Investigate the Effect of Angular Acceleration-Deceleration Pulse Shapes on Brain Response using a Validated Human Head Model

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INTRODUCTION

During the recent decade, the role of the rotational acceleration of head on resulting brain injury has been pursued rigorously in an effort to develop new brain injury criteria[1]. Previous studies used animal, experimental and physical models as test specimens to show focal and diffuse brain injury association with angular loadings of the head. The reported loadings were however, inconsistent in terms of the magnitude of acceleration-deceleration, angular velocity and associated pulse durations[2]. Recently, sophisticated finite element models of the human head have been developed and subjected to rigorous validations[3, 4]. These models have been applied to understand the local tissue response and correlate to pathological injury[5, 1].

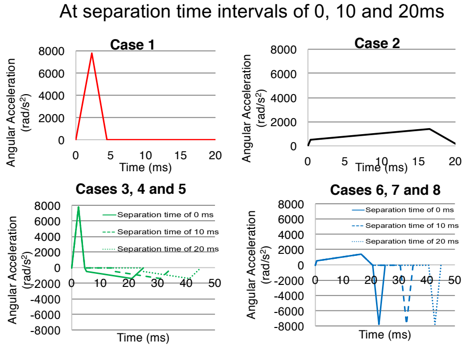
The aim of this study was to investigate effects of different angular acceleration-deceleration loading profiles on local brain responses using a validated GHBMC (the Global Human Body Models Consortium) human head model and to understand the role of the angular pulse shapes on region and tissue specific strain response in an anatomical realistic head model.

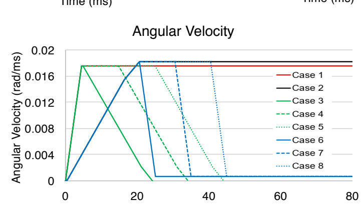
METHODS

Angular head motion loading profiles

Five different angular motion loading time histories were used as a simulation matrix[6]. The loading time history of each of the cases consists of a combination of type A and B curves:

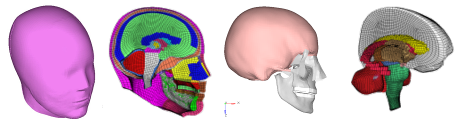
- Case 1 - Acceleration type A only
  Acceleration pulse duration of 4.5 ms with peak acceleration magnitude of 7.8 krad/s^2
- Case 2 - Acceleration type B only
  Deceleration pulse duration of 20 ms with peak acceleration magnitude of 1.4 krad/s^2
- Case 3,4 and 5 - Acceleration type A followed by deceleration type B:
  At separation time intervals of 0, 10 and 20 ms
- Case 6, 7 and 8 - Acceleration type B followed by deceleration type B:
  At separation time intervals of 0, 10 and 20ms





GHBMC F05 head model

- The GHBMC F05 finite element model represents the 5th percentile female population.
- The head model has been recently validated against 31 sets of cadaver impact tests by WSU.

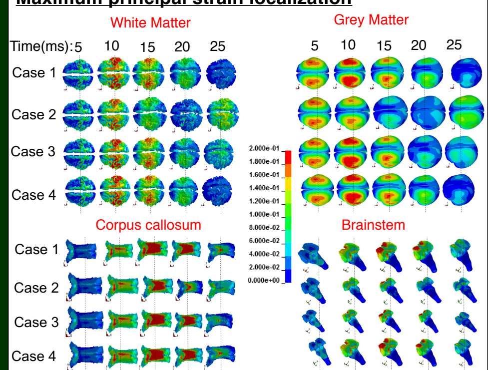


GHBMC F05 head model

- The loading was applied to the head model about the Y axis of the head to produce coronal rotation
- Maximum principal strain (MPS) and cumulative strain (MPS) damage measure (CSDM) were analysed for various structures, regions and tissues: white matter, grey matter, corpus callosum, and brainstem.

