Synchronous Sodium (^{23}Na) and Proton (^{1}H) Radial Imaging of the Human Knee on a Clinical MRI Scanner

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Target Audience: Researchers of Non-Proton MRI

INTRODUCTION:

Sodium (^{23}Na) MRI is under investigation for improving the characterization and assessment of tumor viability[1,2], cartilage health[3-6], renal failure[7,8], tissue damage following stroke[9], and multiple sclerosis[10]. A significant barrier to ^{23}Na MRI is the additional time required to obtain ^{23}Na images[11]. Schemes that acquire both ^{23}Na and ^{1}H images in a single pulse sequence (termed "**synchronous acquisition**" here) can provide additional ^{23}Na image data that complements ^{1}H image data, without a significant scan time penalty when compared to ^{1}H imaging alone.

Synchronous acquisition schemes have been investigated on clinical MRI systems[11-14]. However, the increased complexities in both hardware and pulse sequence have limited their application on clinical scanners. Previous implementations on clinical scanners have used Cartesian acquisition schemes[12-14], resulting in long acquisition times and poor ^{23}Na SNR. This work presents ^{23}Na/^{1}H synchronous dual-nuclear MR imaging (**dnMRI**) with 3D ultra-short radial MRI for better ^{23}Na imaging results than have been previously obtained with Cartesian MRI[13,14].

METHODS:

Hardware: A custom-made ^{23}Na/^{1}H coil was used, consisting of a quadrature ^{23}Na coil (a central circular loop that was spatially decoupled with an overlapped butterfly loop) and ^{1}H linear coil (a butterfly loop spatially decoupled with the ^{23}Na loops) (**Fig. 1**). Transmit switching for both ^{1}H and ^{23}Na channels was accomplished using a ^{23}Na/^{1}H filter that separated the transmit RF to either a quadrature ^{23}Na or linear ^{1}H TR switch. Because the dual-resonant TR switch is still intended for use without losing current imaging functionality, an additional ^{1}H TR switch was placed between the ^{1}H output of the dual-resonant TR switch (**Fig. 2**) and coil. This second ^{1}H TR switch directs the ^{1}H NMR signal toward the receiver path, and (i) pre-amplifies, (ii) converts to 32.6 MHz using an RF mixer, and, (iii) filters the mixed signal using a low-pass filter to pass the 32.6 MHz signal only (Fig. 1). The resultant ^{1}H signal at the carrier frequency of 32.6 MHz is then (iv) attenuated and (v) fed into one of the ^{32}Na receive channels [12]. Both signals are simultaneously sampled at the ^{23}Na resonance frequency subject to the same readout gradients, which results in a higher ^{1}H image spatial resolution by 3.8 times ($=\gamma_{1H}/\gamma_{23Na}$) than the ^{23}Na resolution.

Imaging Study: Three scans were performed with 3D ultra-short radial sampling: a single-nuclear ^{1}H acquisition, a single-nuclear sodium acquisition, and a synchronous ^{23}Na/^{1}H dnMRI acquisition. Identical acquisition parameters for each nucleus were used for both single-nuclear and dnMRI. The scan parameters were (^{23}Na/^{1}H): 40/40 ms TRs, 70 µs/0.27 ms TEs, 70°/25° flip-angles, 400/105 mm FOVs, 3.1/0.8 mm isotropic resolutions, with 256 readout points, 10240 radial lines, 399 Hz/pixel receiver bandwidth, and 6 min 51 sec acquisition time. The study was performed with IRB approval.

During synchronous ^{23}Na/^{1}H dnMRI, the ^{23}Na and ^{1}H transmit occurred sequentially, enabled by the scanner's ability to switch between two frequencies within the same sequence. Sampling for both ^{23}Na and ^{1}H NMR signals at the carrier frequency of 32.6 MHz occurred simultaneously on two ^{23}Na channels.

