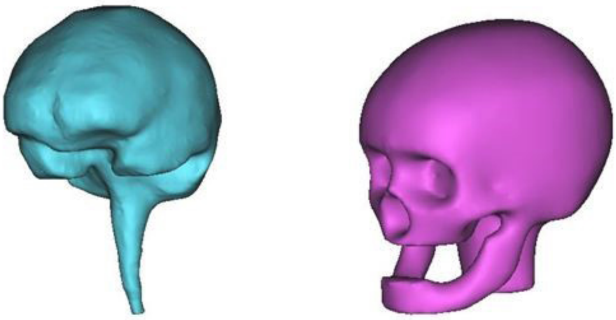

Figure 2. The final model of the skull, meningeal membrane, and brain

to dynamic analysis. The mechanical properties of living tissues of the body especially the brain tissue are always a challenging research subject in the field of biomechanics. Mechanical properties used in this study are assumed elastic for the skull and hyperelastic for brain tissues. Because of the very short time of the impact, the effects of the cervical spine and muscles could be ignored and free boundary condition could be used. The conditions have been considered for the contact between the skull, meningeal membrane and brain tissue as an inseparable connection. At this stage, mesh generation operation was performed and the quality of generated elements was controlled. The mesh of skull and meningeal membrane were shown in Figure 3.

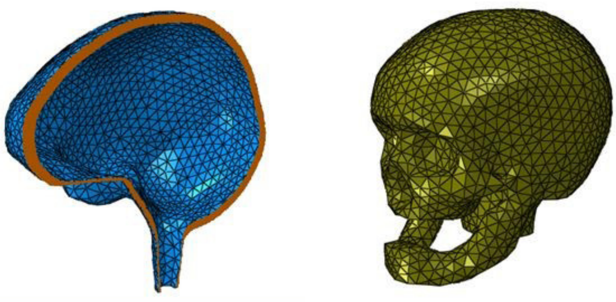

Figure 3. Skull and meningeal membrane mesh

2- 3- Validation

To verify the finite element model, the numerical results were compared with those of cadaver experiment by Nahum et. al. [2]. The impact direction was along the specimen's mid-sagittal plane. The measured pressure on the back of the brain in numerical simulation and experimental test are in good accordance as it could be clearly seen in Fig. 4.

3- Results and Discussion

In order to obtain rotational and translational acceleration experienced by a human head in a side crash, a FEM simulation on LS-Dyna human body dummy has been done as shown in Fig. 5.

Obtained results for maximum von Mises stress as well as maximum pressure in the brain related to Rotational, translational and combined loading could be seen in Figs. 6 and 7.

The simulation results showed that the rotational acceleration, due to the high strain rate in the brain and the increased pressure in meninges, is responsible for rupturing arteries and veins. However, linear acceleration alone does not lead to the severe damage in the brain.

