Geometry- and load-specific optimization of the collagen network's fibre orientation in the lumbar spine's annulus fibrosus

**Introduction**

Previous computational studies demonstrated that the intervertebral disc (IVD) plays a key role in distributing the internal forces across the lumbar spine structure. Within the IVD, together with the nucleus pulposus (NP) pressure, the annulus fibrosus (AF) collagen organization is one of the most influential parameter for the disc stabilization. However, AF collagen organization is not unique and seems to depend on the particularity of spine morphologies. Therefore, any lumbar spine model based on particular geometrical data would require specific definitions of fibre-induced AF anisotropy. Unfortunately, particular AF anisotropies are hardly measurable. Thus, the present project aimed to investigate the stabilization of a L4-L5 lumbar spine bi-segment finite element model as a function of the AF fibre orientations. For this, a mathematical function, based on local AF matrix shear strains, fibre stresses and fibre stress distribution has been proposed. This function was implemented and validated on smaller AF model. Enhancements have been proposed and applied to the L4-L5 model.

**Fibre orientation algorithm (FCQ)**

Hypotheses:
- Maximize fibre stresses (RMS)
- Limit local stress concentrations (RSD)
- Minimize matrix shear strains (MSE)

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\text{FCQ} = \frac{\log(1-e^{a_i})}{\log(1+e^{a_i})} = \frac{\log(1-e^{\beta_i})}{\log(1+e^{\beta_i})} = \frac{\log(1-e^{\gamma_i})}{\log(1+e^{\gamma_i})} = \frac{\log(1-e^{\delta_i})}{\log(1+e^{\delta_i})}
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**Optimisation flow chart**

**Fibre angle implementation**

**Geometry and optimisation path**

**Results**

Graphics show the results of the final FCQ function assessment. The final FCQ formulation permitted to obtain maxima, at their expected positions.

**Conclusion**

Methods and procedure to optimize annulus AF orientations were validated. It was found that an optimal orientation depends mainly on fibre stress and matrix shear stress. The optimizations converged to average angles between 32 and 68 and radial gradients between 10 and 17 degree. Tangential gradients could not be found. Moreover a critical fibre angle could be determined where fibre under uni-axial load are remain unloaded.

Using literature data it was possible to solve one of the main issues of collagen fibre orientations in the AF and to bring together the two hypothesis of either a only radial or only a tangential gradient. Moreover it was concluded that pre-stress respectively hoop stress is an non-negligible factor which has to be accounted for in IVD finite element models.