Dual Tuned Helmholtz Coil for Breast Cancer Imaging

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Introduction

Clinical breast exams have limited specificity and sensitivity for detecting breast tumors [1,2]. Even X-ray mammography, which is used for early screening of breast tumors, has limited sensitivity and does not detect approximately 25% of breast cancers [3]. Dynamic contrast-enhanced MRI (DCE-MRI) has high sensitivity but low specificity; *i.e.*, both cancerous and benign lesions enhance [2]. Additional imaging modalities such as sodium (^{23}Na) MR have the potential to increase the sensitivity and specificity of breast cancer detection because ^{23}Na MR can reflect the disruption of the membrane Na-K pump associated with cancer. Results from a preliminary study suggest that ^{23}Na MR can be used to monitor patient response to chemotherapy [4]. Moreover, recent advances in gradient hardware and pulse sequences have made ^{23}Na MR feasible for quantitative measurements of sodium concentration. The purpose of this study was to investigate the difference between a dual-tuned Helmholtz coil and a dual-tuned surface coil in providing high SNR and high quality B_1 homogeneity for multinuclear imaging as well as perform preliminary breast imaging using the dual-tuned Helmholtz coil.

Methods

Constructing the Dual Tuned Helmholtz Coil. The dual-tuned Helmholtz coil [Fig 1] consists of an inner transmit/receive sodium coil pair constructed on a 6*in outer diameter (OD),* acrylic plastic former (0.125*in* thick wall) and an outer receive-only hydrogen coil pair on a 7*in OD* (0.125*in* thick wall) former. The two coil formers were mechanically attached to a commercial breast coil housing. The inner coil pair was tuned to the Larmor frequency of ^{23}Na at 3.0T, and the outer coil pair was tuned to the Larmor frequency of ^{1}H at 3.0T. An LC blocking circuit was added to the sodium coil to enable sequential ^{23}Na and proton imaging without moving the subject. The blocking circuit effectively opens the sodium coil circuit when imaging at the proton frequency to limit the current in the sodium coil.
Proton and sodium surface coils were also built on a 6*in* cast acrylic former. The coils were tuned to the appropriate frequency, with the sodium circuit again containing blocking circuitry.

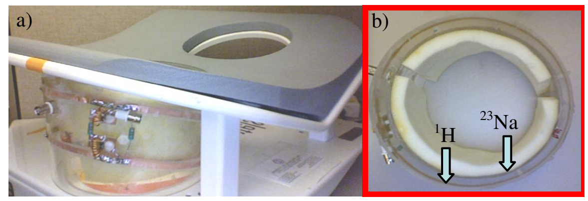

Figure 1. Dual Tuned Helmholtz Breast Coil. *Side view(a) and top view(b) of dual tuned Helmholtz breast coil. Note that the outer coils are for proton imaging, and the inner coils are for sodium imaging.*

Sodium Phantom Imaging Protocol. For both the sodium Helmholtz and the sodium surface coil, ^{23}Na MR images were taken using the 3D cones sequence with the following scan parameters: FOV=16cm, BW=+/-62.5kHz, TR/TE=40/0.6ms, 256 x 256 full resolution imaging matrix (2 x 2 x 4 mm), 80 slices and 8 averages for a total scan time of 5 minutes. The SNR of the coils were evaluated using a single acquisition method [7] on a spherical salt water phantom with similar loading characteristics to the breast. For this method, a large circular region was drawn to cover most of the phantom, and two small circular regions were placed in the background.

Human Imaging Protocol. A healthy female volunteer with no history of breast cancer was imaged in the prone position.

Proton MR Imaging: MR images were acquired on a 3.0T MR scanner (General Electric Med. Sys.) using the custom-built receive-only Helmholtz coil and the body coil for transmit. The IDEAL sequence [5] was used to acquire fat and water images with the following imaging parameters: FOV=20 cm, BW= +/- 62.5 kHz, TR/TE= 8.3/2.2ms, 512 x 192 full resolution imaging matrix (0.39 x 1.04 x 1.70 mm), 62 slices and one average.

