Respiration Induced B0 Variation in Double Echo Steady State Imaging (DESS) in the Breast

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Introduction: The Double Echo Steady State (DESS) sequence has been investigated for diffusion weighted imaging in the breast [1]. While the breast DESS images are free of the off-resonance distortion of EPI diffusion images, they exhibit fairly prominent ghosting artifacts (Figure 3a,b). This artifact is particularly problematic in the second echo, which suffers from low SNR with sufficient diffusion weighting. While ghosting in the phase direction may be due to bulk tissue motion, breast coils utilize adjustable paddles to immobilize the breast, so the breast tissue itself moves minimally. In this work we investigate respiration-induced B0 variation as an alternative source of the ghosting artifacts in DESS breast images. We further investigate the use of a DC navigator to resolve the artifact.

Materials and Methods: Respiratory induced B0 variation in the breast has been shown to be up to 70Hz at 4T [2]. We confirmed a similar level of variation (up to 40 Hz) at 3T through a time series of field maps. These measurements were then used as the basis for B0 variation in the Bloch simulations. The other Bloch simulation parameters were based on our in-vivo DESS acquisition and the tissue properties of fibroglandular breast tissue: TR 30 ms, TE 10 ms, FA 35, T1 1400 ms, T2 50 ms, spoiler area 9.36 G ms/cm, and ADC 1.6×10^{-9} m^2/s.

As opposed to motion-induced linear phase, a B0 variation causes a bulk phase change and therefore a DC navigator may contain sufficient phase information to provide a reasonable correction of the artifact. A DC navigator was incorporated into the DESS sequence consisting of 10 points acquired before the first readout and after the second readout in each TR. To separate out the effect of time-varying B0 error from motion of the breast tissue, a spherical QA phantom was placed in the breast coil with a male volunteer lying on the coil. Phantoms were well padded to prevent any rigid motion. The DESS sequence with a DC navigator was acquired for this experimental set up as well as in a standard breast MR set up with a female volunteer with no phantom present. The imaging parameters were as follows: 3D acquisition, 256 x 256 matrix, 3 mm section thickness, 36-44 slices, 28-36 cm FOV, TR 27 ms, TE1 9 ms, TE2 45 ms, FA 35, spoiler area 9.36 G ms/cm, sequential encoding and no parallel imaging.

After removal of linear phase due to off-isocenter shifts, and phase unwrapping, the measured navigator phase was applied as a bulk phase shift in k-space to its respective echo (nav 1 corrects echo1, nav 2 corrects echo 2). The original and corrected images in both the phantom and the breast were reconstructed and compared based on qualitative assessment of the level of artifact.

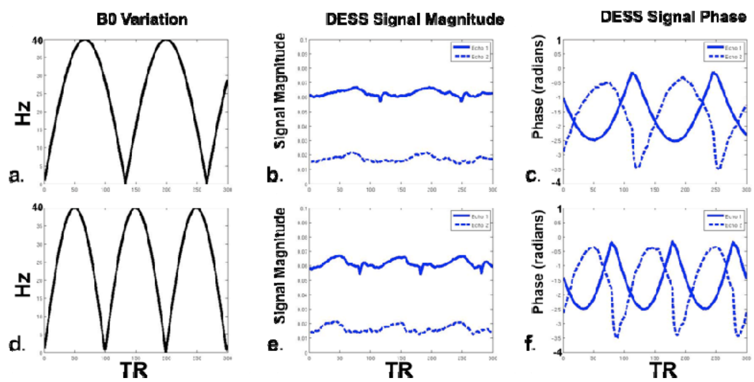

Figure 1. Time dependent B0 variation (left column a: 40 Hz amplitude, 4s period, d: 40 Hz amplitude, 3s period), incorporated into DESS Bloch simulation results in sinusoidal phase variation (c,f, echo 1: solid line, echo 2: dotted line). Amplitude variation is also predicted (b,e, echo 1: solid line, echo 2: dotted line). Amplitude of echo 2 phase variation (f dotted line) increases with increased respiratory rate (d versus a) as does amplitude variation in both echoes (e, solid and dotted line).

Results: The Bloch simulations with time-varying B0 incorporated (Figure 1a,d) show a resultant sinusoidal variation in the phase of both DESS echoes (Figure 1c,f), which would be expected to lead to ghosting in image space. In the images of the male volunteer lying on the breast coil (Figure 2) there is ghosting of the phantom in both echoes (Figure 2a,b) demonstrating that artifact is present despite no motion of the phantom itself. Correction with the DC navigator reduces the level of artifact in both the first and second echo (Figure 2c,d). The artifact is also reduced through the use of the DC navigator in the DESS images in the breast (Figure 3c,d) in comparison to the original level of artifact in the unmodified images (Figure 3a,b).

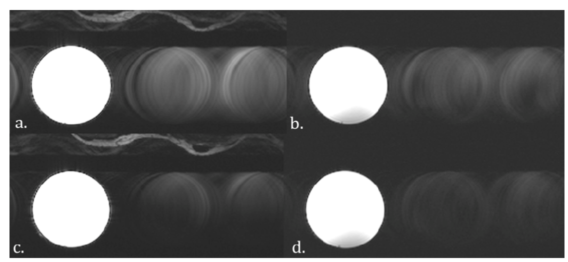

Figure 2. DESS images acquired with a male volunteer and phantom in the breast coil. Original DESS images, echo 1 (a) and echo 2 (b) show ghosting artifact despite immobilization of phantom. Level of ghosting artifact is reduced in both echo 1(c) and echo 2 (d) with DC navigator phase correction.

Discussion: The DESS Bloch simulations and the presence of artifact in the immobilized phantom as well as the absence of the artifact in breath hold scans (not shown here) demonstrate that respiratory induced B0 variation may contribute to the ghosting artifacts in DESS in the breast. The efficacy of the DC navigator to remove the artifacts is variable but promising as a first step for artifact correction. Further artifact characterization and correction must take into account a number of factors including the presence of phase due to actual non-rigid motion of the breast tissue, the variability of B0 variation across the breast, and the complexities of the predicted effect of time-varying B0 on both the DESS signal amplitude and phase.

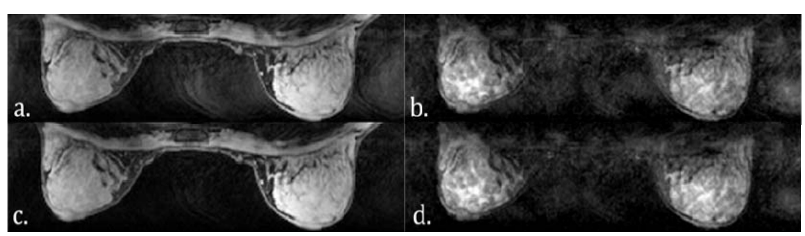

Figure 3. Artifact is present in both DESS echo 1 (a) and echo 2 (b) images in a breast volunteer. DC navigator phase correction greatly reduces the artifact in the first echo (c) while more moderately reducing the level of artifact in the second echo (d).

Conclusion: Respiratory induced B0 variation may contribute to the ghosting artifact in DESS acquisitions in the breast. A DC navigator provides some reduction of this artifact but full artifact correction will require a more sophisticated correction method.

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References: 1. 1.Granlund, et al., *MRI,*2014; 32:330-41. 2. Bolan, et al., *MRM*, 2004; 52:1239-1245.