Ultrafast near-isotropic spatial resolution 3D balanced-SSFP Dixon imaging in the breast

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INTRODUCTION: T_2 imaging in the breast is most commonly performed using a fat suppressed 2D Fast Spin Echo (FSE) pulse sequence. The in-plane spatial resolution is high (<1mm) but the 3-4 mm slice thickness blurs fine structures and makes multi-planar reformatting sub-optimal. Balanced steady-state free precession (b-SSFP) techniques yield high SNR images in short scan times with a T_2-like (T_2/T_1) image contrast. They have been explored for lesion characterization in the liver and, more recently, in the breast [1]. However, b-SSFP sequences are very sensitive to B_0 inhomogeneities, manifesting as banding artifacts and posing major challenges to robust fat suppression in the breast and at high field strengths. We investigated a new 3D technique that combines balanced steady-state free precession imaging with a two-point Dixon fat-water reconstruction algorithm [2] for robust fat-separated volumetric imaging of the breast with near isotropic spatial resolution in short scan times.

METHODS AND MATERIALS: A dual echo bipolar readout 3D balanced steady-state free precession pulse sequence [3] followed by 2-point Dixon fat-water reconstruction algorithm was developed. The 3D bipolar implementation allows catching first available opposed-phase and in-phase echoes. Minimizing TE/TR minimized banding artifacts and scan times despite dual echo acquisition. A 2-point Dixon based fat-water reconstruction ensured robust fat suppression and eliminated the need for fat suppression pulses, avoiding perturbations of steady state magnetization. Bloch equation simulations were performed to determine the bipolar TEs for optimal fat suppression using the Dixon method whilst keeping the TRs short. Bipolar opposed-phase/in-phase TEs of 2.2/3.8 ms at 1.5T field strength provided an optimal compromise between degree of fat suppression and short TR times.
Thirty patients were scanned on a 1.5T GE HDx scanner using an 8-channel breast phased array coil with an IRB approved protocol. For the 3D SSFP Dixon, dual echo TE values were 2.2/3.8 ms at $\pm$125 KHz bandwidth with 5.5ms TR. A 320x320 matrix was used with 1.6 mm section thickness interpolated to 0.8mm yielding a 1x1x0.8 mm spatial resolution and axial bilateral coverage in 90s. Further reduction of scan time was achieved using a fractional FOV in the frequency direction (A/P), a non-separable under sampling scheme [4] with 2x1 phase acceleration and an elliptical k-space acquisition. Comparisons were made with a three-point Dixon 2D FSE technique with 0.83x1x5 mm spatial resolution acquired in 6 minutes, which is the sequence routinely used for T_2 evaluation. 384x320 matrix, TR/TE 5300/94 ms, ETL=8, $\pm$62.5 KHz bandwidth. Images were evaluated for motion artifacts, SNR, lesion visualization, lesion contrast and overall preference.

RESULTS: Figure 1A shows a representative axial section obtained using the 3D SSFP sequence on a patient. Note the uniform fat suppression as well as high in-plane resolution and SNR. A section from the sagittal reformat of the left breast is shown in (b). The excellent resolution of the reformatted image due to the high through-plane spatial resolution of the axial scan (1.6 mm interpolated to 0.8 mm) can be clearly appreciated. Figure 2 shows a comparison of a section from a 3D SSFP Dixon sequence (A) with a 2D FSE Dixon sequence (B) on a patient with a post-operative seroma. The subareolar ducts (white arrow) are better visualized in the 3D sequence due to the high through-plane spatial resolution while identical T_2 contrast is observed. A contrast-enhanced 3D T_1 section is shown in (C) for comparison. Figure 3A shows a MIP image from a 3D SSFP dataset of a biopsy-proven tumour (white arrow) with associated vascularity and increased T_2 signal of the ipsilateral background parenchyma. A 3D T_1 contrast-enhanced MIP is also shown for comparison (3B).

