THE POROMECHANICS BEHAVIOUR OF THE HUMAN MENISCAL TISSUE

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Introduction

Menisci play an important role in knee joint biomechanics, including loads distribution and friction reduction [1-2]. Identifying the mechanical characteristics of these tissues is essential to better understand their physiological function and design a new family of meniscal implants [3]. Meniscal tissue is characterized by a time-dependent response to loads [4]; generally, this behaviour can be modelled as visco-elastic [5] or explicitly as biphasic/poro-elastic [6] when considering a biphasic composition, i.e. a solid matrix (extra-cellular matrix) interspersed by a fluid (mainly water) [7]. These aspects are in common with cartilaginous tissue [8], but are much less described, nevertheless they need specific attention standing meniscal peculiar, fibro-cartilaginous, structure [9]. Here we focus mainly on experimentally measure the anisotropic permeability of the human meniscal tissue in three portions (posterior/central /anterior) and in three directions (vertical, radial and circumferential), as sketched in Fig.1a.

Materials and Methods

Menisci were harvested from donors subjected to total knee replacement; samples labelled as "degraded" by gross investigation of the surgeon were discarded. The study was approved by the local Ethical Committee. Testing protocol was implemented on a multi-axis mechanical tester (Mach-1, Biomomentum Inc. Canada). Cylinders were grouped by the direction (vertical, radial, circumferential), region (posterior, central, anterior) and side (lateral meniscus, medial meniscus) of extraction. Confined compression tests (Fig.1 b), with a constant pressure of 0.07MPa, applied for a total time of 450 seconds, have been performed. Samples were weighted three time during each test to correlate the decrease in weight with the amount of fluid flowing out of the cylinder as result of the applied pressure. This type of test, complemented by fractal dimension studies extrapolated by μCT scans (Fig. 1c, d), enables us to indirectly measure the permeability of the tissue.

Results

We have collected data of the type shown in Fig. 1e. During the test, the fluid pressure contributes to sustain the compressive load while the fluid present in the tissue is slowly extruded through the porous fractal matrix (Fractal Dimension= 2.8, see Fig.1c). Fluid transport across the meniscal tissue is "anomalous" i.e. ruled by a modified version of Darcy's law involving linear fractional operators: $q = -\lambda_\beta D_\beta \nabla q$. q is flux, $\lambda_\beta = \frac{k_\beta}{\mu}$ with k_β being the anomalous permeability and μ the viscosity of the fluid. Through curve fitting of Fig.1e it

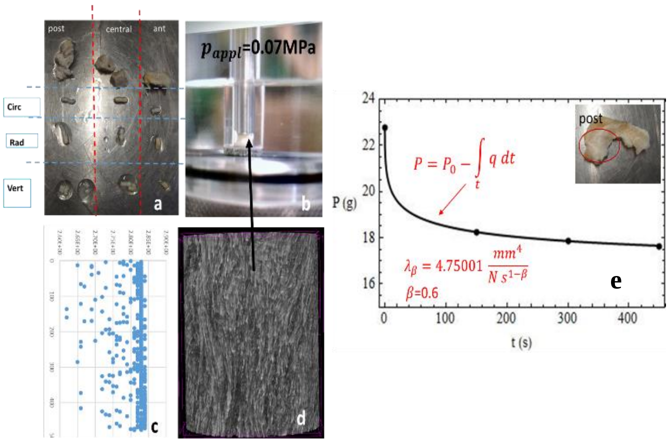

Figure 1: (a) Sample preparation, (b) Confined compression test set up, (c) Fractal dimension distribution obtained by μCTscan. (d) μCTscan of the meniscal sample. (e) Evolution of the weight over time

has been calculated a value of permeability of λ_β and β given below Fig.1e. A systematic study on the anisotropic permeability tensor of the human meniscal tissue will be presented.

References

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