Retrospective enhancement of radially undersampled cardiac cine MR images using prior image constrained compressed sensing (PICCS)

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INTRODUCTION Cardiac cine magnetic resonance (MR) imaging is increasingly being used for qualitative and quantitative evaluation of cardiac function (1). Normally, cine MR images are acquired during a series of breath holds (8-12 seconds each) through the entire heart. While in most patients this is not a problem, for patients that are extremely ill or that have cardiac MR examinations performed under conscious sedation or anesthesia, these breath holds can be a problem. In these patients, real-time cardiac cine MR imaging (MRI) is performed using k-space undersampling techniques (2,3). Real-time cardiac cine MRI is also useful in patients with arrhythmia where segmented cardiac cine MRI is not feasible. A limitation of real-time cardiac cine MRI is the compromised temporal and spatial resolution relative to segmented cardiac cine MRI studies (4). We introduce a novel image reconstruction method, prior image constrained compressed sensing (PICCS) (5,6), to retrospectively enhance radially undersampled cardiac cine MR images.

METHODS For the PICCS reconstruction algorithm, a composite image is reconstructed from all available projection data without any gating. This blurred prior image is then used to constrain the reconstruction of each individual cardiac phase by iteratively solving the following minimization problem:

$$\text{Min}\ [\ \alpha\left\|\nabla_{m,n}(I-I_P)\right\|_{\ell_1}+(1-\alpha)\left\|\nabla_{m,n}I\right\|_{\ell_1}\ ]\ \text{such that}\ \ AI=P\ .$$

Where the discrete gradient operation is given by the following equation:

$$\nabla_{m,n} I=\sqrt{[I(m+1,n)-I(m,n)]^2+[I(m,n+1)-I(m,n)]^2}$$

and A is the forward projection of the image. The flow chart of the proposed method is schematically shown in Figure 1. Numerical simulations were conducted to validate the PICCS algorithm using 16 projections in each cardiac phase. Both rigid translations and deformations were introduced in numerical simulations. To further demonstrate the potential of the PICCS method, in vivo MRI data acquisitions were also performed. A 2D balanced SSFP real-time radial sequence was used to acquire a series of short-axis images on a 1.5T scanner (Philips Achieva, Best, NL) using a 16 channel coil (Invivo Corporation, Pewaukee, WI). Scan parameters were: TR/TE/flip angle = 3.1ms/1.5ms/60°, FOV = 300mm, and slice thickness = 8mm. 32 frames were acquired with 26 projections per frame. Radial acquisitions of consecutive time frames were scheduled using bit reversal ordering of 8 temporal interleaves. The acquired data were gated using the center of mass method from the projection data.

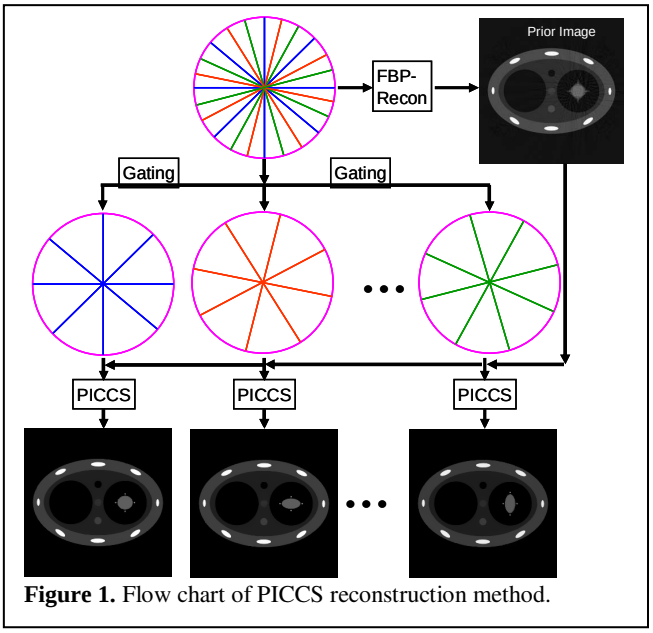

Figure 1. Flow chart of PICCS reconstruction method.

RESULTS AND DISCUSSION

Numerical simulations (Figure 1) demonstrate that the PICCS method enables accurate reconstruction of all motion phases using the blurred prior image and undersampled data sets. Representative reconstructed images from a real-time cardiac cine data set are shown in Figure 2. Radially undersampled data sets reconstructed with FBP result in significantly increased noise and streak artifact. When PICCS reconstruction is used, no appreciable noise or streak artifact is present.

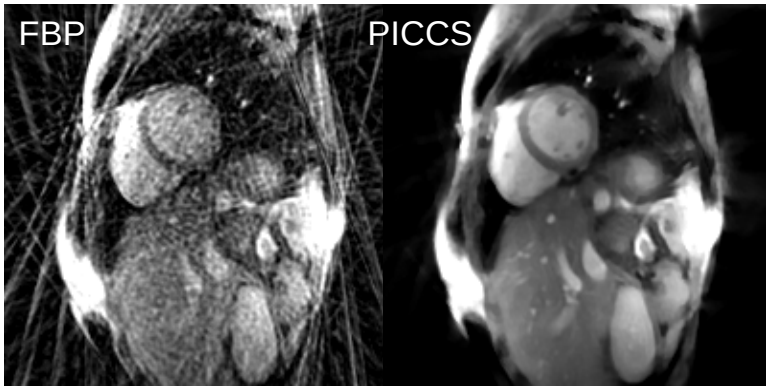

Figure 2. Real-time cardiac cine bSSFP images acquired with radial undersampling (26 projections). Images were reconstructed using filtered back projection (FBP) and PICCS methods. The PICCS image has much less noise than the FBP image and no visible streak artifact.

CONCLUSIONS

Rapid, real-time cardiac cine MRI is very important in patients who are extremely ill, who cannot hold their breath, or have irregular heart rates. This abstract demonstrates the feasibility of using a new reconstruction algorithm, PICCS, to reconstruct radially undersampled cardiac cine MRI images that are of excellent quality. This implies that greater undersampling factors, and therefore greater temporal resolution, could be used to acquire real-time cardiac cine MR images.

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