Brief Report

Accelerated T1rho relaxation quantification in intervertebral disc using limited spin-lock times

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Objective: T1rho relaxation measurement has the potential to identify early biochemical changes in the intervertebral disc. Traditionally, multiple spin-lock times (SLT), often ~5 SLTs, are used to ensure the accuracy and robustness of T1rho mapping. It will be advantageous to use fewer SLT points if comparable accuracy of T1rho mapping can be achieved. In this study, the feasibility of using 3 SLT points to measure intervertebral disc T1rho relaxation time is explored.

Materials and methods: The lumbar spine of 12 subjects (age range: 30-75 years, disc =60) were studied on 3-T MRI. 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 SLTs of 1, 10, 20, 40, and 60 ms were acquired. T1rho maps were generated by fitting each pixel's intensity as a function of SLT using a non-negative least-square fitting algorithm. Images were analysed in the mid-sagittal section. T1rho maps were re-constructed using all 5 SLT points of 1, 10, 20, 40, and 60 ms, and three SLT points of 1, 20, and 60 ms respectively. ROIs included nucleus pulposus (NP), anterior annulus fibrosus (AF) and posterior annulus fibrosus. Values of anterior AF and posterior AF were averaged as the value for AF. Agreement of T1rho measurements using different SLT points was assessed using intra-class correlation coefficient (ICC) on absolute agreement as well as Bland and Altman plot.

Results: There was no significant difference for T1rho values by 5-SLT measurement and 3-SLT measurement in both NP (P=0.63) and AF (P=0.31). The ICC for 5-SLT T1rho measurement *vs.* 3-SLT T1rho measurement was 0.991 and 0.981 respectively for NP and AF T1rho time. The Bland and Altman plots for the comparison showed a mean difference of 3.14 and 1.83 for NP and AF respectively. Polling the T1rho values for NP and AF in 60 discs together, the ICC for 5-SLT T1rho measurement *vs.* 3-SLT T1rho measurement was 0.993, and the Bland and Altman analysis showed a mean difference of 2.56.

Conclusions: This study suggests that adopting 3 SLTs of 1, 20, and 60 ms can be an acceptable alternative for the disc T1rho measurement.

Key Words: Magnetic resonance imaging; disc; T1rho; spin-lock time

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Introduction

T1rho relaxation time, or spin-lattice relaxation time in the rotating frame, stands for the time constant for transverse magnetization decay in a very weak B1 field strength produced by a continuous wave radiofrequency pulse, called spin-lock RF pulse, applied aligned with the transverse magnetization. As the spin-lock field strength is much weaker than the main magnetic field strength B0, T1rho

relaxation time is considered similar to the T1 relaxation time at very low B0, and is sensitive to low frequency motional processes in physiology. As a novel imaging mechanism, T1rho has been proposed for many clinical applications, involving various tissues of brain (e.g., for Alzheimer's disease and Parkinson's disease), knee (e.g., for assessment of cartilage), spine (e.g., for disc degeneration) (1-3). With biliary duct ligation and carbon tetrachloride intoxication induced rat liver fibrosis models, recent studies showed that MR T1rho imaging is able to detect liver fibrosis, and the degree of fibrosis is correlated with the degree of elevation of the T1rho measurements, suggesting liver T1rho quantification may play an important role for liver fibrosis early detection and grading (4,5). Additionally, T1rho imaging has been applied for human liver and consistent liver T1rho measurement has been achieved for healthy volunteers at 3T with multiple spin-lock times (SLTs) (6).

MRI is commonly used for assessment of symptomatic disc degeneration. On T2-weighted MR images, disc degeneration is seen as a reduction in signal of the nucleus pulposus (NP) and inner fibres of the annulus. With more severe disc degeneration, disc height decreases (7). 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., 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. Quantitative disc MR T1rho relaxation time reflecting the intrinsic material properties of disc tissues is being explored (1,8-11). 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 (12). We also documented that while in nucleus pulposus (NP) T1rho and T2 decrease in a similar pattern following disc degeneration, T1rho is better suited for evaluating annulus fibrosus (AF) in degenerated disc than T2 (11). T1rho measurement is theoretically device- and reader-independent, and may have the potential to detect subtle differences in tissue composition that may not be apparent with T2-weighted image-based qualitative or semi-quantitative assessment, therefore would likely to be more useful for early disc changes.

