In Vivo Sodium and Proton T1rho MR Imaging of Human Spine Disc at 3T

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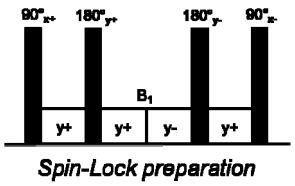
[Introduction] With aging, intervertebral discs undergo biochemical and morphological changes that may lead to degenerative disc disease (DDD) [1]. Loss of proteoglycan (PG), a major component of intervertebral discs, is often associated with early disc changes in DDD. As MR imaging markers for PG in the disc, sodium concentration and proton T_{1rho} relaxation time are reported to be sensitive to PG changes [2]. However, the association between the two markers of human discs in vivo has not been studied. Thus, in this study, we measured and compared sodium concentration and proton T_2/T_{1rho} relaxation times in healthy human lumbar spine discs using a newly developed dual-tuned (DT) torso coil and ultra-short echo-time (UTE) spiral and spin-lock (SL) sequences.

[Methods and materials] All scans were performed using a 3T human scanner (Siemens Medical Solutions, Germany). Two normal volunteer subjects participated in this Institutional Review Board approved study. We used an in-house DT torso RF coil which consisted of 4-channel proton and 8-channel sodium (loop dimension, 150 × 180 mm^2 and 130 × 200 mm^2, respectively) (**Fig. 1**). Scout and proton anatomical image were acquired (**Fig. 2A**). Using the same shim values, sodium MR imaging was performed - 3D UTE sequence [3]; RF hard pulse of 500-μs duration, TR/TE = 150/0.27 ms, readout time = ~15 ms, resolution = 5 mm^3, TA = ~4 minutes, and average = 3. For the quantification of sodium concentration in discs, a homogeneous 60-mM [^{23}Na] saline phantom was used to correct B_1 inhomogeneity (right in **Fig. 2A**). The sodium signal reduction in disc due to the partial volume effect [thickness 8 – 13 mm vs. effective resolution 10 mm (= 5-mm imaging resolution + Hanning filter)] as well as sodium T_1 and T_2 decay was simulated. Sodium T_1 and T_2 of disc was assumed to be 34.1 and 9.7 ms, respectively, on basis of 4% agarose with 153-mM [^{23}Na] (**Fig. 2B**). Sodium images of discs were reformatted using maximum intensity projection. The peak value in disc was measured at various disc levels (**Fig. 2C**). For proton T_2 and T_{1rho} mapping, we used a commercially available spine proton coil (Siemens) to obtain improved B_1-field homogeneity. The imaging protocol was: SL SSFP, low frequency B_1 SL pulse= 0/473 Hz, time of SL (TSL) = 10 - 120 ms (see left figure), TR/TE = 4000/2 ms, and resolution = 1.56×1.56×4 mm^3. The signal was fitted using a*exp{-TSL/$T_{2(1rho)}$}+b in pixel-by-pixel or disc ROI (**Fig. 3**). Following the segmentation of discs on the proton anatomical images, sodium concentration, and T_2 and T_{1rho} of proton over the discs were measured.



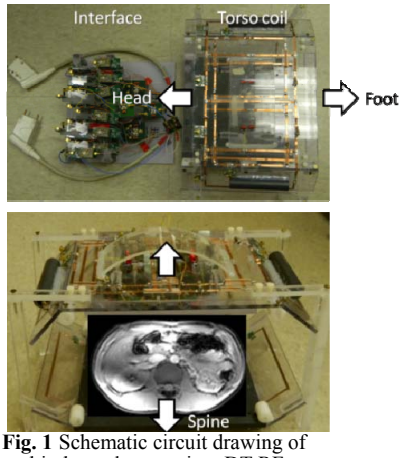


Fig. 1 Schematic circuit drawing of multi-channel transceiver DT RF torso coils. (Upper panel) Interface box (left) and top view of 4-ch proton and 8-ch sodium dual-tuned RF coil (right). (Lowe panel) Frontal view of dual-tuned torso coil. 2-ch proton and 4-ch sodium coil's loops are located each upper and lower coil plate.

