Mechanical characterization of epileptic human brain tissue

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Summary

In this contribution, we present our results on the mechanical characterization of freshly resected epileptic human brain tissue. We test the tissue samples under finite deformation in compression, tension, and torsion, and subsequently fit a two-term Ogden model to the measured response. The obtained material parameters serve as a basis for models predicting the mechanical behavior of human brain tissue under complex loading as it occurs during brain development. In addition, we analyze structural parameters obtained from histological staining of the tested tissue. We use a neural network to detect cell nuclei in the stained images. By combining these data, we find a correlation between total cell density and shear modulus in hippocampal sclerosis samples.

Introduction

Epilepsy cases of focal cortical dysplasia are characterized by malformations of the cortical layers that occur during brain development [1]. Here, we characterize the mechanical properties of epileptic tissue, which will be used as input for a computational model of the developmental process [2] and thus enables us to investigate relationships between microstructure, mechanical properties, and cortical folding.

Methods

We mechanically test tissue specimens shortly after their resection in compression-tension up to 15% strain and in torsion up to 30% shear. The measured data are then fitted with a constrained two-term Ogden model, defined by the strain energy density ψ:

$$\psi = \frac{2\mu}{\alpha_2 - \alpha_1}\left[-\frac{1}{\alpha_1}\sum_{a=1}^{3}(\lambda_a^{\alpha_1}-1) + \frac{1}{\alpha_2}\sum_{a=1}^{3}(\lambda_a^{\alpha_2}-1)\right], \qquad (1)$$

with $\alpha_1 \leq 0$ and $\alpha_2 \geq 0$. After testing, the samples are histologically stained and analyzed for pathological findings. In addition, cell nuclei are detected by a neural network to infer microstructural properties such as the cell density.

Results and Discussion

The obtained material parameters in (Figure 1) characterize the mechanical behavior of tissues with different epilepsy diagnosis. The values are in the range of those obtained for the control specimens from body donors.

In addition, we investigate the relation of microstructural and mechanical parameters. (Figure 2) shows an increase in stiffness, characterized by the shear modulus, with higher cell density for hippocampal sclerosis samples.

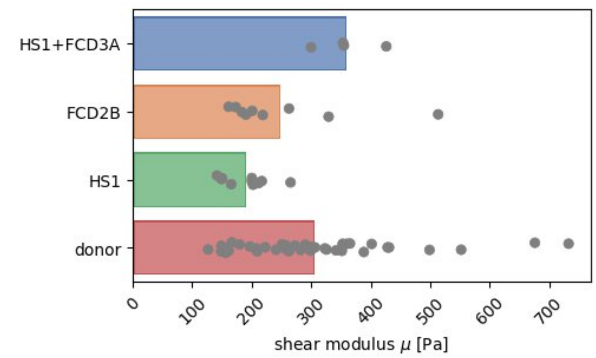

Figure 1: Shear moduli of cortical specimens from patients with epilepsy diagnosis (hippocampal sclerosis **HS1**, focal cortical dysplasia type IIb/IIIa **FCD2B/3A**) as well as control samples from body donors.

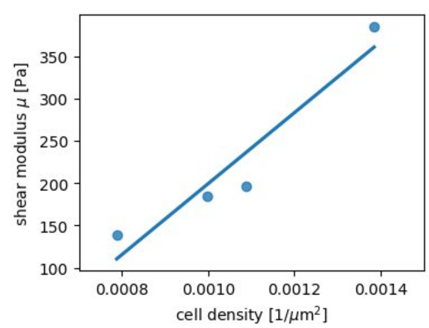

Figure 2: Correlation of cell density and shear modulus for hippocampal sclerosis samples.

Conclusions

We present a parameter dataset characterizing the mechanical behavior of epileptic human brain tissue. In addition, we show a correlation between cell density and stiffness in hippocampal sclerosis samples, indicating the potential of mechanical cues in the diagnosis of neurological conditions related to cell density.

References

[1] Blümcke et al. (2011). *Epilepsia,* **52**: 158–174.
[2] Zarzor et al. (2024). *Sci Rep* **14**: 26103.