PARAMETER IDENTIFICATION OF OVINE LUMBAR DISCS WITH AN ANISOTROPIC, HYPERELASTIC LAW CONSIDERING FIBRE-FIBRE INTERACTIONS

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Introduction

Numerical models of the intervertebral disc, which address mechanical questions commonly make use of the difference in water content between annulus and nucleus, thus separating fluid and solid parts. Despite this simplification, models remain complex due to the anisotropy and nonlinearity of the annulus and regional variations of the collagen fibre density. Nevertheless, it is difficult to reproduce several sets of experimental data with one single set of parameters [Eberlein, 2004]. Although [Adams, 1993] showed that fibre-fibre and fibre-matrix interactions have a significant impact on the load carrying behaviour of annular lamellae, this effect was barely included in constitutive laws.

We adopted a method to describe fibre-fibre interactions proposed by [Peng, 2006] and included it in our existing constitutive law of the annulus. The objective was to investigate to which detail the annulus has to be modelled so that three standard load cases of a specific motion segment can be reproduced simultaneously. In this study we considered the regional variation of the fibre density as well as fibre-fibre and fibre-matrix interactions.

Methods

In a pilot study, a single lumbar ovine motion segment has been tested on a spinal loading simulator with all ligaments and the facet joints removed. A Finite Element model of the specimen has been developed based on CT and MR images.

The annulus was modelled with a hyperelastic constitutive law, which describes the ground substance, the anisotropy arising from the fibres [Markert, 2005] and the interaction between these constituents. Regional variations of collagen density in circumferential, but not in radial direction were included. The invariant χ proposed by [Peng, 2006] essentially describes the shear angle and was implemented in our law in a slightly altered way:

$$\Psi_{\text{fibre-fibre}} = c\chi\Psi_{\text{fibre}} \quad (1)$$

Ψ are the respective strain energy densities and c is a constant which is to be determined. The model was fitted to three sets of experimental data, namely flexion/extension, lateral bending and axial rotation. The Augmented Lagrangian Particle Swarm Optimizer from the pyOpt library was used for the identification of seven material parameters. Finite Element simulations were run in Abaqus 6.10.

Results and Discussion

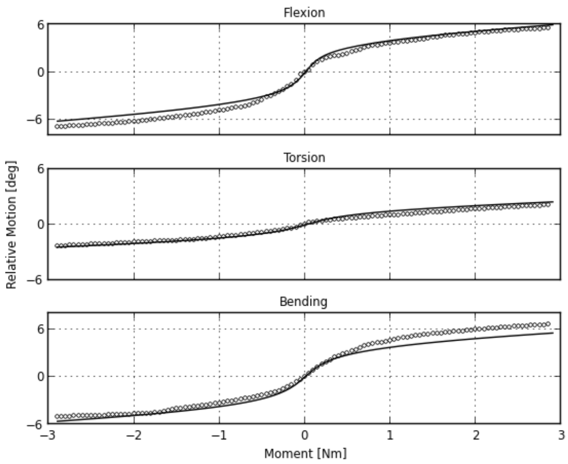

Figure 1: Fitting of experimental moment-angle relations (dots) to the model (solid line) including fibre-fibre interactions

A good fit could be achieved just by describing the anisotropic and nonlinear behaviour of the annulus. However, the fibre distribution did not correspond to the behaviour reported in the literature and the stress-strain relation of the fibres seemed unphysiological. When cross-linking of the fibres was included these issues could be resolved (Fig. 1).

References

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Adams *et al*, Eur Spine J, 2:203-208, 1993.
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