For traditional T1rho imaging applications, multiple spin-lock times, often 5-6 SLTs, are used for T1rho mapping. However, it will be advantageous to use fewer SLT points for the following reasons if comparable accuracy of T1rho mapping can be achieved. Fewer SLT points reduced the overall scan duration when the patients are less likely to lie still. Examinations with fewer SLTs are also helpful to reduce the total RF energy deposition into the patient bodies and so mitigate the safety concern. Recently we documented that using 3 SLTs of 1, 20, and 50 ms can be an acceptable alternative for liver T1rho measurement, while 2 SLTs of 1 and 50 ms do not provide reliable measurement (13). In this study, the feasibility of using 3 SLT points to measure intervertebral disc T1rho relaxation time is explored.

Materials and methods

In total there were 12 subjects (6 females and 6 males; mean age: 49.8 years; age range: 30-75 years old) randomly selected from the data base of 52 subjects we previously reported (11). All subjects were confirmed to have no other spine diseases except disc degeneration. The study was approved by the local human research ethics committee. Written informed consent was obtained from all subjects. To remove the potential confounding role of diurnal disc hydration changes, all subjects underwent imaging in the morning. MRI acquisition was performed on a 3-T clinical system (Achieva, Philips Healthcare, Best, The Netherlands). 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. Volume shimming was employed to minimise B0 heterogeneity.

For T1rho measurement, a rotary echo spin-lock pulse was implemented in a 3D balanced fast field echo (b-FFE) sequence, also called a balanced steady state free precession (bssfp) sequence. Spin-lock frequency was set as 500 Hz and the spin-lock times (TSLs) of 1, 10, 20, 40, and 60 ms were used for acquisition and T1rho mapping. Segmented phase alternating b-FFE readout with centric phase encoding order was used for acquisition. T1rho-weighted images were acquired during the transient status towards the steady state but with T1rho-weighted magnetisation maintained. A rotary echo spin-lock pulse was applied once for every segment length of 80 readouts. A dummy delay time (TD) of 6,000 ms was inserted after each segment acquisition to fully restore the equilibrium magnetisation before the next

Table 1 The T1rho values measured by 5-SLT and 3-SLT in nucleus pulposus (NP) and annulus fibrosus (AF)

Region	T1rho values (ms) in disc		P-value
	5-SLT T1rho measurement	3-SLT T1rho measurement	
NP (n=60)	mean ± sd: 81.0 ± 23.4 ms (range: 48.4-137.4 ms)	mean ± sd: 80.8 ± 23.4 ms (range: 46.3-135.2 ms)	0.63
AF (n=60)	mean ± sd: 55.6 ± 9.2 ms (range: 38.8-80.6 ms)	mean ± sd: 55.4 ± 9.4 ms (range: 37.05-83.25 ms)	0.31

T1rho preparation. TE and TR for b-FFE acquisition were 2.3 and 4.6 ms respectively. The field-of-view (FOV) was 200 mm and the voxel size was 1.0 mm × 1.0 mm. Seven sagittal slices were acquired and the slice thickness was 4 mm. The flip angle was 40° 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. Seven sagittal TSE images were acquired at identical locations as T1rho images.

Image analysis

T1rho 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(SLT)=M0*exp(-SLT/T1rho)

Where M0 and M(SLT) denote the equilibrium magnetisation and T1rho-prepared magnetisation with the spin-lock time of SLT, respectively.

The mono-exponential equation was linearised by logarithm. T1rho maps were generated by fitting each pixel's intensity as a function of SLT using a non-negative least-square fitting algorithm. T1rho was calculated as the inverse of the slope of the corresponding straight-line fit.

Five intervertebral discs (L1/L2-L5/S1) per subject were examined (total =60 discs). T1rho maps were reconstructed using all 5 SLT points of 1, 10, 20, 40, and 60 ms, and three SLT points of 1, 20, and 60 ms respectively. Images were analysed in the mid-sagittal section of the lumbar spine. With T2-weighted images as reference, regions of interest (ROIs) were manually drawn over T1rho map of the discs simultaneously on the image constructed using 5 SLT and 3 SLT. ROIs included nucleus pulposus (NP), anterior annulus fibrosus (AF) and posterior annulus fibrosus. Values of anterior AF and posterior AF were averaged as the value for AF. When an apparent tear was noted in the annulus, the abnormal signal areas were excluded in the ROIs.

Statistical analysis

Statistical analyses were performed using the statistical package SAS, version 9.1.3 (SAS Institute, Inc., Cary, NC, USA). Agreement of T1rho measurements using different SLT points was assessed using intra-class correlation coefficient (ICC) on absolute agreement as well as Bland and Altman plot. According to Fleiss (14), ICC values >0.75 represent good agreement, and values between 0.4 and 0.75 represent fair to moderate agreement. Statistical analyses were done using SPSS 14.0 (Chicago, IL).

