Parallel Methods for Cardiac Imaging

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INTRODUCTION:

Cardiac MR imaging is challenging due to the simultaneous need for moderately high resolution, ability to image during cardiac and respiratory motion, and relatively low SNR of imaging in the heart at the center of the torso. Additional challenges are caused by rapid susceptibility variation caused by the tissue-air interface between the heart and lung. Parallel imaging offers a means of decreasing acquisition time which offers the user more flexibility to meet these challenges. A "standard" cardiac exam for ischemic heart disease at our site consists of localization, cardiac function, perfusion, and viability imaging. Parallel imaging methods and example images for each of these applications are presented.

Auto-calibrating parallel imaging reconstruction is used with the image domain SENSE method. Performance is measured in terms of artifact suppression and spatially varying SNR losses (g-factor). The performance is strongly determined by the number, size, and position of surface coils. Several custom surface coils for cardiac parallel imaging are used at our site (Nova Medical, Rapid Biomedical, and MRI Devices).

FUNCTION:

Cardiac function is typically measured using cine imaging of the heart with 1-2 mm spatial resolution on a stack of slices covering the full heart. Steady state free precession (SSFP) or TrueFISP is most commonly used to provide high contrast between blood and myocardium. LV volumes and ejection fraction may be quantified and regional wall motion abnormalities are characterized by local wall thickening. In order to acquire sufficient spatial and temporal resolution, the acquisition is frequently segmented over many heart beats acquired during a breath-hold. A challenge is to provide non-breath-held real-time imaging with sufficient spatial-temporal resolution, or to greatly reduce the breath-hold duration. Real-time imaging may also be used in patients with irregular heart beats or extreme difficulty holding their breath. Example real-time TrueFISP imaging at 20 fps 128x88, with SENSE rate 4 is shown in Fig. 1. Example cine TrueFISP imaging at 192x160 with approx 50 ms temporal resolution with 3s breath-hold using SENSE rate 4 is shown in Fig. 2. Both use autocalibrating TSENSE reconstruction, and 8-element linear arrays (Nova Medical) acquired on a 1.5T Siemens Sonata.

Imaging of the full heart in a single breath-hold using 3D imaging, and 2D SENSE with 2-dimensional surface coils arrays has great potential to decrease exam time and provide datasets which minimize multi-slice registration errors due to respiratory motion. An example of single-breathold cine function acquired using a TrueFISP sequence with TSENSE rate 4x2=8 is shown in Fig. 3, using 128x104x20 matrix and discarding 4 slices. This is acquired using a 20 heart-beat breath-hold, achieving 40 ms temporal resolution. These data were acquired using the 32 channel 1.5T Siemens Avanto and prototype 32-element 2D-array (Rapid Biomedical). The measured g-factor in the heart region had mean value approx. 2.0, 90% less than 2.8, and 95% less than 3.2.

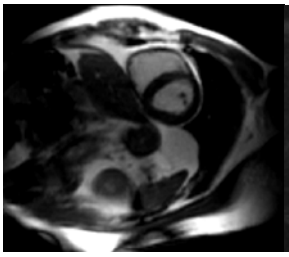

Figure 1.

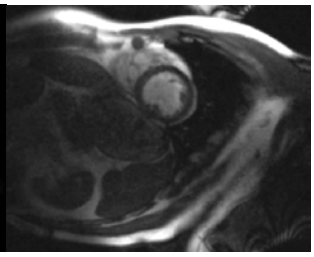

Figure 2.

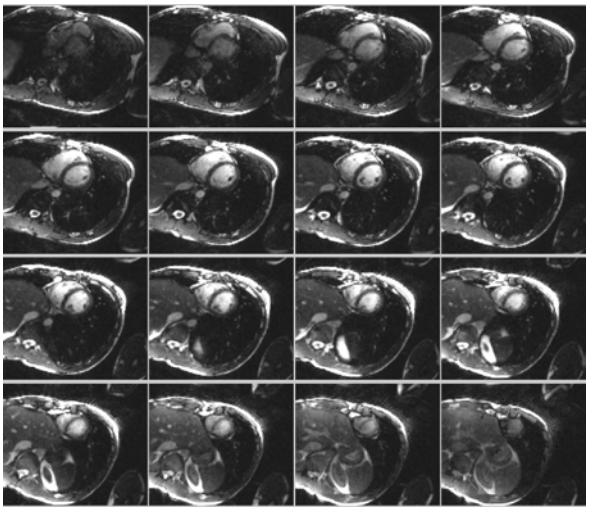

Figure 3.

