Sensitivity of quantitative MRI to the compressive state of the isolated intervertebral discs

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INTRODUCTION

To assess intervertebral disc (IVD) degeneration, relaxation times, diffusion tensor, or spectroscopy parameters are often measured to quantify tissue hydration or composition. 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]. Correlations were found between relaxation times or diffusion parameters and compressive modulus, permeability or hydrostatic pressure. All these studies were performed in vitro, on IVDs not submitted to mechanical loading. However, in vivo, the IVD is submitted to complex loading. Thus, the present question focuses on the influence of mechanical loading during MRI acquisition on the relaxation times, magnetization transfer and diffusion parameters within the IVD. The aims of this study were to 1) design and manufacture an apparatus allowing control of the deformation of the IVD within the MRI system; and 2) quantify the effect of loading on the mapping of MR relaxation times magnetization transfer and diffusion parameters within the IVD.

METHOD

An apparatus allowing the compression of isolated intervertebral discs was designed (Figure 1) and manufactured in ABS. Compression was applied by platens moving up and down, and its amplitude was controlled manually by screw rotation. The chamber was divided into 4 compartments filled with PBS solution to receive 4 discs at the time and fits within the head coil of the MRI system.

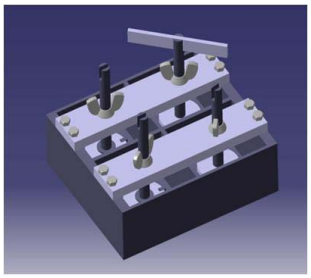

Figure 1: CAD model of the loading system

Twelve discs from fresh young bovine tails were dissected, measured for their thickness with a calliper, wrapped in plastic and directly transported to the MRI facility. Quantitative MR measurements were carried out using a 3T whole-body apparatus (Philips Achieva X-Series). Six discs received 0% (platen positioned at the initial disc thickness), 5% (platen positioned at 95% of the initial disc thickness), 10%, 20% and 40% deformation. 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 MRI analysis was performed using an in house program (Matlab, The MathWorks, Inc). The MT images were obtained using a gradient echo sequence with and without a magnetization transfer saturation pulse. 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. Each map was filtered to remove all remaining artefacts. The annulus fibrosus (AF) and the nucleus pulposus (NP) were segmented using a custom Matlab automated edge-detection code. Mean parameters and histograms were compared for each loading case.

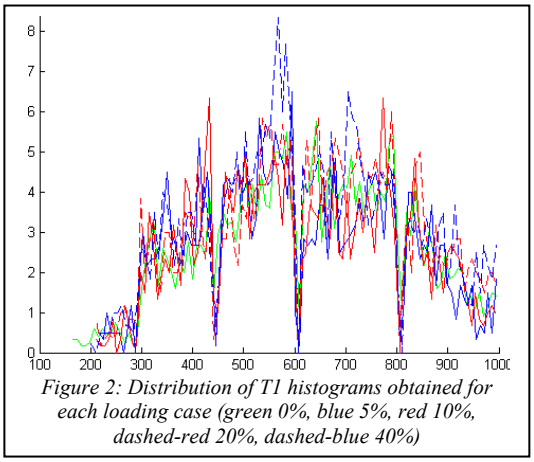

Figure 2: Distribution of T1 histograms obtained for each loading case (green 0%, blue 5%, red 10%, dashed-red 20%, dashed-blue 40%)

RESULTS

T1 varied from 753±339ms at 0% to 740±321ms at 40% in the AF, from 987±147ms at 0% to 966±143ms at 40% in the NP. T2 varied from 51±26ms at 0% to 53±26ms at 40% in the AF, from 117±40ms at 0% to 124±41ms at 40% in the NP. No significant differences were observed between the loading cases for both T1 and T2, and the distribution of T1 or T2 histograms (Figure 2) showed the same profile for each compressive ratio. While increasing the compression loading, the diffusion decreased in the direction of the compressive stress. However neither ADC nor FA maps showed any clear increase or decrease.

DISCUSSION

The apparatus developed to apply compression, controlled by screw rotation, to the disc within the MRI environment was functional. However, the ABS material and the manufacturing process using rapid prototyping created some artefacts due to the presence of air bubbles. These artefacts were easily removed later on in the image treatment using linear filters. For the loading cases, the quantitative MRI acquisition started 5 minutes after the application of the compression to the discs. For each loading, T1 was acquired first, T2 10 minutes later, MT 20 minutes later and diffusion 25 minutes later. Thus each loaded acquisition might include compressed but not relaxed disc for T1 and compressed and partially relaxed discs (25 minutes) for diffusion. However, even if the disc conditions changed between the different MR sequences, loading and relaxation of IVD tissues did not affect the MRI parameters. Quantitative MRI of isolated intervertebral is not sensitive to the compressive state of the disc when changing from 0% to 40% deformation.

REFERENCES

1. Nguyen et al., J Bone Joint Surg Am. 2008, 90(4):796-802. , 2. Périé et al., J. of Biomech. 2006, 39(8):1392-400. , 3. Mwale et al., J. Magn. Reson. Imag. 2008, 27:563–73 , 4. Samosky et al., J Orthop Res. 2005, 23(1):93-101. , 5. Chen et al., Arthritis Rheum 2003, 48(4):1047-56. , 6. Kurkijarvi et al., Magn Reson Med 2004, 52(1):41-6. , 7. Nieminen et al., J Biomech 2004, 37(3):321-8. , 8. Lammentausta et al., J Orthop Res 2006, 24(3):366-74. , 9. Wheaton et al., Magn Reson Med. 2005, 54(5):1087-93. , 10 .Nissi et al., Osteoarthritis Cartilage. 2007, 15(10):1141-8. , 11. Wilke et al., Spine 1999, 24(8) : 755–62.