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

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[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, B_1 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 B_1 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.

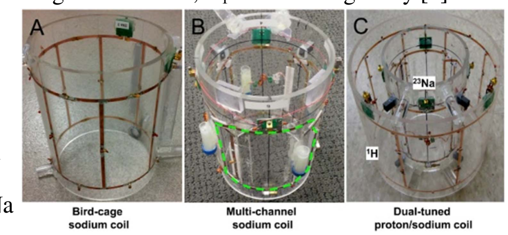

Fig. 1 ^{23}Na RF coils for knee MRI. **A** and **B**, A birdcage and transceiver array ^{23}Na coil. In the transceiver array coil design, four channel coil loops (120 × 150 mm^2) (green-dotted contour) were placed on the coil frame with 20-mm overlapping. **C**, DT ^{1}H/^{23}Na knee coil (birdcage ^{1}H and four-channel ^{23}Na coil).

[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 sinusoidal 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.

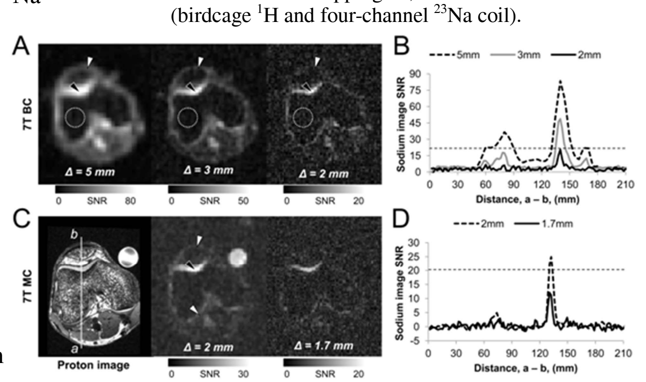

Fig. 2 Spatial resolution limit of ^{23}Na MRI of knee cartilage. **A**, ^{23}Na MR images using birdcage coil. **B**, SNR profiles of ^{23}Na images in A following line a – b in C. **C**, ^{23}Na MR images using transceiver array ^{23}Na coil. (Left panel) DESS ^{1}H anatomy image, and (two right panels) ^{23}Na images. **D**, SNR profiles of ^{23}Na images in C following line a – b in C. Dotted-lines in B and D are the criteria of SNR 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 ± 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 B_1 inhomogeneity and PVE with the morphological information acquired by ^{1}H MRI under DT coil setup. The developed DT ^{1}H/^{23}Na MRI techniques can improve our understanding of biochemical changes in articular cartilage of knee OA patients.

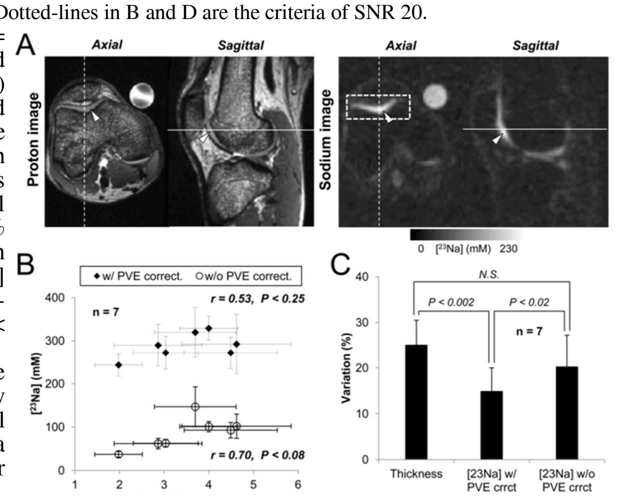

Fig. 3 Quantification of [^{23}Na] in the anterior femoral cartilage. **A**, DESS ^{1}H anatomy and ^{23}Na MR image. White arrowheads indicate the femoral cartilages at anterior part. White dotted rectangle is the analysis region of femoral cartilage. **B**, Measurement of cartilage thickness and [^{23}Na], and those variations within the cartilage. **C**, Relationship between thickness and [^{23}Na].

[Reference] **1**. Kim et al., *MRI*, 30(2012). **2**. Staroswiecki et al., *JMRI*, 32(2010). **3**. Boada et al., *IJIST*, 8(1997). **4**. Moon et al., *Spine*, 37(2012).

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