PERFUSION:

First pass contrast enhanced imaging with single RR temporal resolution for perfusion quantification, and full heart coverage is difficult to attain. Imaging durations must also be kept short to minimize motion related artifacts. Typically, saturation recovery (SR) is used to provide T1-weighted contrast. Parallel imaging may be used to minimize acquisition time, which enables acquisition of more slices and/or 3D imaging, lengthier SR prep time for improved CNR, and/or increased spatial resolution for better visualization of regions with perfusion deficits. The TSENSE auto-calibrating parallel imaging method has been applied to 2D perfusion imaging using SR-TrueFISP, SR-turboFLASH, and SR-GRE-EPI sequences, as well as a 3D perfusion sequence using SR-TrueFISP. Example

images of multi-slice 2D perfusion using SR-GRE-EPI are shown in Fig. 4 for 4 slices, echotrain length=4, and 192x96 matrix (1.5T Siemens Sonata using 8-element array, Nova Medical). An example of 3D perfusion with whole heart coverage is shown in Fig. 5 for SR-TrueFISP sequence with a matrix of 128x80x10 (2 slices discarded) using SENSE with rate 4x2=8 using the 32 channel Siemens Avanto and prototype 32-element 2D array (MRI Devices); 3D images were acquired in approx. 300 ms during mid-diastole.

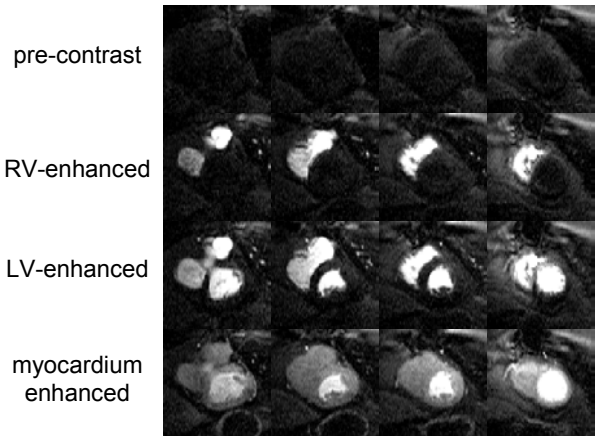

Figure 4.

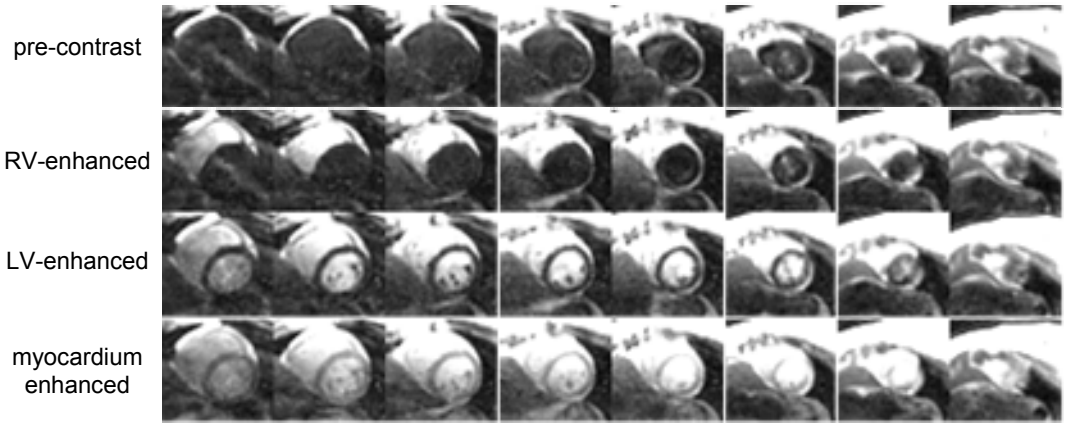

Figure 5.

VIABILITY:

Delayed contrast enhanced imaging is used to detect and characterize myocardial infarction (MI). Parallel imaging may be applied to delayed enhancement imaging for decreased breath-hold duration in conventional segmented scans or to enable single-shot imaging with sufficient spatial resolution for patients with arrhythmias or poor breath-holding ability. Example delayed enhancement images using a phase sensitive inversion recovery (PSIR) sequence are shown in Figures 6 & 7 for segmented turboFLASH and single-shot TrueFISP sequences, respectively, both 2x accelerated using SENSE with 256x128 matrix. These are acquired on a 1.5T Siemens Sonata using an 8-element linear array (Nova Medical). The reference image used for phase sensitive reconstruction and to estimate B1-maps for SENSE was acquired using a low flip angle during alternate heartbeats while the magnetization recovered from the IR preparation. The segmented IR turboFLASH required 6 heartbeats while the single-shot IR TrueFISP required 2 heartbeats. The g-factor in the heart region is typically less than 1.05 for SENSE rate 2 using this 8-element array.

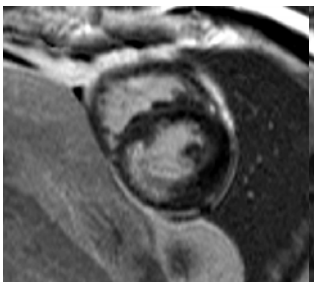

Figure 6.

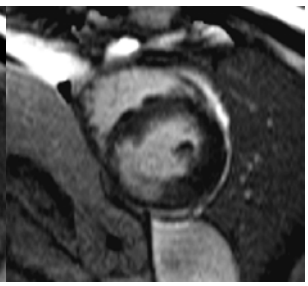

Figure 7.