Quantitative $^{23}$Na MRI of human knee cartilage using dual-tuned $^1$H/$^{23}$Na transceiver array RF coil at 7T

Chan Hong Moon, Jung-Hwan Kim, Tiejun Zhao, and Kyongtac Ty Bae

1Radiology, University of Pittsburgh, Pittsburgh, Pennsylvania, United States, 2MR R&D Collaborations, Siemens Healthcare, Pittsburgh, Pennsylvania, United States

[Introduction] $^1$H MRI provides morphological information about soft tissues, while $^{23}$Na MRI adds biochemical information. One of the major potential clinical applications of $^{23}$Na MRI is a degenerative knee disease associated with osteoarthritis (OA). High field MR (e.g., 7T) can potentially provide higher $^{23}$Na sensitivity, particularly combining with multi-array RF coil technology, thereby pixel resolution can be increased [1,2]. However, in order to acquire accurate quantitative $^{23}$Na concentration ($[^{23}$Na]) of thin knee cartilage of ~2.3 mm, B1 RF inhomogeneity [3] and partial volume effect (PVE) should be corrected. In this study, we developed a dual-tuned (DT) $^1$H/$^{23}$Na knee coil at 7T with high $^{23}$Na signal sensitivity. $^{23}$Na B1 field characteristics of the transceiver array $^{23}$Na coil were investigated and the inhomogeneity was corrected. In addition, point spread function (PDF) of $^{23}$Na image was measured and considered in the PVE correction.

[Methods and materials] All scans were performed using a 7T human scanner (Siemens Medical Solutions, Germany). Seven normal subjects participated in this Institutional Review Board approved study. $^{23}$Na-only birdcage and multi-array DT RF coils were used (Fig. 1) and those $^{23}$Na imaging SNR were compared. High-resolution $^1$H knee images were acquired using a 3D fast double echo and steady state (DESS) sequence (flip angle = 25°, TR/TE = 15/5 ms, resolution = 0.57 mm$^3$). Without repositioning the subject, $^{23}$Na MRI was performed using 3D ultra-short-echo-time spiral sequence (TR/TE = 100/0.27 ms, isotropic resolution = 1.7 - 5 mm$^3$) [4]. $^{23}$Na MR data from all the channels were averaged by vector summation to reconstruct $^{23}$Na (magnitude) image. A series of $^{23}$Na images at >5 mm$^3$ (with all Rx channels on) were acquired with varying RF flip angles centered on 90° – average (vector summed) transmission (Tx) and reception (Rx) field (magnitude) maps were estimated by the sinuosoidal curve fitting [3]. PSF of $^{23}$Na images was measured from the image intensity profile across boundary of a reference cylindrical marker (15-mm diameter) in the radial direction and averaged over the 2π perimeter. $^{23}$Na signal decrease due to PVE, relaxation, and applied filtering was simulated in one dimension with different imaging resolution and cartilage thickness – simulation results were applied in quantification in $[^{23}$Na] considering PDF and cartilage thickness. SNR, cartilage thickness, and $[^{23}$Na] were measured in the anterior femoral cartilage (Figs. 3A, B). Acceptable SNR criterion was set to 20.

[Results and conclusions] $^{23}$Na image SNR acquired with birdcage coil at 2-mm resolution was below 20 (Fig. 2B). By using the multi-channel transceiver array coil, SNR was higher than 20 at 2 mm, but was lower than 20 at 1.7-mm resolution (Fig. 2D). Mean SNR of $^{23}$Na image at 2-mm resolution was measured as 26.80 ± 3.69 (n = 7) in the anterior femoral cartilage using the transceiver array coil. Full-width-half-maximum was measured as 5.2 mm with 2-mm pixel resolution from the PSF of $^{23}$Na image. From the PVE simulation result, the signal decay was linearly changed with the cartilage thickness; signal 0.12 thickness + 0.03. The cartilage thickness was measured in each subject, and PVE was corrected using the equation – mean thickness = $3.53 \pm 0.95$ mm (n = 7) and mean $[^{23}$Na] before and after PVE correction was 86.28 ± 35.90 mM (n = 7) and 288.13 ± 29.50 mM (n = 7) (Fig. 3B). Variation of thickness and $[^{23}$Na] within the cartilage was calculated as the ratio of standard deviation and the mean. Both thickness and $[^{23}$Na] values before PVE correction were varied in similar order across the subjects, but $[^{23}$Na] variation after PVE correction decreased at statistical significance (P < 0.002, n = 7) (Fig. 3C) – mean thickness variation, 25.12 ± 5.37% (n = 7) and mean $[^{23}$Na] variation before and after PVE correction, 20.29 ± 6.92% (n = 7) and 14.94 ± 5.05% (n = 7). In order to evaluate the proposed $[^{23}$Na] quantification and to systematically investigate PVE artifacts in knee cartilage, ex vivo $^{23}$Na MRI of knee cartilage specimen at a sub-millimeter resolution (i.e., << cartilage thickness) is worthwhile.

In conclusion, the developed transceiver-array $^{23}$Na RF coil is more sensitive than the birdcage volume coil. $^{23}$Na in knee cartilage can be accurately quantified after correction of B1 inhomogeneity and PVE with the morphological information acquired by $^1$H MRI under DT coil setup. The developed DT $^1$H/$^{23}$Na MRI technique can improve our understanding of biochemical changes in articular cartilage of knee OA patients.


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