[Results and conclusions] Sodium MR imaging of lumbar spine discs was successfully acquired using a DT torso coil and UTE spiral sequence within reasonable acquisition time (< 15 min) (right in **Fig. 2A**). Sodium concentration of L1 to L5 ranged 190 to 235 mM (**Fig. 2C**), similar to values reported in a previous study [4]. The mean sodium concentration across discs was 214.9 ± 14.4 mM. Additionally, proton T_2 and T_{1rho} mapping was consistently achieved (**Fig. 3D** and **E**). Mean T_2 and T_{1rho} relaxation times of discs were 84.0 ± 1.8 and 114.2 ± 9.5 ms, respectively (**Fig. 3C**). All measures were similar to those reported in other study (T_2 = 92.3 6 ± 27.2 ms and T_{1rho} = 133.1 6 ± 13.8 ms) [5]. The mean sodium concentrations and proton T_{1rho} relaxation times across the discs were compared. Correlation was weak between sodium concentration and T_{1rho} (r = 0.15), whereas a strong correlation (r = 0.75) was noted between T_2 and T_{1rho}. To investigate the significance of this comparative finding and clinical implication, further studies with a larger sample size of subject are essential.

In conclusion, we obtained consistent measurement of sodium concentration and proton T_2 and T_{1rho} relaxation time in lumbar discs from normal subjects using an in-house DT torso coil and UTE and SL sequences at 3T human scanner. MR-based physiological and metabolic measures of intervertebral discs may play an important role as imaging biomarkers for early diagnosis of DDD.

[Reference] **1**, Kent et al., *Chiropr Osteopat* 13 (2005). **2**,Wheaton et al., *MRM.* 54:1087–1093 (2005). **3**, Zhao et al., *ISMRM,* (2009). **4**, Insko et al., *Acad Rad*, 9: 800-804 (2002). **5**, Blumenkrantz et al., *MRM*, 63:1193-1200 (2010).

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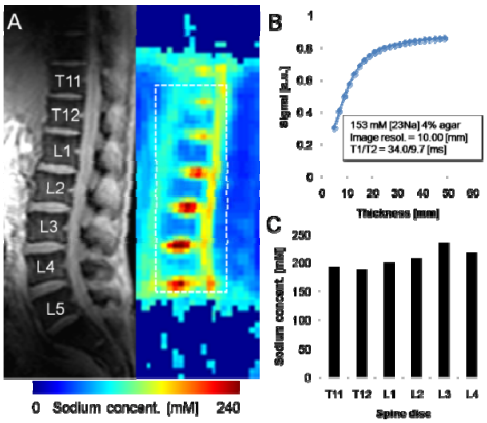

Fig. 2 In-vivo sodium MR imaging of intervertebral disc from normal subject. **A**, (Left) Scout proton sagittal view, and (Right) the corresponding sodium MR image (maximum intensity projection) with B_1 field correction. **B**, Simulation of sodium signal reduction due to partial volume effect (8-13 mm disc thickness vs. 10-mm effective resolution) as well as sodium T_1 (34 ms) and T_2 decay (9.7 ms) of 4% agar. **C**, Sodium concentration of intervertebral discs. Mean value was ~215 mM.

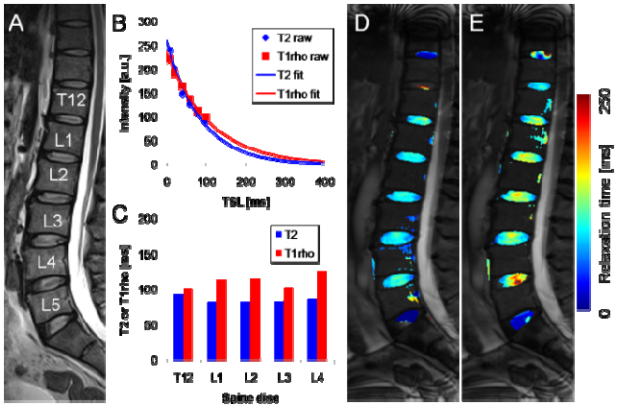

Fig. 3 In-vivo proton T_2 andT_{1rho} mapping of normal human discs. **A**, Sagittal image. **B**, T_2 and T_{1rho} curve fitting for averaged signal in all the discs. **C**, Bar graph of T_2 and T_{1rho} at different discs; mean value was ~86 and ~112 ms, respectively. **D** and **E**, T_2 and T_{1rho} map of intervertebral discs. T_{1rho} value was slightly higher than T_2 value in all discs. Mapping in upper- and lower-most regions (i.e., Txx and L5/S1) was incomplete due to strong susceptibility.