Assessment of mechanical properties of isolated intervertebral discs using quantitative Magnetic Resonance Imaging

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INTRODUCTION

MRI technology has been widely investigated as an early diagnostic tool of intervertebral disc (IVD) degeneration. To that end, correlations were investigated between MRI parameters, biochemical composition and IVD degeneration. More recently, some authors have shown that MRI offers great potential as a sensitive and non-invasive technique for describing the alterations in mechanical properties of IVDs [1-3] or cartilage [4-10].
However, large standard deviations are observed in the determination of the mechanical properties of the IVD and low coefficients of correlation are observed between mechanical properties and MRI parameters. Our hypothesis is that the compressive modulus and the hydraulic permeability of the IVD can be explained by a combination of MRI parameters. Our specific aim is to measure the mechanical properties and MRI properties of isolated IVDs and investigate the relationships between these parameters.

METHOD

Thirty IVDs were harvested from bovine tails, and randomly separated in two groups. The discs of the *control* group (n=15) were wrapped in plastic while the discs from the *digested* group (n=15) were digested in HBSS solution with 5mg/l of trypsin during 24 hours at 37° with shaking.
Quantitative MR measurements were carried out using a 3T whole-body apparatus (Philips Achieva X-Series). A single slice, 5mm thick, was taken in the coronal plane. The relaxation times were determined by using a multiple inversion-recovery turbo spin-echo sequence for T1 and a spin-echo sequence with multiple echo times for T2. The diffusion tensor was extracted from a spin-echo EPI diffusion-weighted sequence, with 15 non-collinear diffusion encoding directions. The MT images were obtained using a gradient echo sequence with and without a magnetization transfer saturation pulse. The MRI analysis was performed using an in house program (Matlab, The MathWorks, Inc). T1, T2, Apparent Diffusion Coefficient (ADC) and Fractional Anisotropy (FA) were extracted from the signal intensity by non-linear regressions to their respective signal expressions.
Two punches, 4mm diameter, were extracted from each IVD, one from the nucleus pulposus (NP) center and one from the posterior part of the annulus fibrosus (AF). Each punch wad divided into four slices of equal thickness. The first one was tested in unconfined compression for the evaluation of the Young's modulus E and radial permeability k_r, the second one in confined compression for the evaluation of the compressive modulus H_A, the third one for direct measurement of the tissue axial permeability k_a, and the last one dedicated to colorimetric assays for the quantification of GAG and collagen contents.
Correlations tests and multilinear regressions (SigmaPlot, Systat Software,Inc.) were investigated between the mechanical properties and MR parameters.

RESULTS

The enzyme treatment induced mechanical changes in both AF and NP. As expected, E and H_A deceased while k_r and k_a increased. The MR parameters showed also differences between the *control* group and the *digested* group. T1 and T2 increased in the NP while remaining constant in the AF, MTR decreased slightly in both AF and NP, FA and ADC decreased.
The correlations between mechanical properties and MR parameters were weak ($r<0.5$), except between MTR and k_r for AF ($r=0.73$) and between T2 and k_a for NP ($r=0.65$). The multiple linear regressions showed low coefficients of determination (0.2-0.35) for the expressions of E or H_A in both AF and NP. In the NP, k_a was predicted mostly by T1 ($p=0.061$), and T2 ($p=0.002$), with a coefficient of determination of 0.59. In the AF, k_r was predicted by T2 ($p=0.045$), MT ($p=0.048$), FA ($p=0.004$) and ADC ($p=0.029$), with a coefficient of determination of 0.55 (Equation 1).

$$k_{radial} = 105{,}61 - 0{,}19*T1 - 1{,}13*T2 + 1{,}02*MT - 299{,}59*FA + 101914{,}04*ADC \qquad \text{Equation 1}$$

DISCUSSION

Relationships were found between axial or radial hydraulic permeability and quantitative MRI parameters in isolated bovine IVDs. For the first time, three different but complementary mechanical tests were used to determine the mechanical properties (unconfined compression, confined compression and direct measure of the permeability) allowing a better understanding of the static mechanical behaviour of IVD tissues. For the first time, isolated discs were used, and the digestion process induced changes in the structural matrix rather than in the biochemical contents. These changes were detected by both mechanical tests and quantitative MRI, and the relationships found between permeability and MRI parameters are valid for both in situ and digested tissues. Future work will include the characterization of the dynamic behavior of IVD tissues, the quantification of other MRI parameters such as T1ρ and CEST, and the investigation of relationships between dynamic mechanical properties and MRI parameters.

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