Validation of Spherical Indentation Methodology to Characterize Material Properties of Brain Tissue

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ABSTRACT

Roughly 1.7 million people sustain a Traumatic Brain Injury (TBI) every year. These injuries include, but are not limited to contusions, edema, hemorrhage, intracranial bleeding, and traumatic axonal injury (TAI). Among the leading causes of clinically treated cases are blunt traumas to the head resulting from falls, automotive accidents, and assault. On the battlefield, Improvised Explosive Devices (IEDs) have led to head injuries resulting in TBI for nearly 40 62% of surviving soldiers. In some of these cases, TBI victims are either unaware of their condition or unable to receive adequate treatment before permanent brain damage has occurred, thus reducing the quality of life of the individual. Situations like these reveal critical gaps in patient care, both in the clinical and battlefield settings. One method of accurately diagnosing TBI severity involves an imaging technique that can discern changes in the material response of brain tissue following injury. Such a technique would utilize stereotactic comparison between contemporary medical imaging systems and the intrinsic mechanical response of brain tissue; therefore, mechanical testing is necessary to quantify and map the local material properties down to the various substructures of the brain at different levels of injury. Spherical indentation is a practical choice capable of determining material parameters with the resolution necessary to develop a detailed stiffness map of both injured and uninjured brain tissue. However, there are limitations associated with spherical indentation. The boundary condition between indenter tip and specimen does not remain constant. Furthermore, the formulation of indentation is based on an elastic half space and hence substrate thickness under the indenter will affect accurate determination of material parameters. To address these limitations and validate spherical indentation methodology, compression and indentation testing is conducted on porcine brain tissue. Since quasi-linear viscoelastic modeling is well defined for compression testing, a comparison of the material properties from both mechanical tests would allow for indentation methodology to be properly validated. Ramp hold tests were performed on 10 porcine brain samples in vitro using a spherical indenter with diameter of 1.3mm. The indenter was pressed a maximum depth of 0.4mm into the samples at a maximum ramp speed of 100mm/s. Samples were cut cylindrically with a 10mm diameter, 10mm tall having mixed white and grey matter. To validate our indentation methodology, uniaxial compression tests were performed on the same samples. Samples were compressed up to 30% after an applied precompression. Force displacement data was measured and the resulting stress relaxation was modeled using quasi-linear viscoelastic theory. An inverse finite element model was constructed to determine the material parameters of our model and contact area between the indenter and specimen.