Interhemispheric Regional Strain Response of an Anatomically Accurate Finite Element Head Model

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I. INTRODUCTION

There is a lack of strain-based brain injury metrics that account for regional responses of the brain. The majority of strain- and strain-rate-based brain injury metrics are developed and validated for whole brain response. The two most common brain injury metrics, cumulative strain damage measure (CSDM) and maximum principal strain (MPS), provide a view of what is happening in the whole brain rather than regional response [1]. CSDM is the volume ratio of elements within the whole brain exceeding a defined threshold to the volume of the brain.

Region-based brain injury metrics may provide improved prediction of injury and improved prediction of the signs and symptoms of injury. Two prior studies demonstrated that regional responses correlated better with injury than with whole brain response; however, they were focused on limited regions of the brain (brain stem shear stress and grey matter intracranial pressure) and the models lacked sufficiently detailed anatomy to investigate additional regions [2-3]. The objective of this study is to show the distribution of strain accumulation for the left versus right hemispheres of the brain using a newly created, anatomically accurate, finite element (FE) head model.

II. METHODS

The MCW-USAARL Head Injury Model (MUHIM) was developed using the SIMon model as a base mesh. The SIMon model was remeshed to increase the mesh density required to identify anatomical regions of interest (ROIs). The refined mesh model was projected over anatomical reference shells extracted from the *fsaverage* template (averaged over 40 healthy adults) [4]. Elements within the refined mesh model corresponding to the reference anatomy were manually selected to create parts defining the anatomical ROIs in model. In addition to the *fsaverage* template, the anatomical ROI location, volume and shape were reviewed with a neurosurgeon. Upon review, the model was further refined to define the hypothalamus and midbrain structures, which were not segmented in the original *fsaverage* template. Anatomic ROIs include the cerebrum grey matter, cerebrum white matter, corpus callosum, basal ganglia, pallidum, thalamus, midbrain, hypothalamus, amygdala, and cerebellum. All anatomic ROIs are symmetric about the midsagittal plane and have separate components for the left and right side. Additional brain structures included the 3rd ventricle, 4th ventricle, lateral ventricle, falx, tentorium, foramen magnum, meninges (pia mater, dura mater, subarachnoid complex), CSF, bridging veins, and a rigid skull (Fig. 1). Material properties for the model were obtained from literature. CSDM was calculated for strains above 0.15 for each anatomic ROI defined in the model. Exposures simulated laboratory tests for a frontal and a left-side impact.

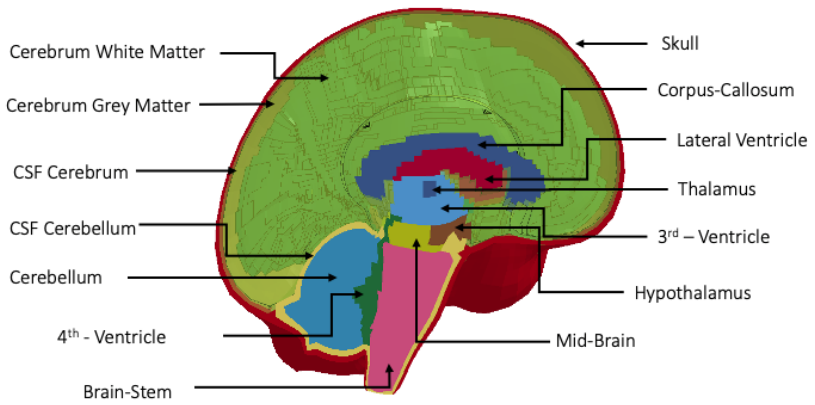

Fig. 1. MCW/USAARL head injury model (MUHIM) displaying several anatomic regions of interest (ROIs), including: skull, cerebral spinal fluid (CSF), cerebrum grey matter and white matter, cerebellum, brain stem, midbrain, hypothalamus, thalamus, corpus callosum, and ventricles (lateral, 3rd and 4th). *Not shown: basal ganglia, pallidum, falx, tentorium, pia, dura, and subarachnoid complex.

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III. INITIAL FINDINGS

For frontal impacts, the CSDM response was consistent about the midsagittal plane for the left- and right-side components, with zero CSDM(15) response in the pallidum and cerebellum; and the highest CSDM(15) response in the hippocampus (0.46), and cerebral grey matter (0.42), respectively (Fig. 2(a)). For lateral impacts, the regional CSDM responses were not symmetric about the midsagittal plane, with large differences occurring in the pallidum (0.87 versus 0.3 on the left versus right sides) and amygdala (0.29 versus 0.04 on the left versus right side) (Fig. 2(b)). Several of the subcortical structures (corpus callosum, basal ganglia, pallidum, thalamus, hypothalamus, and midbrain) had substantially more strain accumulated over their entire volumes for lateral impact compared with frontal impact (Fig. 2).