Sodium Imaging: The sodium MR images were obtained with the Helmholtz coil using a 3D cones sequence [6] with these parameters: FOV=19.2cm, BW= +/- 62.5 kHz, TR/TE=50/0.6ms, 256 x 256 full resolution imaging matrix (2.4 x 2.4 x 4 mm), 80 slices and 12 averages for a total scan time of 17 minutes.

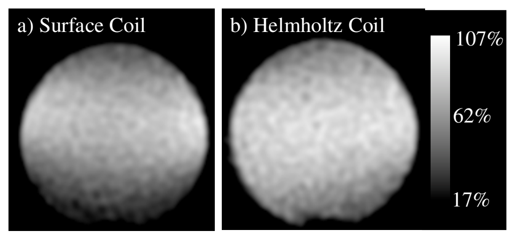

Figure 2. Sodium Images of Spherical Salt Water Phantom: *a) using the surface coil and b) using the Helmholtz coil. The plot is normalized with 100% corresponding to the maximum intensity, and 0% to the minimum. Notice that the surface coil has more coil shading effects than the Helmholtz coil. The edge at the bottom of both images is due to a physical property of the phantom.*

Results

SNR and Homogeneity. In the center slice of the spherical phantom, the SNR of the sodium Helmholtz coil was 33.4, and the SNR for the sodium surface coil was 32.1. The sodium Helmholtz coil has 4% more SNR than the sodium surface coil. Small ROIs were drawn at the top, center, and bottom of the phantom in the central slice. Using the center as reference, the signal intensity decayed 49% at the top and 47% at the bottom for the Helmholtz coil. For the surface coil, the signal intensity dropped 47% at the top and 63% at the bottom. From these results as well as visual inspection of the spherical phantom [Fig 2], it is evident that sodium Helmholtz coil exhibits a more homogeneous signal intensity map than the sodium surface coil.

Breast Imaging. IDEAL fat and water images as well as sodium images of the breast are shown in Figure 3. Dual tuned coils facilitate registration of the sodium images with the IDEAL water images. In concordance with literature, we found that sodium had a greater concentration in glandular tissue than fat.

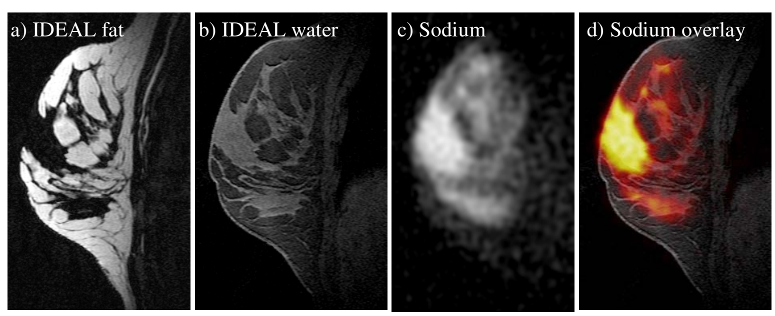

Figure 3. Images of Breast of Healthy Volunteer using Helmholtz Coil: *a) sagittal fat IDEAL image, b) sagittal water IDEAL image, c) sodium image, and d) sodium overlay on water image.*

Discussion

Overall, the dual tuned Helmholtz coil exhibits better homogeneity and higher SNR in phantoms than the surface coil. We have demonstrated the feasibility of performing a combined sodium and high resolution proton MR exam of the breast using a dual-tuned Helmholtz coil without moving the subject from the scanner.

References [1] Jacobs et al., *Technol Cancer Res Treat* 3.6, 2004. [2] Kopans, *Breast Imaging*, 2007. [3] Elmore et al., *JAMA* 293:1245-56, 2005. [4] Jacobs, *Eur Radiol 16*, 2006. [5] Reeder et al., *Mag Reson Med* 51:35-45, 2004. [6] Gurney et al., *Mag Reson Med* 55,3:575-582, 2006. [7] Firbank et al., *Phys Med Biol* 44:N261-N264, 1999.

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