

Mechanical anisotropy in brain tissue – experimental results and implications for modeling

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Abstract

Provide accurate mechanical properties of white matter for finite element (FE) simulation studies of traumatic brain injury (TBI). (1) Measure anisotropic mechanical properties of brain tissue. (2) Identify what features of constitutive models are needed to describe the mechanical anisotropy of white matter.

The simplest adequate transversely isotropic, incompressible, material model of white matter involves three independent parameters: a shear modulus in the plane of isotropy, a tensile anisotropy parameter and a shear anisotropy parameter. These can be estimated from a combination of (1) dynamic shear testing (DST) with displacement either parallel or perpendicular to the fiber axis and (2) indentation with a tip of rectangular cross-section, in which the long axis of the tip is aligned either parallel or perpendicular to the fiber axis [1]. We use a transversely isotropic linear elastic model [2] for characterizing white matter anisotropy.

The storage and loss moduli for white matter were significantly larger when the samples were tested with the primary axonal fiber direction parallel to the direction of shear (Figure 1). No significant differences were observed for gray matter between the two orientations tested. The indentation stiffness values for all samples showed similar patterns of white matter anisotropy and gray matter isotropy (Figure 2). Based on experimental results and FE simulations, assuming the friction coefficient for the contact surface is 0.1 or 0.5, estimates of the model parameters are shown in Table 1.

The study confirms the mechanical anisotropy of white matter, and clearly indicates that contributions of both the I_4 and I_5 strain pseudo-invariants should be included in hyperelastic material models of white matter in FE simulations of TBI.