Cognitive Science and Technology
High Performance Computing

Simulation of early-time head impact leading to traumatic brain injury

Shock physics impact simulations provide medical insights for reducing brain injury

Traumatic brain injuries (TBI) associated with accidental impact may result in a variety of motor and coordination deficits, as well as loss of the brain's capability to perform cognitive and memory tasks and to process information. Consequences of brain trauma begin at the instant of injury as pressure and shear waves propagate through the brain followed by linear and angular accelerations of the brain within the skull. This suggests the existence of threshold levels and/or conditions of mechanical stress experienced by the brain that, if exceeded, lead to neural injury and evolving damage from TBI in the hours and days following an accident.

Sandia, in collaboration with the University of New Mexico Health Sciences Center, is developing numerical simulation models of the human head to study a spectrum of impact and blast wave conditions leading to TBI. Accurate models of the various tissues and geometries of the human head are being created to conduct head injury simulations that will help establish a correlation between incipient levels, rates, and durations of stress experienced by the brain at the onset of TBI. The initial scoping study simulated early-time wave interactions (within 800 micro-seconds after impact) resulting from a 34 mph impact with a plate of glass.

The model is created by importing a digitally processed computer tomography (CT) scan of a healthy female head into the material definition package of a Sandia shock physics hydrocode run on a parallel architecture computer employing 64 processors. The digital process segmented all soft tissue and bone into three distinct materials: skull, brain, and cerebral spinal fluid. Preliminary constitutive models were formulated for the skull, brain, fluid, and glass plate.

Results suggest the occurrence of the classic coup-contrecoup insult to the head, where the frontal lobes experience significant compressive pressure as the shock wave propagates into the brain from the impact. Simulation results display sagittal (side) views of the compressive pressure in the frontal region (Figure 1, back page) and tensile pressure in the occipital region (Figure 2, back page). Regions of significantly elevated deviatoric (shearing) stress are displayed in Figures 3 and 4 (back page), containing plots of the von Mises stress magnitude related to distortional (shearing) strain experienced by the material. The tearing action resulting from this type of stress could lead to cell and tissue damage.

A principal goal of this work is to establish a quantitative correlation between specific levels of stress/strain energy and the neurological conditions that lead to TBI. Once such correlations exist, this approach will be used to investigate mitigating strategies (e.g., protective headgear), which protect against the conditions under which TBI occurs.

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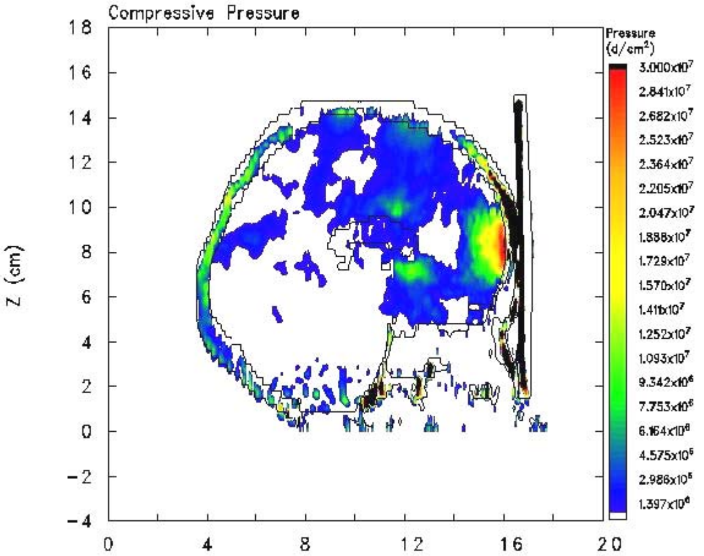

