Identifying constitutive parameters for the axon and matrix: A Finite Element and Neural Network Approach

Maryam Majdolhosseini*[1], Zhou Zhou[1], and Svein Kleiven[1]

[1]Division of Neuronic Engineering, KTH Royal Institute of Technology – Sweden

Abstract

Diffuse axonal injury is a common brain trauma affecting the axons in the white matter. The micro-mechanical environment endured by the axon is directly relevant to the surrounding matrix. Finite element (FE) models are used to study axonal behaviour under injury conditions at cellular and tissue levels. While most FE models focus on isolated axons, many models study axons embedded in the tissue. However, these models use material properties for the matrix derived from small-strain experiments or neglect the viscoelastic properties of the matrix, limiting the model's applicability at the high-strain regime that is more relevant to injury. This study investigates the mechanical behaviour of axons and their surrounding brain matrix under high strains (up to 30%) and high strain rates (up to 30/s). Axonal properties were derived from experimental data on the stretching of isolated axons, and the matrix properties were estimated indirectly from experimental data on the brain tissue under multiple loading modes (i.e., tension, compression and shear) using inverse parameter identification that combined FE and neural network approach. First, around 350 FE simulations were run, changing the matrix material properties. The properties were selected randomly in a chosen window using Latin hypercube sampling. Based on the FE simulation results, a neural network (NN) model was trained to predict the effect of matrix properties on brain tissue behaviour, namely, stress-strain curves. Then, optimization methods were used to predict the best matrix properties that match experimental observations. The final model was validated using FE simulations, confirming the reliability of the identified matrix properties. The calculated shear modulus of the axon is approximately 10 kPa, with relaxation modulus ranging from 6.5 to 10 kPa. The optimum shear modulus of the matrix was estimated to be 0.85 kPa, with relaxation moduli below 1 kPa. The FE validation simulations aligned well with the experimental data, with a mean absolute error of 53.7 Pa, demonstrating the model's effectiveness. This approach provides a reliable framework for characterizing composite materials with missing properties. Moreover, the material properties derived in this study can be used in future simulations and models of axonal injury.

---

*Speaker