Institute of Medical & Biological Engineering

MODELLING THE MECHANICAL ROLE OF CROSS-BRIDGING IN THE ANNULUS FIBROSUS

UNIVERSITY OF LEEDS

[1]BJ Luxmoore, [1]VN Wijayathunga, [1]S Rehman, [2]K Wade, [2]S Rodrigues, [2]N Broom, [1]RK Wilcox

mnbjl@leeds.ac.uk

[1]School of Mechanical Engineering, University of Leeds, U.K.; [2]Deptartment Of Chemical and Materials Engineering, University of Auckland, New Zealand

INTRODUCTION

- Histological studies have shown cohesion and bridging between the lamellae of the annulus fibrosus[1] (AF) of the intervertebral disc.
- Interlamellar biomechanics are not yet fully understood[2].

Finite element (FE) modelling techniques were used to investigate the role of inter-lamellar interactions:

1. At the whole disc level with a simple, generic model.
2. At the lamellar level with specimen specific models of AF tissue.

METHOD

DISC MODEL

In the generalised disc model the AF was represented as a series of concentric rings (Fig.1). Interaction properties between the rings were varied to represent different levels of relative interlamellar motion:

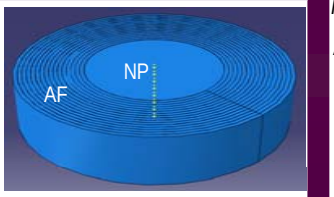


Fig.1: Generalised disc model

a. "homogenous" (tied connections between lamellae)
b. "frictionless"
c. "intermediate" (some friction between lamellae).

AF LAMELLAR MODELS

3D model (tissue structure):

- Micrographs of serial slices of AF tissue, 30µm thick, cut at fibre angle (Fig 2).
- Images reconstructed as a 3D specimen specific model of the tissue structure (Fig 4).

Fig.2: DIC micrograph of AF tissue

2D models (microtensile test):

- Single slices, 60µm thick, loaded in tension and imaged under the microscope at intervals of 0.5mm extension.
- 2D specimen specific models of single slices created.
- Behaviour of models with and without cross-bridges compared.

RESULTS

DISC MODEL

- Frictionless model: stiffness 18% lower and radial bulge 53% higher than homogenous (Fig 3)

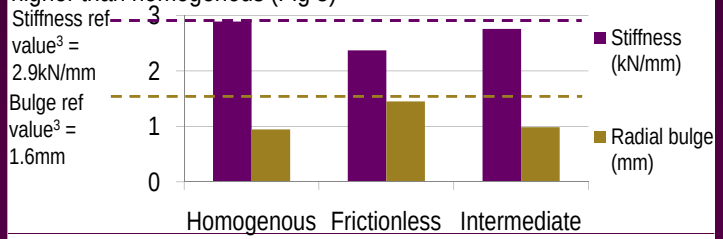
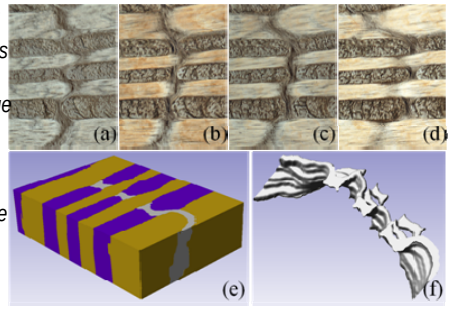


Fig.3: Axial stiffness and radial bulge of disc model with varied interlamellar interaction

AF LAMELLAR MODEL

Fig.4: (a-d) serial micrographs of AF tissue[1]; (e) specimen specific model of the AF tissue sample showing in-plane lamellae (yellow), sectioned lamellae (purple) and cross bridge (white); (f) cross bridge isolated from the model



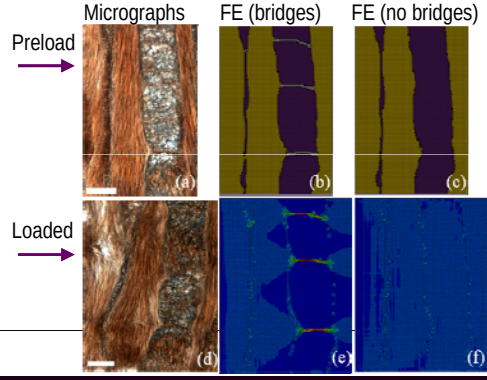


Fig.5: (a) Unloaded micrograph;(b,c) unloaded FE model with and without bridges; (d) loaded micrograph (e,f) loaded FE model with and without bridges showing von mises stress (blue indicates regions of low stress, red: high stress)

CURRENT WORK

- Bridged or a sheathed model of AF tissue more appropriate?
- Material property variation.

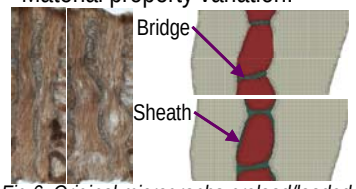


Fig.6: Original micrographs preload/loaded. FE model details showing bridges/sheaths.

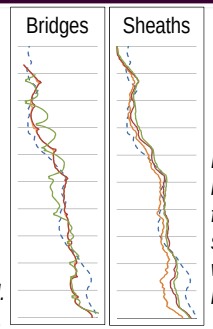


Fig.7: Internal boundary traces for bridges and sheaths models with variation in bridge stiffness

DISCUSSION

- This study investigated representation of relative interlamellar motion effects the mechanical behaviour of the disc model.
- Representation of the interlamellar interactions was achieved, improving the realism of tissue simulations.
- Specimen specific tissue models allowed the complex 3D structure of the tissue constituents to be probed in detail.
- Tensile tests provided data for model calibration and validation.
- Model deformed with similar characteristic puckering of the interlamellar boundary at cross-bridge connections.
- Stress concentrations were observed at these intersections.
- Understanding how and where stress concentrations arise in the AF will help better explain disc degeneration pathology[4].

SIGNIFICANCE

- Improved understanding of tissue constituents will aid the development of tissue repair and substitution treatments for discs.
- Understanding of tissue behaviour has been improved.
- Methodology will be applied in future studies.

References

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