In vivo co-registered proton T1rho and sodium MRI of the human knee

S. Niyogi[1], M. Kasam[1], R. S. Beesam[1], A. Borthakur[1], and R. Reddy[1]
[1]Radiology, University of Pennsylvania, Philadelphia, PA, United States

Objective

To combine sodium and proton $T_{1\rho}$ MRI to obtain information about both structural and molecular changes in cartilage and thereby increase the reliability of diagnostic imaging of incipient changes in osteoarthritic patients.

Background

Osteoarthritis (OA) is a degenerative disorder resulting from the biochemical breakdown of articular cartilage in the synovial joints. A loss of proteoglycans (PG), a component of the extracellular matrix in cartilage, has been shown to be the predominant change in early OA. $T_{1\rho}$ MRI has been shown to be sensitive to the interactions between macromolecules, such as proteoglycans and collagen, and bulk water (1-3). It can then be used as an indicator of the early biochemical changes. Another early biochemical change resulting from the loss of negatively charged proteoglycans induced by OA involves the loss of sodium ions from cartilage to balance fixed charge density (4). Sodium MRI has also been used previously to explore this mechanism. Previous studies have shown the correlation between these two methods of inquiry into the health of articular cartilage to be quite strong (5). This study aims to produce innately co-registered three-dimensional image sets by collecting all data without altering the positioning of the patient. The benefits attained by this method include an increased localization of data collected because the same image slices (with identical thickness and spacing) are acquired.

Methods

All human studies were approved by the Institutional Review Board. The knees of three healthy volunteers (mean age: 29) were imaged on a 3T Siemens Trio MRI scanner. To obtain higher filling factor, in the preliminary experiments, we used a custom-built sodium birdcage radiofrequency (RF) coil placed inside a vendor-supplied proton head coil (USA Instruments, Aurora, OH). A custom-built apparatus (Fig. 1) was used to support and extract the sodium coil from within the proton coil between image acquisitions. The sodium and $T_{1\rho}$ MRI experiments were performed sequentially with the same slice positions and thickness. Images were then used to generate sodium and $T_{1\rho}$ maps offline as described in (3, 4).
Sodium MRI was performed using a 3D fast gradient-echo pulse sequence (turbo-FLASH) with the following parameters: TE/TR= 3.3/18ms, FOV=200mm, Acquisition Matrix=128x64, Number of Slices=10, Slice Thickness=5mm, and 195 signal average for a total imaging time of 30 minutes. Upon completion of the sodium scans, the sodium coil was extracted along the support apparatus without disturbing the position of the subjects' knees. 3D proton $T_{1\rho}$-weighted images were then collected using the steady-state free precession based SLIPS sequence with the following parameters: TE/TR=2.7/5.4ms, FOV=200mm, Acquisition Matrix=256x128, Number of Slices=20, Slice Thickness=5mm, Delay Time=1s, spin-lock Amp=500Hz. Additional slices were obtained with the SLIPS sequence to avoid slice-wrap artifact in the desired image volume. Five acquisitions were collected with various spin-lock durations (1-40ms) to generate a $T_{1\rho}$ map of the knee. Acquisitions were performed using the same volume center in two orientations (axial and coronal) to examine patellar and femoral cartilages, respectively, in under 30 minutes.

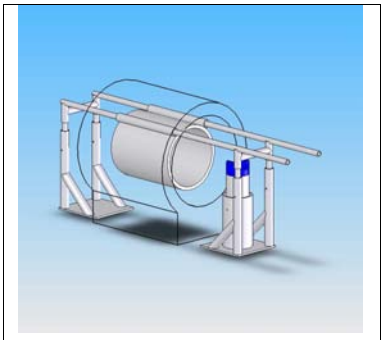

Figure 1. Apparatus used for restraining subject's leg and extracting sodium coil from proton coil

Results and Discussion

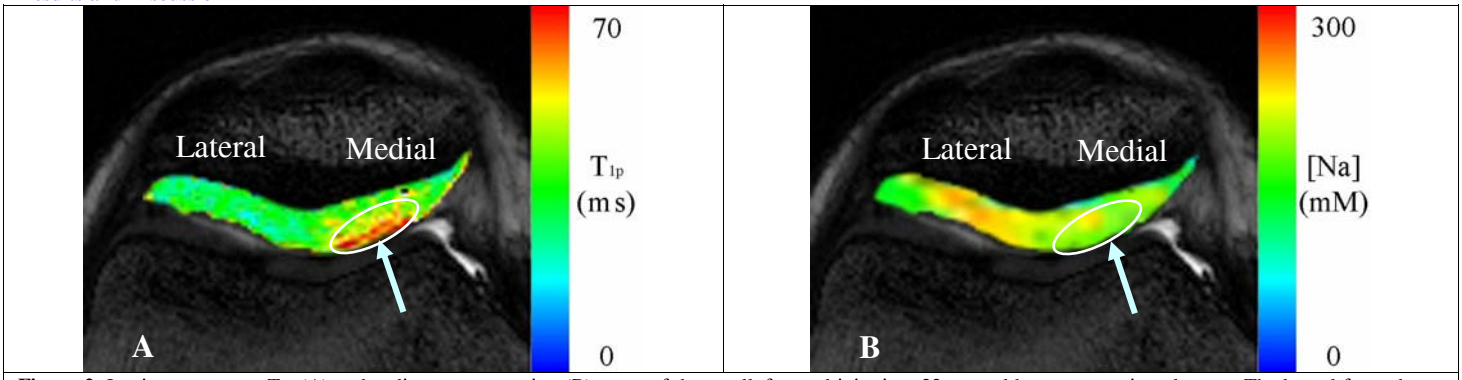

Figure 2. In vivo transverse $T_{1\rho}$ (A) and sodium concentration (B) maps of the patellofemoral joint in a 22 year-old asymptomatic volunteer. The lateral facet shows normal looking cartilage (green) with relatively low values of $T_{1\rho}$ (31±8 ms) and high sodium concentration (252±25 mM). The medial facet shows a focused (shown by arrow) elevation of $T_{1\rho}$ (59±8 ms) in red and a corresponding decrease in sodium concentration (202±13 mM).

These characteristic co-registered maps show (Fig. 2) an almost inverse correlation between $T_{1\rho}$ and sodium data. A similar trend was observed in the two other subjects. Sodium maps can be used to calculate the tissue's fixed charge density (FCD), which is a map of the PG distribution, while T1ρ maps provide integrated changes due to both PG and collagen. Additionally, the same $T_{1\rho}$ data set provides a 3D structural image of cartilage that can be used to compute changes in cartilage volume and thickness. These results demonstrate that it is feasible to obtain a high-resolution $T_{1\rho}$ map and a lower-resolution sodium map of human knee *in vivo* simultaneously at 3T. These integrated measures provide an increasingly reliable set of metrics for determining early degradation of articular knee cartilage.

Acknowledgments

This work was performed at an NCRR-funded Research Resource (RR02305) and supported by grants from NIH (R01-AR045242, R01-AR045404, R01-AR051041).

References

1. Regatte, R.R., *et al. Radiology* **229**: 269-274, 2003.
2. Li, X., *et al. Magn Reson Med* **54**: 929-936, 2005.
3. Wheaton, A.J., *et al. J Orthop Res* **23**: 102-108, 2005.
4. Shapiro, E.M., *et al. Magn Reson Med* **47**: 284-291, 2002.
5. Wheaton, A.J., *et al. J Magn Reson Imaging* **20**: 519-525, 2004.