Increasing the Scanning Efficiency of 3D FSE – IDEAL for Volumetric Breast Coverage

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Introduction: For many clinical applications, volumetric 3D acquisition of T_2-weighted FSE images with and without fat suppression is desirable. Previous results demonstrated bilateral breast coverage in approximately 10 minute acquisitions (1) by integrating IDEAL (Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation) chemical shift imaging (2) with 3D-FSE-Cube (3), which acquires very long echo trains with variable flip angle refocusing (4) and 2D ARC partial parallel imaging (5). To maximize SNR in IDEAL processing, three gradient echoes are required. Previous methods acquired each of these echoes in separate repetitions, thus increasing scan time by 50% compared to a pair of acquisitions with and without fat suppression. In this work, we demonstrate increased scanning efficiency by acquiring two echoes per refocusing RF pulse and thus eliminating the scan time increase. The new 3D-FSE-Cube-IDEAL provides volumetric T_2-weighted water-only, fat-only, in-phase and out-of-phase images of both breasts in approximately 7 minutes of scan time with robust fat-water separation.

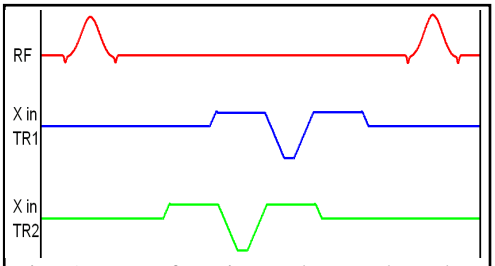

Fig. 1. RF refocusing pulses and readout (X) gradients during 2 separate TRs. –0.4 ms and +2.8 ms echoes are acquired during TR1; and –2.0 ms and +1.2 ms echoes are acquired during TR2.

Methods: The three water-fat echo-shifts (with respect to the spin echo) of $-\pi/6$, $+\pi/2$, and $+7\pi/6$ correspond to –0.4 ms, +1.2 ms, and +2.8 ms at 1.5T respectively. The pulse sequence was modified to acquire the –0.4 ms and +2.8 ms echoes by gradient refocusing between each pair of refocusing pulses (Fig. 1). In a subsequent pulse sequence repetition, the echoes were shifted in time so that the second gradient echo at +1.2 ms and an additional gradient echo at –2.0 ms were acquired. For cases where the timing between the echoes exceeds +3.2 ms ($4\pi/3$) based on frequency (readout) resolution and receiver bandwidth, a fractional readout acquisition was used to maintain the +3.2 ms time difference that is optimal for IDEAL to provide maximum SNR (2).

3D-FSE-Cube-IDEAL was implemented on a GE 1.5T scanner (GE Healthcare, Waukesha, WI). With IRB approval and informed consent, the sequence was evaluated on volunteers using an 8-channel breast coil (GE Healthcare Coils, Cleveland, OH). Imaging parameters included: TR = 2500 ms, TE_{eff} = 98 ms, BW = ±83.33 kHz, ETL = 64, matrix = 288 × 256 × 98, 80% fractional readout, FOV = 320 × 320 mm^2 and 2 mm slice thickness. ARC parallel imaging (×2 along R/L phase encoding and ×2 along S/I slice encoding) was used in an axial acquisition. The four water-fat phase shifted images were processed using an investigational 4-point IDEAL algorithm including homodyne to reconstruct water-only, fat-only, in-phase (water+fat) and out-of-phase (water-fat) images. The scan time was 7 min 20 sec, achieving complete coverage of both breasts, with near-isotropic spatial resolution of 1.1 × 1.2 × 2.0 mm^3 (interpolated to 0.6 × 0.6 × 1.0 mm^3).

