A 3T Sodium and Proton Breast Array

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INTRODUCTION: Cancer is responsible for a quarter of all deaths in the United States (1). Breast cancer is estimated to include 29% of all new cancer cases in women in the United States during 2012, resulting in 14% of cancer related deaths (1). Early detection and improved treatment have increased breast cancer survival rates in the United States over the past two decades (1). While proton (^{1}H) MRI is used for cancer detection due to its improved sensitivity when compared to mammography and ultrasound, ^{1}H-MRI suffers from intermediate specificity, which can result in false positive studies leading to unnecessary interventions (2). Because sodium (^{23}Na) concentration is known to increase in malignant lesions when compared to surrounding healthy tissues (3), ^{23}Na-MRI may be able to increase specificity, potentially improving evaluation and assessment of breast lesions (4).

Phased array coils can improve the SNR of ^{23}Na-MRI. Phased arrays use multiple surface coils to obtain high SNR, due to the surface coils' close proximity to the imaged sample or subject and each coil's limited noise volume. We present a new dual resonant breast coil design consisting of a 7-channel ^{23}Na receive array, a larger ^{23}Na transmit cylinder, and a 4-channel ^{1}H transceive array. Novel decoupling methods are employed for both the receive and transmit loops to achieve excellent ^{23}Na-SNR. The ^{23}Na array causes ^{1}H RF shielding, resulting in regions with ^{1}H signal voids when using a large ^{1}H coil (such as the scanner's body coil). A novel ^{1}H transmit coil positioned over the ^{23}Na phased array yields good ^{1}H-SNR with the ^{23}Na array present.

This work compares the performance of our new array design to that of a coil used in prior studies consisting of a ^{1}H and a ^{23}Na loop containing decoupling traps. Comparisons were performed both in a phantom and in vivo. The new design achieves excellent ^{23}Na-SNR over the sensitive volume (ranging from 2 to 5 times that of the trap design) at high resolutions (1.4x1.4x4mm in vivo) in reasonable scan times (~20 minutes), while also providing good image quality for conventional ^{1}H imaging.

METHODS: ***Phased Array (Fig. 1A):*** *^{23}Na Receive Loops:* Six circular receive loops with 65mm diameters surround a single 75mm diameter loop on a fiberglass hemispherical former (Fig. 2A). Active/passive decoupling occurs with a single active/passive circuit (Fig. 2B). The loops were positioned using standard overlap techniques [5]. No ^{1}H decoupling was implemented.

^{23}Na Transmit Coil: The ^{23}Na transmit coil consisted of 5 copper loops connected at their capacitors so that it behaved similar to a single-turn solenoid coil (Fig. 2C). Decoupling was achieved with serial crossed diodes that were biased only during ^{23}Na transmission and unbiased during ^{23}Na reception or ^{1}H sequences (Fig. 2C,D).

^{1}H Transceive Loops: A 4-channel array was implemented over the ^{23}Na-array (Fig. 1A,2A). The loops were superimposed over the ^{23}Na array and bisected the ^{23}Na loops as much as possible to reduce ^{23}Na shielding of the ^{1}H RF signal. The ^{1}H loops contained serial crossed diode pairs that were biased during ^{1}H imaging and unbiased during ^{23}Na imaging.

Trap Coil (Fig. 1B): For comparison purposes, a coil was used that consisted of a single transmit/receive ^{1}H loop and a single transmit/receive ^{23}Na loop. The ^{1}H and ^{23}Na loops were decoupled using traps. This coil was also placed over a fiberglass hemispherical former.

Studies (Table 1)*:* To image ^{23}Na in a NaCl/$CuSO_4$ phantom and the breast of a normal volunteer with silicone implants, we used a fast-gradient spoiled sequence using the 3D cones k-space trajectory [6] on a Siemens Trio 3T scanner. Phantom scan parameters were: TR/TE = 50/0.27 ms, flip angle = 70°, voxel size = 2.5x2.5x2.5mm, FOV = 22.5cm, averages = 75, scan time = ~1.5hours. In vivo scan parameters were: TR/TE = 40/0.27ms, flip angle = 70º, voxel size = 1.4x1.4x4mm, FOV = 22.4cm, averages = 20, scan time = 19min30sec. A standard GRE hydrogen acquisition was also performed with scan parameters: TR/TE = 11/4.7 ms, flip angle = 25º, voxel size = .81x.81x1.2mm, FOV = 156x156x106mm, scan time = 3min6sec.

