Correlation between ADC and T1ρ-Relaxation Time for In-Vivo Assessment of Intervertebral Disc Degeneration

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Purpose:

Despite demonstrating a tremendous potential over the years, the role of MRI in study of intervertebral disc (IVD) degeneration remains still relatively limited. A part of the reason is current lack of a standard in MRI that can provide a quantitative and objective in vivo assessment of the levels of disc degeneration. The only accepted standard based on disc morphology currently available, such as Pfirrmann and Thompson grading system [1, 2], is inadequate in that the degenerative process which is fundamentally a continuum is characterized into a small number of categories. Subsequently, the subjective nature and inherent ambiguity associated with such standard based on visual assessment of disc morphology are prone to yield a large variation and uncertainty in any quantitative measurement of the degenerative process when correlation with such assessment is sought. Additionally, multifactor etiologies of disc degeneration and biochemical changes within disc that are expected to precede any change in disc morphology likely require a quantitative in vivo assessment that is capable of addressing different underlying aspects of the degenerative process. This is especially important for the evaluation of early degenerative stages prior to morphological manifestation as well as in the assessment of techniques that aim to halt or reverse the degenerative process in IVD. Presented here is a preliminary result in which we investigated the potential of and correlation between two promising MRI measurements for in vivo quantification of disc degeneration: apparent diffusion coefficient (ADC) and $T1_\rho$-relaxation time, both of which had been investigated previously but never in conjunction with each other.

Methods:

Fifteen lumbar IVDs in 3 healthy male volunteers with no history of back injuries are included here (age: 29, 33, & 43 yrs). Each subject was scanned on a 3T Philips scanner with Philips' CTL-spine RF-coil (Philips Medical Systems, Best, Netherlands) for 15-sagittally-sliced T2w (TR/TE=5000/120 ms), DWI and a series of $T1_\rho$-weighted scans with varying values of time of spin-lock (TSL). The DWI was based on a single-shot EPI (FOV/thickness=310/3mm, TR/TE=4000/66ms, acquisition-matrix=116x117 (192x192 image-matrix)), and performed with two b factors (b_0=0 and b_1=600 sec/mm^2) in each of the three orthogonal directions for generation of a rotationally invariant ADC-map (ADC-trace) in identical geometry as that of the T2w. The $T1_\rho$ protocol was based on a 3D balanced turbo field-echo [3] (3D bTFE; FOV/thickness=310/3mm, TR/TE=3.1/1.6 ms, flip-angle=10°, 192x192 image-matrix, acquisition-time=1.5 min) with the $T1_\rho$-weighted magnetization prepared by a three-pulse cluster consisting of two 90° hard pulses and a low power spin-lock (SL) pulse in between. Four different TSL values (10, 20, 40, and 80 ms) were used while the amplitude of SL pulse was fixed at 500 Hz for calculation of $T1_\rho$ relaxation time. Both ADC and $T1_\rho$ values reported here are based on mono-exponential fitting over the region-of-interest (ROI) averaged image intensities rather than pixel-by-pixel variety: $S_{b1}=S_{b0}*\exp(-b_1*ADC)$ and $S(TSL)=S_0*\exp(-TSL/T1_\rho)$. The ROI was drawn manually on the central slice of the $T1_\rho$-weighted image (w/ TSL=10 ms) and co-registered to the matching slice in DWI (Fig. 1: a typical ROI shown in red). Visual classification of disc degeneration was also performed on the mid-slice T2w image based on the criteria of Pfirrmann grading system.

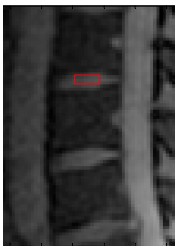

Figure 1

Results:

The mid-slice T2w image and the corresponding color-coded $T1_\rho$-map and ADC-map for each of the 3 subjects are shown below (Fig. 2). The scatter plot below summarizes the ROI-based $T1_\rho$ and ADC values (Fig. 3). In Figure 3, the lumbar discs from 29 yr, 33 yr, and 43 yr old subject are marked with square, diamond, and triangle shape, respectively; the green, yellow, and red colors represent visual classification of disc degeneration (Pfirrmann grade II, III, and IV, respectively; healthier to more degenerative).

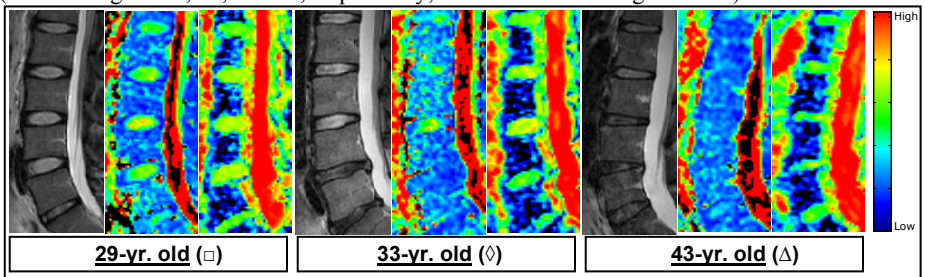

Fig. 2 (above): T2w-image, color-coded $T1_\rho$-map and ADC-map, respectively, for each subject for visual comparison (the same color-scale used for $T1_\rho$ & ADC-map, respectively).
Fig. 3 (right): The solid line represents the fitted linear correlation between ADC and $T1_\rho$ values using Pearson statistics ($r = 0.85$, $P < 0.0001$).

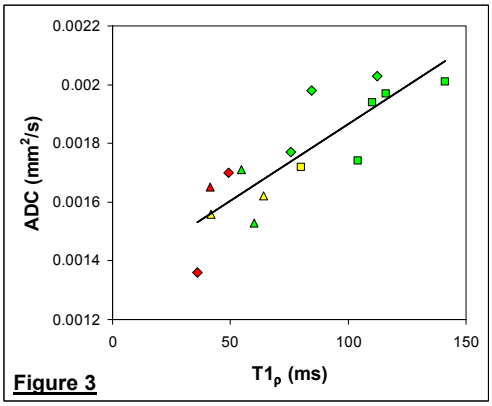

Figure 3

Conclusions:

Early stages of IVD degeneration can be characterized by loss of proteoglycan in the disc nucleus pulposus. The $T1_\rho$ parameter describes the spin-lattice relaxation in the rotating frame, which probes the slow motion interactions between motion-restricted water molecules and their local macromolecular environment (e.g., extracellular matrix (ECM)). As such, it has been previously shown to strongly correlate with proteoglycan content of ECM in IVD [4], demonstrating $T1_\rho$ as a potential biomarker of early disc degeneration. Thought to reflect changes in disc matrix integrity, measurement of ADC via DWI have also demonstrated to be capable of quantitatively characterizing disc degeneration in vivo [5]. Despite a small sample size, our study demonstrates a feasibility of quantifying IVD degeneration based on in vivo measurements of $T1_\rho$ and ADC, between which a strong linear correlation is evident. The multifactorial nature of pathogenesis of disc degeneration makes very unlikely that a single measurement serves as a do-it-all biomarker and calls for a combined approach where different aspects of the disease can be characterized together.

References: [1] Pfirrmann et al. Spine 2001; 26:1873-8. [2] Thompson et al. Spine 1990; 15: 411-5. [3] Witschey et al. J Magn Reson Imaging 2008; 28:744-54. [4] Auerbach et al. Eur Spine J 2006; 15:S338-44. [5] Beattie et al. J Orthop Sports Phys Ther 2008; 38:42-9.

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