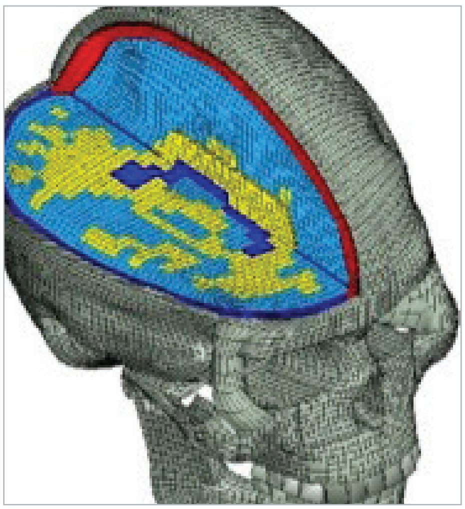
Success Story

Developing an Injury Threshold for Human Brain Concussion



Key Highlights

Industry
University/Research, Biomedical

Challenge
Develop a complete understanding of injury mechanisms for mild traumatic brain injury or concussions in order to prevent or mitigate injury occurrence.

Altair Solution
Establish a meaningful injury criterion through the use of field concussion data and finite element modeling of the head based on Altair HyperMesh.

Benefits
Traumatic brain injuries constitute a significant portion of injury resulting from vehicle crash and sports collisions. Development of strategies to prevent and mitigate these injuries can reduce the heavy emotional, economic, and social price of these injuries for future products.

Background

The Bioengineering Department at Wayne State University in Detroit, Michigan houses one of the largest continuously active biomedical research programs in the United States. For over 70 years, faculty and researchers have made significant biomedical advances through close collaboration between the Department and WSU's School of Medicine.

Directed by Dr. King Yang, Professor of Bioengineering, the Department's Bioengineering Center is a leading laboratory focused on research into impact trauma, low back pain, and sports injury biomechanics. Current projects include vehicle side and rear impact crashworthiness analysis, head injury modeling, and lower extremity injury simulation. In 1998, the computational model for brain injury developed by Bioengineering Center faculty and students was recognized by the Smithsonian Institution with the Computer World Smithsonian Medal.

Mild Traumatic Brain Injury: A Leading Cause of Disability and Mortality

Traumatic brain injury (TBI) resulting from blunt head impact is a major cause of disability and mortality in the United States. Approximately 2 million TBI cases occur each year. The great majority of these injuries are classified as mild traumatic brain injury (MTBI) or concussion. There is increased awareness of sports-related MTBI as an important public health problem affecting a large number of people despite the use of protective headgear. As a cure is not available, the only alternative is to develop intervention strategies. Determining head injury interventional threshold criteria for athletes, and specifically for American football, is a primary area of study for the Center.

Keywords: HyperMesh, HyperMorph®, biomechanics, head injury simulation

Wayne State University

"HyperMesh finite element modeling and morphing tools have been fundamental to the development of the Wayne State University Brain Injury Model" – Dr. King H. Yang

Dr. King-Hay Yang is a Professor of Biomedical Engineering and the Director of the Bioengineering Center in the College of Engineering at Wayne State University in Detroit, Michigan.

The Bioengineering Center developed head injury protection standards based on tolerance curves derived from animal concussion test acceleration results and cadaveric skull fractures induced by flat surface impact on the forehead. However, these standards cannot account for the complex motion of the brain within a deformable skull. Additionally, they neglect the contribution of angular head acceleration to injury causation. Furthermore, the directional sensitivity of the head is not taken into account.

Current football helmets have a padding system to prevent severe head injury, but do not effectively prevent concussion. Development of MTBI-preventing athletic headgear for football and other sports requires a greater understanding of injury mechanisms and thresholds.

Biomedical studies of human concussion that relate mechanical input to localized brain tissue deformation, pressure, and stress/strain response are needed to properly assess brain injury development. A meaningful head injury criterion must identify a threshold below which no loss of function occurs, and a ceiling beyond which irreversible changes to brain function occur. Such information is crucial to the design of effective head protection systems. Computer models capable of simulating impact events provide significant assistance to researchers in the development of threshold criteria for MTBI. Finite element (FE) based computational models of the human head are now capable of simulating fine anatomic detail and tissue-level characteristics for impacts leading to injury. The Wayne State University Head Injury Model (WSUHIM) is the most sophisticated of several FE models developed for head injury assessment. Introduced in 1993, WSUHIM has a long history of development using Altair's HyperMesh® as its exclusive modeling platform.