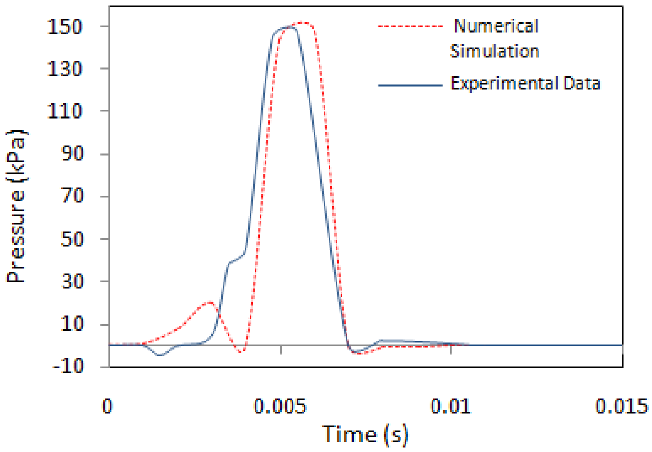

Figure 4. FEM and Nahum experimental test results of the pressure on the brain

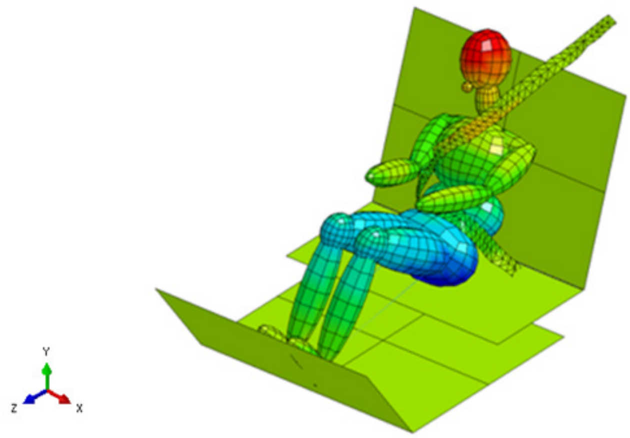

Figure 5. FEM human body model for side crash simulation

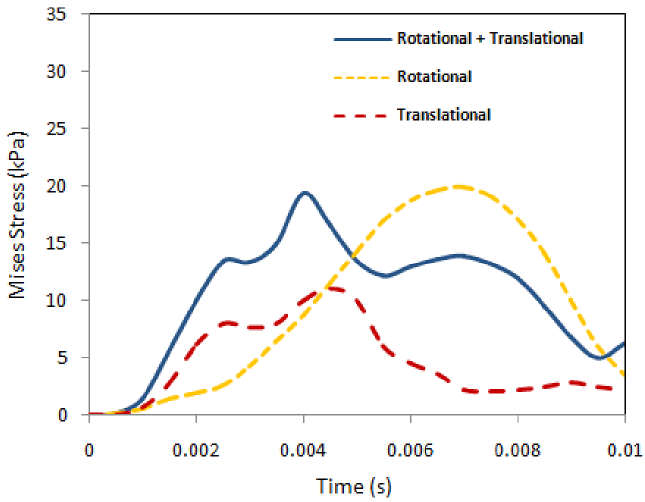

Figure 6. Maximum von Mises stress in the brain during the crash time

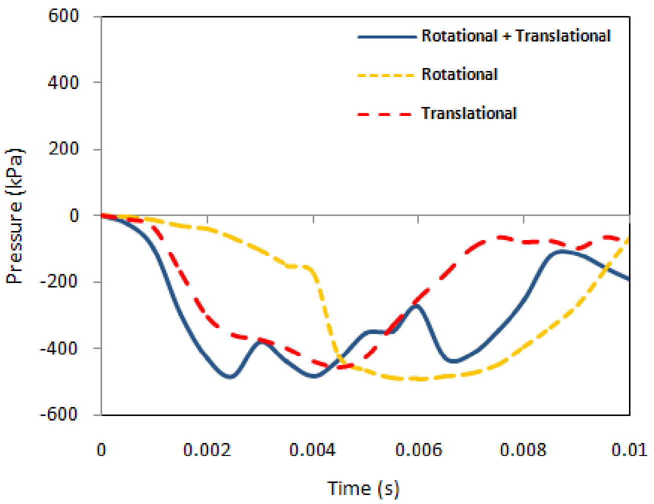

Figure 7. Maximum pressure in the brain during the crash time

4- Conclusions

The brain pressure was validated against intracranial pressure data reported by Nahum et al. the obtained results from simulation correlated well with experimental results. The acceleration of the driver's head in side and frontal impact, obtained from accident tests, were applied to the finite element model. Brain injuries caused by both of side and frontal impact were investigated. The focus was aimed at getting the brain strain and stress responses and minimum pressure of meningeal membrane to study SDH and DAI Injuries. Computational results indicate that the intensity of SDH and DAI injuries is caused by frontal impact 3.7 and 1.5 times more than side impact, respectively.

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