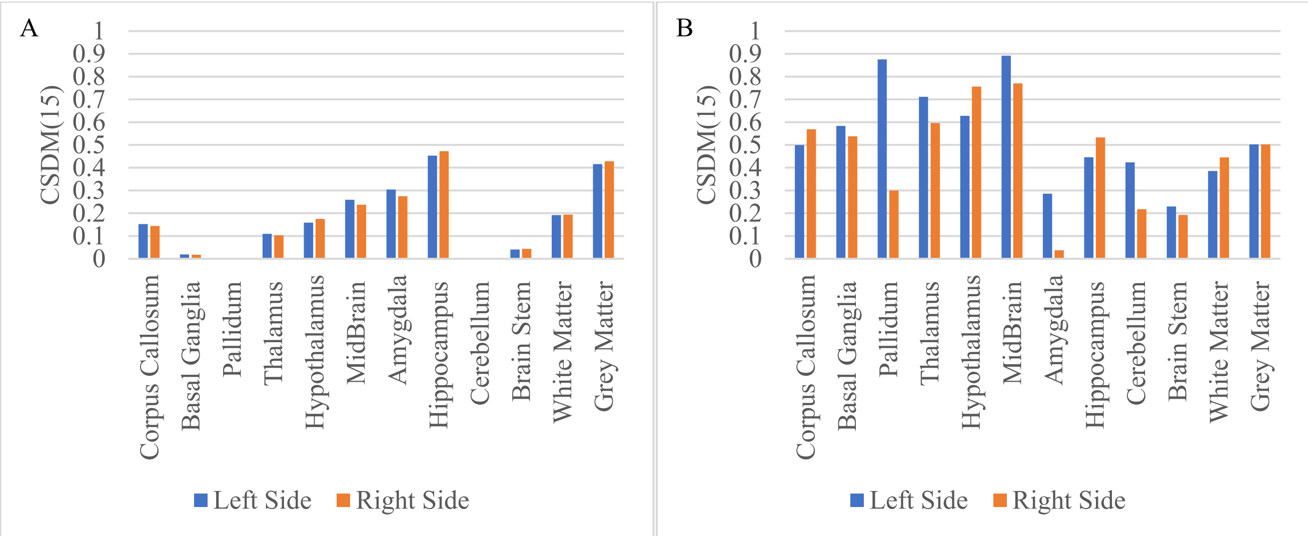

Fig. 2. Regional CSDM(15) response for (a) frontal and (b) lateral (left side) impacts at 6 m/s. Bars show the left and right side components of the brain for each region reported.

IV. DISCUSSION

The MUHIM response to frontal impacts was consistent for the left- and right-side components due to the model symmetry about the midsagittal plane. The MUHIM response to lateral impacts showed a range of differences between the left- and right-side components. The corpus callosum, hypothalamus, hippocampus and cerebral white matter had larger strain response in the right side than the left; the basal ganglia, pallidum, thalamus, midbrain, amygdala, brain stem and cerebellum all had larger strain response in the left side (side of impact); and the cerebral grey matter showed a nearly symmetric response (Fig. 2(b)). The corpus callosum and hypothalamus ROIs are contained near the midsagittal plane, with less mass located laterally. Though connected at the midsagittal plane, the thalamus and midbrain have substantial mass located laterally, and the basal ganglia, amygdala and pallidum are all located lateral to the midsagittal plane. While the hippocampus ROI is located the furthest from the midsagittal plane compared to the other subcortical structures, the strain accumulation did not follow the same pattern (larger strain accumulation occurred on the right side). The difference in the hippocampus strain accumulation may be driven by contrecoup response on the right side as opposed to coup response on the impacted side due to the distance from the midsagittal plane; however, this phenomenon is still under investigation.

Prior research reporting regional response has largely focused on either major regions (e.g. cerebrum or cerebellum) or has not reported interhemispheric response. The interhemispheric differences under lateral loading were unexpected in this study. Additional investigation to understand the importance and relevance of interhemispheric responses of the brain under multiple loading directions and magnitudes is needed.

V. REFERENCES

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