DEVELOPMENT OF AN LS-DYNA FINITE ELEMENT MODEL OF THE CRANIO-CEREBRAL COMPLEX FOR UNDERSTANDING BIOMECHANICS OF TRAUMATIC BRAIN INJURY

Binu Oommen[1], David Nicholson[1], Ted Conway[1], Alexandra Ahlqvist[1], Gerald Bertetta[2]

[1] Department of Mechanical Engineering, University of Central Florida, Orlando, FL, USA
[2] Department of Physical Therapy, University of Central Florida, Orlando, FL, USA
E-mail: boommen@ucf.edu

INTRODUCTION

Traumatic Brain injury (TBI) is a leading cause of death and disability among children and young adults in United States, with an estimated 1.5 million Americans sustaining TBI (CDC, 1999). The cranio-cerebral complex is the most severely affected region during an automobile accident. This is because of transfer of high amount of kinetic energy to the upper extremity of the body during an accident. Pressure variations with respect to space and time cause brain tissue to deform beyond the level of recovery. Pressure gradients are produced as a result of linear acceleration involving both the absolute motion of the brain and its relative displacement with respect to the skull during a head impact (Goldsmith, 1992). Accurate modeling of the cranio-cerebral complex is necessary to predict the correct distributions of strains during an injury to the brain. Computational techniques such as the finite element method provide a means to study the tolerance level for the head during an impact.

This paper describes the development of a three-dimensional hexahedral LS-DYNA finite element model for the cranio-cerebral complex, based on fresh CT scans for the skull model and MRI images for the brain model. The components modeled to study the injury mechanism are brain, cerebrospinal fluid (CSF), dura and the skull. LS-DYNA is a finite element code with special features for modeling shock and impact.

METHODS

For modeling the three dimensional geometry of the skull and brain, horizontal slices of fresh CT scans and MRI data of a living Human Head, are used, at an incremental distance of 2 mm in the superior-inferior direction. The CT data are imported into MIMICS, a software used for the visualization and segmentation of CT and MRI data. The combination of manual segmentation and automatic discretization based on threshold values is used to create the regions of interest for the skull. The same methodology is adopted to create the outer contours of the brain using MRI data.

The geometric data of the skull and brain are exported as IGES files into I-DEAS, a general-purpose solid modeling and finite element software code. The data from MIMICS are used to create three-dimensional solid model of skull and brain in I-DEAS. The surface that forms as the interface between the skull and the brain is used to represent the cerebrospinal fluid (CSF). A constant thickness of 1.5 mm is assumed for the CSF. In real life the distance between the dura and brain is negligible, but for modeling purposes a realistic thickness for CSF needs to be assumed to avoid numerical instabilities during the solution phase.

The surface data of the brain, skull, CSF and dura are exported from I-DEAS as STL files into GeoMagic Studio, an imaging software which enables the surface data to be edited and smoothed. Non-uniform Rational B-Spline (NURBS) surfaces are created at the final stage and are imported in IGES format into TRUEGRID, a meshing software. The surfaces are used to create the hexahedral mesh for the brain and CSF and 4 noded shell elements for the dura.

RESULTS AND DISCUSSION

Figure 1 shows several views of the developed hexahedral Finite Element (FE) model for the brain, to be used for the impact analysis. The brain model consists of 19894 elements and 24096 nodes.

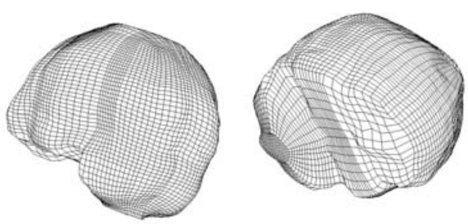

Figure 1: Finite Element Model of Brain

Figure 2 shows the FE model of CSF, which surrounds the brain and is primarily responsible in attenuating the shocks. The CSF consists of 4998 elements and 10876 nodes. Also modeled is the Dura matter using 4 noded shell elements. The Skull is modeled as hexahedral elements, which represent three layers of bone material, with the inner and outer layer representing the compact bone of skull and middle layer representing the diploe layer of the cranium (Kleiven, 2002).

The brain will be modeled as a homogeneous material using the Non-Linear

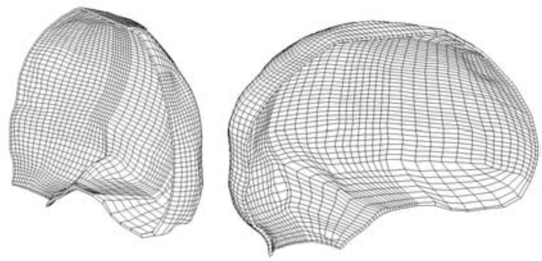

Figure 2: Finite Element Model of CSF

Viscoelastic constitutive model developed by Mendis et al (Mendis et al, 1992). A summary of the properties which used in the simulation, is shown in Table 1.

Table 1 Properties used for FE Modeling

Tissue	Modulus (GPa)	Density (Kg/m^3)	ν
Outer Table	E =15	2.00	0.22
Inner Table	E =15	2.00	0.22
Diploe	E =1	1.30	0.24
Brain	Hyperelastic	1.04	0.499
Dura	E =0.0315	1.13	0.45
CSF	K = 2.1	1.00	0.5

The explicit non-linear finite element code LS-DYNA is used to evaluate the shock and stress underlying brain damage mechanics. The broad goal of this research is to predict the extent of cognitive neurologic dysfunction and understand the overall role of impact conditions in the pathophysiology of TBI.

REFERENCES

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