AN IMPROVED FINITE ELEMENT MODEL TO SIMULATE THE BRAIN ACCELERATION DUE TO A FRONT IMPACT

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Introduction

Traumatic brain injuries (TBI) are among the most common severely disabling injuries in the U.S. Approximately 1.7 million cases occurred in civilians annually during 2002-2006[1]. The Finite Element (FE) method has been widely used to investigate the injury mechanism of TBI, because it is technically difficult to quantify the responses of the brain tissues to impact in experiments. One of the technical challenges to build a FE model of a human head is the modeling of the cerebrospinal fluid (CSF) of the brain. The CSF is a body fluid that occupies the subarachnoid space and the ventricular system around the brain and spinal cord. In the current study, we proposed an improved FE model of human head-brain complex, in which we applied membrane elements to construct the CSF layer.

Methods

The FE model was constructed using the meshes available in an existing, generic data base (Materialise, Leuven, Belgium) and it included all of the essential anatomical structures of a human head, i.e., skin, scalp, skull, cerebrospinal fluid (CSF) layer, brain, medulla, spinal cord, cervical vertebrae, and discs (Fig. 1, Left). The CSF was constructed using membrane elements, whereas all other components were constructed using three-dimensional continuous solid elements. The entire FE model was constructed by using a commercially available software ABAQUS (version 6.9); no other advanced mesh software was needed to generate the current FE model. The scalp, skull bone, cervical discs, and vertebral bone were considered to be linearly elastic. The CSF was considered as an elastic and incompressible medium with a small shear modulus. The skin, brain, medulla, and spinal cord were considered to be hyperelastic and viscoelastic.

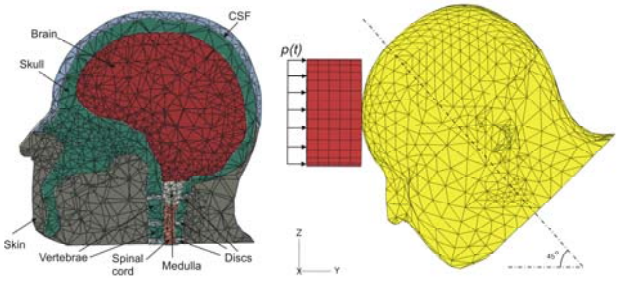

Figure 1. FE model of the head-brain complex. Left: Cross-sectional view of the model. Right: Set-up of the numerical calibration test.

The set-up of the numerical test was to mimic cadaveric tests (Fig. 1, Right). The object impacted the head at the forehead and in the mid-sagittal plane. The impacting object was cylindrical and had a diameter of 50 mm and a height of 30 mm. The impact force, as measured in the previous experiment, was applied uniformly at the back of the cylindrical impact pad [*p(t)*]. The pressures in the brain tissues at four locations, as well

as the head accelerations calculated using the proposed model, will be compared with the experimental data and simulations in the literature.

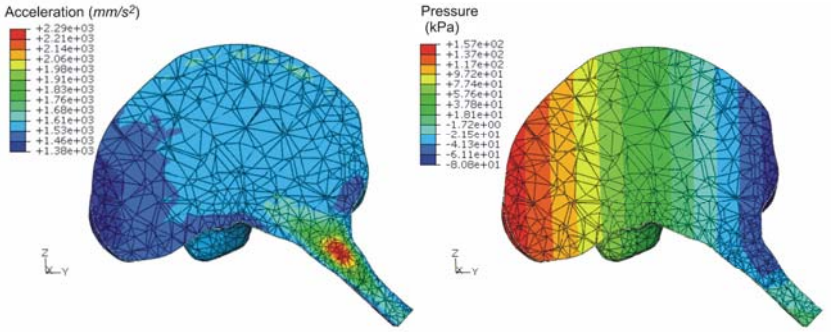

Figure 2. Simulated distributions of the acceleration (Left) and intracranial pressure (Right) across the brain tissues at *t=6 ms*, when the impact force reached the maximum.

