Toward improved T1-weighted breast imaging at 7T: preliminary results and comparison with 3T

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Introduction: The drive for 7T breast MRI has been fueled by improved SNR compared to clinical 1.5T and 3T magnets. 7T breast imaging with two-channel receive arrays (1-2) have demonstrated more than double SNR over 3T, while gains of up a factor of six have been realized with a 15-channel array (3). Despite the promise for higher SNR and therefore the potential for improved spatial resolution and sensitivity to breast cancer detection, 7T MRI presents significant image quality hurdles that must be overcome to approach the image quality routinely attained at 1.5T and 3T. 7T has been hindered by high-field complexities including non-uniform B1+ and B0, as well as uncharted sequence parameters and inconsistent fat suppression (FS). In this report, we focus on customizing the essential clinical sequence, T1-weighted 3D gradient echo with and without FS to achieve high image quality and high fat-fibroglandular contrast. Images were acquired with the resolution used in our center's clinical protocol (1.9 mm^3) and with increased resolution (0.2 mm^3) at both 3T and 7T. The efficacy of 7T FS in the presence of B1+ variation was also examined.

Methods: All images were acquired on a 7T whole body scanner (MAGNETOM, Siemens) using a bilateral two-channel transmit-receive coil (1) or 3T scanner (TIM Trio, Siemens) using a bilateral seven-channel receive-only coil (Invivo Corp.). The study was approved by our local IRB and four volunteers were scanned after informed written consent was obtained. Two of these volunteers were referred to our institution because of a family history of breast cancer and were scanned with contrast at 3T and 7T. Gadolinium-DTPA (Magnevist) was administered with a dose of 0.1 mmol/kg body weight at a rate of 2 mL/s (hand injected at 7T).

Parameters TE and flip angle in a 3D gradient echo sequence (VIBE on Siemens systems) were explored with and without SPAIR (spectrally adiabatic inversion recovery) FS to minimize chemical shift interference artifacts and maximize contrast between fat and fibroglandular tissue. Modifications were made to the 3T product SPAIR pulse for operation at 7T; the pulse duration was reduced from 23ms to 10ms to match the fat-water spectral separation at 7T and the assumed T1 value of fat was increased to 540ms based on phantom and *in vivo* measurements. SPAIR FS was favored at 7T because its adiabatic pulse reduces sensitivity to B1+ variation. This was examined by imaging with various transmit reference voltages for which the nominal reference was calibrated in the peripheral fat using a gradient echo based sequence with a series of 'saturation-no-recovery' images with varying preconditioning pulse flip angles (4) centered on the fat resonance frequency. Images were acquired with baseline clinical resolution of $1.1\times1.1\times1.6mm^3$ (uninterpolated) and high resolution = 0.6mm isotropic (uninterpolated) with the following parameters: TE/TR/nominal flip angle = 1.56ms to 2.75ms/minimum allowed (<5ms)/12°, slices = 144 (baseline resolution) and 208 (high resolution), unilateral sagittal acquisition, bandwidth = 540 Hz/pixel, no partial Fourier, and acquisition time = 1:17, 2:09, 4:28 and 6:02 min (baseline resolution without FS, baseline resolution with FS, high resolution without FS, and high resolution with FS).

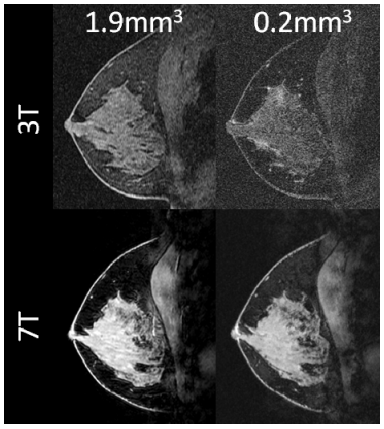

Fig. 1. Subject A. 7T FS images show superior SNR and contrast.

For subject B, 3D images were acquired at 3T using clinical parameters: TE/TR/flip angle = 1.05ms/3.57ms/12°, 288 slices, uninterpolated resolution = $1.1\times1.1\times1.7mm^3$, bilateral sagittal acquisition, partial Fourier = 3/4 (slice and phase), fat saturation, and acquisition time = 1:48 min. For subject A, 3D images were acquired with the same 3T parameters as those above, except without partial Fourier, 540 Hz/pixel, 144 slices at baseline resolution (acquisition time = 1:11 min), 208 slices at high resolution (acquisition time = 5:15 min), and unilateral sagittal acquisition to more closely match 7T parameters.

