Sub-Millimeter Breast Imaging and Relaxivity Characterization at 7T

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Introduction: Clinical breast MRI performed at 1.5T has a high sensitivity for the detection of breast cancer compared with mammography. Current clinical MRI breast protocols typically call for sub-millimeter in-plane pixels, though sub-millimeter slice thickness is difficult to achieve at 1.5T due to limited SNR. The sensitivity and specificity of breast MRI may be improved with higher spatial or temporal resolution afforded by increased magnetic field strength. Further, the breast may be a prime candidate for high field imaging given that typical hindrances such as poor B_1 penetration, B_1 inhomogeneity, and susceptibility artifacts are expected to be mild compared to high field abdominal imaging. Despite these promising attributes, few studies have explored the advantages offered by 7T (1-6). In this work, several facets of breast imaging at 7T are examined: first, *in vivo* SNR is measured at both 3T and 7T; second, images with 0.6 mm isotropic voxels are collected to illustrate the potential of high-resolution breast imaging; third, *in vivo* breast tissue relaxation times are reported for the first time at 7T; finally, B_0 mapping is performed to assess shimming robustness which is especially important for this application where the region-of-interest is off-center and fat suppression is critical.

Methods: A two-channel transmit/receive bilateral breast array similar to that described in Ref. (1) was constructed for operation at 7T. The array consisted of two solenoids with 15 cm diameter and 9 cm height. A commercially available four-channel receive array with 16 cm diameter and 10 cm height was used for 3T imaging (Invivo Corp.).

Non-contrast bilateral breast MRI was performed on a 31 year old volunteer at 3T and 7T (MAGNETOM, Siemens Healthcare) and a 48 year old volunteer at 7T. Both subjects gave informed written consent for this study, which was approved by our internal review board. SNR was measured in gradient echo images with identical parameters at both fields: TE = 4.07 ms, TR = 200 ms, flip angle = 20°, voxel size = 1.17×1.17×3 mm^3, and bandwidth = 300 Hz/pixel. A set of 3D gradient echo images with 0.6mm isotropic voxels were acquired in the sagittal plane with the following parameters: fat saturation, TE = 1.92 ms, TR = 4.37 ms, flip angle = 10°, bandwidth = 540 Hz/pixel, and slices per slab = 208.

T_1 was mapped using spin echo images with an inversion preparation and four TIs. Signal intensities at each pixel were fit to the function $S(TI) = |S_0[1 - 2\alpha \exp(-TI/T_1) + \exp(-TR/T_1)]|$ using an unconstrained nonlinear optimization search algorithm in Matlab, where S_0 is the equilibrium magnetization and α is the inversion efficiency. Imaging parameters at 7T were: single slice in the coronal plane; TI = 22, 390, 1600, and 6500 ms; TR = 7500 ms; voxel size = 2.34×2.34×3mm^3; bandwidth = 700 Hz/pixel (fat-water shift = 1.4 pixels); and 3/4 Fourier encoding. The following parameters were used at 3T: TI = 22, 275, 1150, and 5500 ms; TR = 6000 ms; voxel size = 2.34×2.34×5 mm^3, and BW = 600 Hz/pixel (fat-water shift = 0.7 pixels). T_2 was mapped in the same coronal slice by fitting signal intensities from spin echo images at 32 echo times to a mono-exponential decay model $S(TE) = A + S_0 \exp(-TE/T_2)$, where A is the signal offset and TE = 13.1 ms to 419.2 ms with 13.1 ms steps. Other imaging parameters were: TR = 3500 ms, voxel size = 1.17×1.17×3mm^3 (7T), voxel size = 2.34×2.34×5mm^3 (3T), bandwidth = 700Hz/pixel (7T), and bandwidth = 540Hz/pixel (3T). To characterize the relaxivity of fibroglandular and adipose tissues, the two dominant species in breast tissue, a double-Gaussian curve was fit to each histogram generated from the T_1 and T_2 maps.

The B_0 field was measured after running the vendor-provided shimming algorithm. $\Delta B_0 = \Delta\theta/(2\pi \cdot \Delta TE)$ was applied to transverse gradient echo images, where $\Delta\theta$ is the signal phase difference between images with TE = 7.14 ms and 8.16 ms at 7T, and TE = 4.92 ms and 7.38 ms at 3T.

