

Abstract

Traumatic brain injury (TBI) remains a leading cause of death and disability. Regardless of this notable burden, the complex biomechanics of fall-induced TBI are inadequately understood. Although personalised and anatomically detailed finite element head models (FEHMs) can be used to simulate real-world fall accidents, facilitating the study of head impact and injury mechanisms, the research field still warrants the development of novel computational frameworks with enhanced injury mechanisms so that established FEHMs can further be tuned using real-world accident modelling to investigate the brain injury mechanism. These limitations restrict the application of state-of-the-art FE models in forensic and biomechanical utility in real-world TBI predictions. This thesis develops computational frameworks for multibody fall reconstruction, anthropometric personalisation of the IITD finite element head model (IITD-FEHM), and anatomically localised bridging-vein rupture modelling to advance intracranial injury prediction from global metrics to subject-specific, spatially resolved prediction. The first study used the MADYMO Hybrid III dummy and a full-factorial multibody dynamics framework to reconstruct falls in several parametric configurations, altering body orientation, trunk lean angle, foot placement, and surface friction. This methodology successfully reproduced clinically documented damage sites, giving the kinematic boundary conditions needed for further FE analysis. The second investigation addressed the critical issue of model generalisability by implementing and validating a geometric scaling protocol on the IITD-FEHM. Subject-specific anthropometric scaling improved Location Index and Overlap Index, quantitative measures of three-dimensional spatial correspondence between simulated and radiologically confirmed lesions, by 26.4–31.3%. In the third study, an anatomically detailed bridging-vein and superficial cerebral vein model was developed and embedded within the IITD-FEHM. A logistic function governing bridging vein

rupture was calibrated at 50% risk at the mean ultimate strain ($\epsilon = 0.30$), and the model was validated using five cadaveric pendulum experiments. This model was used to predict localised rupture and the SDH region for three real-world fall reconstructions. The model achieved 88.9% sensitivity, 76.2% specificity, and an overall accuracy of 80.0%, with case-level AUC values ranging from 0.905 to 0.976 and a combined AUC of 0.892. This thesis introduces a validated, posture-aware fall reconstruction methodology, shows the need and quantifies the benefit of anthropometric personalisation for subject-specific FEHM deployment, and transforms vascular injury modelling from a global, threshold-based paradigm to an anatomically localised framework capable of predicting SDH occurred in falls.

Keywords: *Traumatic brain injury; finite element head model; subdural hematoma; fall investigation and reconstruction; anthropometric personalisation; injury metrics; bridging vein rupture; LS-DYNA; computational injury biomechanics; forensics investigation.*