Developement of multi-tranceiver dual-tuned knee coil at 3T

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Introduction : Sodium MR imaging has been shown to be a sensitive imaging biomarker for early diagnosis of knee articular cartilage pathologies. Despite the initial promising results, sodium MR imaging is intrinsically challenging on many levels because of low in vivo concentrations and the requirement for a high-sensitive RF coil for imaging. Recent studies [1-4] reported the use of a specially designed knee coil to improve sodium signal to allow for the acquisition of diagnostic-quality in vivo sodium MRI. Furthermore, it is critical to have sodium MRI co-registered with proton MRI to be clinically useful. This requires a dual-tune sodium/proton coil. Traditionally, to achieve high SNR in single-nucleus imaging, volume transmission coils combined with local receiver coil arrays have been used. However, due to voluminous size of the combination of transmission and receive coil, this configuration is not easily adaptable for a dual-tuned RF coil. As an alternative dual-tuned coil configuration that permits high SNR and signal uniformity for both nuclei, a multi-transceiver array design was proposed at 7T [4]. In this study, we have developed and improved a dual-tuned RF coil for proton and sodium imaging of human knee cartilage in vivo at 3T.

Materials and methods : All scans were performed using a 3T human scanner (Siemens Medical Solutions, Erlangen, Germany). Four normal volunteer subjects were scanned in this Institutional Review Board approved study. The dual-tuned knee coil consisted of 4-channel proton and 8-channel sodium coil (180 × 130 mm^2 and 135 × 85 mm^2, respectively). Each proton loop was tuned at 123.2 MHz with the reflection parameter S11 ranging from -15 to -20 dB (**Fig. 1A**). Each sodium coil loop was tuned at 32.58 MHz with matched S11 parameter ranging from -15 to -20 dB (**Fig. 1B**). To assess the coil sensitivity, SNR was measured using 75-mM saline homogeneous phantom (**Fig. 2**) and subjects (**Fig. 3**). To test the proton coil performance, T2-weighted 3D dual echo steady state (DESS) imaging was acquired as the anatomical reference. The scan parameters were: flip angle = 25°; TR/TE = 15/5 ms; slice thickness = 1.5 mm; in-plane resolution = 0.75 mm^2; matrix size = 256 × 256; and parallel imaging factor = 2. For the sodium imaging, a 3D ultra-short echo time (UTE) spiral sequence [5] was used. Scan parameters were: RF hard pulse of 500-µs duration; TR/TE = 100 – 150/0.27 ms; readout time T_{RO} = ~15 ms; isotropic resolution = 5 mm^3; scan time = ~4 minutes; and average = 2-3 times. SNR was measured in cylindrical ROIs with different radius to investigate the distance dependency from the coil (**Fig. 2A**). Moreover, SNR and CNR(against surrounding bones) were measured in three cartilage compartments which were manually drawn by the radiologist based on the proton image acquired (**Fig. 3A**).

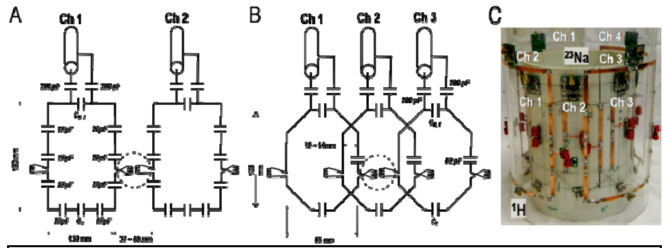

Fig. 1 Schematic circuit drawing of multi-channel transceiver knee RF coil. A, Four-channel proton coil. B, Eight-channel sodium coil. C, Assembled dual-tuned RF coil. Red inductors indicate the inductive decoupling between non-adjacent loops to isolate each channel**.**