Results: 0.6 mm isotropic images had plentiful SNR at 7T, while SNR was adequate at 3T (Fig.1.). The 7T image shows potential for identification of small ducts and lesions. However, poor fat suppression can be seen in posterior periphery and fat-water chemical shift artifacts are observed. Fig. 2 shows 7T SNR was 2-3 times greater than that at 3T, highlighting the potential of 7T breast imaging. T_1 and T_2 maps (Fig. 3) show clear delineation of fat and fibroglandular tissue. This delineation is further demonstrated in the 2D histogram (Fig.4). Gaussian fitting-based relaxivity values for each subject are given in Table 1. Values at 3T are similar to those in Ref. (7). B_0 shimming at 3T was satisfactory, while the 7T B_0 map shows that, despite the large offset between the right and left breasts, each individual breast is fairly well-shimmed (Fig.5).

Conclusions: The feasibility of high-resolution 7T breast imaging has been demonstrated with substantial SNR gain over 3T. T_1 and T_2 were reported for the first time *in vivo*, enabling future pulse sequence timing optimization.

References: 1) Lee, et al. Proc ISMRM 2006; p.2900. 2) Umutlu, et al. Acad Radiol 2010; p.1050–1056. 3) Umutlu, et al. Proc ISMRM 2009; p.4132. 4) Warmington, et al. Proc ISMRM 2009; p.3006. 5) Kumar, et al. Proc ISMRM 2010; p.3812. 6) Li, et al. Proc ISMRM 2010; p.3816. 7) Edden, et al. JMRI 2010. p.982-987..

Table 1. Longitudinal and transverse relaxation times.

		Fibroglandular		Adipose	
Subject	B_0	T1 (ms)	T2 (ms)	T1 (ms)	T2 (ms)
A, 31 years	7T	1622 ± 724	64 ± 25	656 ± 163	115 ± 18
B, 48 years	7T	1551 ± 608	59 ± 21	695 ± 220	107 ± 26
A, 31 years	3T	1290 ± 532	94 ± 22	452 ± 23	126 ± 14

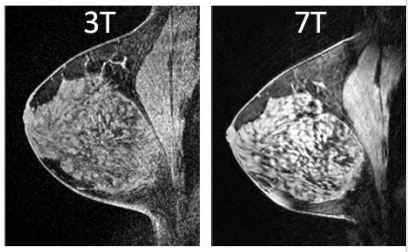

Fig.1. 0.6 mm isotropic images.

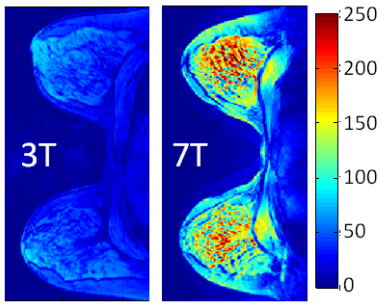

Fig.2. SNR maps.

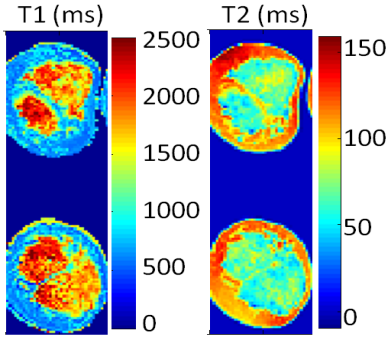

Fig.3. T_1 and T_2 maps (subject A, 7T).

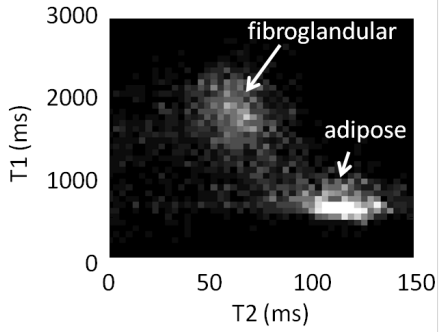

Fig.4. 2D histogram for subject A at 7T (pixel count versus T_2 and T_1).

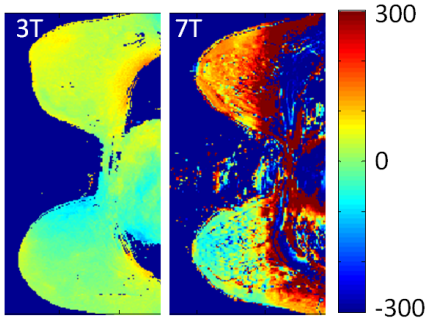

Fig.5. B_0 maps (Hz).