MECHANICAL PROPERTIES OF THE HUMAN PIA-ARACHNOID COMPLEX

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Introduction

To study brain biomechanics during a head impact and better understand the mechanisms of traumatic brain injury (TBI), finite element (FE) models of the human head are frequently used. The cranial meninges are crucial structures to protect the brain against injury, showing the importance of including those structures into FE models. However, only little is known about the mechanical behavior of the human pia-arachnoid complex (PAC), forming the two innermost meningeal layers [1–3]. Therefore, in this study, bulge inflation experiments are performed on human PAC samples in order to determine their in-plane mechanical properties.

Materials & Methods

PAC tissue is carefully removed from fresh human brain tissue and cut into square samples with sides 30 mm. Sample thickness is measured prior to testing by means of two lasers, located on either side of the sample. During testing, samples are inflated at a constant volume rate until predefined pressure levels are reached as shown in Fig. 1. Full-field deformation of the samples is captured using 3D digital image correlation of the applied speckle pattern and pressure is measured.
The mechanical response of PAC tissue is fitted to the first order Ogden constitutive model (equation 1) [4] using an inverse parameter identification framework based on the virtual fields method [5], including full-field displacement data and region-specific sample thickness.

$$\psi = \frac{2\mu}{\alpha^2}(\lambda_1^\alpha + \lambda_2^\alpha + \lambda_3^\alpha - 3) \qquad (1)$$

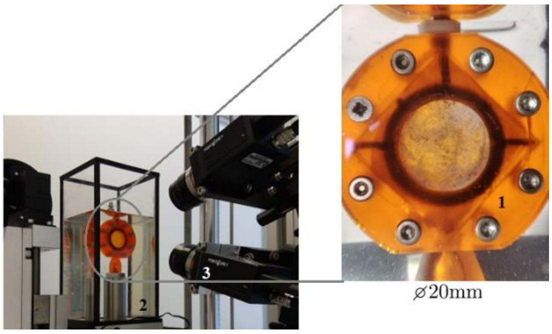

Figure 1: Experimental set-up. A tissue sample (1) is mounted into the bulge inflation device and submerged in a temperature-controlled saline bath (2). The pressure and deformation of the sample are measured by a pressure sensor and a stereo camera system (3), respectively.

Results

The obtained material parameters of one PAC sample are μ = 0.16 MPa and α = -37.46 with normalized root mean square error NRMSE = 0.05. Fig. 2 shows a scatter plot of the experimental stretches in the sample along the main axes at the final loading step of 12.14 kPa.

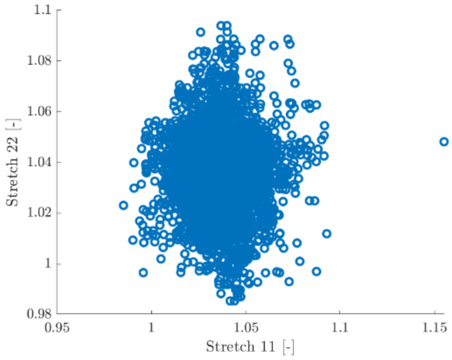

Figure 2: A point cloud of the experimental stretches along the main axes derived from the full-field displacement measurements showing the different stretch ratios present in the sample.

Discussion

Preliminary results show a heterogeneous stress and stretch distribution in the PAC tissue during testing due to the inhomogeneous sample thickness. As seen in Fig. 2, the fitting is based on multiple stretch ratios $\frac{\lambda_{11}}{\lambda_{22}}$ and therefore contains more information than e.g. a typical planar biaxial experiment. The use of full-field deformation data makes it possible to address the sample heterogeneity and to eventually differentiate between the mechanical properties per sample region. More samples will be included in the future in order to obtain a representative set of material parameters for human PAC tissue, necessary for accurate computational predictions of stress and strain patterns in the brain during TBIs.

References

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