**Introduction:** Finite element (FE) models have become an important tool to study load distribution in the healthy and degenerated disc. However, model predictions require accurate constitutive models and material properties. As the mechanical properties of the intervertebral disc are regulated by its biochemical composition and fiber-reinforced structure, the constitutive law used to describe this complex tissue requires careful consideration. While numerous studies have investigated the annulus fibrosus compressive and tensile properties, specific conditions required to determine model parameters for the osmoviscoelastic model are not available.

Therefore, the objective of this study was (1) to complement the existing material testing in the literature with confined compression and tensile tests on human annulus fibrosus and (2) to use this data, together with existing nucleus pulposus compression data to tune a osmoviscoelastic material constitutive law. The osmoviscoelastic material constitutive law and the experimental data were used to describe the fiber and non-fiber properties of the human disc.

**Materials and Methods:** The FE model [1,2] is composed of an elastic non-fibrillar solid matrix, a 3D viscoelastic collagen fiber structure, and an osmotically pre-stressed permeable extrafibrillar fluid.

The material properties of $G_m$, $k_0$, $M$, $E_0$, $E_f$, and $\eta$ were determined by fitting the model to the average experimental data from confined compression experiments of nucleus and annulus tissue, as well as uniaxial tensile tests in circumferential direction of the annulus. For the nucleus, we used data from a previously published study on human tissue [3]. The same protocol was applied for the confined compression study of the annulus. The fitting of the viscoelastic properties was performed on a data set from the 6% and 10% maximum strain ramp and relaxation increments.

The fitting of the confined compression experiments determined primarily the shear modulus ($G_m$) of the non-fibrillar matrix, the initial permeability ($k_0$) and the positive constant ($M$) of the model. While the fitting of the annulus fibrosus tensile tests determined primarily the material parameters of the fibrillar matrix ($E_0$, $E_f$, $\eta$).

The curve fitting procedures were performed iteratively, using a multidimensional unconstrained nonlinear minimization procedure available in Matlab. From within this Matlab procedure ABAQUS was called to simulate the different experiments.

**Results:** The compressive material properties of normal disc tissue were $G_m=1.23$ MPa, $M=1.57$, and $k_0=0.65e^{-4}$ mm$^4$/Ns; the tensile fiber material parameters were $E_0=77.0$ MPa, $E_f=500$ MPAs, and $\eta=1.8c3MPa$-$s$. The goodness of fit ranged from 0.88 to 0.96 for the four experimental conditions evaluated.

**Discussion:** The osmoviscoelastic FE model of the disc used for this curve fitting procedure showed good conformity with the experimental data for the confined compression relaxation of the nucleus (fig 1a) and annulus. However, in the first half of the ramp phase of the confined compression, the computed reaction force was overestimated by the model. This was only seen in the annulus simulation, not the nucleus. The reason for this overestimation is unclear. A possible explanation could be the permeability change under structural compaction in the annulus or the simplified fiber structure. Also, the fits of both tensile test simulations were in good agreement with the average experimental values and emphasized the need for a viscoelastic material law for the annulus collagen fibers (fig 1b).

Limitations are the number of samples used in the experimental tests (n=3). However, directly using experimental data to determine model parameters as applied here is an advantage over most disc finite element models, which simply utilize average data from the literature.

The tensile data underlined the viscoelastic behavior of human annulus tissue. The compressive properties, defined through confined compression experiments of nucleus [3] and annulus tissue, combined with the viscoelastic properties of the annulus were applicable for adjusting the material law. The osmoviscoelastic constitutive material law emphasized the interdependency of the strong swelling ability of the tissue and the viscoelastic nature of the collagen fibers. This is especially important for numerical models to further study the load sharing behavior with regard to disc degeneration and regeneration.

**References:**