Simulation of Head Impact Leading to Traumatic Brain Injury

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1. Motivation

- Traumatic Brain Injury (TBI) occurs as a result of impact or blast wave loading to the human head.

- Many cases result in TBI developing days or weeks after impact or blast event.

- Over 5 million people live with disabilities associated with TBI (source: Center for Disease Control).
2. Description of Work

• Conducted brief study simulating *early-time* wave interactions in human head resulting from impact with windshield in an automobile crash

• Crash Conditions:
  - 15 m/sec (34mph) head-on vehicle collision with stationary barrier
  - Occupant unrestrained → head impacts windshield at 15 m/sec
3. Methodology

• Data:
  - 3D digital CT scan of healthy female head segmented into skull, brain, and cerebral spinal fluid (CSF) for head geometry definition in CTH hydrocode

• Simulations:
  - Material properties of bone, brain, CSF, & glass collected from literature to create constitutive models
  - Head impact simulations run on parallel architecture computer using 64 processors
  - Analysis separates effects due to pressure (volume changing) & deviatoric stress (shearing, tearing)
4. Initial Configuration
Sagittal Plane (glass at right)

Time: 0
5. Initial Configuration
Axial Plane (glass at top)

Time: 0
6. Compressive Pressure: Sagittal View

Scale: Red=30 bars, Blue=1.4 bar

Time: 0.3 msec
7. Compressive Pressure: Axial View

Scale: Red=35 bars, Blue=1.5 bar

Time: 0.3 msec
8. Tensile Pressure: Sagittal View

Scale: Red=12 bars tensile, Blue=1.1 bar

Time: 0.4 msec
9. Tensile Pressure: Axial View
Scale: Red=8 bars tensile, Blue=1 bar

Time: 0.4 msec
10. Summary of Results
Pressure Distribution

• Pressure plots 6-9 display coup-contrecoup insult

• Coup Insult (plots 6 & 7):
  - Frontal brain lobes experience 25-30 bars compressive pressure for 0.1 msec duration

• Contrecoup Insult (plots 8 & 9):
  - Compressive waves release at occipital skull section → 3-4 bars tensile pressure in occipital brain region for 0.1 msec duration
11. Deviatoric Stress: Sagittal View
Scale: Red=27 bars, Blue=1.4 bar

Time: 0.4 msec
12. Deviatoric Stress: Axial View
Scale: Red=30 bars, Blue=1.4 bar

Time: 0.4 msec
13. Summary of Results
Deviatoric (Shear) Stress Distribution

• Deviatoric Stress plots 11 & 12 show focusing of shear (tearing) stresses:
  - Large frontal region in brain below 3rd ventricle experiences shear stress levels up to 30 bars (plot 11)
  - Shear stress level of ~25 bars concentrated in frontal brain region in proximity to lateral ventricles (plot 12)
14. Discussion of Results
Pressure Stress

• Predicts classic coup-contrecoup insult
  - Frontal brain region experiences compression
  - Occipital brain region sustains both compressive & tensile stresses
    • Cell damage associated with this phenomenon are due to changes in cell volume
    • Different degrees of damage possible depending on cell tolerance of compressive vs. tensile stress
    • Tolerance levels unknown (focus of future research)
15. Discussion of Results

Deviatoric (Shear) Stress

- Predicts localized regions of elevated shear stress around ventricles containing CSF
  - Possible tearing of ventricle membranes
    - Interior hemorrhaging of cerebrum
  - Potential for tearing of neuron membranes (cell-level damage)
    - Tearing damage of neurons causes loss of electrical conductivity → loss of functionality on cellular level
16. Remarks

- Current results are encouraging.
- Future work will involve:
  - Use of higher-resolution scan data containing greater differentiation of tissue types:
    - Brain: gray & white matter, Corpus callosum, cerebellum, dura mater, & stem; Scalp; Cranium bones
  - Further use of advanced constitutive models
  - Identifying threshold stress & strain rate conditions leading to TBI
17. Refined Data Example
Scalp (right view from hydrocode)
18. Refined Data Example
Brain (right view from hydrocode)
19. Final Remarks

• Applications of simulation capability:
  - Demonstrate mitigating potential of various protective headwear designs against conditions leading to TBI

• Military: Blast & shock wave loading from Improvised Explosive Devices (IED)
• Civilian: Head protection from contact impact & flying sports equipment (balls, bats, etc.)