An in vivo comparative study of T1rho and T2 relaxation times for evaluation of lumber disc degeneration at 3.0 Tesla MRI

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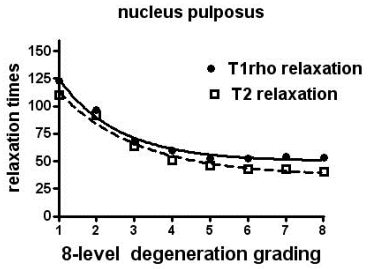
Introduction: Early signs of disc degeneration are manifested by biochemical changes, including a loss of proteoglycans, a loss of osmotic pressure and hydration (1). In the later stages of disc degeneration, evident morphologic changes occur, including a loss of disc height, disc herniation, annular tears, and radial bulging (2). While lumbar spinal fusion is currently used for surgical treatment of low back pain with advanced degeneration, earlier stages of disc degeneration may be amenable to emerging alternative treatments (e.g., nucleus replacement, cell therapy, growth factor therapy) that may preclude the morbidity associated with fusion. Non-invasive quantitative assessments for these early degenerative changes are needed and will become more important as these emerging treatment technologies develop. T1rho relaxation measurement, which probes the interaction between water molecules and their macromolecular environment, is suggested to have the potential to identify early biochemical changes in the intervertebral disc. In cadaveric human discs it was shown that in the nucleus pulposus T1rho strongly correlates with proteoglycan content (3). *In vivo* studies have demonstrated differences in mean T1rho values between the nucleus and the annulus and have shown a correlation between T1rho values and degenerative grades at 1.5 T (4,5). More recently, in an in vivo study using 3.0T, Blumenkrantz *et al.* reported that the values of T1rho and T2 were significantly correlated (6). The purpose of the current i*n vivo* 3.0 T MRI study is to determine relative performance of T1rho and T2 relaxation times in their assessment of disc degeneration with reference to an 8-level disc degeneration grading systems (7). The 8-level disc degeneration grading systems is an expanded version of the original Pfirrmann 5-level grading system for disc degeneration and has been successfully applied in a number of clinical studies, proving high discriminatory power. With this grading system, grade 1 corresponds to no disc degeneration, grade 2 corresponds to mild disc degeneration, grade 4/5 corresponds to moderate disc degeneration, grade$\geqslant$6 indicates an existence of disc space narrowing, while grade 8 corresponds to end-stage degeneration (7).