RESULTS:

Figure 3 shows the results of single and synchronous ^{23}Na/^{1}H acquisitions in the knee of a healthy volunteer. The synchronous ^{23}Na and ^{1}H dnMRI images within the same sequence (**Fig. 3**) have minor (~6%) SNR losses for both ^{23}Na and ^{1}H images when compared to ^{23}Na and ^{1}H single-nuclear MRI. The minor loss in SNR is caused by slight gradient timing differences that result in slight changes between the single and synchronous image reconstructions. The ^{1}H data had a 3.8 times higher resolution and smaller FOV than the ^{23}Na data.

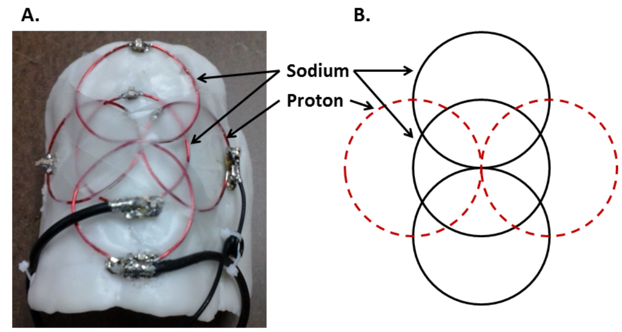

Figure 1: (A) Picture and (B) schematic of the ^{1}H/^{23}Na knee coil used in this study. The ^{23}Na portion consisted of a butterfly loop that was used in quadrature with a spatially decoupled central loop.

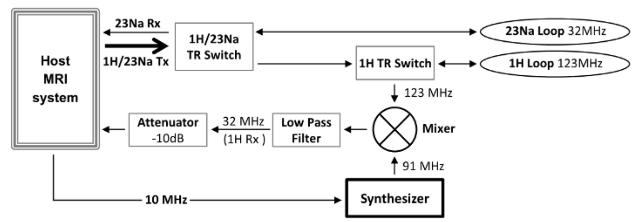

Figure 2: Transmit/receive hardware for both ^{1}H and ^{23}Na. Arrows indicate transmit/receive pathways during ^{23}Na/^{1}H dnMRI.

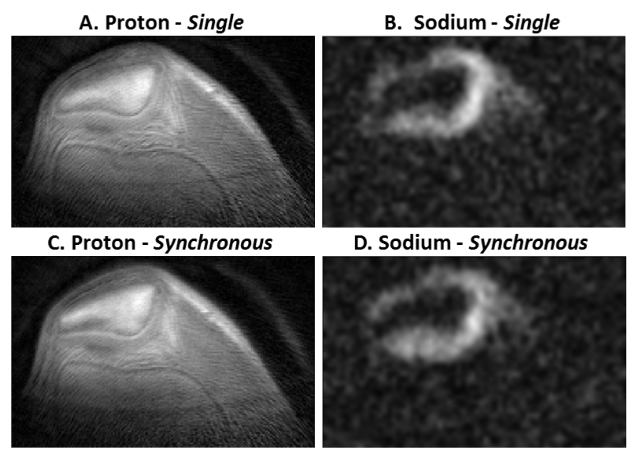

Figure 3: (A) ^{1}H and (B) ^{23}Na images obtained in two separate 7 minute single-nuclear MRI scans. (C) ^{1}H and (D) ^{23}Na images synchronously obtained in a single 7 minute dnMRI acquisition.

DISCUSSION AND CONCLUSION:

This work has demonstrated synchronous acquisition of both ^{23}Na and ^{1}H nuclei on a clinical scanner using a radial acquisition scheme. Synchronous imaging enabled acquisition of both ^{23}Na and ^{1}H images in what normally would require twice the scan time for the same sequential single-nuclear MRI acquisitions. Synchronous dnMRI ^{23}Na/^{1}H image acquisition is very attractive due to the significant decreases in imaging time when compared to sequential ^{23}Na and ^{1}H imaging. In addition, the ^{1}H data measured synchronously during the dual-nuclear acquisition may be used to improve the quality of the non-proton data, such as identifying and correcting motion-corrupted FID data and/or water-^{1}H navigated non-proton MR imaging/spectroscopy.

ACKNOWLEDGEMENTS: This work was partly supported by NSF CBET 1133908, VA Merit Review Grant, Margolis Foundation, VISN 19 MIRECC.

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