Rapid DCE Breast MRI using TSENSE Accelerated 3D Spiral Imaging

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Introduction: Although dynamic contrast enhanced (DCE) breast MRI has shown great promise in discriminating benign and malignant breast lesions [1], imaging limitations still force a tradeoff between temporal and spatial resolution. 3D spiral imaging with a water-selective spectral-spatial excitation provides robust fat suppression and high spatio-temporal resolution [2, 3]. A further increase of temporal resolution can be achieved with undersampling in the slice-encoding direction. TSENSE, which incorporates temporal filtering with parallel imaging, has been proposed to accelerate dynamic imaging without the need for acquisition of coil sensitivity maps [4]. Here we demonstrate the combination of TSENSE and 3D spiral imaging for DCE breast MRI.

Methods: Imaging was conducted with a GE 1.5T Excite scanner and an 8 channel "VIBRANT" phased-array breast coil. We scanned one normal volunteer with a tube external to the breast to simulate contrast enhancement using a bilateral protocol, and five high-risk patients using a unilateral protocol. All scans used a 40° flip angle, "stack-of-spirals" imaging trajectory with 8 (bilateral) or 9 (unilateral) spiral interleaves, TR of 26.8 ms (bilateral) or 31.3 ms (unilateral), 20 x 20 cm^2 FOV in-plane (1.2 mm x 1.2 mm resolution) and 32 phase-encoded k-space sagtittal planes per breast with 3.6 mm-thickness. With an acceleration factor of 2, we acquired phase encoded planes in a time-interleaved fashion, alternating between even and odd planes. The scan time for 3D volume coverage (half of the planes) was 6.86 s (bilateral) or 4.5 s (unilateral). For the volunteer scan, Gd-DTPA was infused rapidly into the tube and washed out with saline infusion. For unilateral vivo exams, 4 of 8 coil elements were used and Gd-DTPA was injected after the 8^{th} temporal frame.

After 2D gridding in each sagittal plane, SENSE reconstruction was done in axial reformatted planes. To estimate coil sensitivities, full-FOV unaliased coil images were acquired by averaging the last 20 frames (post-contrast) to eliminate the rapid signal change following injection. Coil images were normalized by root sum of squared magnitudes and used as sensitivity maps. To stabilize SENSE reconstruction and reduce noise increases in high g-factor regions, we used Tikonov regularization [5] to find the solution $\mathbf{x}^{\lambda}$ that minimizes

$$\mathbf{x}^{\lambda} = \arg\min_{\lambda} \left\|\mathbf{S}\mathbf{x} - \mathbf{y}\right\|_2^2 + \lambda\left\|\mathbf{x} - \mathbf{x}^*\right\|_2^2 .$$

λ is a regularization parameter, **x** is an unfolded image, **S** is a sensitivity map matrix and **y** is an observable folded image. A full-FOV image reconstructed from two adjacent temporal frames (view sharing) was used as prior information, $\mathbf{x}^*$. As images reconstructed from view sharing have the same temporal resolution as unaccelerated time series, the regularization parameter trades off between the increase in temporal bandwidth and reduction of the noise from ill-conditioned inversion. λ was chosen as 0.1, which does not affect the decrease of temporal resolution much. Slight residual aliasing artifacts were suppressed by a temporal low pass filter with a passband cut-off of 0.425 normalized to the sample rate, corresponding to 85 % of available bandwidth.

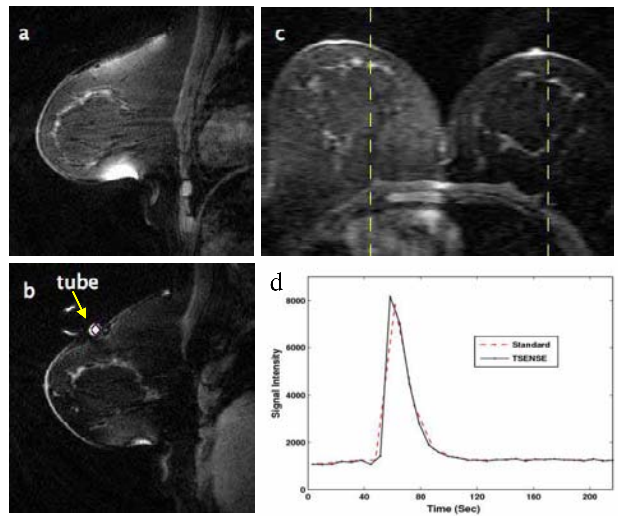

Figure 1: Bilateral breast imaging with simulated contrast enhancement in a tube. (a-b) Two unwrapped slices from right breast (a) and left breast (b) and (c) one axial reformat from TSENSE reconstruction. The circle in a tube indicates the ROI for which contrast enhancement was measured. Dashed lines in (c) indicate locations corresponding to the slices (a) and (b). (d) Signal enhancement curves obtained from standard and TSENSE reconstruction.

Results: Figure 1 shows two unfolded sagittal slices which are FOV/2 apart, and an axial reformat from the TSENSE reconstruction of a bilateral acquisition and the signal enhancement curves measured in the tube from the original and accelerated images. Note the increased enhancement rate resolved by the improved temporal resolution of the TSENSE reconstruction. Figure 2 shows unfolded slices, an axial reformat and the signal enhancement curves from a unilateral acquisition in a patient with a breast tumor. Again, the improvement in temporal resolution with TSENSE over the standard reconstruction is reflected by the steeper initial slope on the enhancement curve.

Conclusions: TSENSE with an acceleration factor of 2, combined with 3D spiral imaging increased temporal resolution in bilateral breast DCE imaging to 7s, without extra scan time to get sensitivity maps. Possible errors from the sensitivity maps calculated from acquired images themselves were eliminated using SENSE regularization and temporal low pass filtering, yielding no visible aliasing artifacts.

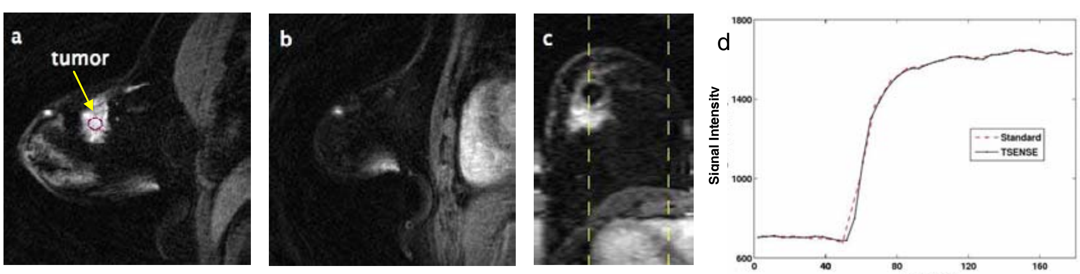

Figure 2: Representative unilateral breast imaging. (a-b) Two unwrapped slices and (c) an axial reformat from TSENSE reconstruction. Two dashed lines in (c) indicates locations corresponding to the slices (a) and (b). After injection of contrast, signal enhanced in observed tumor in (a). (d) Signal enhancement curves obtained from standard and TSENSE reconstruction.

References
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