A feasibility study of *in vivo* $T_{1\rho}$ imaging of the intervertebral disc

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Introduction:

Intervertebral disc degeneration is characterized by biochemical and morphologic changes, which lead to lower back pain, stiffness, and decreased mobility [1]. Early markers of the disease include decreased glycosaminoglycan (GAG) content and loss of the water in the nucleus; late-stage structural changes include severe dehydration of both the nucleus and annulus and decreased disc height [1]. Current magnetic resonance imaging (MRI) techniques, such as T_1 and T_2 weighting, are effective in identifying late-stage, structural changes. However, an imaging technique for detection of early biochemical changes has not yet been established. Quantitative $T_{1\rho}$ imaging, which probes the interaction between water molecules and their macro-molecular environment, has potential to identify early biochemical changes in the intervertebral disc. Previous studies have quantified $T_{1\rho}$ relaxation time in intervertebral disc specimens *in vitro* [2,3], however, to our knowledge, no *in vivo* quantification studies of $T_{1\rho}$ in the intervertebral disc have been documented. Therefore, the purpose of this study is to demonstrate the feasibility of quantifying $T_{1\rho}$ relaxation time in the nucleus and annulus of the non-degenerative intervertebral disc, using *in vivo* MR imaging at 3T.

Methods:

Eight healthy volunteers (mean age = 32.5 years, age range = 25-60 years) were scanned using a GE SIGNA 3T echo-speed system (GE Healthcare, Waukesha, WI) and a four-channel, phased array spine coil. After a 3-plane localizer, axial $T_{1\rho}$-weighted images were acquired using a spiral sequence (TE/TR = 5.8/2000 ms, flip angle = 90°, FOV = 20 cm, slice thickness = 3 mm, bandwidth = 100 KHz, interleaves = 14/slice, data points = 4096/interleaf, spin lock (SL) frequency = 300 Hz, $TSL_1/TSL_2/TSL_3/TSL_4$ = 20/50/80/110 ms, scan time ~ 13 minutes (Figure 1)) [4]. Additionally, axial T_2-weighted images (TE/TR 85/5200 ms, FOV = 20 cm, slice thickness = 3 mm, bandwidth = 35.7 KHz, matrix = 288 x 224, scan time ~ 5 minutes) were acquired. $T_{1\rho}$ maps were computed using the following equation: $S(TSL) \propto \exp(-TSL/T_{1\rho})$ (Figure 2). The signal to noise ratio (SNR) was calculated from $T_{1\rho}$-weighted images using the following equation: SNR = mean signal/standard deviation of noise. The nucleus and annulus of the intervertebral disc were segmented from the T_2-weighted image using a threshold-based method, and the segmented region of interest (ROI) was superimposed on the $T_{1\rho}$ map (Figure 3). The average $T_{1\rho}$ values of the nucleus and the annulus, of the intervertebral discs between S1 and L5, L5 and L4, and L4 and L3, were calculated for each subject. Statistical analysis was performed using JMP software (SAS institute, Cary, NC). A least squares model was created and fit to the median $T_{1\rho}$ values, treating the subject as a random effect. The model effects were the region (nucleus and annulus), disc number, and their interaction. Student's t-tests were used for post-tests.

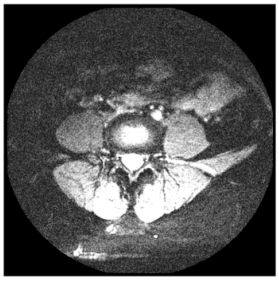

Figure 1: Axial $T_{1\rho}$-weighted image.

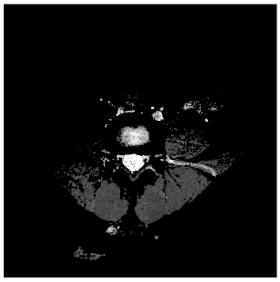

Figure 2: Axial $T_{1\rho}$ map. The median $T_{1\rho}$ value was 118±33 ms for the above nucleus, and was 75±19 ms for the above annulus.

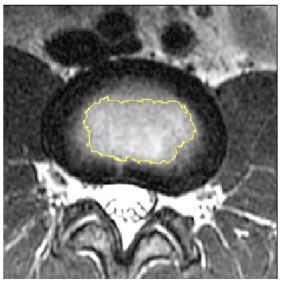

Figure 3: T_2-weighted image. The nucleus was segmented using a threshold-based technique, and the resulting segmented ROI (in yellow) was superimposed on the $T_{1\rho}$ map.

Results:

The average SNR of the $T_{1\rho}$-weighted images at TSL_{20}, TSL_{50}, TSL_{80}, and TSL_{110} was 19, 16, 12, and 10, respectively. Table 1 shows the average median $T_{1\rho}$ values for the annulus and nucleus for each disc. The overall average median $T_{1\rho}$ value (24 discs, 3 from each subject) was 114.4 (±23.8) ms for the nucleus and 84.6 (±12.6) ms for the annulus (Figure 5). The results of the Student's t-tests show that the median $T_{1\rho}$ values of the nucleus and the annulus were significantly different ($p = 0.0004$). All other effects were not significant.

Disc	T1ρ (ms) nucleus	T1ρ (ms) annulus
S1/L5	108.4(31.5)	74.5(11.0)
L5/L4	113.8(21.8)	86.3(11.9)
L4/L3	120.2(18.6)	91.6(9.7)

Table 1: Average median $T_{1\rho}$ values for the nucleus and annulus of different discs ($n_{disc\ 1} = 8$, $n_{disc\ 2} = 8$, $n_{disc\ 3} = 8$). The standard deviation is in parenthesis.

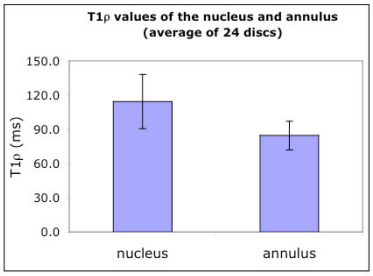

Figure 5: Average median $T_{1\rho}$ values for the nucleus and annulus. Error bars represent the standard deviation.

Discussion:

This study demonstrates the feasibility of using spiral imaging at 3T for *in vivo* $T_{1\rho}$ quantification in the intervertebral disc, and shows that the median $T_{1\rho}$ value in the nucleus is significantly greater than that of the annulus. These results may be attributed to the differences in biochemical composition (such as hydration and GAG content) between the nucleus and the annulus. The relatively large standard deviations of the measurements may be due in part to the segmentation method used for differentiating the nucleus and annulus. These results demonstrate the potential of *in vivo* $T_{1\rho}$ quantification as a tool for monitoring degenerative disc disease.

References:

[1] W. Blitterswijk, J. et al., *BMC Complementary and Alternative Medicine*, 2003. 3(2).

[2] Regatte, RR. et al. 12th ISMRM 2004: 1544.

[3] Regatte, RR. et al. 5th ORS 2004.

[4] Li, X, et al. *Proc. 26th IEEE EMBS* 2004: 1032-1035.

Acknowledgements: This work is supported by NIH grant RO1 A917762.