An Anatomically Accurate Finite Element Brain Model: Development, Validation and Comparison to Existing Models

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Abstract

Each year, approximately 1.7 million people in the United States suffer from traumatic brain injury (TBI). To prevent and treat these types of injuries, fundamental injury mechanisms need to be well-characterized and understood. Finite element (FE) models are powerful tools for studying brain injury. Currently validated models include: Kungliga Tekniska Högskolan (KTH), the Simulated Injury Monitor (SIMon), the Dartmouth Head Injury Model (DHIM), the Wayne State University Brain Injury Model (WSUBIM) and head models from the Total HUman Model for Safety (THUMS) and the Global Human Body Models Consortium (GHBMC) [1–6]. One limitation of these models, however, is the simplification in representing the brain with a smooth surface. This ignores the intricate folds throughout the brain which effects the local tissue response.

The overall goal of this study was two-fold. The first objective was to create a high resolution, anatomically accurate brain FE model from the International Consortium for Brain Mapping (ICBM) brain atlas. The second objective was to validate this atlas-based brain model (ABM) against localized brain motion data for three experimental configurations and use an objective rating method to quantitatively compare performance between the ABM and five additional validated brain FE models.

The ABM was developed from the ICBM brain atlas [7, 8]. The model was created by converting each atlas into an element with custom code developed in MATLAB. The model consists of 6 parts: brain, CSF, ventricles, falx, tentorium, and a rigid skull. All material properties were derived from SIMon, excluding the brain model. The material parameters used for the brain were identified through multi-objective, multidirectional optimization using a Latin hypercube design (LHD) method.

The ABM was validated against localized motion from three cadaver tests conducted by Hardy el al. (2001, 2007). Each impact was simulated in LS-DYNA by subjecting the model to the appropriate boundary conditions. Brain deformation at locations of experimental neutral density targets (NDTs) was computed and compared to experimental data. Error between experimental and predicted displacements for each NDT was quantified using a powerful metric called CORA (CORrelation and Analysis), and objective method rating that evaluates the correlation to time-varying curves [44]. Similar to the method used for the ABM, validation results for SIMon, GHBMC, and THUMS were obtained through simulation and performance

quantified with CORA. Results for the KTH and DHIM models were obtained from published literature.

In the current study, an anatomically accurate brain model was developed and validated against the robust validation data set of localized brain displacements in three impact configurations. The current study is the first to propose CORA as a metric for evaluating and comparing validation performance between models. The results of this comparison show that a few models, including the ABM and KTH, consistently perform better than the other models. Looking at the average CORA score between the three configurations per model, the ABM scores best. This result indicates that of the models considered, the ABM demonstrates the strongest ability to predict local brain deformations under a range of impact severities and directions.

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