MODELING THIN LAYER HYPERELASTIC SOFT BIOLOGICAL TISSUES THROUGH MACRO-SPHERICAL COMPRESSION TESTS

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Introduction

The study of the mechanical behavior of soft biological tissues associates the difficulty in obtaining adequate specimens with the need for repeatability validation on tests. It is of great value to obtain hyperelastic properties from different regions of the same tissue under physiological conditions [1] while preserving specimen integrity. The Hertz model allows the calculation of force-indentation depth curve by considering an elastic semi-infinite body submitted to spherical indentation. Subsequent developments, see for instance [2], generalized Hertz solution to the case of non-linear constitutive behavior of the body. The present study proposes a method of determining non-linear stress-strain relationship of finite thickness hyperelastic plates under non-destructive spherical compression tests. The model creation and validation were done by implementing optimization algorithms and finite elements analysis.

Methods

A 2D finite element axisymmetric model was created in Abaqus (Dassault Systèmes, France). The compressed homogeneous plate presented was characterized by a neo-Hookean hyperelastic constitutive relation and was compressed by a spherical rigid body. Plates of different thicknesses were loaded and the contact radius, generated by the compression, was evaluated as a function of sphere displacement for various geometrical configurations (ratio between plate thickness H and sphere radius R). A fitting procedure was applied to the obtained curves enabling determination of the representative stress σ^* vs representative strain ϵ^* response. The approach was then validated by being compared to other finite element simulation results with different material constitutive laws such as neo-Hookean, Mooney-Rivlin, Ogden and linear elastic.

Results

An example of simulation result is shown in Fig 1 for a plate twice thicker than the spherical tool. Obtained results are shown in Fig 2 comparing the constitutive laws used and σ^*-ϵ^* curves deduced from the model. Two dimensionless sample thicknesses ($h=H/R$) are considered for two constitutive laws namely for neo-Hookean (Fig 2a) and Ogden (Fib 2b) materials. The results were satisfactory for all materials except linear elastic one (not presented here). Results confirmed that non-linearities did not influence the geometry of contact during simulations, as stated in [1].

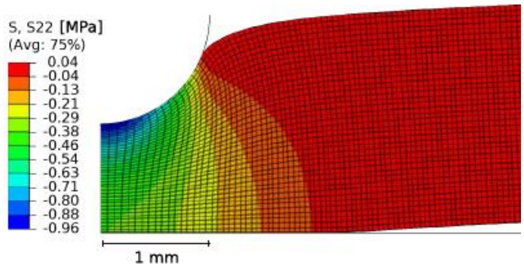

Figure 1: Finite element result for a sample (h=2) with superimposed S_{22} stress field (compression direction).

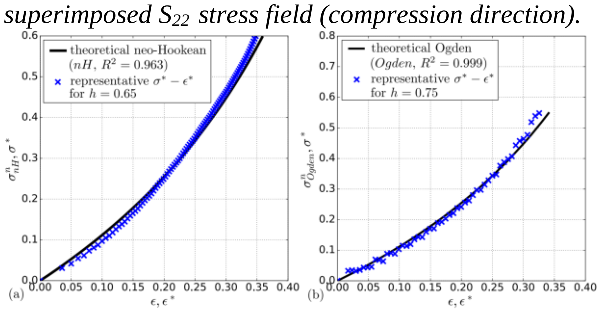

Figure 2: representative σ^*-ϵ^* compared to a) neo Hookean σ^n_{nH} and b) Ogden σ^n_{Ogden} theoretical stress-strain relation.

Discussion

The presented method allowed setting up relations that take into consideration spherical compression tests in which the contact conditions between a physiologically relevant sized tool and the sample are non-linear, in the context of a non-uniaxial stress-strain state. Enhancing prior work [3], the model enables a precise evaluation of stress and strain relation for classical non-linear material laws. Currently, investigations are carried out to deal with limitations such as isotropy, homogeneity and quasi-incompressibility of the material. This model is applied to study the temporomandibular joint disc behavior which generally exhibits internal stresses [4]. Usually, sample harvests release these stresses. It can be avoided thanks to spherical compression tests on the whole disc.

References

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