MULTI-MODAL NUMERICAL-EXPERIMENTAL SETUP TO IMPROVE THE IDENTIFIABILITY OF THE MATERIAL PARAMETERS OF SOFT TISSUES

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Introduction

Finite Element Analysis (FEA) gains popularity in the biomedical field when it comes to study the interaction between soft tissues and medical devices. Yet, the modelling of the behaviour living tissues is challenging. Indentation tests, combined with inverse FEA, are among the preferred approaches for the *in-vivo* characterisation of tissues. However, the identifiability of the parameters may be insufficient when data come from only one experimental modality [1]. The difficulty to compute a unique set of material parameters for soft tissues may lead to critical errors in the prediction of their response to external loads. A method to evaluate the identifiability of soft tissue material parameters from simulated data using homogeneous isotropic hyperelastic materials has been proposed recently [1]. The current study aims to extend this work to heterogeneous (bi-layer) samples, and to validate it using indentations of silicone bi-layer samples with simultaneous measurements of the indentation forces and the surface deformations, using 3D Digital Image Correlation (3D-DIC).

Methods

Bi-layer silicone cylindrical samples, with radius and heights of 60 mm, were designed for this study. The top layer was composed of Ecoflex 00-20 and the bottom layer was Ecoflex 00-30 (Smooth-On, USA). A random speckle pattern was painted on the samples' surfaces. Indentations were performed with a hemispherical indenter, radius 5 mm, with controlled displacement, δ, up to 10 mm. Stereo-cameras recorded the indentation sites deformation as shown in Figure 1.

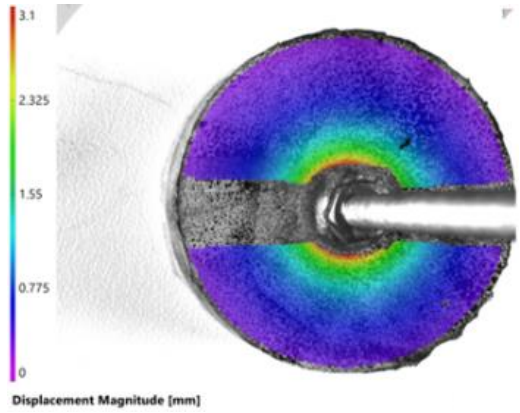

Figure 1: Indentation of a cylindrical silicone sample with displacement measurements using 3D-DIC.

FEA was conducted to replicate the experimental procedure. The axisymmetric model of the cylindrical sample was assigned with isotropic, hyperelastic materials using the symmetrical Ogden-Moerman model with 2 parameters, c and m [2]. The objective function (Equation 1) was a combination of the indenter reaction force errors (F_f) and the surface displacement errors (F_u) and was computed for each δ. The weight factor, η, varied between 0 and 1 to modulate the influence of each measurement. The objective function was evaluated for multiple values of $p_1 = (c_1, m_1)$, for the bottom layer, and $p_2 = (c_2, m_2)$, for the top layer.

$$F_{obj}(p_1,p_2;\delta) = \eta F_f(p_1,p_2;\delta) + (1-\eta)F_u(p_1,p_2;\delta) \quad (1)$$

Results

The objective function grids were computed for all values of δ and η. An example for the bottom layer is shown in Figure 2. In this case, identifiability was optimal for η = 0.5, since the uncertainty area around is the smallest, and a unique set of parameters could not be obtained using only the force-depth data, as the uncertainty are spans nearly the entire parameter range.

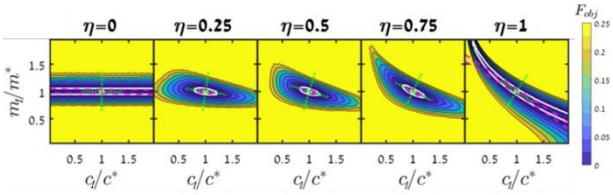

*Figure 2: Identification of the bottom layer parameters at δ = 10 mm. The * accounts for parameters optimised according to experimental data.*

Discussion

The identifiability of material parameters is important for soft tissue modelling since these parameters are crucial for predicting the response to external loads [3]. Increasing the input data, e.g., by adding 3D-DIC measurements, could improve the identifiability, and thus, enhance the accuracy and precision of analyses. For more complex constitutive behaviours, including viscoelasticity or anisotropy, further data could be required. In the future, ultrasound indentations with various orientations will be performed to complete the input data set. An experimental campaign on the soft tissues of healthy subjects is also planned for evaluating the method with *in-vivo* data.

References

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3. A. Macron et al, *Clin Biomech*, 71:92–100, 2020.