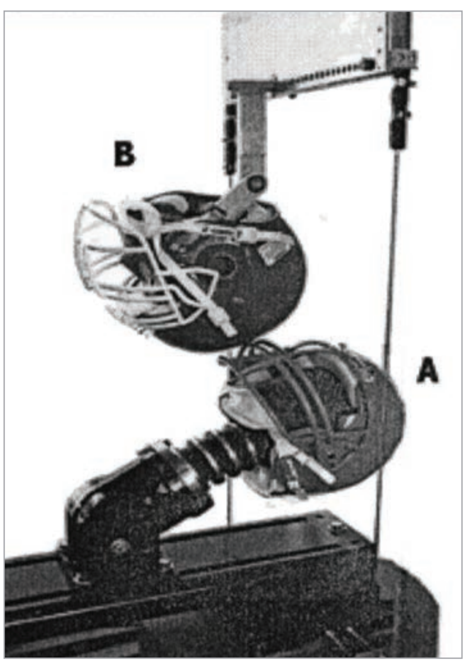


Fig. 1 Simulation of static test, displacement contour

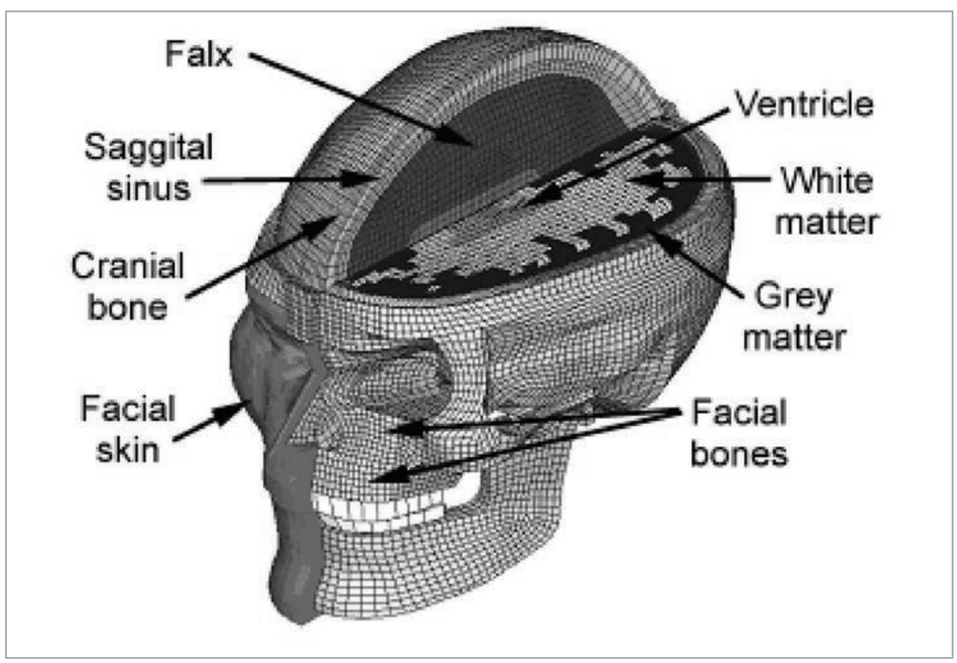


Fig. 2 The WSUHIM Showing Various Components of the Head

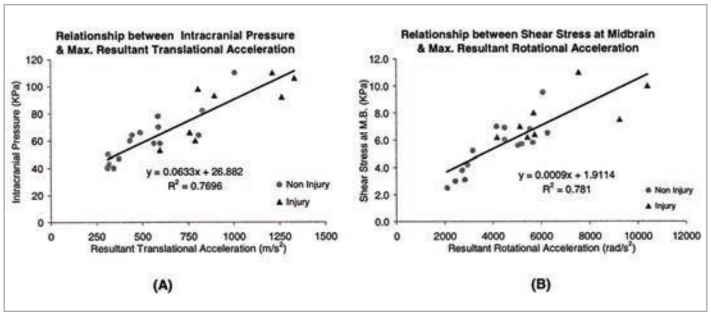


Fig. 3 Relationship Between Intracranial Pressure and the Maximum Translational Acceleration (A) and Between Shear Stress the Mid-Brain and Maximum Rotational Acceleration of the Head (B)