Results

Example of placement of T1rho maps constructed with 5 SLTs and with 3 SLTs is shown in *Figure 1*. There was no significant difference for T1rho values by 5-SLT measurement and 3-SLT measurement in both NP (P=0.63) and AF (P=0.31) (*Table 1*).

The ICC for 5-SLT T1rho measurement *vs.* 3-SLT T1rho measurement was 0.991 and 0.981 respectively for NP and AF T1rho relaxation time. The Bland and Altman plots for the comparison are shown in shown in *Figure 2*, with mean difference of 3.14 (95% limits of agreement: −5.96, 6.36) and 1.83 (95% limits of agreement: −3.35, 3.83) for NP and AF respectively. Polling the T1rho values for NP and AF in 60 discs together, the ICC for 5-SLT T1rho measurement *vs.* 3-SLT T1rho measurement was 0.993, and the Bland and Altman analysis showed a mean difference of 2.56 (95% limits of agreement: −4.80, 5.24) (*Figure 2*).

Discussion

Accurate and precise T1rho mapping is challenging under the scan time constraint because multiple SLTs are usually required and a long delay time is also often necessary in the spin-lock pulse sequence for longitudinal magnetization restoration. The reduction of the applied SLT numbers is an apparent strategy to enhance T1rho imaging efficiency as long as the accuracy and reliability of T1rho mapping could be maintained (13,15). In addition, a high frequency spin-lock pulse is usually associated with high SAR and total RF energy deposition, which may be a safety concern for T1rho MR imaging, particularly at high field such as 3T (16).

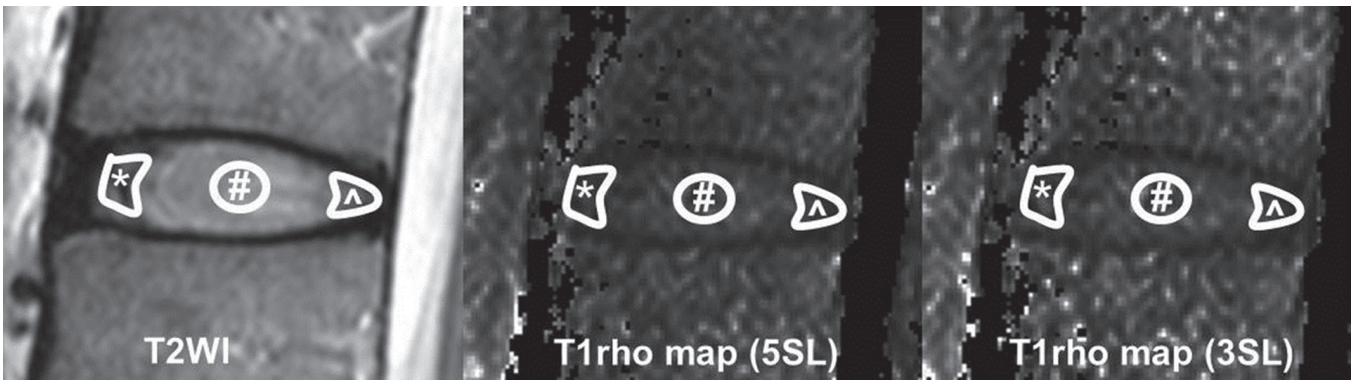

Figure 1 An example of placement of regions-of-interest (ROIs) over nucleus pulposus (#), anterior annulus fibrosus (*) and posterior annulus fibrosus (^) in one disc. Left, T2 weighted image; middle, T1rho maps constructed with 5 SLTs; right, T1rho maps constructed with 3 SLTs

