Viscoelastic characterization of porcine brain tissue in the quasi-static and high-frequency domain

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Summary

A persistent problem in the mechanical characterization of brain tissue are inconsistent responses, when experiments in different time or length scales are conducted. However, multi-modality testing is essential to calibrate a model that is applied to finite element simulations in the time and frequency domain. This contribution aims to combine the mechanical responses conducted in varying time scales. Porcine brain tissue was tested with two different experimental techniques. At the rheometer, the material response in the time domain was examined. The high-frequency behavior of the tissue was studied via magnetic resonance elastography. To compare the results in the different time scales, the viscoelastic storage and loss modulus were calculated. The combined study of the moduli indicates that the tissue is more elastic in the quasi-static regime and more viscous at high frequencies.

Introduction

Mechanical modeling is a powerful tool for understanding brain mechanics and predicting injury and disease [1]. To obtain a reliable finite element model, which can be applied under various loading conditions, it is essential to incorporate mechanical tests with varying modalities into the calibration process. However, a persistent problem in the mechanical characterization of brain tissue is the inconsistent stiffness values resulting from the use of different testing techniques [2]. Particularly challenging are experiments with varying time and length scales.

This study characterizes the mechanical behavior of porcine brain tissue over an extended time range. It combines two experimental techniques, that vary in time and length scales.

Methods

We mechanically characterized two brain areas, Corona Radiata (CR) and Putamen (P). With a rheometer, we studied the material behavior in the time domain and under nonlinear deformations. The experiments include compression, tension and torsional shear tests in the large-strain regime under cyclical loading and relaxation. For frequency-domain characterization under linear deformation, we employed magnetic resonance elastography (MRE). A tabletop MRE system, which is described in detail in [3], measures vibrations induced in the tissue by a piezoelectric actuator. This measurement technique enables to acquire vibration data from 200 to 2100Hz. All experiments were conducted at 37°C to mimic in vivo conditions.

To compare the material behavior in the different time regimes, we calculated the viscoelastic storage and loss modulus. Using the commercial FE package ABAQUS, we obtained the mechanical parameters of the rheometer experiments in an inverse material parameter identification. The material behavior was modeled by combining the hyperelastic Ogden model with the viscoelastic Prony series, which are easily transformed into storage and loss moduli. For the MRE experiments, the viscoelastic moduli were determined by fitting an analytical solution of the shear wave to the measured wave [3].

Results and Discussion

Both experimental techniques were combined to study the material behavior over an extended time regime. The response at 0Hz corresponds to the quasi-static Rheometer measurements. Figure 1 shows the mean storage and loss modulus for the two brain areas.

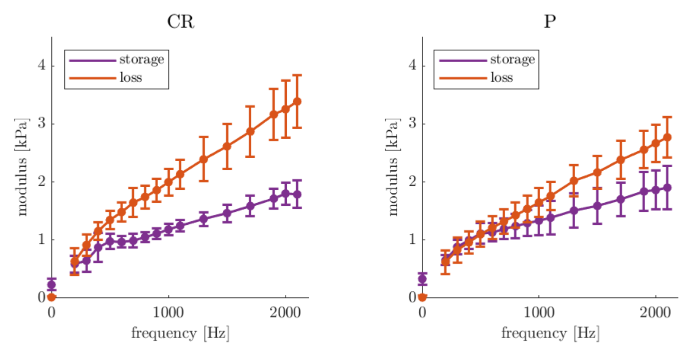

Figure 1: Mechanical characterization of Corona Radiata (CR) and Putamen (P) for frequencies from 0Hz to 2100Hz. The storage modulus indicates the elasticity and the loss modulus quantifies the viscous dissipation of the material.

In the quasi-static regime, the material behavior is more elastic than viscous. However, in the high-frequency regime, the viscosity increases rapidly, so that the loss modulus is up to three times as high as the storage modulus at 2000Hz.

Conclusions

The results suggest that the viscoelastic brain tissue switches from a higher elasticity in the low frequency domain to a more viscous behavior for higher frequencies. A closer look at the frequency range between the two experiments is necessary to characterize the crossover point.

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References

[1] Goriely, Alain et al. (2015). *Biomechanics and modeling in mechanobiology*, **14, 5**: 931-65.
[2] Faber, Jessica et al. (2022). *Current protocols*, **2,4**: e381.
[3] Braun, Jürgen et al. (2018). *Magnetic resonance in medicine* **79,1**: 470-478.