Results: FS in 7T images was more uniform and effective while maintaining the inherent SNR advantage over 3T, resulting in higher image quality (Fig. 1, left column). Improved SNR at 7T allowed dramatic reduction in voxel size (Fig. 1, right column). In all subjects, 7T SPAIR FS was consistent throughout the entire breast volume due to the 1kHz bandwidth allowed by the fat-water spectral separation. In subject B, fibroglandular:fat contrast was approximately 9.4:1, compared to 1.8:1 at 3T (Fig. 2, middle column) which allowed improved differentiation of normal fibroglandular tissue. Higher spatial resolution at 7T allowed improved visualization of the internal enhancement pattern of normal tissue in post-contrast subtracted images (Fig. 2, right column). SPAIR FS was effective over a wide range of transmit voltages (Fig. 3) (imitating B1+ inhomogeneity) which was essential for application at 7T where the peripheral fat transmit reference voltage was 24±18% greater than that in the center fibroglandular tissue due to constructive RF interference in the center. Fibroglandular:fat contrast in unsuppressed images was lower at 7T (1:1.9) compared to 3T (1:2.7), in part due to longer T1 relaxation times at 7T and to the 7T volume coil with higher sensitivity in the center compared to the 3T surface coil with higher relative sensitivity in the periphery (Fig. 2, left column). 7T Images without FS show strong fat-water interference dependency on TE, where the artifact is reduced when fat and water are in-phase at TE=2ms (Fig. 4).

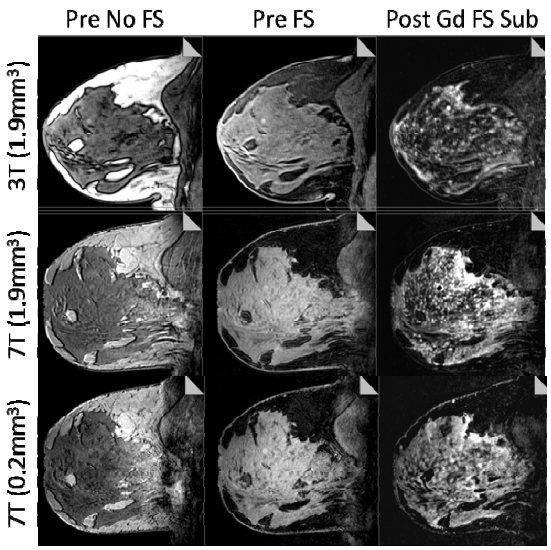

Fig. 2. Subject B. Pre-contrast images with and without FS, and third phase post contrast FS subtracted images at 3T at standard resolution (top row), 7T at standard resolution (middle row), and 7T with high resolution (bottom row).

Conclusion: This preliminary study showed that high resolution breast MRI can be performed at 7T with reliable SPAIR FS despite B0 and B1+ inhomogeneity encountered at high field. High SNR afforded at 7T was exploited for $0.2mm^3$ resolution which translates into improved visualization of morphologic details.

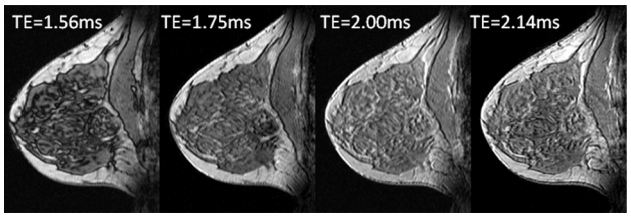

Fig. 4. Subject C. 7T images without FS illustrate the dependency of fat/water interference artifacts on TE.

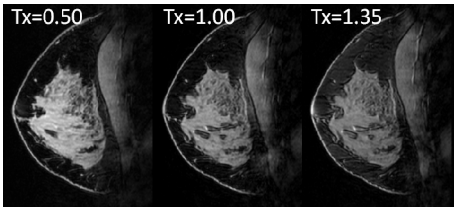

Fig. 3. Subject A. 7T FS images with different transmit voltages where unit voltage was calibrated in the fat. Fibroglandular:fat contrast was 18.3:1, 8.2:1, and 3.5:1.

Ref: 1) Brown R, et al. Proc ISMRM 2011. 2) Korteweg M, et al. Invest Radiol 2011. 3) Zheng T, et al. Proc ISMRM 2011. 4) Breton E, et al. NMR Biomed 2009.