Materials and methods: The study subjected included 4 normal volunteers (3 males and 1 females; mean age: 32.8 years, age range: 28-42 years) and 34 patients with low back pain (14 males and 20 females; mean age: 49.8 years, age range: 23-72 years). MRI acquisition was performed on a 3T clinical scanner (Achieva, Philips Healthcare). A 12-channel receive-only spine coil was used as the signal receiver to cover the lumbar spine, and the built-in body coil was used as the signal transmitter. For T1rho measurement, a rotary echo spin-lock pulse was implemented in a 3D balanced fast field echo (b-FFE) sequence. Spin-lock frequency was set as 500 Hz and the spin-lock times (TSLs) of 1 ms, 10 ms, 20 ms, 30 ms, 40 ms, and 50 ms were used for acquisition and T1rho mapping. A dummy delay time of 6000ms was inserted after each segment acquisition to fully restore the equilibrium magnetization prior to the next T1rho preparation. TE and TR for b-FFE acquisition were 2.3 ms and 4.6 ms respectively. The field-of-view (FOV) was 200mm and the voxel size was 1.0mm ×1.0mm. Seven sagittal slices were acquired and the slice thickness was 4mm. The flip angle was 40 degrees and the number of signal averages (NSA) was one. A sensitivity-encoding (SENSE) factor of 2 was applied for parallel imaging to reduce the phase encoding steps and hence the acquisition time. A multi-echo turbo spin echo (TSE) pulse sequence was used for T2 mapping. Seven sagittal TSE images were acquired at the identical locations as T1rho images. TSE imaging parameters included: FOV = 200mm, voxel size = 1.0mm ×1.0mm, slice thickness = 4mm, echo train length (ETL) = 7, TEs = 16, 32, 48, 64, 80, 96, and 112ms, TR=2300ms. NSA = 1, and SENSE factor = 2. T1rho and T2 maps were computed on a pixel-by-pixel basis using a mono-exponential decay model with a home-made Matlab program (Mathworks, Natick, MA, USA): M(TSL)=M0*exp(-TSL/T1rho) and M(TE)=M0*exp(-TE/T2) Where M0 and M(TSL) denote the equilibrium magnetization and T1rho-prepared magnetization with the spin lock time of TSL, respectively. M(TE) denotes the magnetization acquired with the echo time TE. These two mono-exponential equations were linearized by logarithm. T1rho and T2 maps were generated by fitting each pixel's intensity as a function of TSL and TE using a non-negative least-square fitting algorithm, respectively. T1rho and T2 were calculated as the inverse of the slope of the corresponding straight-line fit. Five intervertebral discs (L1/L2 – L5/S1) per subject were examined. Images were analyzed in the mid-sagittal section of the lumbar spine. With TSE images as reference, regions-of-interest (ROIs) were manually drawn over the T2 and T1rho maps. ROIs included nucleus pulposus (NP), anterior annulus fibrosus (AF) and posterior annulus fibrosus (Fig 1). Values of anterior AF and posterior AF were averaged as the value for AF. The 8-level disc degeneration evaluation was carried out by an experienced radiologist.

Results: The relationship between NP relaxation times of the discs and 8-level disc degeneration grading is shown in Fig 1. For both T1rho and T2 relaxation times, as the degeneration grading increased, the relaxation times decreased. The quadratic coefficient (±SE) was 3.61±0.45 ($p<0.0001$) and R^2=0.65 for T1rho relaxation time; and quadratic coefficient was 3.33±0.43 ($p<0.0001$) and R^2=0.70 for T2 relaxation time. There was no significant trend difference for the T1rho and T2 values decrease over degeneration grade increase (p=0.67). The relationship between AF relaxation times and 8-level grading of the discs is shown in Fig 2. For T1rho relaxation time, as the degeneration grade increased, relaxation time decreased. On the other hand, the trend of T2 relaxation time decrease was much flatter. The slope (± SE) was -2.80±0.38 ($p<0.0001$) and R^2=0.23 for T1rho relaxation time; and slope was -1.18±0.36 (p=0.0014) and R^2= 0.05 for T2 relaxation time. There was significant difference for the slopes of T1rho and T2 value decrease over disc degeneration (p=0.002).



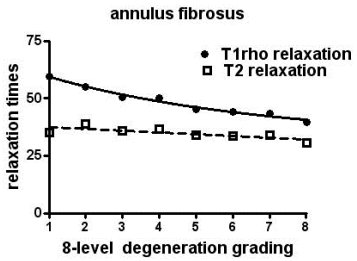


Fig 1: Nucleus pulposus T1rho relaxation time and T2 relaxation time vs 8-level disc degeneration grading.

Fig 2: Annulus fibrosus T1rho relaxation time and T2 relaxation time vs 8-level disc degeneration grading.

Discussion: This study confirmed that the previously reported negative relationship between relaxation time (T1rho and T2) and disc degenerative grade (5,6, 8-11). Same as previous reports, there were overlaps of T2 value and T1rho value between different semi-quantitative grades, i.e. T2 value and T1rho cannot clearly separate disc degeneration of different grades. Our study showed for the NP, T1rho and T2 relaxation times followed the same trend with their correlations to semi-quantitative gradings. On the other hand, T1rho relaxation time offered distinct advantage over T2 relaxation time in the evaluation of AF degeneration. While there were almost no changes of T2 values as the disc degeneration grades increased, T1rho decreased apparently as disc degeneration grades increased.

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