Investigation of Head Injury Mechanisms through Multivariate Finite Element Simulation

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Abstract

Over 1.7 million people sustain a Traumatic Brain Injury (TBI) annually in the United States, 52,000 of whom die. Nearly one third of TBIs resulting in death are the result of motor vehicle crashes (MVCs) or pedestrian impacts. To mitigate occupant injury in MVCs, vehicles are subject to government safety standards and are also given star ratings through the New Car Assessment Program (NCAP). These crash tests use anthropomorphic test devices (ATDs) to measure head linear acceleration (HIC) and have the ability to measure rotational velocity. Supplementing the resultant linear acceleration of the head with measures of rotational velocity and acceleration such as the Brain Injury Criterion (BrIC) has been proposed in both Europe and the USA. A link between these two measures and real world injury has been historically minimal.

Through simulation and analysis of 1,340 head impact scenarios with the Global Human Body Models Consortium (GHBMC) 50th percentile head model, the correlation between ATD measurable values and brain tissue injury metrics has been established. 260 simulations involved translational/ rotational movement of the head absent of direct impact, while the rest involved impacts with soft, compliant, and hard surfaces with elastic moduli ranging from 165kPa to 210GPa and impactor speeds ranging from 3 to 10m/s. Both spatial and anatomical regions of interest (ROIs) were developed for the GHBMC brain based on impact location. The anatomically defined ROIs were elements of the frontal and temporal lobes as well as the elements directly surrounding the ventricles. The spatially defined ROIs were defined by elements in 30°, 60°, >90°, and >150° cones with respect to the angle between the brain CG and impactor location. These ROI cones were then subdivided into deep, intermediate, and outer subregions for more detailed analysis.

Total strain accumulation in the brain was found to be dependent on the rotation direction as measured by Cumulative Strain Damage Measure (CSDM). On average, any head rotation that involved axial plane rotation (SAE J211 z-direction), exhibited higher strian values than any rotation that did not involve this directionality. Thus, the brain is more sensitive to z-direction rotation than other directions. Many simulations demonstrated a discrepancy between AIS injury risks as predicted by HIC and BrIC. Pressure in the brain tissue just deep to impact site, which has been proposed as an injury mechanism for contusion in the literature, has been calculated for impacts with hard surfaces. The 90th percentile of pressure in this ROI has been assessed for correlation with both BrIC and HIC. As the measured HIC for a simulation increases, so does the

pressure in this ROI. No such correlation was found for BrIC. Thus, HIC is a better predictor of pressure in the brain. Ten similar injury mechanism hypotheses have been evaluated for injuries including intraventricular hemorrhage, epidural hematoma, diffuse axonal injury, and subdural hematoma. The results of this work will inform understanding of head injury mechanisms and the ability of ATD measurable data to predict specific head injuries in both consumer and regulatory crash tests.