Results

The predicted time histories of the intracranial pressures at frontal, posterior fossa, parietal, and occipital positions using our model agree well with the experimental data[2] and the simulation[3] in the literature, indicating that the physical effects of the CSF layer have been accounted for in the proposed modeling approach (results not shown). Our simulation results indicated that the maximal acceleration magnitude was not on the surface of the brain tissues, but in the core of the medulla region of the brain (Fig. 2, left), while the maximal/minimal pressure values were found on the surface of the brain (Fig. 2, right).

Discussion

The acceleration of the brain tissue has been used as the injury criteria in the ergonomic design. The well accepted head injury criteria (HIC) is based on the time histories of the accelerations obtained in the experiments[4]. However, the accelerations are measured on the skin surface in conventional engineering analysis. Our analysis indicated that the maximal acceleration at the skin surface will be approximately 12% lower than that in the brain, which appears in the medulla region. Our findings are also consistent with the clinical observations[5] that the medulla appeared to be one of the most vulnerable parts during a TBI.

References

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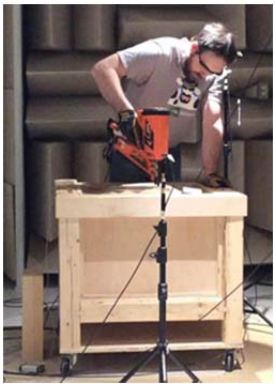

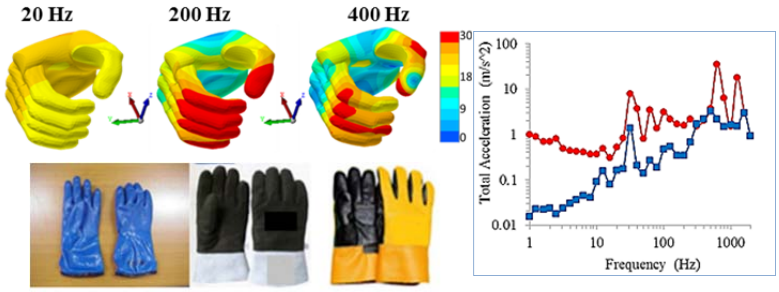

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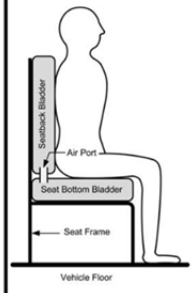

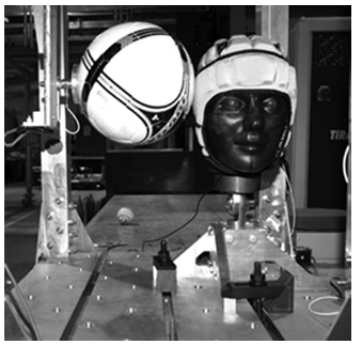

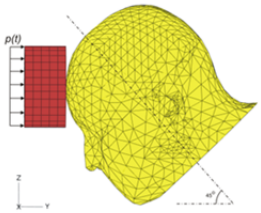

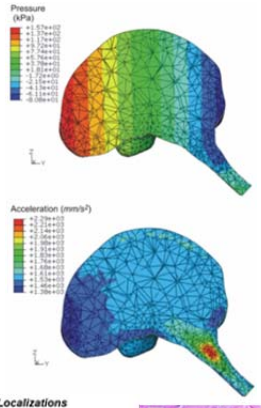

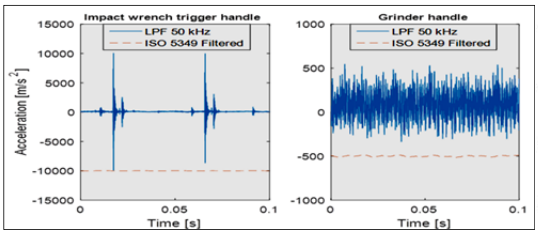

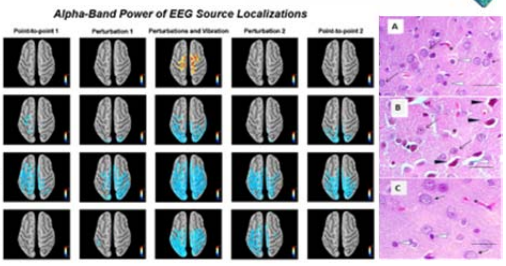

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