NAFEMS UK Regional Conference 2018 - Abstract Submission

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Please identify the event for which your submitting?	NAFEMS UK Conference 2018
Will you be the presenting author?	Yes
Presentation Title	An inverse finite element methodology to derive non-linearly viscoelastic material properties
Relevant Themes / Keywords	Inverse FE, Biomechanics, Viscoelasticity, Material characterisation, Non-linear material behaviour

Abstract (plain text)

INTRODUCTION

Most biological tissues demonstrate complex structural and material behaviour determined by their function; they are inhomogeneous, anisotropic and non-linearly viscoelastic. Quantifying their material behaviour is necessary to understand their functional anatomy and pathophysiology, develop biomimetic materials, design medical devices, and improve the biofidelity of computational models. In cases of load bearing soft tissues such as the human heel fat pad and the intervertebral disc (IVD), their complex microstructure increases the difficulty of this task; dissecting and testing coupon samples disrupts the structural integrity leading to non-representative results. The aim of this study was to develop an inverse finite element (FE) modelling optimisation algorithm to bypass the need to harvest individual samples from structures of interest in order to acquire their material behaviour.

Two examples of tissues that have been characterised using this algorithm are presented in this study; the heel fat pad [1] and the IVD [2]. The heel fat pad consists of fat globules retained by fibrous tissue and its structural behaviour can be represented by the quasi-linear viscoelastic (QLV) model [3].

The IVD mainly consists of the nucleus pulposus, a gelatinous tissue, and the annulus fibrosus (AF), which is a fibre reinforced matrix. In this study, the terms of the QLV model and the Young's modulus (YM) of the fibres of the AF were quantified across strain-rates that represent a range of loading environments, from daily activities to injury.

METHODS

The inverse FE algorithm was developed based on the derivative-free downhill-simplex method[4] and was implemented in MSC.Marc (v2017, MSC.Software, CA, USA). This algorithm detects the local minimum or maximum of an objective function specified by the user. The objective function was formed to calculate and minimise the difference between experimental and numerical force traces. Experimental results for characterising the behaviour of the heel fat pad were obtained from in situ testing of five cadaveric human heels in quasi-static and dynamic compression using a materials testing machine and a drop tower, respectively. Similarly, for the IVDs, in situ compressive tests of increasing rates were performed on ten bovine vertebral body-disc-vertebral body specimens using a servo-hydraulic materials testing machine. A subject-specific FE model was developed for each specimen for both studies to simulate all tests. The material properties of interest were modified in each iteration of the algorithm until experimental and numerical results were achieving relative error of less than 5%.

RESULTS

The terms of the QLV model were obtained from each subject-specific optimisation and averaged to derive the mean behaviour of the heel fat pad ($C10=0.1$ MPa, $C30=7$ MPa, $A1=0.06$, $A2=0.77$, $A3=0.02$, $\tau1=1$ ms, $\tau2=10$ ms, $\tau3=10$ s). Similarly, the YM of the fibres of the AF was found to be related the strain-rate (SR), following a logarithmic relationship ($YM=36.6*\ln(SR)+589$).

DISCUSSION

The state-of-art inverse FE method developed in this study has been used successfully to derive the non-linearly viscoelastic material behaviour of the heel fat pad and IVD. In addition to other biological tissues, the methodology presented here can be used to characterise the behaviour of other materials or structures that demonstrate nonlinear behaviour, such as foams, rubbers, and lattice structures.

REFERENCES

1. Grigoriadis, G., et al., 2017. Material properties of the heel fat pad across strain-rates. J. Mech. Behav. Biomed. Mater. 65, 398–407.
2. Newell N., et al., 2017 Material properties of bovine intervertebral discs across strain-rates. J. Mech. Behav. Biomed. Mater. 65, 824–830
3. Fung, Y., 1981. Biomechanics: Mechanical Properties of Living Tissues. Springer-Verlag.
4. Nelder, J.A., Mead, R., 1965. A simplex method for function minimization. Comput. J. 7, 308–313.

Please enter any additional comments or messages here	My abstract included some equations that couldn't be copied here - that's why the mathematical expression of the QLV model is not given while its terms are presented in the results.
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