VISCOELASTIC RESPONSE OF HUMAN MENISCI DURING STRESS-RELAXATION UNDER CONFINED COMPRESSION

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Introduction

The objective of this study was to determine the viscoelastic properties of human meniscal tissue during stress-relaxation under confined compression conditions using both *in-vitro* and FE analyses. Further, it was hypothesized that two different underlying biphasic models lead to significantly different predictions for the aggregate modulus (H_A) and permeability (k).

Methods

Coplanar plugs (Ø 4.6 mm), obtained from the anterior and posterior horn, and pars intermedia of lateral and medial menisci of 25 donor knees (57.5 ± 10.5 yrs; $n_{total} = 150$) were exposed to stress-relaxation tests under confined compression conditions at three compression levels (ε_i =10%, 15%, 20%). Each strain level was held constant for 90 minutes to ensure equilibrium state was reached. H_A and k were determined solving a one-dimensional diffusion equation (Mow, 1980; Frank, 1987) using an iterative least square algorithm:

$$\sigma_t = \sigma_{t\to\infty} + 2 * H_A * \varepsilon_i * e^{(-(\frac{\pi}{h_0})^2 * H_A * k * t)} \quad (1)$$

where σ_t is the time-dependent strain, $\sigma_{t\to\infty}$ is the equilibrium stress, and h_0 the initial sample height. Subsequent FE modelling using the previously *in-vitro* determined geometries, properties, and boundary conditions resulted in 150 individual calculations. Strain-dependent permeability was introduced following the Holmes-Mow formulation (Holmes, 1990):

$$k = k_0 (\frac{J - \varphi_0}{1 - \varphi_0})^2 e^{\frac{1}{2} M (J^2 - 1)} \quad (2)$$

where k_0 equals the initial permeability, J the Jacobian of the deformation gradient tensor, φ_0 initial porosity and M the strain-dependence coefficient; while H_A was calculated as:

$$H_A = \lambda + 2\mu \quad (3)$$

where λ and μ are the Lamè parameters of the drained solid structure. Parameter optimisation was then performed to solve the inverse finite element problem. Gaussian distributed data were examined using two-factor repeated measures ANOVAs with t-test post-hoc testing when significant (SPSS). Linear regression was used to check the correlations (SPSS), and $p \leq 0.05$ was considered statistically significant.

Results

Aggregate modulus and permeability calculated with the diffusion equation (Eq. 1) were statistically higher ($p \leq 0.01$) than those obtained with subsequent FE analyses (Fig. 1).

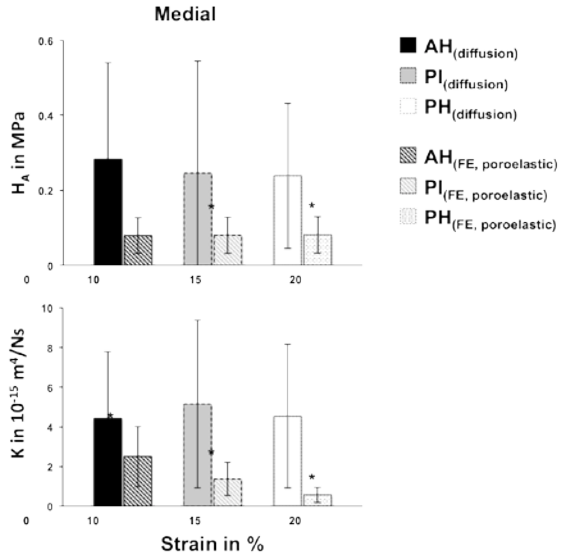

*Fig. 1: Aggregate modulus (H_A) and permeability (k) values of medial menisci, divided into AH: anterior horn; PI: pars intermedia; PH: posterior horn, obtained from in-vitro investigations and FE analyses at three different strain levels (10%, 15%, 20%) (Mean values ± SD; n = 25; *p<0.05). Lateral menisci had comparable characteristics.*

Discussion

To the authors knowledge this is the first study investigating the stress-relaxation of human menisci under confined compression. Despite the results of the two approaches being statistically different, they show adequate values when compared with literature. Thus our hypothesis could be confirmed. The results might contribute to a better understanding of the complex nature of meniscal tissue and might also have an impact on the design of future meniscal substitutes. Furthermore, it implicates that when comparing viscoelastic properties of meniscal tissue, both the test conditions and the underlying model should be considered.

References

Frank *et al*, J Biomech, 20:615-27, 1987.
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