Synchronous ^{1}H and ^{23}Na dual-nuclear MRI on a clinical MRI system, equipped with a time-shared second transmit channel

Joshua D Kaggie[1,2], Nabraj Sapkota[1,2], Kyle Jeong[2], Xianfeng Shi[3], Glen R Morrell[1], Neal K Bangerter[1,4], and Eun-Kee Jeong[1]

[1]*Utah Center for Advanced Imaging Research, Radiology, University of Utah, Salt Lake City, UT, United States,* [2]*Physics, University of Utah, Salt Lake City, UT, United States,* [3]*The Brain Institute and Department of Psychiatry, University of Utah, UT, United States,* [4]*Electrical and Computer Engineering, Brigham Young University, UT, United States*

INTRODUCTION:

Sodium (^{23}Na) MRI has the potential to help improve 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]. ^{23}Na and ^{1}H images are typically acquired sequentially in separate MRI sequences[11], creating a significant barrier to the clinical usefulness of ^{23}Na-MRI. Schemes that acquire from both ^{23}Na and ^{1}H nuclei in a single pulse sequence (which we term "**synchronous acquisition**") could potentially provide additional multi-nuclear image data to complement ^{1}H image data without a significant scan time penalty compared to ^{1}H imaging alone.

This work interleaves ^{23}Na and ^{1}H transmit pulses and simultaneously acquires data from both nuclei within a single pulse sequence. Synchronous ^{1}H/^{23}Na images have only been reported by Keupp[11] of a human knee in vivo, due to the increased hardware difficulties in obtaining synchronous images. Keupp's solution[11] requires modification of internal scanner components, such as modifying the input feeds into the RF amplifier. We present a new solution for synchronous dual-nuclear imaging on a 3T Tim Trio clinical MRI scanner equipped with multi-nuclear option.

METHODS:

Hardware: A custom-made ^{1}H/^{23}N coil was used consisting of a single ^{23}Na loop concentric with a single ^{1}H loop. Transmit switching for both ^{1}H and ^{23}Na channels was done using a commercial dual-resonant TR switch (Stark Contrast, Erlangen, Germany). 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. 1**) and coil. The ^{1}H TR switch (i) amplified the ^{1}H signal, (ii) converted to 32.6 MHz using an RF mixer, and, (iii) filtered 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].

Sequence: Synchronous imaging of ^{23}Na occurred with a standard GRE sequence for ^{23}Na, and a GRE or SE sequence for ^{1}H, with both ^{1}H and ^{23}Na transmit and receive occurring in the same sequence. However, the ^{1}H and ^{23}Na transmit did not occur simultaneously, to take advantage of the scanner's ability to switch between two frequencies within the same sequence without modification of the scanner's internal hardware. Sampling for both ^{1}H and ^{23}Na at the carrier frequency of 32.6 MHz occurred simultaneously on two ^{23}Na channels. Because a longer TR is desired for the ^{1}H SE acquisition than that of the ^{23}Na GRE acquisition, multiple ^{23}Na acquisitions occur between the ^{1}H acquisitions.

RESULTS:

The ^{1}H/^{23}Na dual-nuclear MRI obtained ^{1}H-GRE phantom images synchronously with ^{23}Na-GRE images of three orthogonal planes (**Fig. 2**). Because the ^{1}H and ^{23}Na signals are acquired using the same gradients for readout and phase-encoding, the ^{1}H image data has a 3.8 times higher resolution and smaller FOV.

Figure 3 shows the result of a synchronous ^{1}H/^{23}Na of the breast of a healthy volunteer. Both GRE and SE sequences were performed for acquisition of conventional ^{1}H images. Synchronous ^{23}Na-GRE imaging was performed throughout the duration of both of these ^{1}H sequences.

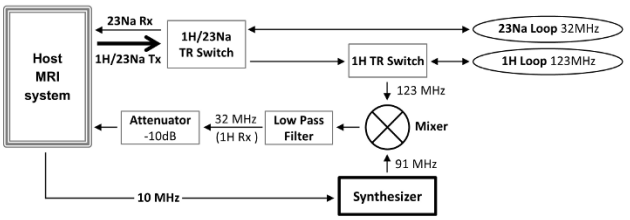

Figure 1: Transmit/receive hardware for both ^{1}H and ^{23}Na. Arrows indicate transmit / receive pathways.

