Correlations between Quantitative MRI and Mechanical Parameters of Human Intervertebral Discs with Different Grades of Degeneration

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INTRODUCTION
The dramatic changes in morphology, composition and structure that occur in the intervertebral disc (IVD) with aging and degeneration are accompanied by specific changes in mechanical properties of the disc material [1,2]. Evaluation of these changes in the IVD hinges on the ability to objectively and non-invasively assess the disc matrix composition and integrity. Different studies on human IVDs have correlated intervertebral disc matrix composition and integrity to the longitudinal magnetization recovery of T1, the transverse magnetization decay T2, the magnetization transfer ratio (MTR), and apparent diffusion coefficient (ADC) [3,4]. Correlations and multiple linear regressions have been also identified between quantitative magnetic resonance imaging (qMRI) parameters, biochemical and mechanical parameters of targeted enzyme matrix denaturation and buffer-treated bovine IVDs (24, 25). To this end, qMRI analysis can be used to correlate MRI signals with mechanical properties of NP and AF tissue in order to predict structural changes in discs with degeneration. The aim of the present study was to determine how quantitative MRI parameters can predict biomechanical properties in human discs with different grades of degeneration.

MATERIALS AND METHODS

Experimental Groups: Ten whole lumbar spine specimens, 5 discs per spine, were obtained through organ donations via Héma-Québec within 24 hours after death. Age of donors was from 32 to 77 years. The samples were vacuum sealed in plastic bags for MRI.

MRI Procedure: The MRI examinations were carried out in a 1.5T whole-body Siemens Avanto system using the standard circularly polarized head coil. The samples were placed in a sagittal orientation and T1, T2, MTR, and ADC were measured as described previously with the phase-encoding in an anteroposterior direction to account for the effect of the collagen fibril orientation on MRI determinations [1]. All discs (n=50) were then graded from T2-weighted images according to the classification system described by Pfirrmann [5]. Numerical analysis of quantitative MRI was performed using a custom code written in MATLAB (Mathworks, Natick, MA) allowing the selection of the regions of interest and the calculation of average signal intensities from all images. Regions of interest were traced manually as polygonal shapes with no contact with the endplate tissues and were reproduced identically on all T1, T2, Ms/Mo ratio, and diffusion images. Regions of interest were traced manually as polygonal shapes with no contact with the endplate tissues and were reproduced identically on all T1, T2, Ms/Mo ratio, and diffusion images.

Mechanical Testing Procedure: Mechanical tests were performed on 5 mm diameter cylindrical plugs of tissue, which were cut to an average thickness of 1.6±0.4 mm using a cryostat. Confined compression tests were performed with a single ramp to 5% compressive strain with material parameters (aggregate modulus HA and permeability k) obtained from a linear biphasic fit. Shear testing was carried out using a rheometer (TA Instruments) fitted with flat platens covered with 100-grit sand paper contained within a humidified chamber. The specimens were subjected to a frequency sweep with amplitude of 10% shear strain and a logarithmic span from 0.03 to 30 Hz with 22 steps. Steady state dynamic shear modulus and phase angle were calculated for each step, and were fit with exponential functions:

\[ G'(r) = G'_1 + G'_2 \omega^α \delta \]  

Statistical Methods: Correlations between qMRI and mechanical parameters were investigated using Pearson test performed on Graphpad Prism software (GraphPad Software, La Jolla, CA, USA). Correlation between a mechanical parameter and an MR parameter in the same region of the disc was considered significant with p<0.05 in order to account for multiple comparisons.

RESULTS
When the tissues were analyzed separately, for the NP tissue significant correlations were found between T2 and shear modulus \( G'(r) \) (r = -0.465, p = 0.022), and between diffusion ADC and \( k_0 \) (r = 0.4, p = 0.047). For the AF tissue significant correlation were found between T1 and \( k_0 \) (r = 0.372, p = 0.047) and between T1 and permeability k (r = -0.468, p =0.043).

![Figure 1: Correlations between mechanical parameters and qMRI parameters of the NP.](image1)

![Figure 2: Correlations between mechanical parameters and qMRI parameters of the AF.](image2)

DISCUSSION
This study examined changes in human IVD quantitative MRI and mechanical properties in relation to increasing grades of degeneration. Importantly, the results are consistent with our previous studies in bovine model and indicate sensitivity to distinct changes at varying levels of degeneration [1]. Interestingly, correlations were found between T2, shear modulus and ADC in the NP while correlations were found between T1 and \( k_0 \) and between T1 and permeability k in the AF. This may relate to the fact that T1 has been predominantly correlated to water content, while T2 is influenced by tissue anisotropy (orientation of collagen fibers), collagen concentration, and water content in tissues. The results show that it is now possible to develop correlations and multiple linear regressions in human IVDs which are essential for developing quantitative MRI as diagnostic tool for IVD degeneration.

SIGNIFICANCE
We conclude that quantitative MRI can be used as an accurate and non-invasive diagnostic tool in the detection and quantification of matrix composition and material properties of the human IVD and can therefore become a very important diagnostic and treatment assessment tool in determining the functional state of the disc.

REFERENCES

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