# In Vivo Sodium and Proton T1rho MR Imaging of Human Knee Cartilage at 3T

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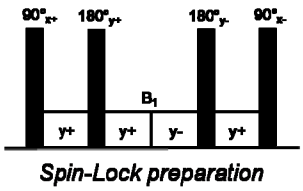
**[Introduction]** Knee OA is a common cause of disability in the aging population [1]. Early signs of OA involve changes in matrix composition of cartilage, such as a decrease in glycosaminoglycan (GAG) concentration. Detection of these changes using an in vivo imaging technique is clinically preferred. $^{23}$Na atoms are closely associated with a high fixed-charge density which is present in proteoglycan sulfate and carboxylate groups of GAG [2]. For this reason, the sodium concentration in cartilage (measured by MR imaging) has been shown to be directly correlated with GAG content, which has been used for detecting and tracking changes of early OA [3]. Additionally, proton $T_{1rho}$ is sensitive to macro-molecular water interactions in the cartilage and the change is known to be associated with PG loss [4]. In this study, we measured and compared the sodium concentration and proton $T_2$ and $T_{1rho}$ of human knee cartilages in vivo at 3T.

**[Methods and materials]** All scans were performed using a 3T human scanner (Siemens Medical Solutions, Germany). Four normal volunteer subjects were scanned using a protocol approved by our Institutional Review Board. We used a dual-tuned knee RF coil consisting of a 4-channel proton and 8-channel sodium coil (dimension 180 × 130 mm$^2$ and 135 × 85 mm$^2$, respectively) [5]. The measured transmission inhomogeneity was approximately 11% for a homogeneous phantom and 15% for human knees (**Fig. 1**). For sodium MR imaging, proton scout and anatomy images were acquired and $B_o$ shimming was adjusted. A 3D ultra-short echo time (UTE) [6] was then applied with the following parameters: RF hard pulse of 500-μs duration; TR/TE = 100 – 150/0.27 ms; readout time = ~15 ms; resolution = 3 mm$^3$; TA = ~4 minutes; and average = 2 to 3. For the quantification of sodium concentration of cartilages, a homogeneous 75-mM [$^{23}$Na] saline phantom was used to calibrate $B_1$ inhomogeneity. Sodium $T_1/T_2$ relaxation time of 153-mM [$^{23}$Na] saline and 4% agar with 153-mM [$^{23}$Na] was measured as 42.7/17.6 ms and 34.1/9.7 ms, respectively. Reduction in sodium signal due to the partial volume effect including $T_1$ and $T_2$ sodium signal decay was estimated approximately 77% at the center of 2.5-mm thick cartilage phantom. For proton $T_2$ and $T_{1rho}$ mapping, we used a commercially available knee multi-channel $^1$H coil (Siemens) to take advantage of a volume excitation that generates improved homogeneous $B_1$ field. MR imaging was performed with spin-lock (SL) SSFP sequence: low frequency $B_1$ SL pulse= 0/473 Hz; time of SL (TSL) = 10, 20, 40, 60, 80, 100, 120 ms (see left figure); TR/TE = 4000/2 ms; and resolution = 0.78×0.78×2.5 mm$^3$. The signal was fitted using $a*exp(-TSL/T_{2(1rho)})+b$ in pixel-by-pixel. Following the segmentation of patella, tibial, and femoral cartilages on the proton anatomy images, we measured sodium concentration, and $T_2$ and $T_{1rho}$ of proton over these cartilages.



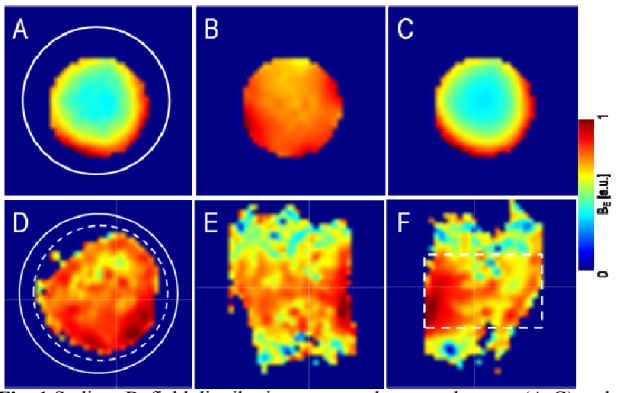




**Fig. 1** Sodium $B_1$ field distribution measured over a phantom (A-C) and a human knee (D-E); using dual-tuned coil (sensitivity, transmission, and reception field), respectively. White circle represents the boundary of sodium coil, and white-dotted region is for the effective knee cartilage imaging area. Average $B_1$ transmission field inhomogeneity error within the white-dotted cylindrical volume was ~11% for the phantom and ~15% for the human knee. Note that the reception field is weighted greater to the periphery near the receiver coils, which is a typical characteristics of the sum of field magnitude from multi-channel coils.

