D16 The Biomechanics of Head and Brain Injury

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Learning Overview: After attending this presentation, attendees will better understand the uniquely different forces associated with linear acceleration and those associated with rotational/angular acceleration, along with their effects on head and brain injury, which will assist in the identification of potential mechanical causes of trauma.

Impact on the Forensic Science Community: The mechanisms that cause focal and diffuse injuries to the head and brain are unique, with an absence of correlation between the two. This presentation will impact the forensic science community by increasing understanding of these mechanisms to assist forensic investigators in identifying potential mechanical causes of trauma at the scene of the incident.

There are two primary mechanisms associated with traumatic head and brain injury—impact loading and impulse loading. A direct blow transmitted primarily through the center of mass of the head produces impact loading, which can result in extracranial focal injuries such as contusions, lacerations, and external hematomas, as well as skull fractures and underlying brain contusions due to coup and contrecoup brain motions. Rotational movement of the brain relative to the skull induces impulse or inertial loading, which can cause concussion. Inertial loading at the surface of the brain can cause subdural hemorrhage due to bridging vein rupture, whereas its effects on the neural structures deeper within the brain can produce axonal (nerve) injury.

Research conducted in the 1940s first cited angular (rotational) acceleration as the principal mechanism in brain injury. The importance of rotational acceleration in brain injury causation was further investigated in studies involving live primates and physical models, concluding that angular kinematics contributes more than linear kinematics to the generation of concussive injuries, subdural hematomas, and diffuse axonal injuries.

The lab has conducted extensive research on unprotected and helmeted head impacts on a variety of surfaces for the purpose of characterizing head and brain impact features. An array of tri-axial linear accelerometers and tri-axial angular rate sensor installed at the center of mass of a Hybrid III headform is used to quantify the impact. Data from the analog sensors were acquired in accordance with Society of Automotive Engineers (SAE) J211, using a National Instruments® (NI) compact DAQ data acquisition system and LabVIEW™. The raw data was then filtered in MATLAB® using a phaseless eighth-order Butterworth filter with cutoff frequencies of 1,650Hz and 300Hz for the linear accelerometers and angular rate sensors, respectively. An analysis method validated by Takhounts allows for use of an Anthropomorphic Test Device (ATD) to establish a kinematically based Brain Injury Criterion (BrIC) for various types of diffuse brain injury. This method was utilized to express risk of brain injury according to the revised Abbreviated Injury Scale (AIS) scale in terms of peak angular head kinematics.

Results show that the head experiences a primary impact, quantified in terms of peak linear acceleration. Interestingly, impact-related angular velocity of the brain is defined into two peaks: an initial, generally smaller peak that occurs almost concurrent with the peak linear acceleration, followed by a larger inducted angular velocity peak. Angular acceleration is divided into three components—direct, induced, and rebound—the magnitude of which is related to the gradient and magnitude of angular velocity. These induced and rebound responses have been overlooked in prior research, but explain why seemingly innocuous impacts can cause devastating effects.

These metrics are quite important in understanding the mechanisms of head and brain injury. An unprotected head impacted by or on a hard surface will likely produce high linear and angular accelerations. Since the duration of impact is typically very short, the effects tend to be more focal, including skull fractures and brain contusions. Whereas impact on or with a softer surface, or involving a helmet, will mitigate some of the linear acceleration by increasing impact time, reducing the likelihood of focal head and brain injuries, but moderate angular kinematics acting on the brain over a longer duration can produce devastating neurological effects, including traumatic axonal injury, hemorrhages, and fatality.

The information and new discoveries to be shared in this presentation will educate forensic investigators as to the uniquely different forces associated with linear acceleration and those associated with rotational/angular acceleration, along with their effects on head and brain injury, which will assist in the identification of potential mechanical causes of trauma.

Biomechanics, Head Injury, Brain Injury