Intervertebral disc T1rho relaxation mapping with spin-lock 3D b-FFE imaging at 3T

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Introduction: Quantitative $T_{1\rho}$ imaging (1) is a non-invasive MRI technique that has been shown to be sensitive to interactions between motion restricted water molecules and their surrounding macromolecular environment. $T_{1\rho}$-weighted contrast is produced by transverse magnetization relaxation in the presence of an on-resonance continuous wave (cw) RF pulse (spin-lock pulse). $T_{1\rho}$ quantification should be helpful in identifying early interverterbral disc degeneration (2). In this study, a time-efficient spin-lock 3D balanced fast field echo (bFFE) imaging was developed for rapid *in vivo* interverterbral disc $T_{1\rho}$ relaxation mapping at 3T. It shows that median $T_{1\rho}$ value of the nucleus pulposus is greater than that of the annulus, consistent with results from previous studies (3). Significant reduction of $T_{1\rho}$ relaxation was found to be an indication of early interverterbral disc degeneration.

Methods: The proposed spin-lock 3D bFFE sequence was implemented and applied for $T_{1\rho}$ quantification in three healthy volunteers on a 3T Philips Achieva MRI scanner with a spine coil. The diagram for the sequence is shown in Fig. 1. The unwanted bright fat signal was firstly suppressed by a spectrally selective RF pulse and the associated dephase gradient. The following $T_{1\rho}$ relaxation consists of an excitation pulse ($90^o{}_x$), two spin-lock cw pulses (+y, -y, spin-lock frequency: 500Hz) and a restoration pulse ($90^o{}_y$). Spin-lock times (TSLs) of 1, 10, 20, 30 and 40ms were used for $T_{1\rho}$ relaxation mapping. A half-alpha pulse and four startup pulses with dummy-scans were used to approach the steady-state but with $T_{1\rho}$-weighted preparation maintained. The subsequent normal phase alternating bFFE readout was used for acquisition. The delay time (TI) after acquisition was set as 4000ms to restore equilibrium magnetization prior to the next $T_{1\rho}$ preparation. TE and TR were 2.5ms and 5.0ms respectively. The matrix size was 448x448x6 and the flip angle was 50^o. The $T_{1\rho}$-weighted images with different TSLs were processed using an IDL program on a pixel-by-pixel basis to obtain the $T_{1\rho}$ relaxation map using the equation of $S(TSL)=Aexp(T_{1\rho}/TSL)$.

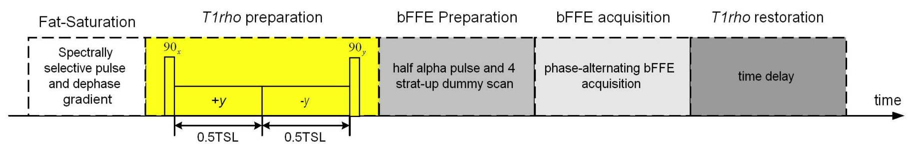

Fig.1. Diagram of the spin-lock bFFE imaging sequence for $T_{1\rho}$ quantification

Results: Scan time for each TSL was 46 seconds and the total scan time for $T_{1\rho}$ mapping with five TSLs took around five minutes. $T_{1\rho}$ weighted lower lumbar images with different TSLs and the calculated $T_{1\rho}$ relaxation map for one subject were shown in Fig. 2. It was seen that the median $T_{1\rho}$ value of the nucleus pulposus was greater than that of the annulus. The mean $T_{1\rho}$ values of the nucleus for each IVD were 103ms (L1L2), 133ms (L2L3), 54ms (L3L4) 100ms (L4L5) and 70ms (L5S1), respectively. A trend of reducing $T_{1\rho}$ values from L2L3 to L5S1 was evident except L3L4, consistent with previous report in (3). The significant reduction of $T_{1\rho}$ value at L3L4 may indicate early disc degeneration. This degenerative change was confirmed by a radiologist's diagnostic reading who was blinded to $T_{1\rho}$ results.

Discussion: Spin-lock 3D bFFE imaging allows acquisition for full coverage of spine without slice gap in sagittal orientation within 5 minutes with high spatial resolution. The considerable time savings make it feasible for a clinical $T_{1\rho}$ quantification scan protocol. Scan time could be further reduced by reducing the delay time for magnetization restoration. bFFE provides a time efficient acquisition with high signal-to-noise ratio under steady state. However, the acquisition under steady state eliminates parts of $T_{1\rho}$-weighted contrast, so the $T_{1\rho}$-weighted preparation has to be acquired during the transient state prior to the steady state (4). Thus, the multi-shot segmented k-space acquisition should be employed. bFFE imaging is also sensitive to B0 imhomogeneity and prone to banding artifact, so good shimming performance is critically required. Although the $T_{1\rho}$ map shows a little bit noisy due to the fine spatial resolution and small pixel size, it could be improved by reducing the matrix size or employing smoothing filters during post-processing.

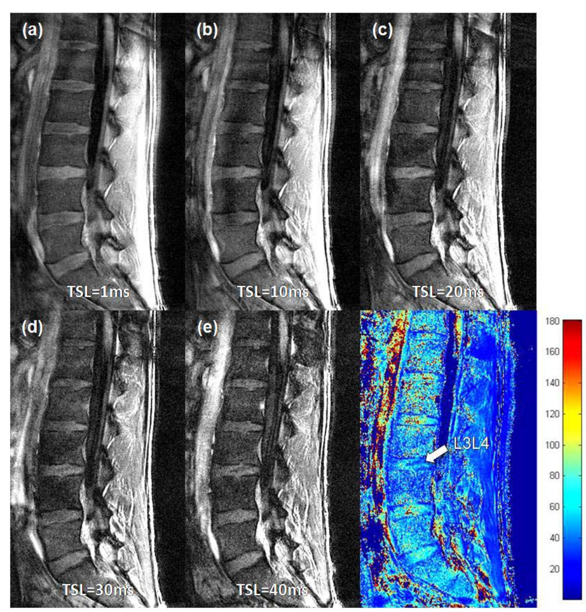

Fig.2. $T_{1\rho}$ weighted lower lumbar images with different TSLs and the calculated $T_{1\rho}$ relaxation map.

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