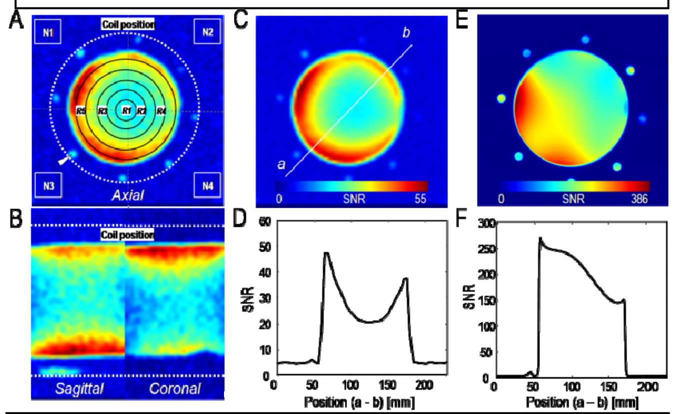

Fig. 2 SNR measurement of proton and sodium MR image. **A** and **B**, Axial and Sagittal and coronal view of sodium image. ROIs are defined as cylindrical regions with different radius. Reference markers (white-arrowhead) are attached to the inner wall of sodium coil cylindrical frame (white-dotted circle). **C** and **E**, SNR map of sodium and proton image. **D** and **F**, SNR profile of sodium and proton image following *a−b* white line in C.

Results and conclusions : We developed and successfully implemented a dual-tuned coil at 3T for sodium and proton imaging of knee cartilage in vivo. SNR measured in phantom was 210-220 in proton MRI and 21-38 for sodium MRI. In subjects, high resolution proton anatomy and high-contrast sodium MR imaging were consistently acquired. Base on the high-resolution DESS image, knee cartilages (patella, femur, and tibia) could be clearly segmented from other bones or tissues (**Fig. 3A**). In sodium imaging, the cartilage, fluid collection, and popliteal was shown to be hyper-intense contrast (**Fig. 3B**). The measured SNR and CNR in segmented cartilages (i.e., patella, femur, and tibia) were 38.4 ± 9.6, 32.1 ± 5.9, and 26.5 ± 1.0, and 20.7 ± 7.6, 19.3 ± 3.5, and 14.6 ± 2.4 (N = 4), respectively. The dual-tuned MR imaging facilitated the measurement of changes in both morphology and sodium concentration of knee cartilages and the discovery of imaging biomarkers for structural and physiochemical changes associated with osteoarthritis (OA). Multi-channel RF coil configuration improved the coil sensitivity for sodium. Moreover, multi-transceiver RF coil allowed for the reduction in size of the dual-tuned proton/sodium coil fitted to the knee while maintaining high sensitivity. Further studies on B1 phase shimming are essential to produce a homogenous B1 field and to test the accuracy and reliability of sodium concentration measurement in knee cartilage.

References : [1] Staroswiecki et al. *ISMRM*, p384 (2007). [2] Gold et al. *ISMRM*, p3969 (2009). [3] Wang et al. *JMRI*, 30:606-614 (2009). [4] JH Kim et al. *ISMRM* (2010 proceeding). [5] Zhao et al., *ISMRM*, 2009

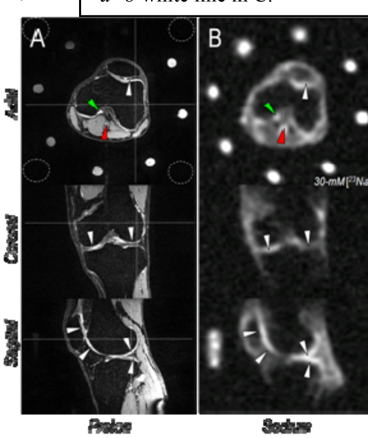

Fig. 3 In-vivo proton and sodium MR imaging of normal human knee. **A**, Proton DESS MR image; axial, coronal, and sagittal view from top to bottom panel at thin-white line. **B**, Corresponding sodium MR images and SNR measurement. White-arrowheads indicate the cartilages and green- and red-ones represent the fluid collection and popliteal vessel, respectively. SNR in patella, femur, and tibia knee cartilage was measured as 38.4 ± 9.6, 32.1 ± 5.9, and 26.5 ± 1.0 (N = 4), respectively. CNR in