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A cohesive interface approach to model the inter-lamellar behaviour of the intervertebral disc annulus fibrosus

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INTRODUCTION - The method of representing the inter-lamellar behaviour in Finite Element (FE) models of the disc has been shown to affect the gross disc mechanics [1]. This study aim was to develop an approach to produce inter-lamellar models of the Annulus Fibrosus, i.e. constitutive models of interaction between lamellae.

METHODS (Figure 1) - Mature ovine intervertebral discs were used in the present study as a model for the discs of the human lumbar spine. The annulus fibrosus was dissected and radial slices were subjected to mechanical tests. Images were taken under conventional and differential interference contrast (DIC) microscopy. The images before and during loading were used to produce 2D computational models of the annulus structural behaviour. The DIC images were analysed (ImageJ, U.S. N.I.H., USA) to extract the edges between lamellae and converted into quadrilateral FE meshes (ScanIP 5.1, Simpleware Ltd, UK, and Abaqus 6.12, Dassault Systèmes). Each lamella was modelled with Holzapfel's anisotropic hyperelastic constitutive behaviour, with one fibre orientation per lamella. For this, model parameters were identified to fit to experimental data on the behaviour of tissue components (the proteoglycan matrix and the collagen fibres) [1]. Several modelling hypotheses were tested for the inter-lamellar behaviour: fully bonded conditions, simple frictionless behaviour, friction behaviour with a Coulomb contact, and delamination behaviour, with or without friction, through the use of a cohesive interface model. Displacement boundary conditions were applied reproducing the measured external displacement on the conventional microscopy images. Adequacy of the inter-lamellar behaviour model was assessed by comparing computational and experimental deformed geometries, specifically the change in lamellar interfaces.

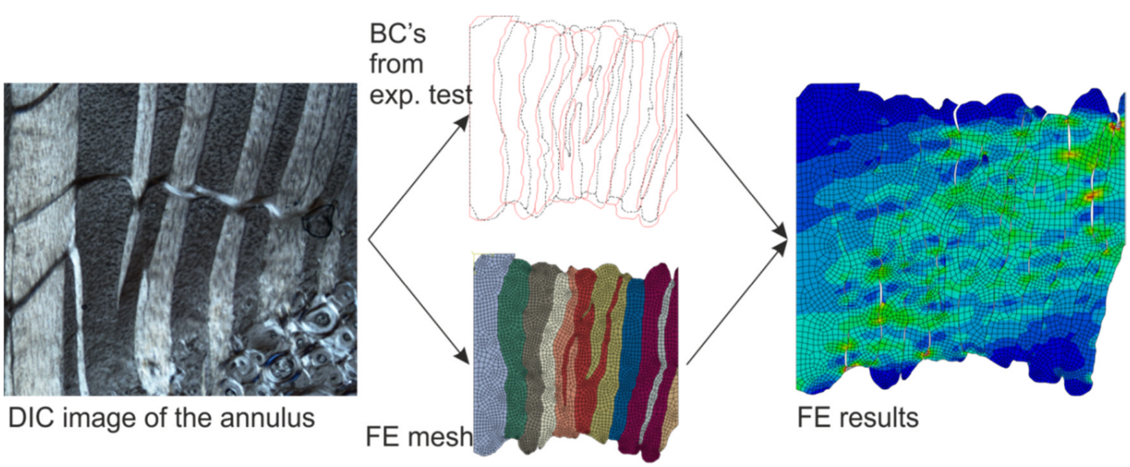

Figure 1: Methods: from DIC image to boundary conditions (in red the sample segmentation before testing, in black the segmentation at the end of a tensile test) and mesh extraction, to FE results depending on the assumed inter-lamellar behaviour (here with a cohesive interface, no friction)

RESULTS AND DISCUSSION - The fully bonded model's stiffness was about 2.5 times the frictionless model's, twice the cohesive model's, and 1.5 times the friction model's. Using a cohesive interface allowed the representation of the observed local delamination when the annulus was under tension. However the full calibration of the interface model requires further mechanical tests, specifically under shear. The inter-lamellar behaviour is thus an important feature to consider in a numerical model of the annulus fibrosus structural aspects along with the strength of the fibres and their orientation.

[1] Mengoni M., Wijayathunga V.N., Jones A.C. & Wilcox R.K. (Dec 2013) Structural Modelling of the Annulus Fibrosus - an Anisotropic Hyperelastic Model Approach at the Lamellar Level [4 pages], In P. Nithiarasu and R. Löhner (Eds.) Proceedings of the *3rd International Conference on Computational & Mathematical Biomedical Engineering*, ISSN 2227-9385 (to appear)