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 B1 penetration, B1 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, B0 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 = 1.17x1.17x3 mm3, 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.

T1 was mapped using spin echo images with an inversion preparation and four TIs. Signal intensities at each pixel were fit to the function $S(TI) = |S_0[1 - 2\alpha \exp(-TI/T1) + \exp(-TR/T1)]|$ using an unconstrained nonlinear optimization search algorithm in Matlab, where $S_0$ is the equilibrium magnetization and $\alpha$ 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 = 2.34x2.34x5 mm3, and BW = 600 Hz/pixel (fat-water shift = 0.7 pixels). T1 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 $S(TE) = A + S_0 \exp(-TE/T1)$, 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 = 1.17x1.17x3mm3 (7T), voxel size = 2.34x2.34x5mm3 (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 T1 and T2 maps.

The B0 field was measured after running the vendor-provided shimming algorithm. $\Delta B_0 = \Delta B(2\pi\Delta TE)$ was applied to transverse gradient echo images, where $\Delta B$ is the phase shift 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. T1 and T2 maps (Fig. 3) show clear delineation of 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). B0 shimming at 3T was satisfactory, while the 7T B0 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. T1 and T2 were reported for the first time in vivo, enabling future pulse sequence timing optimization.


Table 1. Longitudinal and transverse relaxation times.

<table>
<thead>
<tr>
<th>Subject</th>
<th>B0</th>
<th>T1 (ms)</th>
<th>T2 (ms)</th>
<th>T1 (ms)</th>
<th>T2 (ms)</th>
</tr>
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<tbody>
<tr>
<td>A, 31 years</td>
<td>7T</td>
<td>1622 ± 724</td>
<td>64 ± 25</td>
<td>656 ± 163</td>
<td>115 ± 18</td>
</tr>
<tr>
<td>B, 48 years</td>
<td>7T</td>
<td>1551 ± 608</td>
<td>59 ± 21</td>
<td>695 ± 220</td>
<td>107 ± 26</td>
</tr>
<tr>
<td>A, 31 years</td>
<td>3T</td>
<td>1290 ± 532</td>
<td>94 ± 22</td>
<td>452 ± 23</td>
<td>126 ± 14</td>
</tr>
</tbody>
</table>

Fig.1. 0.6 mm isotropic images.

Fig.2. SNR maps.

Fig.3. T1 and T2 maps (subject A, 7T).

Fig.4. 2D histogram for subject A at 7T (pixel count versus T1 and T2).

Fig.5. B0 maps (Hz).