Figure 1

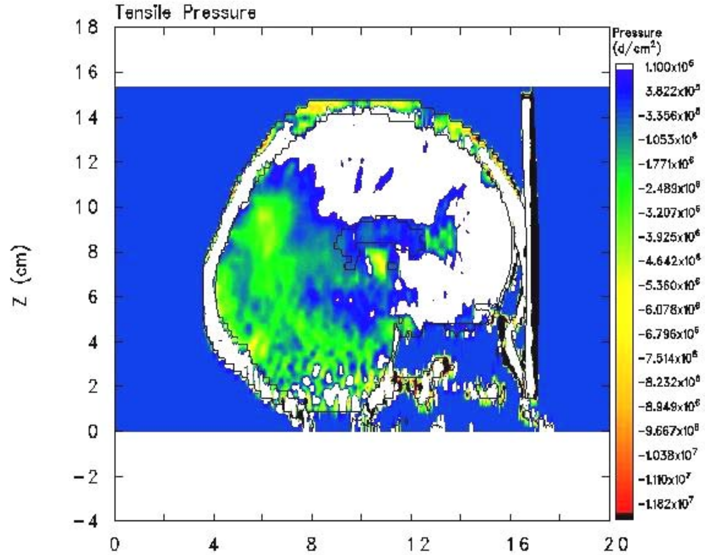

Figure 2

Distribution of compressive and tensile pressures in the sagittal plane (side view) 0.3 msec and 0.4 msec after impact, respectively. Left scale: red: 30 bars, blue: 1 bar; Right scale: red: 12 bars (tensile), blue: 1 bar (compressive).

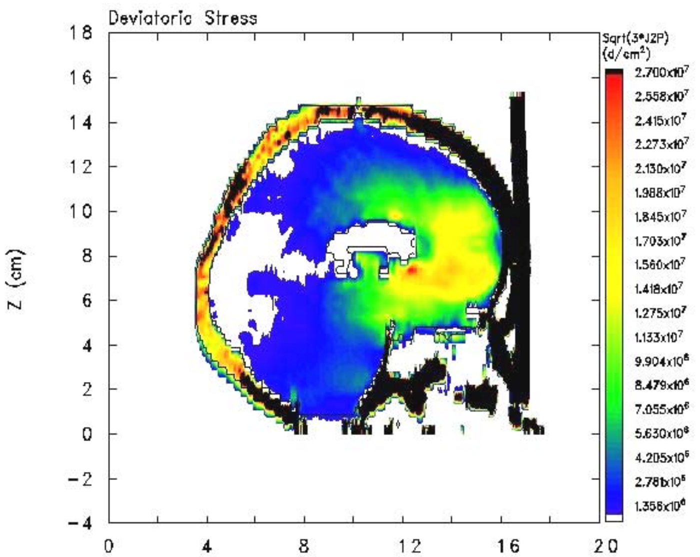

Figure 3

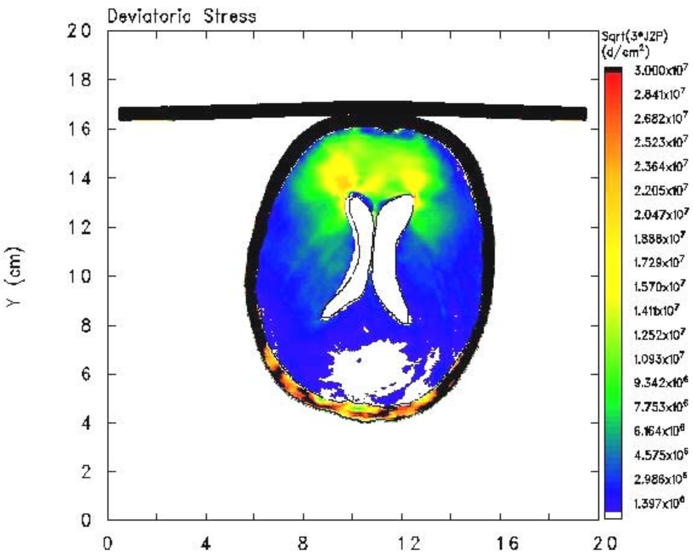

Figure 4

Distribution of deviatoric (shearing) stress in the sagittal and axial planes (side and top views) 0.4 msec after impact. Scale: red: 30 bars, blue: 1 bar.

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