Changes in Quantitative Magnetic Resonance Imaging Parameters and Biomechanical Properties in Human Intervertebral Discs with Different Grades of Degeneration

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 the disc material properties, including alteration of the compressive modulus, hydraulic permeability, and tensile properties of the annulus fibrosus (AF), and alteration of the elastic modulus, shear modulus, and swelling pressure of the nucleus pulposus (NP) [1, 2]. Evaluation of these changes in the IVD hinges on the ability to objectively and non-invasively assess the disc composition and integrity. To this end, quantitative magnetic resonance imaging (MRI) analysis, using the relaxation times T1, T2 and T1rho, the magnetization transfer (MTR), and the apparent diffusion coefficient (ADC) can be used to correlate MRI signal to disc tissue degeneration. The purpose of the present study was to determine the relationship between quantitative MRI parameters and 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 Transplant Quebec 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 [3]. 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.

Mechanical Testing Procedure: Mechanical tests were performed on thirty-eight (38) 5 mm diameter cylindrical plugs of tissue, which were cut to an average thickness of 1.6±0.4 mm using a cryostat. 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. After the specimen was placed on the lower platen, the upper platen was lowered until a 0.1N normal force was recorded. Following a 20 min equilibration, 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. The test concluded with a 0.5Hz logarithmic strain sweep from 1-500% with 20 steps. Steady state dynamic shear modulus and phase angle were calculated for each step in the frequency and strain sweeps. Confined compression tests were also performed with a single ramp to 5% compressive strain with material parameters (aggregate modulus H_a and permeability k) obtained from a linear biphasic fit.

RESULTS
Results showed that the relaxation times T1 and T2 significantly decreased in both the NP and AF with increasing degeneration grades (Figure 1). In contrast, the MTR and ADC had a tendency to augment with increasing grade. Compressive modulus (H_a), hydraulic permeability (k), and shear modulus tended to decrease in disc of higher grade of degeneration while the phase angle tended to be elevated (Figure 2).

DISCUSSION
This study examined changes in human IVD quantitative MRI and mechanical properties in relation to increasing grades of degeneration. The effect of degeneration on the biomechanical properties and quantitative MRI parameters is consistent with our previous studies in a bovine model [1] and indicates sensitivity to distinct changes at varying levels of degeneration. The similarities found between quantitative MRI parameters for AF, NP and whole disc suggest that they are affected uniformly across the disc with degeneration. Trends of decreased compressive and shear moduli of AF from grades 3-4 of degeneration are consistent with decrease in T1 and T2. The trend of decreased shear modulus and increased phase angle with degeneration grade paints a clear picture of diminished fiber integrity. The decrease in H_a with degeneration grade contrasts another study indicating compressive modulus increases from healthy to degenerated states [2]. Therefore, there is likely to be different trends with early and late stages of degeneration.

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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