The large strain response of brain tissue

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The Large Strain Response of Brain Tissue

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Introduction

Brain injury is the major cause of fatalities in traffic accidents. To reduce traumatic brain injury during crash situations, a better understanding of injury mechanisms in the brain is required. Finite Element (FE) models are being developed (Figure 1, right), in order to predict the mechanical response of the contents of the head during impact. They contain a detailed geometrical description of anatomical components of the head but lack accurate descriptions of the mechanical behaviour of brain tissue.

Objective

The purpose of this study was to experimentally characterise the mechanical behaviour of brain tissue and to develop a constitutive model that is able to describe the behaviour of brain tissue in:

- large strain behaviour (up to a strain of 20%),
- complex loading paths (loading/unloading),
- different deformation modes (shear - compression).

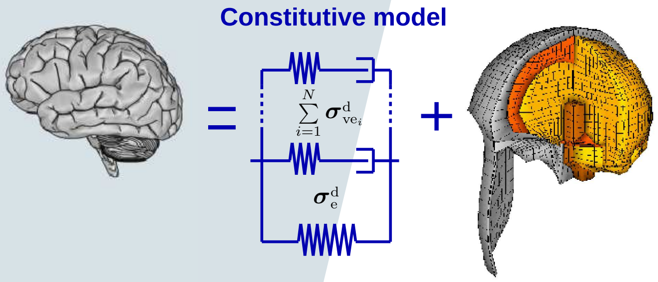

Figure 1 *Schematical representation of FE modelling.*

Methods

An improved eccentric sample placement was used in shear experiments on an ARES II rotational rheometer. Shear measurements consist of:

- loading/unloading cycles with a constant shear rate and increasing strain levels (Figure 2 left),
- stress relaxation tests with constant shear rate and increasing strain levels (Figure 2 right).

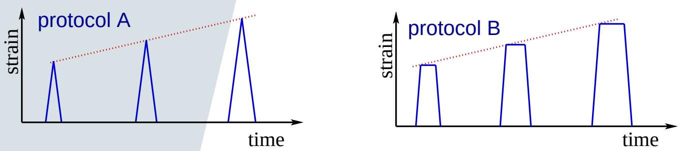

Figure 2 *Testing protocols.*

Compression experiments were performed on an MTS device and consist of stress relaxation tests with a constant shear rate.

Model

Based on the stress relaxation measurements, a non-linear viscoelastic model was developed to describe the mechanical behavior of brain tissue (Figure 1, middle). The viscoelastic modes $\boldsymbol{\sigma}^{\mathrm{d}}_{\mathrm{ve}}$ were modeled by an elastic Mooney-Rivlin model and an Ellis model was chosen to describe the stress-dependence of the viscosity. The elastic part $\boldsymbol{\sigma}^{\mathrm{d}}_{\mathrm{e}}$ was described by a Neo-Hookean model modified with a damping function:

$$\boldsymbol{\sigma}^{\mathrm{d}}_{\mathrm{e}} = G_{\mathrm{e}} \left[(1 - A) \exp\left(-C\sqrt{I_1 - 3} \right) + A \right] \mathbf{B}^{\mathrm{d}}$$

Results

In the following figures, experimental results (black line), the model fit (red line), as well as model predictions (blue line) are shown.

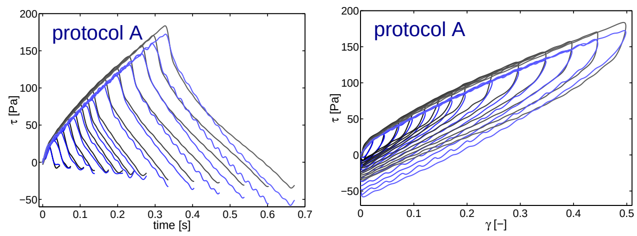

Figure 3 *Shear tests protocol A.*

No significant immediate change in mechanical behaviour due to previous deformation was found (protocol A).

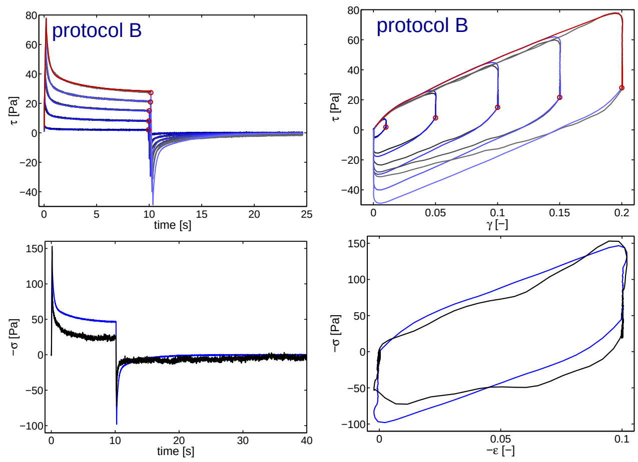

Figure 4 *Top: shear tests protocol B; bottom: compression tests.*

Conclusions

The model showed:

- a good prediction in the loading phase of shear deformation,
- a lack of accuracy in the unloading phase,
- a partially qualitative description of the behaviour in compression.

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