On the effect of the inter-lamellar behaviour in a finite element model of the annulus fibrosus

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Introduction

Computational models of the inter-vertebral disc (IVD) can give insights into the significance of deformation patterns of the IVD in its naturally loaded configuration as well as post-trauma or post-intervention. The structural behaviour of the Annulus Fibrosus depends not only on its lamellar architecture but also on the interaction between the lamellae [1]. The aim of this study was to compare the effects of different computational approaches for the inter-lamellar behaviour during axial loading of the disc.

Methods

A Finite Element model of a mature ovine L1-L2 IVD was built from an MRI scan, including the nucleus, the annulus and the extremities of the vertebral bodies. Considering the nonlinear, directional behaviour of the collagen fibres, an anisotropic hyperelastic model was used for the lamellar tissue [2] and calibrated against ovine data [3]. For each of the 8 lamella, one preferential fibre direction was assumed, with adjacent lamellae having supplementary fibre angles. Axial compression was simulated by applying a displacement 10% of the disc height. Five modelling assumptions were tested for the inter-lamellar behaviour: fully bonded, frictionless contact with or without cohesive behaviour, and Coulomb friction with low or high friction coefficient. The apparent stiffness of the model and the value of the maximal disc bulge were measured to represent the bulk response of each model. A model with a homogeneous annulus was used as baseline. In this case, two fibre directions were defined at each point.

Results

Computed values of bulge and stiffness are depicted on Figure 1. Inclusion of distinct fibre orientation in fully bonded lamellae increased the bulge of the annulus and reduced the apparent stiffness of the sample. Inclusion of the lamellae along with classical contact formulations showed a less pronounced bulge increase but a lower stiffness. The friction coefficient used did not affect the results particularly. However, inclusion of possible separation of the lamellae significantly increased the bulge while decreasing the stiffness.

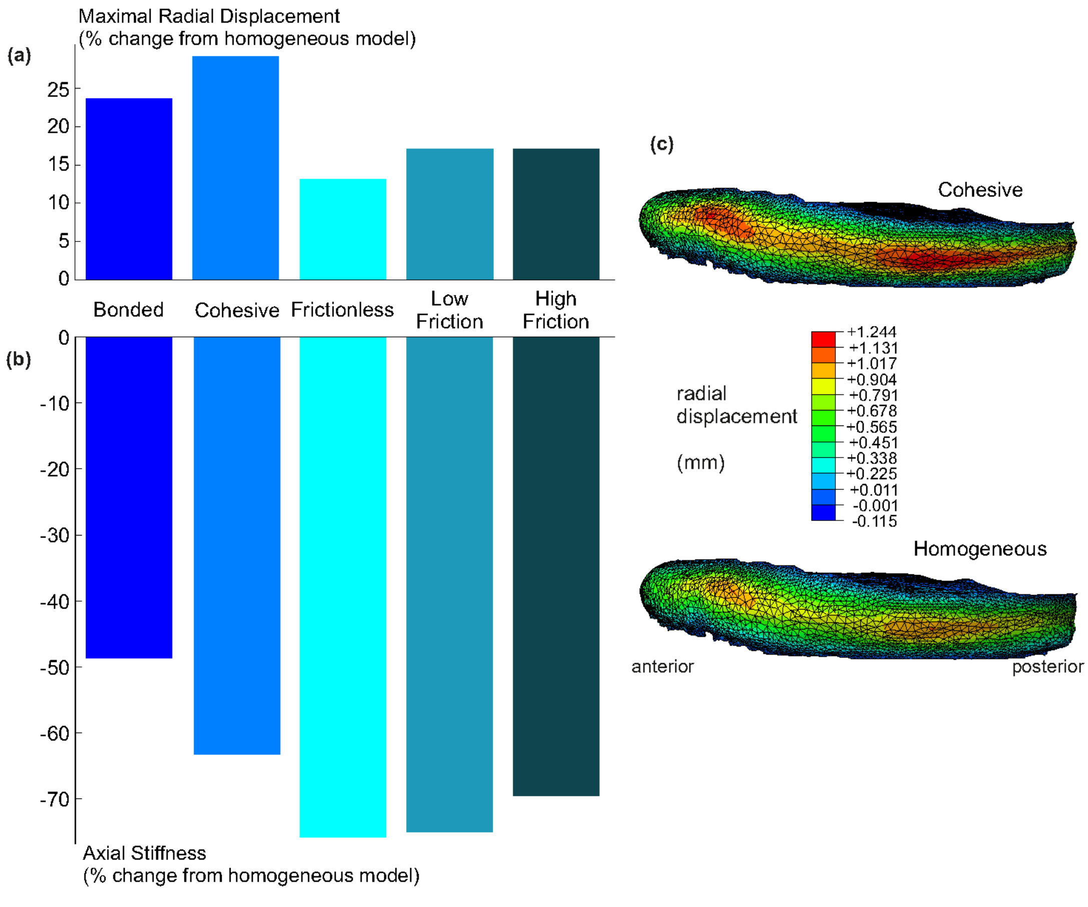

Figure 1: Change in **(a)** bulge and **(b)** axial stiffness function of the interlamellar behaviour with respect to an homogeneous model. **(c)** Displacement maps from a lateral view.

Discussion

The overall behaviour of a homogeneous AF is significantly different from a model including separate lamellae, even if these are bonded together. This may partly be due to the low number of lamellae considered in the model. Increasing that number, thus reducing the thickness of each lamella might decrease this difference. However, inclusion of the inter-lamellar behaviour, particularly allowing delamination, increases the differences in both the overall bulge of the disc and its stiffness. In the future, including validated inter-lamellar behaviour will enhance our ability to model the inter-vertebral disc mechanics.

Funded by: WELMEC, a Centre of Excellence in Medical Engineering funded by the Wellcome Trust and EPSRC

References

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