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METHOD TO REVERSE-ENGINEER HEAD IMPACT CONDITIONS LEADING TO A TRAUMATIC BRAIN INJURY BY COMBINING CT AND MRI IMAGES AND A FINITE ELEMENT MODEL OF THE HEAD AND BRAIN

Thais Manlius[3*], Clémence Delteil[1,2], Yves Godio-Raboutet[3], Pierre Simeone[4,5], Éric Wagnac[6,7], Nicolas Bailly[3], Lionel Thollon[3]

[1] Forensic Department, Assistance Publique-Hôpitaux de Marseille, La Timone, 264 rue St Pierre, 13385 Marseille Cedex 05, France
[2]Aix Marseille Univ, CNRS, EFS, ADES, Marseille, France
[3]Aix Marseille Univ, Univ Gustave Eiffel, LBA, Marseille, France
[4]Aix Marseille University, AP-HM, Department of Anesthessiology and Critical Care Medicine, University Hospital Timone, Marseille, France
[5]Aix Marseille University, CNRS, Inst Neurosci Timone, UMR7289 Marseille, France
[6]Department of Mechanical Engineering École de technologie supérieure, 1100 Rue Notre-Dame Ouest, Montréal, H3C 1K3, QC, Canada
[7]Research Center, Sacré-Cœur Hospital Montreal, 5400 Boul Gouin O, Montréal, H4J 1C5, QC, Canada
*Email: thais.manlius@univ-eiffel.fr

ABSTRACT

Understanding impact conditions and injury mechanisms leading to Traumatic Brain Injury (TBI) is critical in forensic medicine and to improving protection and care. Current imaging tools (CT scan, MRI) enable precise descriptions of the injuries at the time of image acquisition but do not inform on the head impact condition or injury mechanism. Detailed finite element (FE) head and brain models allow reconstruction of impact conditions and prediction of brain deformation. This study aims to determine impact conditions leading to a severe TBI case by reverse-engineering the injury observed on imaging data using an FE head and brain model.

A pedestrian-car accident with severe head injury was reconstructed. CT scans revealed fractures of the malar tripod, the floor of the left orbit, and the left maxilla. Discrepancies emerged between imaging findings and clinical symptoms. A mesencephalic lesion in the right hemisphere near the corticospinal tracts was seen on an MRI performed at a distance from the accident, but not on the initial CT scan.

A scaled FE head and brain model, including subject-specific internal brain structures, was developed using HYPERMESH software. The study simulated a head-on-ground impact. A parametric study was performed to determine the most plausible scenario(s) that produced both the fracture seen on the CT-observed fracture and the MRI-detected brain damage without predicting injury in undamaged areas. Four crash parameters were examined: normal impact velocity, tangential impact velocity, X-axis and Z-axis impact angles. Stress and strain in the skull and brain were used to predict injury: the simulation best predicting both facial fracture and brain damage was selected.

The optimal impact scenario varied between 5.6 m/s and 6 m/s for normal velocity and between 0 and 1 m/s for tangential velocity, with the X-axis ranging between 2° and –3° and the Z-axis between –12° and 6°. Under these conditions, the simulated fracture closely matched that observed in the CT scan, with Von Mises stress exceeding 150 MPa. The selected scenarios showed regions near the maximum principal strain threshold of 0.21 at the corticospinal tracts mesencephalic level, consistent with mesencephalic injury and the patient's left hemiplegia.

This preliminary study demonstrates a personalized scaled brain FE head model capability to identify impact conditions and analyze a real TBI case injury mechanism using medical images (CT, MRI). Future work will apply and refine this methodology across additional TBI cases to enhance our brain injury mechanism understanding in forensic medicine and protection.