RESULTS: 2*3Na Performance**:* In phantom studies, the ^{23}Na-SNR demonstrated a 2-5x increase (Fig. 3), with a mean SNR of 241±93 for the phased array and 69±16 for the trap coil within the hemispherical volume of the breast former. Similar results were observed in vivo, with the phased array displaying a 3 – 4x increase in ^{23}Na-SNR over the trap coil. Improved ^{23}Na-SNR is evident in these images with noticeably improved depiction of small anatomic features within the breast (Fig. 4A,B).

1H Performance: The ^{1}H-SNR in the new four-element array had a mean of 8.8±1.6 and the trap coil had a mean of 9.8±2.2 inside the silicone implants, which contains most of the breast volume. The phased array obtains good ^{1}H images with reasonable homogeneity (Fig. 4D).

CONCLUSION: The in vivo sodium images show a level of detail and structure not previously achieved in sodium imaging of the breast, in a scan time of only 20 minutes. This composite coil also demonstrates an array superposition technique that can improve decoupling between ^{1}H and ^{23}Na array coils, so that excellent ^{23}Na and good ^{1}H images can be obtained without repositioning the subject. High quality ^{23}Na images of the breast may improve the specificity of breast MRI for the detection and characterization of breast cancer.

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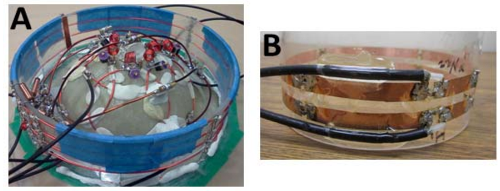

Figure 1: (A) 7-channel ^{23}Na and 4-channel ^{1}H phased array. (B) Trap coil containing a ^{1}H and a ^{23}Na loop.

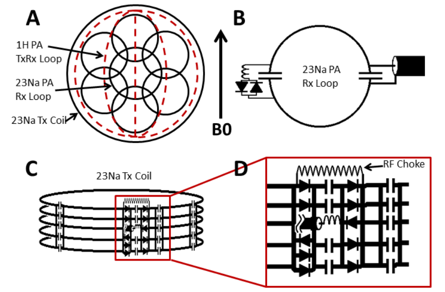

Figure 2: (A) Top-view schematic of the phased array coil layout. (B) ^{23}Na Rx loop circuit diagram. (C) ^{23}Na Tx loop circuit diagram. (D) ^{1}H TxRx loop circuit diagram.

Study	Sequence	Scan Time	TR/TE	Angle	Avgs	FOV (mm)	Voxel Size (mm)
23Na Phantom	3D Cones	~1.5 hrs	50/0.27	70º	75	225x225 x225	2.5x2.5x2.5
23Na In Vivo	3D Cones	~20 min	40/0.27	70º	20	224x224 x200	1.4x1.4x4
1H In Vivo	GRE	~3 min	11/4.7	25º	1	156x156 x88	.81x.81x1.2

Table 1: Study parameters.

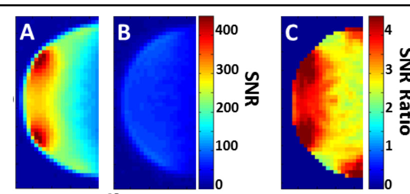

Figure 3: Phantom ^{23}Na-SNR maps of the central sagittal slice using the (A) phased array and (B) trap coil. (C) Ratio of the phased array to trap coil SNRs.

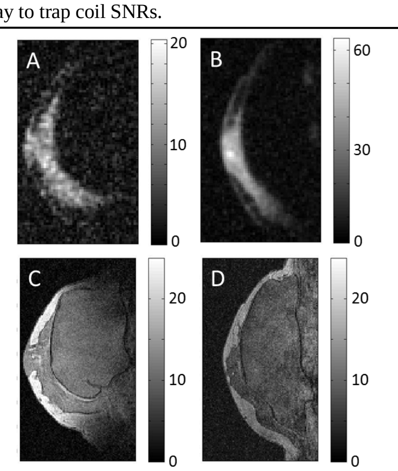

Figure 4: In vivo images of a normal volunteer obtained using the (A,C) trap coil and (B,D) phased array. Sodium images obtained using the (A) trap coil and (B) phased array. Proton images obtained using the (C) trap coil and (D) phased array.