RESULTS

Maximum principal strain localization



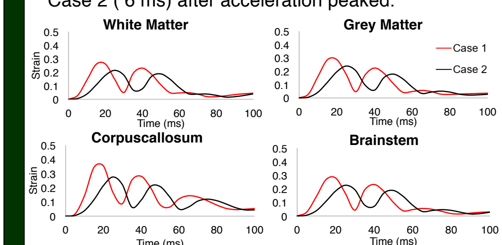
MPS experienced by the white matter, gray matter, corpus callosum and brainstem at different time points during loading

MPS time histories

Case 1 vs. Case 2

Single phased loading cases

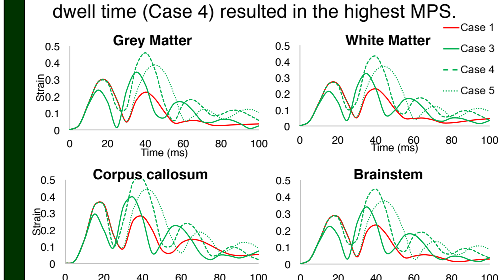
- MPS magnitude in the major structures/tissues was higher from acceleration type A (0.27-0.36) than type B (0.24-0.28).
- MPS peaked much later (>16 ms) in Case 1 than Case 2 (6 ms) after acceleration peaked.



Case 1 vs. Cases 3, 4 and 5

Acceleration type A followed by deceleration type B pulse at various dwell time in between

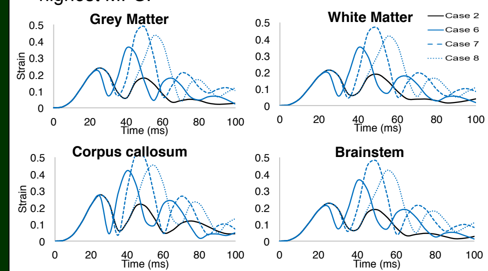
- Peak MPS magnitudes were higher in Cases 3,4 and 5 (0.37-0.5) than in Case 1 in all regions.
- Dwell time duration increased peak MPS with 10 ms dwell time (Case 4) resulted in the highest MPS.



Case 2 vs. Cases 6, 7 and 8

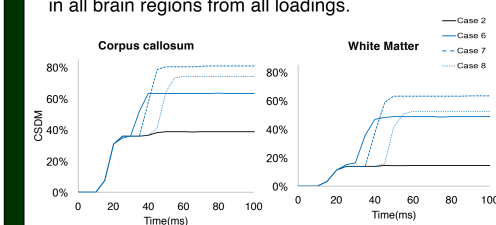
Acceleration type B followed by deceleration type A pulse at various dwell time in between

- MPS was significantly increased (from 0.28 to 0.52) due to the inclusion of the deceleration A later one in addition to the acceleration B.
- Again, dwell time duration increased peak MPS with 10 ms dwell time (Case 7) resulted in the highest MPS.



CSDM

- CSDM was compared at MPS levels of 0.10, 0.15 and 0.20 for white matter, grey matter, corpus callosum and brainstem.
- 10 ms dwell time resulted in the most volumetric failure followed by 20 ms and 0 ms separation time in all brain regions from all loadings.



CSDM in the corpus callosum and white matter at 0.1 MPS

DISCUSSION / CONCLUSIONS

- Under the loading at the same angular velocity magnitude but differing peak and duration of the acceleration or deceleration, the brain tissue strained differently at various regions.
- The biphasic acceleration pulse with longer duration-lower magnitude (type B) followed by shorter duration-higher magnitude (type A) produced greater strains in all regions than other forms of biphasic and single phase.
- Brain strain increased with increasing dwell time only till some extent (i.e. at10 ms) after that increased in separation time would reduce strain in the brain.
- Corpus callosum was the highly strained structure irrespective of type of loading forms applied in the coronal plane.
- This study suggested that the both magnitude and duration of the acceleration-deceleration is of importance for brain injury production as predicted by the strain responses in a brain model.

Acknowledgement:

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