D16 A Predictive Finite Element Human Head Model to Assist Forensic Scientists

Jean-Sébastien Raul, Strasbourg 67085, FRANCE; Caroline Deck, PhD, Strasbourg, AE 67000, FRANCE; Franck Meyer, PhD, Icube, Strasbourg 67000, FRANCE; Nicolas Bourdet, PhD, Icube, Strasbourg 67000, FRANCE; Blandine Schnedecker, MD, UML, Pointe à Pitre, GUADELOUPE; Remy Willinger, IMFS, Strasbourg, FRANCE*

Learning Overview: The goal of this presentation is to present a predictive Finite Element Head Model (FEHM) and to illustrate how this tool could assist forensic scientists in the elucidation of traumatic head injury cases by using a brain injury criterion based on multiscale computation of axonal elongation of real-world head trauma.

Impact on the Forensic Science Community: This presentation will impact the forensic science community by showing the possible use of the finite element method in head injury cases.

In forensic science, it is often difficult to corroborate the causation of a head injury as a result of an accident or an assault. Clinical examination of the injuries may provide knowledge about the mechanism of injury, but there is often uncertainty to discriminate the aftermath of injury due to a fall or blow and to estimate the plausibility of a given head trauma explanation. Head injury tolerance study is necessary to assess the brain injury risk for a given impact hypothesis during forensic investigation. Regardless of rapid advances in technology and knowledge in forensic science, it is still considerably difficult to describe the causation of injuries. The consequence of axonal injury leads to cognitive and permanent disabilities and fatalities in most Traumatic Brain Injuries (TBIs).[1,2] In both the severe and mild TBIs, Diffuse Axonal Injury (DAI) is the most common pathology.[3] DAI is characterized by dynamic tensile elongation of axonal fibers and consequential fiber rupture.[4] However, the structural signature of this microscopic-level injury is not easily captured by conventional medical imaging methods and the results are difficult in DAI diagnosis. Computational head models, on the other hand, can be deployed to study the DAI mechanism, especially for the definition of brain injury tolerance limits.[5,6]

The main objective of this study is to present a FEHM and explain how this tool could assist forensic scientists in the interpretation of traumatic head injury cases by using a brain injury criterion based on multiscale computation of axonal elongation of real-world head trauma.[5] First, the implementation of new medical imaging data coming from Diffusion Tensor Imaging (DTI) into the FEHM in order to mimic the main axon bundles was performed to improve the brain constitutive material law with more efficient heterogeneous anisotropic visco-hyper-elastic material law and enable it to compute axon elongation at the time of impact.[7] This model was then validated against all existing data available in the literature in terms of skull fracture as well as in terms of brain pressure and brain displacement.[5]

Further, well-documented head trauma cases were simulated by using this FEHM in order to derive head injury criteria.[5,8] Based on the statistical analysis of different intra-cerebral parameters, it was shown that axon strain was the most relevant candidate parameter to predict DAI. The proposed brain injury tolerance limit for a 50% risk of DAI has been established at 14.65% of axonal strain, resulting in good accordance with experimental studies based on cell culture.[5,9,10]

To demonstrate the ability of this advanced FEHM to localize neurological injuries, a well-documented case report is presented. The case report summarizes a 29-year-old construction worker of 95kg weight and a height of 1.82m. He was found unconscious on the floor by his colleagues, with his head on a wooden board. The victim fell from a scaffold at an indeterminate level. The first medical observations were reported as fainting, vomiting, left tympanic perforation, and ear hemorrhage. Scans were then performed and showed frontal bilateral contusions, left temporal contusions, blood in the left auditory canal and in the left mastoid cells, as well as a left petrous bone fractures with a left lambdoid suture disjunction. The victim left the hospital after five days but showed severe neuropsychological dysfunction and memory failure. Neurological evaluation was carried out after ten months of cerebral trauma and showed very important changes of cognitive functions (memory; lack of concentration, reasoning and planning; anxiety and depression). These functions are related to the cortical structures (associative neo-cortex) and sub-cortical structures and they require an efficient inter-hemispherical transfer via the corpus callosum. These disorders correspond with frontal, temporal, and corpus callosum injury. This case was then reconstructed numerically with the FEHM and a good correlation was found between the simulation and actual fracture pattern. Moreover, brain axonal strain calculated was higher than the 50% risk of DAI, which is in accordance with the case report of an unconscious victim. The location of the elements with the highest axonal strain values corresponds to the location of the corpus callosum and the frontal lobe and is coherent with the medical report.

HNBi N°3.8 Interreg V Rhin Supérieur project—FEDER.

Reference(s):

1. Langlois, J.A., Rutland-Brown W, Wald M.M. The Epidemiology and Impact of Traumatic Brain Injury: A Brief Overview. *Journal of Head Trauma Rehabilitation*, 2006, 21:375-378.
2. Faul M., Xu L., Wald M.M., Coronado V.G. Traumatic Brain Injury in the United States: emergency Department Visits, Hospitalizations and Deaths 2002–2006. *Centers for Disease Control and Prevention, National Center for Injury Prevention and Control*, 2010, Atlanta, GA.
3. Gentry L.R., Godersky J.C., Thompson B. MR Imaging of Head Trauma: Review of the Distribution and Radio Pathologic Features of Traumatic Lesions. *American Journal of Roentgenology*, 1998 150:663–672.
4. Arfanakis K., Haughton V.M., Carew J.D., Rogers B.P., Dempsey R.J., Meyer M.E. Diffusion Tensor MR Imaging in Diffuse Axonal Injury. *American Journal of Neuroradiology*, 2002, 23: 794–802.

5. Sahoo D., Deck C., Willinger R. Brain Injury Tolerance Limit Based on Computation Of Axonal Strain. *Journal of Accident Analysis & Prevention*. 2016, 92:53-70.
6. Takhounts, E.G., Hasija, V., Ridella, S.A., Tannous, R.E., Campbell, J.Q., Malone, D., Danelson, K., Stitzel, J., Rowson, S., Duma, S., 2008. Investigation of Traumatic Brain Injuries Using the Next Generation of Simulated Injury Monitor (SIMon) Finite Element Head Model. *Stapp Car Crash Journal*. 52, 1–32
7. Sahoo D., Deck .C, Willinger R. Development and Validation of an Advanced Anisotropic Visco-Hyperelastic Human Brain FE Model. *Journal of the Mechanical Behavior of Biomedical Materials*. 2013, 33:24-42.
8. Sahoo D., Deck C., Yoganandan N., Willinger R. Development of Skull Fracture Criterion Based on Real World Head Trauma Simulations Using Finite Element Head Model. *Journal of the Mechanical Behavior of Biomedical Materials*, Volume 57, pp 24-41, 2016.
9. Morrison III B., Cater H.L., Wang C.C-B., Thomas F.C., Hung C.T., Ateshian G.A., Sundstrom L.E. A Tissue Level Tolerance Criterion for Living Brain Developed With an *In Vitro* Model of Traumatic Mechanical Loading. *Stapp Car Crash Journal*, 2003, 47: 93–105.
10. Bain A.C., Meaney D.F. Tissue-Level Thresholds for Axonal Damage in an Experimental Model of Central Nervous System White Matter Injury. *Journal of Biomechanical Engineering*, 2000, 16:615-622.Finite Element Head Model, Axonal Strain, Head Injury Prediction Tool.

Finite Element Head Model, Axonal Strain, Head Injury Prediction Tool