

Comparison of the Micro and Macro Mechanical Properties of Brain Tissue Phantoms.

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Introduction

The brain can sustain injury at both cellular (micro) and tissue (macro) levels due to forces acting upon it, resulting in short- and long-term neurological problems [1]. This has led to a large body of research attempting to characterize these damaging loading conditions and find ways to minimize them [2]. However, testing on live subjects raises ethical concerns and testing on animal or human tissues can be challenging. As a result, researchers have turned to creating brain-mimicking phantoms to study the impact of various loading phenomena [3-6]. To develop these phantoms, it is necessary to understand the mechanical properties of brain tissue, which has been the subject of extensive research with a recent paper compiling the findings of 121 studies since 2006 [7]. From these studies it has been established that brain tissue is highly compliant, behaves nonlinearly, and exhibits compression tension asymmetry, hysteresis, conditioning, and stress relaxation, with properties varying depending on the brain region being tested [8].

Damage to the brain can occur over a range of timescales, rapidly (milliseconds) in the case of sudden acceleration or deceleration in traffic incidents, or gradually (minutes to hours) during neurosurgical procedures [9]. The biphasic nature of brain tissue means that the response will be different in both these loading scenarios [7]. As a result, different phantoms have been developed to simulate the brain under different loading scenarios. Commonly these studies include tests on brain tissue for comparison, but these results can vary significantly between research groups.

This study utilizes the standardized test methodology for characterising brain tissue recommended by [7] and a needle insertion test method presented in [6] supplemented with correlation techniques [10] to characterize brain phantoms. This is used to reach conclusions on the suitability of each phantom to represent brain tissue in each simulated damaging loading condition, with the aim to fabricate a multi-material brain phantom which replicates the regional variation observed in the human brain.

Method

A series of different brain phantom formulations are subjected to three loading scenarios, namely uniaxial loading, micro indentation, and needle insertion. Where appropriate stereo digital image correlation is performed on the penetrated surface and in cases where the phantom is sufficiently transparent a laser-based image correlation technique is used to observe the strain profile around the needle while being inserted.

Results

The results of this study are used to inform material choices for a multi-material brain phantom (Fig 1) that replicates the regional variation in mechanical properties observed in the human brain. This phantom can be adapted to verify computational studies, gain insight into strains present during surgical procedures, and study potentially traumatic impact scenarios.

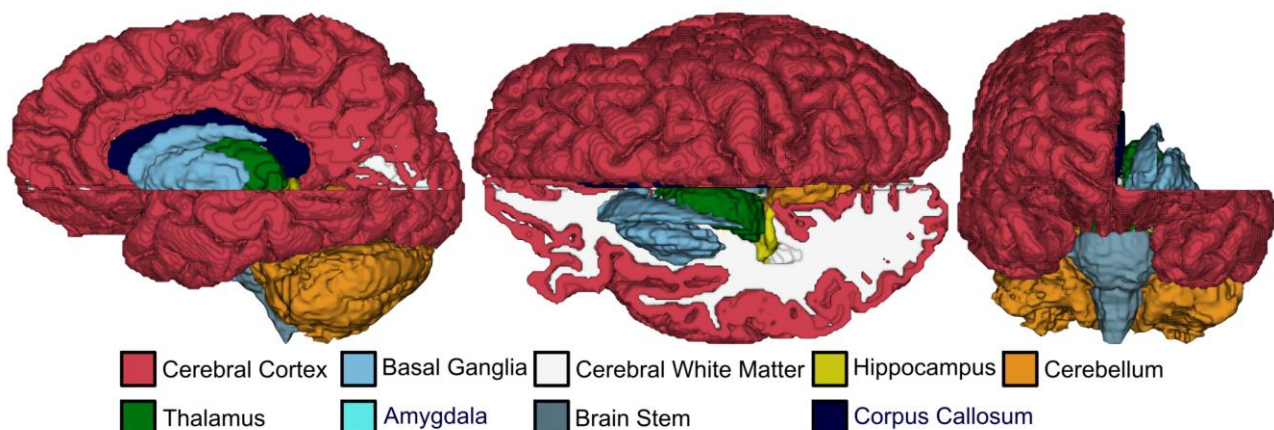


Fig 1. Diagram showing a cross section of a segmentation created from a brain MRI scan. Tissues are separated into regions which have been shown to have differences in mechanical properties [11]. This will form the anatomical bases of the multi-material model.

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