# In Vivo Sodium MR Imaging of Rabbit Lumbar Disc using Dual-tuned coil at 3T

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**[Introduction]** Degenerative disc disease (DDD) is a common chronic condition that may lead to back pain, limited activity, and disability. A major macromolecule component of disc is proteoglycan (PG) and associated glycosaminoglycan (GAG) side chains [1]. Early signs of DDD involve changes in disc matrix composition including reduced GAG concentration [2]. Sodium $^{23}$Na atoms are closely associated with high fixed-charge density present in PG and carboxylate groups of GAG. Therefore, non-invasive measurement of disk sodium content can be used as a potential biomarker for early detection of DDD. In this study, we developed proton and sodium MR imaging protocols for rabbit lumbar spine disc using a dual-tuned (DT) RF coil and ultra-short echo time (UTE) spiral sequence and measured sodium concentrations in normal rabbit discs.

**[Methods and materials]** All scans were performed using a 3T human scanner (Siemens Medical Solutions, Germany). Eleven New Zealand white rabbits were studied: <1 year old, female, and 5.2 + 0.4 kg. DT MR imaging was performed using an in-house multi-channel DT coil (designed for human knee imaging). DT coil consisted of 4-ch proton and 8-ch sodium coil with 120-mm diameter and 150-mm height [3]. Rabbits fit snuggly within the coil and were positioned supine at the center of coil. Form pads were inserted between the body and coil to minimize motion during the scan. Proton scout, T2-weighted TSE, and double-echo steady-state (DESS) images were acquired (**Figs. 1A** and **B**): TSE – TR/TE = 3500/109 ms and resolution = 0.6×0.6×3 mm$^3$; DESS – TR/TE = 14/5 ms and resolution = 0.6×0.6×3 mm$^3$. Sodium MR imaging (**Fig. 1C**) was performed using the same shim values as the proton imaging and 3D UTE spiral sequence [4] - RF hard pulse of 500-μs duration, TR/TE = 100 – 150/0.27 ms, readout time = ~15 ms, resolution = 2 mm$^3$, and TA = 27 minutes. To quantify sodium concentration of the disc, a homogeneous cylindrical phantom filled with 4% agar with 30-mM [$^{23}$Na] (120-mm diameter and 150-mm height) was imaged using the same parameters as sodium imaging of the rabbit, and was used to correct $B_1$ field inhomogeneity (**Fig. 2A**). Sodium images of the rabbits were co-registered with that of the phantom on the basis of eight 60-mM reference markers that were placed on the wall of sodium coil plastic frame.

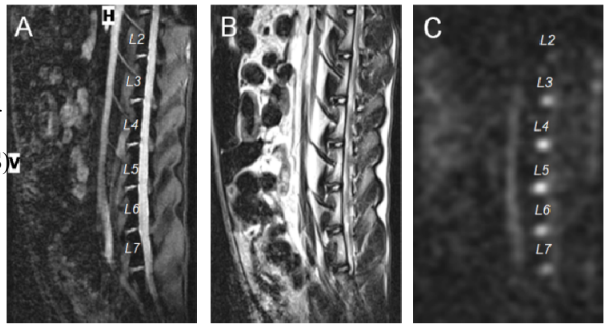


**Fig. 1** In-vivo MR imaging of rabbit spine discs. **A**, T2-weighted TSE. **B**, DESS. **C**, sodium MR image in sagittal view. Abbreviation; H – head, V – ventral. Note that discs appear blurred longitudinally due to a long echo time (109 ms) in B, and short T2 (< 4 ms) and Hanning filter smoothing effect in C.

The signal reduction associated with the thin disc size (mean ~1.4 mm thickness measured), relative to the effective sodium imaging resolution (4 mm considering Hanning filter with FWHM of half imaging bandwidth), was simulated. Parameters considered in the simulation included $T_1$, 17.6 ms and T2 decay, 9.7 ms of sodium signal acquired from 4% agar with 153-mM [$^{23}$Na] (**Figs. 2B** and **C**). Sodium concentration was measured in L2 to L7 lumber discs (**Fig. 3B**).

