The use of $T_{1\rho}$-weighted imaging to assess intervertebral disc degeneration

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INTRODUCTION:

As a leading cause of lumbar spine related lower back pain, intervertebral disc degenerative disease is a common medical and social problem. Proteoglycans, specifically chondroitin sulfate, a nearly linear biopolymer made up largely of repeating disaccharide units consisting of a uronic acid and glucosamine sugar residue, have been shown to be an integral compound in the characterization of degenerative levels [1]. As level of degeneration increases, the concentration of proteoglycans in the nucleus pulposus (NP) and the annulus fibrosus (AF) decreases. $T_{1\rho}$ relaxation time is the spin-lattice relaxation in the rotating frame. It has been shown, that $T_{1\rho}$ is correlated to the concentration of large charged molecules [2]. The purpose of this study was to quantify $T_{1\rho}$ relaxation times of cadaveric intervertebral disc specimens to assess degree of degeneration compared to biochemical assays that verified absolute concentrations of collagen and proteoglycans.

MATERIALS AND METHODS:

A total of 11 cadaveric human lumbar discs were harvested from patients ranging from 27 to 85 years of age. Specimens were scanned using a GE SIGNA 3.0 Tesla echo-speed system (GE Healthcare, Waukesha, WI) and a four-channel phased array spine coil. After a 3-plane localizer, coronal $T_{1\rho}$-weighted images were acquired using a spiral sequence (TE = 5.8 ms, TR = 2000 ms, flip angle = 90°, field of view = 24 cm, slice thickness = 4 mm, bandwidth = 100 KHz, interleaves = 14/slice, data points = 4096/interleaf, $TSL_1/TSL_2/TSL_3/TSL_4$ = 20/50/80/110 ms, spin lock frequency = 300 Hz) [3]. Additionally, coronal T_2-weighted images (TE = 85 ms, TR = 5200 ms, field of view = 24 cm, slice thickness = 4 mm, bandwidth = 35.7 KHz, matrix size = 288 x 224) were acquired. $T_{1\rho}$ maps were computed using the following equation: $S(TSL) \propto \exp(-TSL/T_{1\rho})$. The nucleus and annulus of the intervertebral disc were segmented from the T_2-weighted image, and the segmented region of interest (ROI) was superimposed on the $T_{1\rho}$ map (Figure 1). The average $T_{1\rho}$ values of the nucleus and the annulus were calculated for each disc. Proteoglycan and collagen biochemical analyses (Biocolor Ltd., N. Ireland) were conducted on 3 mm biopsy punches taken from the annulus fibrosus and nucleus pulposus of each sample. These biochemical concentrations (μg/mg) were then compared directly to Thompson Grade (a visual grading system for degenerative disc) and acquired $T_{1\rho}$-weighted maps.

RESULTS:

Fig. 1 shows a T_2-weighted image (A) as an example of the segmentation of the nucleus pulposus (NP) from the annulus fibrosus (AF). The T1ρ-weighted images are shown for the varying degrees of degeneration (B-D). Noticeable differences are apparent in the $T_{1\rho}$-weighted image as the disc material degenerates, particularly in uniformity and concentration. Table 1 shows mean and standard deviation of median $T_{1\rho}$ within the AF and NP regions. The comparison is also made to collagen and proteoglycan (PG) biochemical assays. PG concentration is positively correlated (R = 0.23) to decreases in $T_{1\rho}$ relaxation time and localization of decreased $T_{1\rho}$ is apparent in the $T_{1\rho}$-weighted images. Collagen concentration was negatively correlated (R = -0.34) to $T_{1\rho}$ relaxation time. It was difficult to distinguish the difference between nucleus and annulus in Thompson Grade 5 discs, and thus the $T_{1\rho}$ was the average of nucleus and annulus, which both have decreased relaxation times.

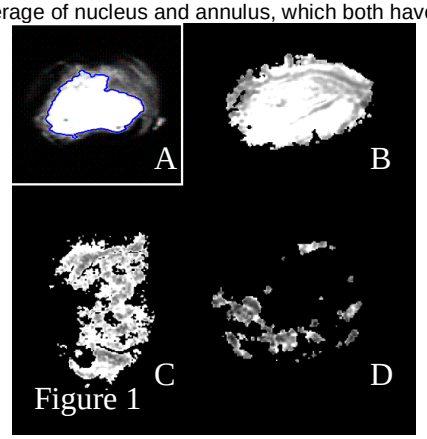

Figure 1

A. The nucleus was segmented from the T_2-weighted image and the resulting segmented region of interest (ROI) was superimposed on the $T_{1\rho}$ map.
B. $T_{1\rho}$ map of a grade 1 disc
C. $T_{1\rho}$ map of a grade 3 disc
D. $T_{1\rho}$ map of a grade 4 disc

Table 1

Thompson Grade	Region	$T_{1\rho}$ (ms)	Total Collagen (μg/mg)	Total PG (μg/mg)
1	AF	68 ± 33.7	0.59 ± 0.36	235.85 ± 103.51
1	NP	129 ± 59.7	0.22 ± 0.20	330.15 ± 73.11
3	AF	48.7 ± 28.8	1.37 ± 0.86	290.94 ± 302.50
3	NP	45.3 ± 22.8	0.73 ± 0.93	248.08 ± 98.66
5	AF and NP *	44 ± 17.2	0.98 ± 0.95	110.55 ± 65.565

* In Thompson Grade 5 the intervertebral disc regions are difficult to discriminate, and for this reason, the annulus fibrosus and nucleus pulposus were averaged together in this preliminary study.

DISCUSSION AND CONCLUSIONS:

The reported data suggests that decreases in $T_{1\rho}$ relaxation times and decreases in concentration of proteogylcans with respect to Thompson Grade. The decrease in rotating spin-lattice relaxation times is most likely a result of the change in magnetic environment caused by the loss of proteogylcans, collagen molecules and water. The role of collagen degradation has been shown to be linked to disc degeneration, and the effects of the collagen matrix on environment [4]. These findings support the potential of using *in vivo* $T_{1\rho}$ imaging to aid in the non-invasive assessment of intervertebral disc degeneration.

REFERENCES:

[1] Maroudas A. Nutrition and metabolism of the intervertebral disc. In: Ghosh P, editor. The Biology of the Intervertebral Disc. Volume 2. Boca Raton: CRC Press; 1988. p 1-37.
[2] Regatte, R.R., et al., Proteoglycan depletion-induced changes in transverse relaxation maps of cartilage: comparison of T2 and T1rho. Acad Radiol, 2002. 9(12): p. 1388-1394.
[3] Li, X.,et al. T1rho Relaxation Quantification Using Spiral Imaging: A Preliminary Study, 26th Annual Inter. Conf. of IEEE Eng. in Medicine and Biology Society (EMBS), San Francisco, USA, September 2004.
[4] Keshari, KR, et al. Quantitative High-Resolution Magic Angle Spinning (HR-MAS) NMR of the Intervertebral Disc: Toward an Objective, Non-invasive Measure of Degeneration, Spine, Submitted 2004

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