IDENTIFICATION OF TRANSVERSLY ISOTROPIC CONSTITUITIVE PARAMETERS USING *IN-VIVO* MACRO-INDENTATION METHODS

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INTRODUCTION

Many biomedical applications require the reliable identification of anisotropic soft tissue material properties for the use in numerical models, such as finite element analysis (FEA). Soft tissues exhibit large inter-subject and intra-subject variability in their material properties [1]. Therefore, a set of parameters must be identified for each individual person because there cannot exist applicable average properties in the literature. Further, standard mechanical tests are not suitable for *in-vivo* identification of material properties as extracting tissue samples is too invasive. Therefore, nowadays the identification is commonly achieved using a macro-indentation test. This test involves pressing on the tissue complex and measuring the force at varying indentation depths. Then, due to the absence of an analytical solution, the parameters are commonly identified using inverse FEA (iFEA), in which simulated results and experimental data are iteratively compared.
Recently, it was shown that force-depth data is insufficient in determining the material properties for a two-parameter hyperelastic model, and that full-field surface deformation data (e.g., using digital image correlation) improves the identifiability [2]. Consequently, the aim of this study is to expand the identifiability analysis to anisotropic materials (with three and more parameters).

METHODS

First, we perform a numerical identifiability analysis for transversely isotropic hyperelastic models, which represent material that have a single preferred fiber direction by accounting for the stretch in the fiber direction. To evaluate the identifiability for a specific constitutive law, we consider the objective function (Eq. 1) that quantifies how the simulated results are affected by changes of the different parameters.

$$F_{uf}(\boldsymbol{p}, \boldsymbol{p}^*) = \eta F_f(\boldsymbol{p}, \boldsymbol{p}^*) + (1-\eta) F_u(\boldsymbol{p}, \boldsymbol{p}^*) \qquad (1)$$

Where F_f is the reaction force error, F_u is the surface displacement error, η is a weight factor, p is the parameter vector and p^* is the target parameter vector. We then analyze the sensitivity of the objective function to changes in the parameters for different indentation depths and values of η.
Finally, we use iFEA to minimize the objective function based on experimental results of an indentation test on transversely isotropic synthetic tissue phantoms. We validate these results by conducting biaxial stretch experiments to derive the parameters analytically.

Results

As shown in Figure 1, for a two-parameter constitutive law, the force-depth data creates an area where multiple parameter sets give similar simulated results. This structure exists in anisotropic material parametrizations as well, and we expanded these results into three (and more) parameter anisotropic material constitutive laws to identify the uniqueness of the gathered parameters in our experiments.

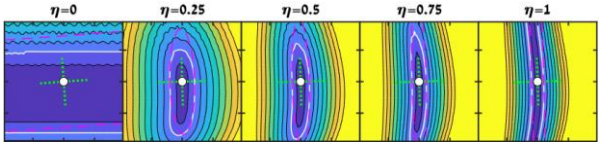

Figure 1: The 2D-space of possible two parameters solutions for a nearly incompressible 1st order Ogden constitutive law (x axis – mechanical parameter c, y axis – mechanical parameter m), where each contour line represent a 5% increase in the error, and the white dot represents the "ground truth" parameter set.

Discussion

Analyzing the identifiability of anisotropic material properties is an important step before conducting iFEA using experimental results. The addition of surface displacement data to the force-depth data increases the certainty in the resulting parameters.
Future work will employ indentations with an instrumented ultrasound, to obtain muscle fiber directions informing a transversely isotropic model.

References

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