**[Results and conclusions]** The $T_2$ and $T_{1rho}$ mapping of human knee was successfully achieved (**Figs. 2B** and **C**). The $T_2/T_{1rho}$ relaxation times were quantified in each knee cartilage segment; 46.9 ± 5.3/ 53.9 ± 4.2 (patella), 51.7 ± 4.8/ 61.1 ± 3.5 (femur), 44.7 ± 7.4/ 50.6 ± 6.4 ms (tibia) (N = 4), which are slightly higher than those (45.5 ± 3.3 ms) reported in a previous study [7]. We postulate that our SL preparation pulse was more resistant to existing Bo inhomogeneity in micro environment than a typical SL preparation pulse, resulting in longer MR relaxation times. The mean sodium concentrations of the cartilages measured after the correction for $B_1$ inhomogeneity and partial volume effect were 229.7 ± 15.4 mM/L (femur), 204.9 ± 24.0 (tibia) (N = 4), which were within normal physiological ranges reported in a previous study [8]. In conclusion, we obtained consistent proton $T_2$ and $T_{1rho}$ relaxation times and sodium concentration in knee cartilage from normal subjects using an in-house dual-tuned knee coil and in-house sequences at 3T. We believe MR-based physiological and metabolic measures of knee cartilage change may play an important role as imaging biomarkers for early detection of knee osteoarthritis.

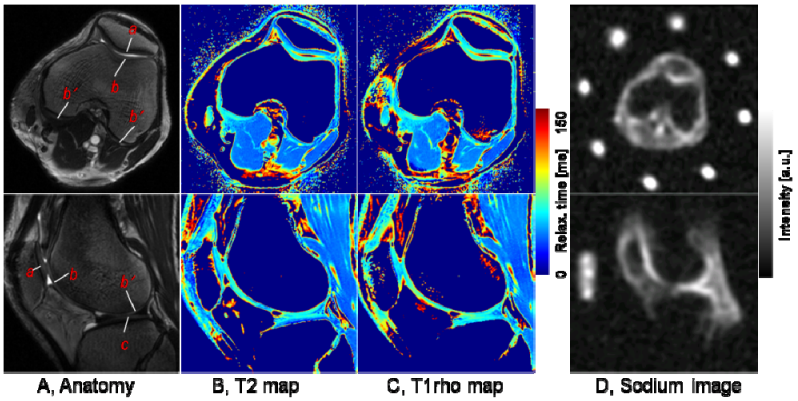



**Fig. 2** In-vivo proton (**A**), $T_2$ (**B**), $T_{1rho}$ (**C**), and sodium MR imaging (**D**) of normal human knee. (Upper) Axial and (Lower) sagittal view. MR imaging parameters are 1) SL imaging – TR/TE = 7000/3 ms, $B_1$ = 0/400 Hz (for $T_2/T_{1rho}$ mapping), and TSL = 10 to100 ms, resolution = 0.78×0.78×2.5 mm$^3$, 2) Sodium imaging – TR/TE = 100/0.26 ms, TA = 12 min, resolution = 3 mm$^3$. White cylindrical objects in D are 30-mM reference markers with 4% agar. Annotation; a – patella, b and b' – femoral, and c – tibial cartilage. Cartilages show $T_{1rho}$ slightly higher than $T_2$ value in that region of hyper-intense sodium signal.

**[Reference]** **1**,Felson et al., *Rad Clin North Ameri*, 42:1-9 (2004). **2**, Reddy et al., *MRM,*39:697-701 (1998). **3**, Burstein et al., *Inv Rad*,35:622-638 (2000). **4**, Wheaton et al., *MRM.* 54:1087–1093 (2005). **5**, Kim et al., *ISMRM*, 2011 submitted. **6**,Zhao et al., *ISMRM*, 2009. **7**, Li et al., *MRM*, 61:1310-1318 (2009). **8**, Wang et al., *JMRI*, 30:606-614 (2009). **[Acknowledgements]** Supported by RSNA Research Scholar grants RSCH1025.