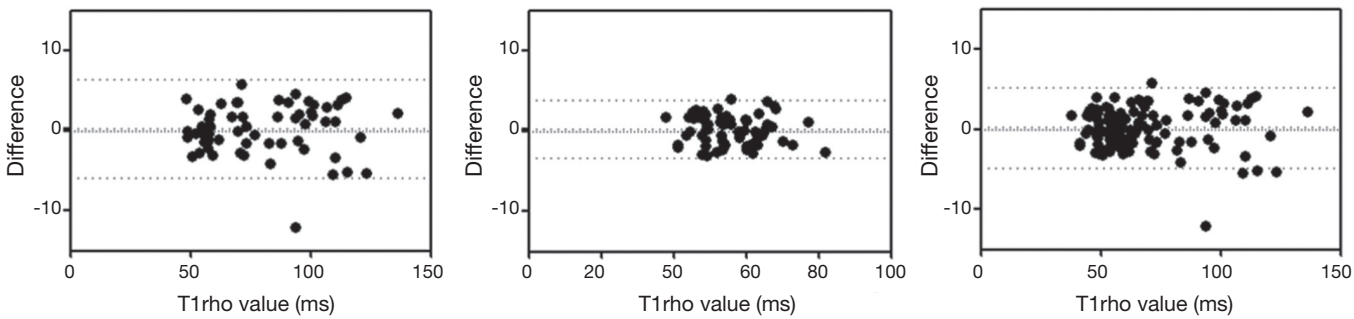

Figure 2 The Bland and Altman plots for the comparison of measurement by 5-SLT and 3-SLT in nucleus pulposus (left), annulus fibrosus (middle), and nucleus pulposus & anterior annulus fibrosus (right)

Examinations with fewer SLTs are helpful to reduce the total RF energy deposition into the patient bodies and so mitigate the safety concern. The preliminary results from this study suggest using 3 SLTs of 1, 20, and 60 ms may be an acceptable alternative when fast acquisition is desired for intervertebral disc T1rho imaging without compromising the precision of T1rho mapping.

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Disclosure: The authors declare no conflict of interest.

References

1. Blumenkrantz G, Zuo J, Li X, et al. In vivo 3.0-tesla magnetic resonance T1rho and T2 relaxation mapping in subjects with intervertebral disc degeneration and clinical symptoms. Magn Reson Med 2010;63:1193-200.
2. Borthakur A, Sochor M, Davatzikos C, et al. T1rho MRI of Alzheimer's disease. Neuroimage 2008;41:1199-205.
3. Pakin SK, Xu J, Schweitzer ME, et al. Rapid 3D-T1rho mapping of the knee joint at 3.0T with parallel imaging. Magn Reson Med 2006;56:563-71.
4. Wang YX, Yuan J, Chu ES, et al. T1rho MR imaging is sensitive to evaluate liver fibrosis: an experimental study in a rat biliary duct ligation model. Radiology 2011;259:712-9.
5. Zhao F, Wang YX, Yuan J, et al. MR T1ρ as an imaging biomarker for monitoring liver injury progression and regression: an experimental study in rats with carbon tetrachloride intoxication. Eur Radiol 2012;22:1709-16.
6. Deng M, Zhao F, Yuan J, et al. Liver T1ρ MRI measurement in healthy human subjects at 3 T: a preliminary study with a two-dimensional fast-field echo sequence. Br J Radiol 2012;85:e590-5.
7. Griffith JF, Wang YX, Antonio GE, et al. Modified

Pfirrmann grading system for lumbar intervertebral disc degeneration. Spine (Phila Pa 1976) 2007;32:E708-12.
8. Johannessen W, Auerbach JD, Wheaton AJ, et al. Assessment of human disc degeneration and proteoglycan content using T1rho-weighted magnetic resonance imaging. Spine (Phila Pa 1976) 2006;31:1253-7.
9. Blumenkrantz G, Li X, Han ET, et al. A feasibility study of in vivo T1rho imaging of the intervertebral disc. Magn Reson Imaging 2006;24:1001-7.
10. Auerbach JD, Johannessen W, Borthakur A, et al. In vivo quantification of human lumbar disc degeneration using T(1rho)-weighted magnetic resonance imaging. Eur Spine J 2006;15 Suppl 3:S338-44.
11. Wang YX, Zhao F, Griffith JF, et al. T1rho and T2 relaxation times for lumbar disc degeneration: an in vivo comparative study at 3.0-Tesla MRI. Eur Radiol 2013;23:228-34.
12. Johannessen W, Auerbach JD, Wheaton AJ, et al. Assessment of human disc degeneration and proteoglycan content using T1rho-weighted magnetic resonance imaging. Spine (Phila Pa 1976) 2006;31:1253-7.
13. Zhao F, Deng M, Yuan J, et al. Experimental evaluation of accelerated T1rho relaxation quantification in human liver using limited spin-lock times. Korean J Radiol 2012;13:736-42.
14. Fleiss JL. Reliability of measurement. The design and analysis of clinical experiments. New York: John Wiley & Sons, 1986.
15. Yuan J, Zhao F, Griffith JF, et al. Optimized efficient liver T(1ρ) mapping using limited spin lock times. Phys Med Biol 2012;57:1631-40.
16. Santyr GE, Fairbanks EJ, Kelcz F, et al. Off-resonance spin locking for MR imaging. Magn Reson Med 1994;32:43-51.

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