Constrained Reconstruction of Dynamic Contrast Enhanced Tumor MR Data with Respiratory Self-Gating

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Introduction: Dynamic Contrast Enhanced (DCE) MRI is a powerful technique for tumor diagnosis. The method can be used to assess a tumor's response to drug treatments by studying changes in its vascularity and perfusion. However, acquiring full k-space data for each time frame in a conventional fashion can limit the coverage of tumor and the temporal and/or spatial resolutions. The recently proposed compressed sensing /constrained reconstruction methods [1-3] can be used to overcome some of these limitations by reconstructing high quality images from severely undersampled k-space data. Here we propose to apply the spatio-temporal constrained reconstruction (STCR) method [3] that uses L1 norm constraints in time and space dimensions on undersampled DCE tumor data. The technique is used in conjunction with the recently proposed respiratory self-gated radial DCE-MRI strategy [4,5]. Respiratory gating significantly reduces the temporal variations in the signal due to breathing and leads to enhanced sparsity in the temporal gradient. The results obtained on lung and liver tumors demonstrate the promise of the approach for lesion assessment.

Methods: 3D hybrid radial DCE data were acquired on a Siemens 1.5 T Sonata scanner from patients with lung and liver lesions. Scan parameters were as follows: TR=3.2 ms, TE=1.5 ms, flip angle = 30°, FOV: 380X380 mm^2, slice thickness=5mm, matrix size: 192 (readout) X 4000-8000 (total projections). Golden angle (111.246°) view order scheme [4-6] was used to advance subsequent view angles in the kx-ky plane, while the inner-most loop (kz) was phase encoded. Unlike interleaved radial acquisitions with equally spaced angles [7], the golden angle scheme offers the flexibility of choosing arbitrary time frames (both the number of views and the temporal position) during reconstruction. Respiratory self-gating was performed retrospectively by using peak signal intensity of each radial line [8,9]. Undersampled data (55 views) from the end-expiratory phase of each respiratory cycle was subsequently used for the reconstruction. For comparison, STCR of both the gated and the ungated undersampled radial data was performed by iteratively minimizing C shown in the equation below.

$$C = \left\| WF\tilde{m} - \tilde{d} \right\|_2^2 + \alpha_1 \left\| \nabla_t \tilde{m} \right\|_1 + \alpha_2 \left\| \nabla_s \tilde{m} \right\|_1$$

In the above equation, W is the undersampling scheme, F represents the Fourier transform, $\tilde{m}$ is the reconstructed image data, $\tilde{d}$ is the acquired k-space data, and ∇t and ∇s represent the temporal and spatial gradient operators, respectively. α_1 and α_2 are the corresponding weighting factors for the constraint terms. The constraint terms are approximated using total variation functionals [10] in the corresponding dimensions.

Results: Figure 1 shows a schematic of the respiratory self-gating signal obtained from the lung tumor dataset. Large temporal variations are present due to respiration. The red circles in the plot represent the end expiratory phase (local maxima) which is smoothly varying and hence the gated subset of images, each centered at the end expiratory point, better satisfy the temporal constraint in the above equation. Since the rate of tumor enhancement (> 20sec baseline to peak) is typically significantly lower than the respiratory rate, respiratory gating does not affect the kinetics of the tumor perfusion. Figure 2 shows the results from the lung (a-d) and liver (e-h) tumor datasets. Figures 2a and 2e show the undersampled images reconstructed using 55-views that are centered at each end-expiratory peak. Figures 2b and 2f show corresponding time frames from STCR reconstructions without respiratory self-gating. Results from respiratory self-gating followed by STCR are shown in Figs 2c and 2g respectively. These images have reduced streaking and blurring compared to both the undersampled and ungated STCR results. The signal intensity time curves for the lesions are shown in Figs 2d and 2h. The curves from the self-gated data are much smoother and the kinetics are unaffected by respiration.

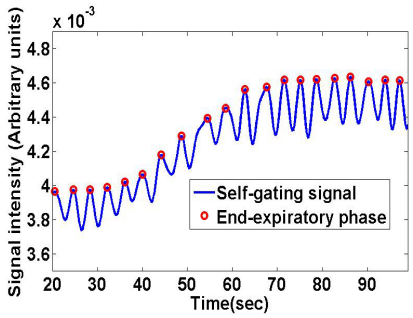
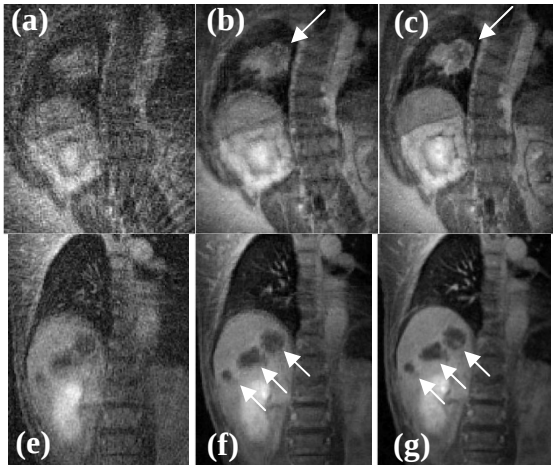
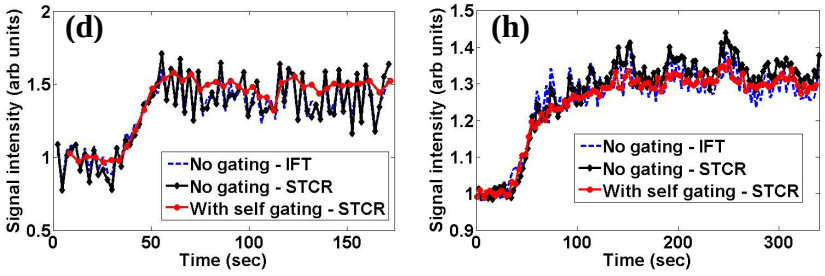


Figure (1). Respiratory self-gating: The self-gating signal is obtained from the peak signal magnitude of each view which crosses kz=0. The red circles at each crest indicate end expiration.

Conclusion: Respiratory self-gating technique using the golden angle acquisition scheme improves the L1 norm constrained reconstructions by reducing the temporal variations due to breathing. The approach offers a promising framework to accelerate DCE-MRI of lesions located in regions severely affected by respiratory motion.





Figure(2).Comparison of reconstructions for lung (a-d) and liver (e-h) tumor datasets. **(a,e)** Images reconstructed using 55 spokes/time frame without any constraints. **(b,f)** Corresponding STCR reconstructions without respiratory self-gating and **(c,g)** with respiratory self-gating. The arrows indicate the locations of the lesions. **(d,h)** Comparison of mean intensity time curves for the tumor ROIs.

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