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Constitutive Model Identification and Validation for Spinal Cord Finite Element Analysis Under Complex Loading

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ABSTRACT

Finite element (FE) modeling has been shown to be a noninvasive and validated method for investigating the biomechanical environment of the spinal cord. However, given the spinal cord's inherently complex loading conditions and a lack of consensus on its material properties nowadays, choosing appropriate material properties remains challenging. This choice critically depends on the type of mechanical tests performed and the constitutive models employed, both of which can significantly affect numerical computations. Understanding these effects is therefore essential for building realistic FE models. The objective of this study is to select a constitutive models of spinal cord tissues suitable in order to develop simulation of the cerebrospinal fluid (CSF) induced stresses on spinal cord.

The selection process is three folds: 1) two studies characterizing the spinal cord mechanical properties (indentation [1] and unconfined compression [2]) on swine spinal cord specimens were selected in the literature. Experimental data (engineering stress-strain curve) were fitted using four constitutive models: linear elastic, ogden hyper-elastic, viscoelastic, and quasi-linear viscoelastic models. And the corresponding FE models were constructed to replicate each mechanical test configuration using the material properties previously defined. These FE models underwent validation through comparison with physical measurements (RMSE), 2) The resulting constitutive parameters were then used as initial values in an FE-based optimization process so that the final constitutive model would fit with multi-modal experimental data, ensuring consistent performance across different loading scenarios. 3) Finally, optimized constitutive models and non-optimized models were incorporated into an FE simulation of the spinal cord subjected to CSF pulsation, thereby evaluating how choices of mechanical tests and constitutive models influence the simulation outcomes.

The proposed talk will present and discuss the different constitutive model tested and their suitability to model the spinal cord's mechanical behavior under complex loading conditions. Finally, the proposed methodological framework will be used for designing biomechanical tests that effectively inform constitutive model development for complex loading simulations.

Reference:

[1] Bailly, N., Wagnac, E. & Petit, Y. Regional mechanical properties of spinal cord gray and white matter in transverse section. Journal of the Mechanical Behavior of Biomedical Materials 163, 106898 (2025).

[2] Masoumipour, A. Experimental characterization and viscoelastic finite element modeling of a porcine thoracic spinal cord submitted to axial compression. (École de technologie supérieure, 2021).