Deformable Headform Design Choices: An Evaluation of Brain Simulant Stiffness Influence on Intracranial Displacements and Strain

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Introduction

Novel deformable polymeric headforms are currently under development as a new tool for assessing helmet performance and evaluating brain injury risk. These headforms often incorporate elastomeric brain tissue simulants to replicate the brain tissue response to impact or blast wave loading events. Previous research has highlighted a significant correlation between the mechanical properties of brain tissue and the rate of loading, indicating a notably stiffer response in the context of brain injury. While Sylgard 527, a widely-used elastomeric brain tissue simulant, features an elastic moduli similar to that of brain tissue and has been employed to model the human brain's response, its mechanical properties have been found to be softer than brain tissue under high strain rate events. This disparity could potentially lead to elevated intracranial strain measurements in deformable headforms. Therefore, the present study aims to compare the *in situ* intracranial displacements and strains of various brain tissue simulant formulations, each possessing differnet stiffness properties, to recent cadaveric impact datasets. Through this comparison, we will evaluate their impact on intracranial strain and enhance our understanding of brain injury mechanisms.

Method

The tunable stiffness of brain simulants was achieved by mixing two commercially available polydimethylsiloxan (PDMS), Sylgard 527 and Sylgard 184, with different ratios, from soft to stiff, which were pure 527, 40:1, 20:1 and 10:1. The brain simulants with differnet stiffness were used to prepare four different deformable closed headforms, based on the BIPED Mk2, which was originally developed by DRDC for studying brain injury under blast loading conditions. These headforms were subjected to a series of 3 m/s impacts from a 13.3 kg linear impactor ram with a neoprene rubber end cap , replicating conditions seen in recent cadaveric studies. The intracranial displacement and strain was measured using a high-speed X-ray imaging system. The surrogate brain deformation was tracked using embedded radiopaque markers at an X-ray capture rate of 5,000 fps. Digital Image Correlation analysis was employed to calculate displacement and strain fields within the headform, and CORA analysis was subsequently performed on intracranial displacements between previous cadaver head and headform impacts.

Results

Figure 1 (a) and (b) shows the displacement trajectories and resultant displacement in frontal region. The comparison of intracranial displacements revealed that while the soft brain simulant (pure 527) had the closest approximation of the displacements to progression of displacements seen in the cadaveric head impact results, the stiffer materials exhibited closer response when optimizing for displacement amplitudes. Moreover, the stiffer material demonstrated better performance in terms of strain amplitudes when comparing the intracranial strain. Figure 1b shows the intracranial displacement and Figure 1c shows the strain comparison in frontal region.

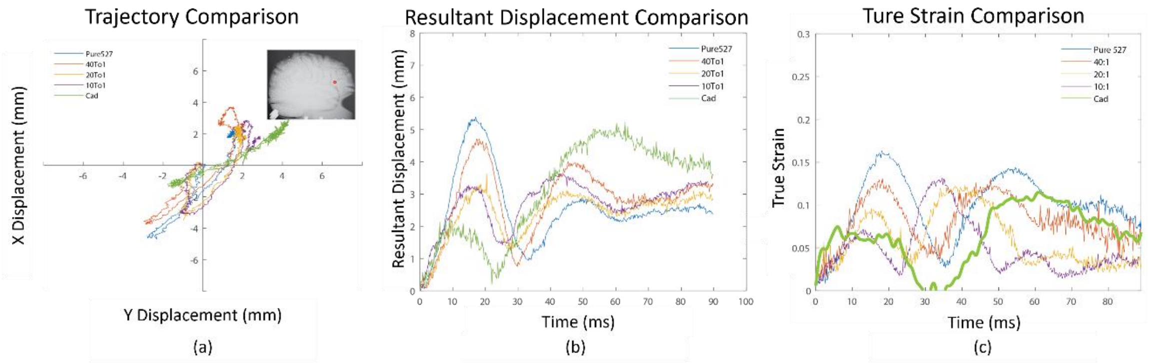

Figure 1 The response comparison of different brain simulants and recent cadaveric impact dataset from selected location in frontal region: (a) Trajectory Comparison; (b) Resultant Displacement Comparison; (c) Ture Strain Comparison.

Conclusions

The examination of various brain simulant formulations has highlighted that the stiffness of the brain simulants can be used to optimize brain simulant selection. However, further refinement of boundary conditions is required to enhance the biofidelity of the headform.