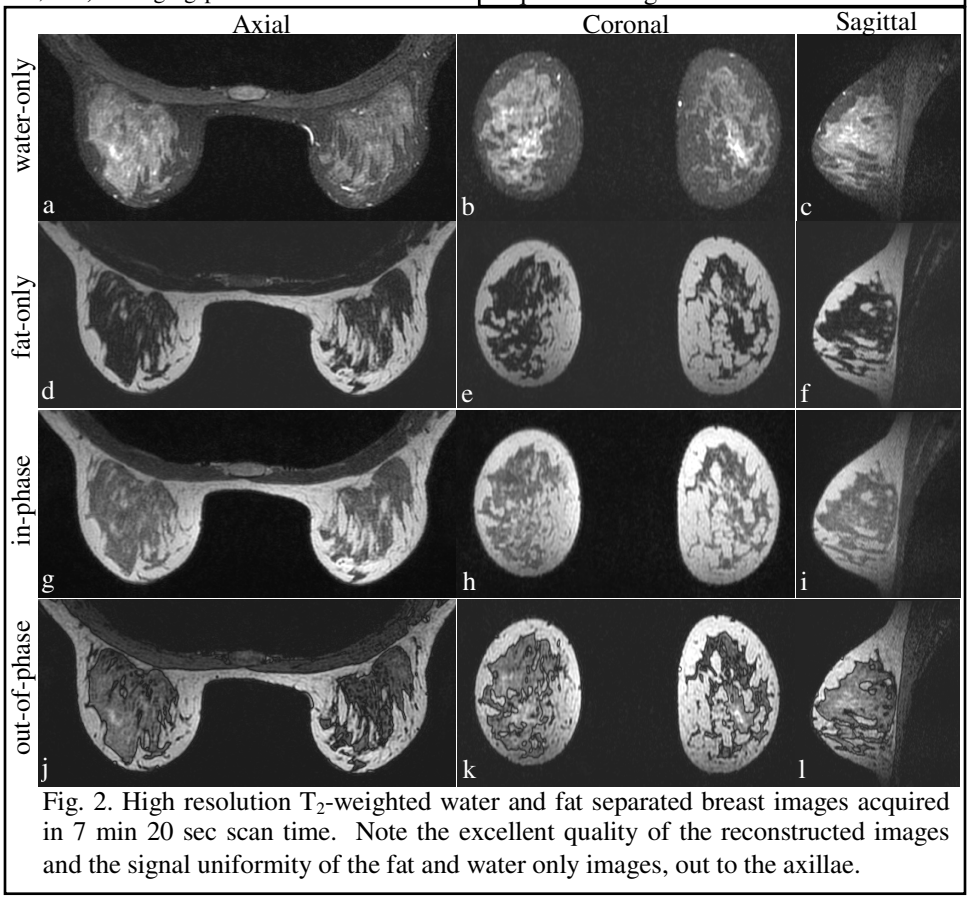

Fig. 2. High resolution T_2-weighted water and fat separated breast images acquired in 7 min 20 sec scan time. Note the excellent quality of the reconstructed images and the signal uniformity of the fat and water only images, out to the axillae.

Results: Fig. 2 shows high-resolution T_2-weighted water and fat separated breast images in different orientations. The images were acquired axially (a, d) and reformatted into coronal (b, e) and sagittal (c, f) orientations. Synthesized in-phase and out-of-phase images are also shown in Fig. 2g through Fig. 2l. All images demonstrate high spatial resolution in different orientations acquired in a clinically feasible scan time.

Discussion: By acquiring two gradient echoes per refocusing RF pulse, the scan time is reduced by one-third, making the scan time equivalent to acquiring two separate 3D volumes, with and without fat suppression. The IDEAL approach offers robust fat-water separation in regions with significant B_0 inhomogeneities (e.g. breast) as well as in-phase and out-of-phase images with higher SNR compared to separate acquisitions. The additional gradient echo acquired at –2.0 ms also increases SNR by a factor of 1.2 compared to a 3 point IDEAL acquisition.

Reference: 1) Madhuranthakam et. al. ISMRM 07; p. 1631. 2) Reeder et. al. MRM 05; 54: p. 636. 3) Busse et. al. MRM 08; 60: p. 640. 4) Mugler et. al. ISMRM 2000; p. 687. 5) Beatty ISMRM 07; p. 1749.