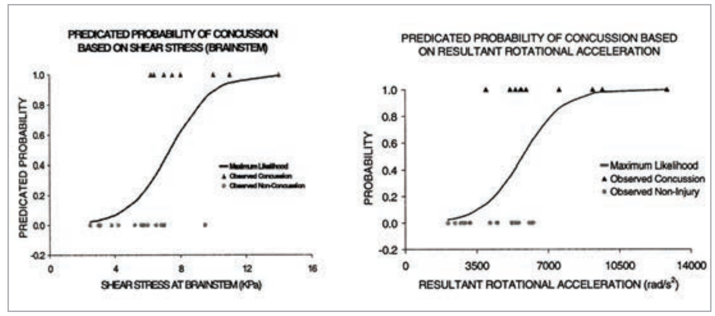


Fig. 4 Logistic Plots of the Predicted Injury Probability Based on Shear Stress at Brainstem Predicted By Model and the Input Head Rotational Acceleration

Method for Modeling Traumatic Brain Injury Data from Football Field Events

NFL players play four preseason, sixteen regular, and additional playoff games each season. Approximately 150 players are diagnosed with apparent or suspected MTBI every year. During 2003-04, a research study identified several confirmed concussion cases gathered from team physicians who treated the injured players. Game videos of the confirmed cases were then used to determine head kinematics, including impact velocity and location.

Laboratory-based reconstructions of the impact events were conducted by using two Hybrid III anthropomorphic test dummy heads wearing exemplar helmets similar to those worn by the injured players. The two Hybrid III heads were each instrumented with nine linear accelerometers and the heads were attached to Hybrid III necks instrumented with six-axis load cells. The injured (usually the struck) player was represented as a stationary helmeted head form, while the non-injured (usually the striking) player was represented by a helmeted head form that moved at the relative velocity derived from the game video (Fig 1).

Using the laboratory-derived head kinematics data, case-by-case FE-based simulations were completed using the Wayne State University Head Injury Model (WSUHIM). The model has fine anatomic detail of the cranium and brain with more than 300,000 HyperMesh elements (Fig. 2).

The WSUHIM simulates all essential features of a 50th percentile male head, including 15 different material properties for the brain and surrounding tissues. The model includes viscoelastic gray and white brain matter, membranes, ventricles, cranium and facial bones, soft tissues, and slip interface conditions between the brain and dura. The WSUHIM used in this study was modified by Dr. Liying Zhang to improve mesh quality and material definitions. HyperMesh enabled these changes to be made efficiently and accurately. The cranium of the modified FE model was loaded by translational and rotational accelerations measured from 24 laboratory head impact reconstructions. “HyperMesh finite element modeling and morphing tools have been fundamental to the development of the Wayne State University Head Injury Model” said Dr. Yang

Simulation Results and Proposed Head Injury Criterion

The FE simulations allowed for predictions of the intracranial pressure distribution and local stress/strain of intracranial mechanical responses for a given input associated with either a concussion or a non-injury event.

For this study, the mechanical response parameters of intracranial pressure and brain shear stress, both predicted by the simulation model, were selected as the most promising indicators of MTBI. Statistical analyses were completed to assess relationships between injury outcome and head kinematics. The following conclusions resulted from the simulation study:

1. It was concluded that intracranial pressure can serve as a global response indicator for MTBI.
2. High translational shear stress concentrations were found to be localized in the upper brain stem and thalamus regions. The induced shear stress may alter brain function leading to mild brain injury.
3. Linear regression analyses of the simulation results showed that translational head acceleration had a greater influence on intracranial pressure responses in comparison with rotational acceleration (Fig 3).
4. Predicted shear stress response in the upper brainstem was the best injury predictor over other brain response parameters, based on linear logistic regression analyses (Fig 4).

An injury tolerance based on head kinematics was also proposed, applicable to football and across a broad range of activities. Altair HyperMesh played a key role in providing accurate finite element modeling capability for these studies and has been the exclusive mesh modeling tool for the WSUHIM since its inception in 1993.

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