CONCLUSION: The proposed dual echo bipolar 3D SSFP acquisition with a 2-point Dixon-based fat-water separation method yields excellent fat suppression and high SNR with a T_2 like contrast in the breast. A near isotropic 1mm x 1mm x 0.8mm spatial resolution axial bilateral coverage was achieved in less than 1.5 minutes which enabled reformatting with excellent image quality. A detailed study exploring the T_2/T_1 contrast properties of 3D SSFP in the breast is underway. Maximum intensity projections of the 3D SSFP Dixon dataset can also provide adjunct information about the tumoural blood supply without the need for Gadolinium contrast.

REFERENCES: [1] Klifa et al. JMRI 25:502–510 (2007) [2] Ma et al. MRM. 52:415-419 (2004) [3] Bayram et al Proc. ISMRM, p 4050 (2009) [4] Beatty et al. Proc ISMRM, p1749 (2007)

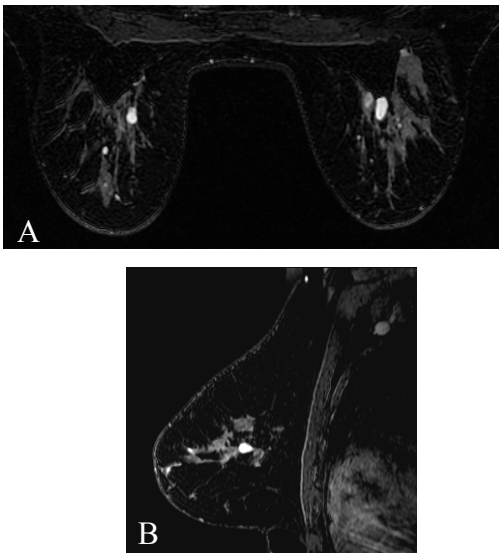

Figure 1. A representative axial "water-only" section from the proposed 3D SSFP Dixon sequence (A) and a sagittal reformatted section from the axial slab. Note the excellent spatial resolution of the reformatted image due to the near-isotropic axial scan resolution.

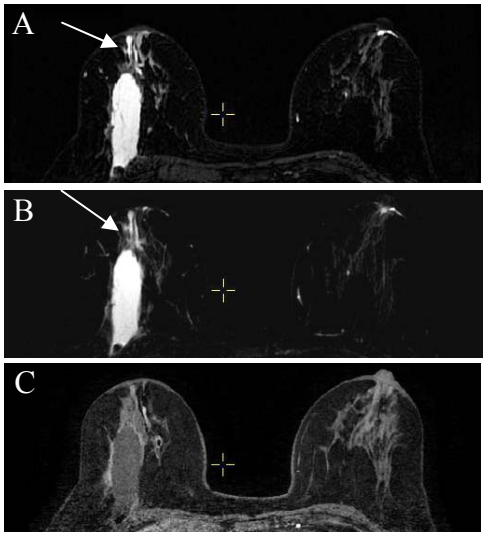

Figure 2. Comparison of 3D Dixon SSFP (A) and 2D FSE Dixon (B) in a patient with post-operative seroma. Note the clarity of the sub-areolar ducts and identical T_2 contrast in (A) compared to (B). A T_1 contrast-enhanced 3D SPGR section is shown in (C).

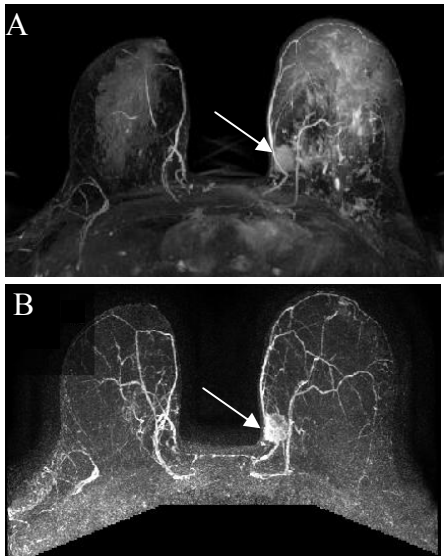

Figure 3. MIP from the 3D Dixon SSFP (A) depicting the tumor vascularity without the need for Gadolinium contrast. A contrast-enhanced 3D SPGR MIP is shown in (B) for comparison.