Highly-Accelerated Golden-Angle Radial Acquisition with Joint Compressed Sensing and Parallel Imaging Reconstruction for Breast DCE-MRI

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INTRODUCTION: DCE-MRI has emerged as a powerful tool for assessing tumor microcirculation. Pharmacokinetic analysis of DCE-MRI data provides estimates of the vascular transfer constant (K^{trans}) which has shown promising results in breast cancer discrimination [1,2]. Despite these promising results, it remains challenging to utilize such technique in clinical applications of screening patients at high risk for the breast cancer due to the difficulty of acquiring DCE-MRI data with sufficiently high spatial and high temporal resolutions over a large field of view for bilateral breast imaging. Recently, it has been shown that the compressed sensing (CS) reconstruction technique with radial undersampling schemes can be used for fast imaging of the breast [3]. Further acceleration can be achieved by combining CS with parallel imaging [4]. We have recently developed a new reconstruction method that combines compressed sensing and parallel imaging for radial trajectories (k-t RASPS: RAdial SParse-Sense), which provides high spatial and high temporal resolution images without significant temporal blurring. The objective of the present study was to investigate the feasibility of using the k-t RASPS method for DCE-MRI studies of breast cancer and to assess the effect of temporal resolution on dynamic enhancement kinetics.

METHODS: Unilateral breast MRI was performed on six patients who underwent MRI-guided biopsy scans as part of their clinical care, using a Siemens 3T scanner with a 7 channel breast coil (InVivo). DCE-MRI data were acquired using a 3D radial VIBE sequence with golden-angle (GA) scheme (380 views, image matrix = 256 x 256, TR/TE = 3.6/1.47 ms, fat suppressed, image resolution = 1.1 x 1.1 mm, slice thickness = 2 mm, 72 slices, and scan time = 55.5 s/measurement). Following the acquisition of one baseline pre-injection image, a single dose of Gd-DTPA (Magnevist, Bayer) with concentration of 0.1 mM/kg body weight was injected at 3 mL/second into an antecubital vein, during which scanning was continued for another 5 measurements.

Conventional gridding and k-t RASPS image reconstructions were performed with the same data. Taking the advantage of the GA scheme, image reconstruction was performed with 21, 13, and 8 radial views for temporal resolutions of 3.1, 1.9, and 1.2 s/frame, respectively. The GA-k-t RASPS (GA-CS) image reconstruction was performed by minimizing the function $\|R \bullet E \bullet x - y\|_2 + \lambda \|T \bullet x\|_1$, where y is the undersampled k-space data, x is the image to be reconstructed, T is an operator that calculates the temporal total variation, and E is an operator that combines multiplication with the coil sensitivities and Fourier transformation. Further, R is a gridding operator that interpolates onto the spokes of the trajectory in k-space. The minimization was performed using a nonlinear conjugate gradient algorithm. Coil sensitivity maps were calculated using the adaptive coil combination method [5] with the temporal average of the gridded images as coil calibration reference. The reconstruction algorithm was implemented in MATLAB (MathWorks, MA).

RESULTS & DISCUSSION: Figure 1 shows a representative example image reconstructed with full 380 radial views. The dynamic curves of the left ventricle and a lesion are also shown to demonstrate the temporal blurring that is often seen with conventional high spatial resolution breast images. Figure 2 presents the results of image reconstruction with sub-sets of radial views. Compared with the gridding image reconstruction, the GA-CS method was able to reconstruct images without noticeable streaking artifacts and with good fat suppression and high conspicuity of most morphological features, such as the fibroglandular tissue, skin layer, and the suspicious small lesion (as indicated by the red ROI in Fig.1). Dynamic enhancement curves shown in Fig.3 demonstrate that the GA-CS curves match well with those of the gridding images (i.e., no noticeable temporal blurring) and show less noise. Future study will include assessment of images with different temporal resolutions in terms of estimation of pharmacokinetic model parameters.

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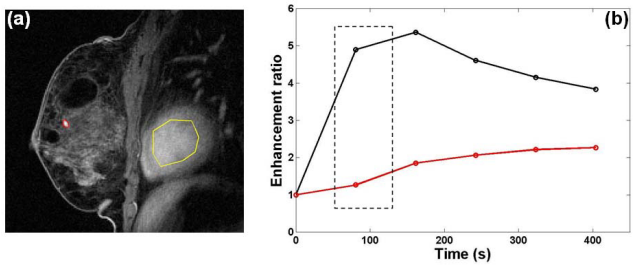

Fig.1 (a) A representative image reconstructed using the conventional gridding with 380 radial views. A total of 6 frames of images at this resolution (55.5 s/f) were reconstructed. Regions of interest were selected for the left ventricle (yellow) and a suspicious lesion (red). (b) Contrast enhancements from the high resolution images with full views for the left ventricle (black line) and the suspicious lesion (red line). The dashed line box indicates the duration corresponding to that shown in Fig.3.

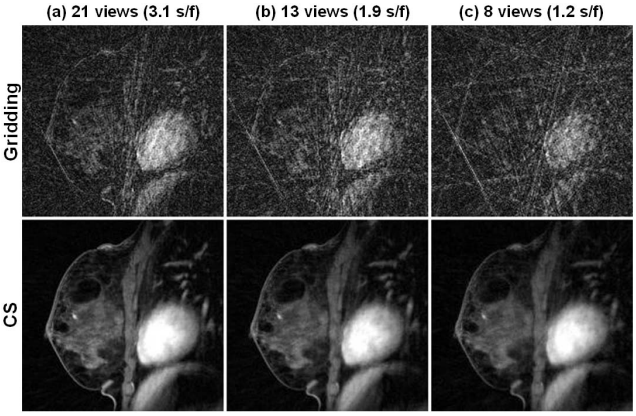

Fig.2 Images reconstructed for high temporal resolutions using the conventional gridding (top row) and the proposed GA-CS (bottom row) methods. Note that the spatial features of the image are well preserved for all images reconstructed using the GA-CS method whereas it is hard to appreciate the breast parenchyma in the gridding images.

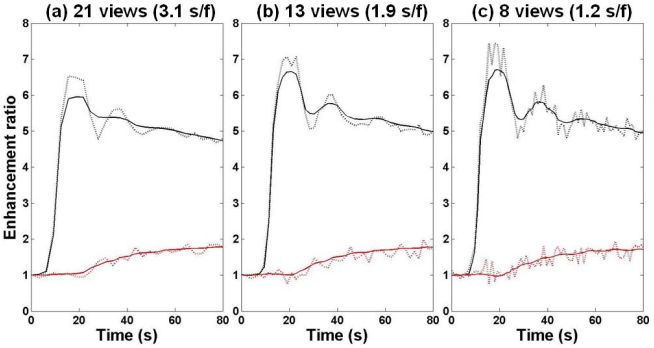

Fig.3 Dynamic contrast enhancement curves from the images reconstructed with three temporal resolutions shown in Fig.2. The black lines are for the left ventricle ROI shown in Fig.1 and the red lines for the suspicious lesion ROI in Fig.1. The full lines are from the GA-CS reconstructed images and the dotted lines are from the gridding.