**[Results and conclusions]** High-resolution and high–contrast proton anatomy images of rabbit disc were acquired in all 11 rabbits. The morphology of discs was well delineated in the DESS images, while high $T_2$ contrast in the discs was evident in the T2-weighted TSE images (**Figs. 1A** and **B**). The current coil coverage for the sodium imaging was effective for visualization of L3 to L6 discs, although L2 and L7 discs were faintly visible (**Figs. 2B** and **C**). Intense sodium signal was evident in L3 to L6 discs. The sodium concentration of L2 to L7 discs was measured above 200 mM, and the mean value was 258.7 + 24.7 mM (N = 11), within the range of previously reported values [5]. Nevertheless, sodium concentration measurements showed a longitudinal positional gradient from center to periphery of the coil; measurements at L3 to L6 discs (close to the coil center) were greater than those at L2 and L7. This indicates that sodium measurements were affected by coil sensitivity, despite the correction for $B_1$ field inhomogeneity and soft-tissue thickness.

In conclusion, we successfully obtained high-resolution, high-contrast proton and sodium MR imaging and measured sodium concentration of normal rabbit spine discs using an in-house dual-tuned RF coil and ultra-short echo time spiral sequence at 3T. Further study is necessary to demonstrate difference in sodium concentrations between normal and degenerative disc models in rabbits in order to validate quantitative sodium imaging biomarker for degenerative disc disease.

**[Reference]** **1**. Borthakur et al., *NMR in BioMed,* 19:781-821 (2006). **2**. Pearce et al., *Biochem J*, 157:753–763 (1976). **3**. Kim et al., *ISMRM*, 2011 submitted. **4**, Zhao et al., *ISMRM*, 2009. **5**, Insko et al., *Acad Rad*, 9: 800-804 (2002).

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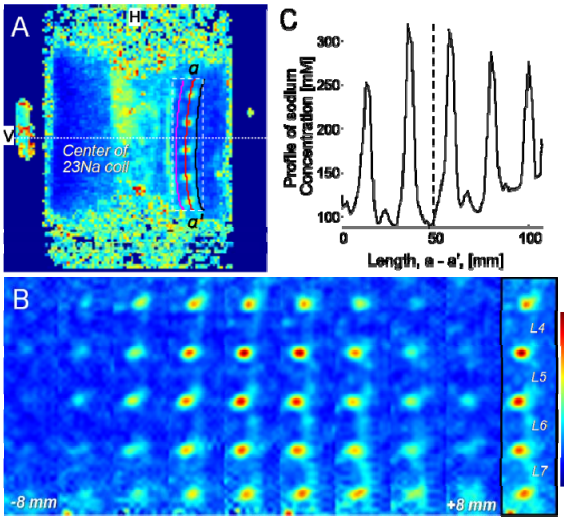


**Fig. 2** Sodium MR imaging of rabbit lumbar discs (L2 – L7). **A**, Sagittal view. $B_1$ inhomogeneity field was corrected. **B**, Magnified sodium image of lumbar discs (white box in A). (Inset) Maximum intensity projection. **C**, Profile of sodium concentration measured from maximum intensity projection image (Inset in B) along a – a′. Black-dotted line is the sodium coil center. Note sodium concentration gradient from center to periphery of the coil.

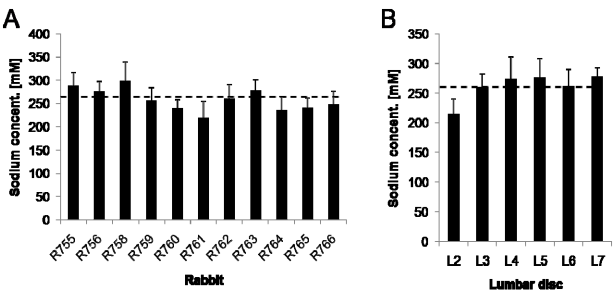


**Fig. 3** Sodium concentration in rabbit lumbar discs (L2 to L7). **A**, Mean sodium concentration across lumbar discs for 11 rabbits; total means sodium concentration was 258.7 ± 24.7 mM (N = 11). **B**, Sodium concentration for lumbar discs from L2 to L7.