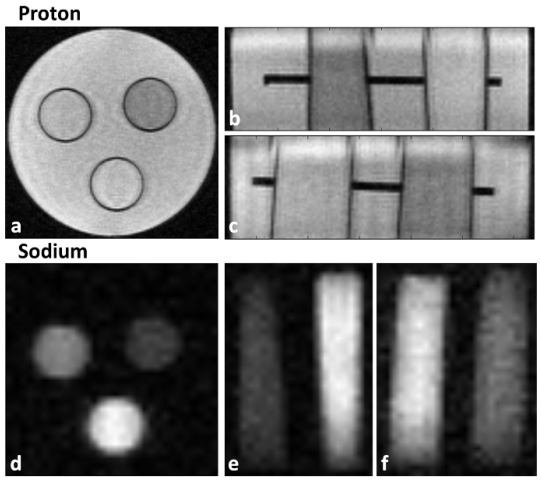

Figure 2: **(a-c)** Proton and **(d-e)** sodium images acquired during a single 20-minute 3D GRE acquisition. Three orthogonal slices are shown for both proton and sodium images.

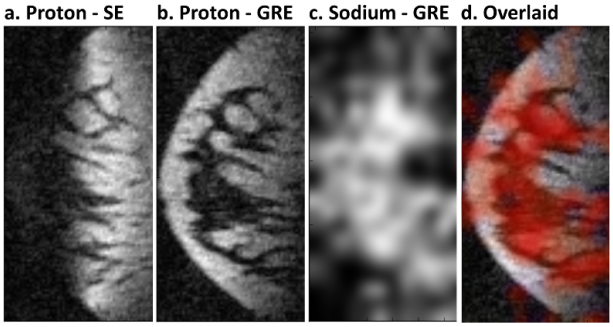

Figure 3: Synchronous **(a)** ^{1}H-SE, **(b)** ^{1}H-GRE, and **(c)** ^{23}Na-GRE images. The ^{1}H-SE and ^{1}H-GRE images were each acquired in 20 minutes, while the ^{23}Na-GRE image was acquired by averaging the ^{23}Na data acquired during the entire 40 minutes of ^{1}H imaging (for a total scan time of 40 minutes). **d:** The ^{23}Na-GRE image overlaid onto the ^{1}H-GRE image.

DISCUSSION AND CONCLUSION:

We have demonstrated synchronous acquisition of both ^{1}H and ^{23}Na nuclei on a clinical scanner, in what normally would require twice the scan time for the same sequential acquisitions. Synchronous ^{23}Na and ^{1}H image acquisition is very attractive due to the significant decreases in scan time when compared to sequential ^{23}Na and ^{1}H imaging. In addition, synchronous MRI is attractive for improving the correlation between ^{23}Na and ^{1}H data. This work demonstrates a viable technique to acquire dual-nuclear image data without increases in scan time, and without modifying the scanner's internal hardware.

ACKNOWLEDGEMENTS: This work was partly supported by NARSAD Independent Investigator Grants, NSF CBET 1133908, VA Merit Review Grant, Margolis Foundation, VISN 19 MIRECC, DA031247, R21MH096858, R01EB002524 and the Utah Science Technology and Research initiative.

REFERENCES:

1. Ouwerkerk R, et al. Radiology 2003;227(2):529-537.
2. Ouwerkerk R, et al. Breast Cancer Res Treat 2007;106(2):151-160.
3. Borthakur A, et al. Osteoarthr Cartilage 2000;8(4):288-293.
4. Reddy R, et al. Magn Reson Med 1998;39(5):697-701.
5. Borthakur A, et al. Radiology 2002;224(2):598-602.
6. Wheaton AJ, et al. Radiology 2004;231(3):900-905.
7. Maril N, et al. Magn Reson Med 2006;56(6):1229-1234.
8. Rosen Y, Lenkinski RE. Acad Radiol 2009;16(7):886-889.
9. Thulborn KR, et al. Neuroimaging Clin N Am 2005;15(3):639-653, xi-xii.
10. Inglese M, et al. Brain 2010;133(Pt 3):847-857.
11. Stehning C, et al. Proceedings of 19th ISMRM. 2011. p 1501.
12. Jeong EK, et al. Proceedings of 21st ISMRM, 2013; SLC, Utah, USA. p 2781.