SENSE Accelerated 3D Imaging of Myocardial Infarction using Phase Sensitive Inversion Recovery

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INTRODUCTION

Following administration of Gd-DTPA, infarcted myocardium exhibits delayed hyperenhancement and can be imaged using a true-FISP (SSFP) sequence. We present experimental results that demonstrate 3-d imaging with phase sensitive inversion recovery (PSIR) acquired in a single breath-hold using parallel MR based on the SENSE method [1]. PSIR has a number of benefits [2] including consistent contrast and appearance over a relatively wide range of inversion recovery times (TI), improved contrast-to-noise ratio, and consistent size of hyperenhanced region.

METHODS

The parallel MR SENSE method is applied to 3d imaging in the phase encode dimension to reduce the number of phase encodes by a factor R=2. In this manner it is possible to acquire the entire 3d volume in a single breath-hold acquisition. Using a true-FISP imaging sequence with rate R=2 SENSE, the complete set of phase encodes (k_y) for each partition encode (k_z) is acquired in a single heartbeat. Using Gd-DTPA with an inversion recovery acquisition sequence it is desirable to use 2 heart beats for almost full magnetization recovery. Therefore, it is possible to acquire a low flip angle readout reference image during alternate heart beats without increasing the breath-hold duration or decreasing the T1 contrast of desired IR image. The sequence timing is illustrated in Figure 1. Phase sensitive cardiac imaging poses unique challenges due to the combination of field inhomogeneity, motion, and low SNR, which make it difficult to obtain a reliable estimate of the background phase and B1-maps. The approach we have taken uses the reference image acquired at the same cardiac phase, during the same breath-hold acquisition during alternate heart beats to estimate both the background phase and surface-coil field maps. This type of acquisition provides a reference image with good spatial resolution and eliminates mis-registration errors due to motion.

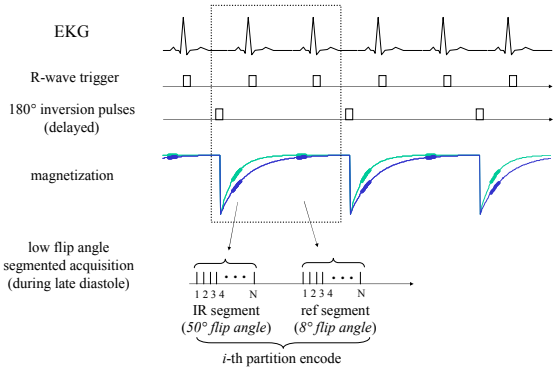

Figure 1. Pulse sequence diagram for gated, segmented *k*-space acquisition of IR and reference images. Data for IR and reference images are collected every other heartbeat with a single partition encode acquired each pair of heartbeats.

All experiments were conducted using a Siemens Sonata 1.5T MR imaging system. Imaging was performed during diastasis (prior to atrial filling) using a gated segmented acquisition of *k*-space over several heartbeats during a single breath-hold. A true-FISP 3d sequence using a 256x128x10 acquisition matrix for both IR and reference resulted in an imaging duration of approximately 180ms per heartbeat for 20 heartbeats total duration including the reference.

The phase and partition encode ordering was sequential with all phase encodes acquired each heartbeat for a given partition encode. The T1-weighted IR image was acquired using a 50° flip angle, while the reference used a 8° flip angle. Typical Imaging parameters are listed in Table 1.

Table 1. Typical Imaging Parameters

scanner:	1.5T Siemens Sonata
pulse sequence:	true FISP
k-space acquisition:	ECG Gated, Segmented
coils:	8-element cardiac phased array (Nova Medical)
resolution:	256 frequencies x 128 phase encodes x 10 partition encodes
TR:	2.8 ms
segment duration:	180 ms (using R=2 SENSE acceleration)
breath-hold duration:	20 heart beats (2 beats per partition)
slice thickness:	8 mm (typical)
RF flip angle:	50° IR image readout (8° for reference image readout)

A simplified block diagram of the phase sensitive SENSE reconstruction is shown in Fig. 2. The T1-weighted IR images were acquired with phase encodes corresponding to FOV/2 spacing, and reconstructed to obtain the full FOV. The reference image was acquired with the same number of phase encoding steps using full-Fourier k-space sampling over the full FOV (or 2x FOV for no-wrap). Thus the spatial resolution of the reference image was approximately ½ the spatial resolution of the IR image (or ¼ for no-wrap reference). The B1-maps derived from the reference images were used for optimal B1-weighted combining [3] to form a complex reference image, and for SENSE processing [1] to form the full FOV IR image.

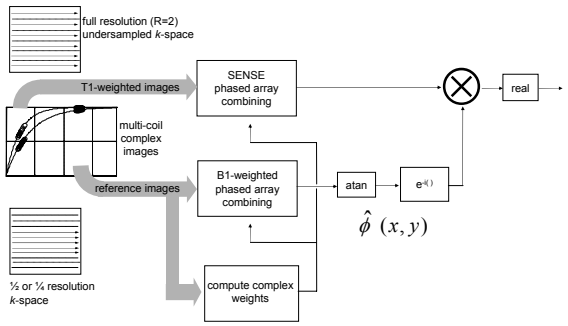

Figure 2. Block diagram showing the phased-array phase-sensitive SENSE accelerated reconstruction of IR image using a separate reference image acquired after magnetization recovery.

Images were acquired from n=6 patients with coronary artery disease under a clinical research protocol approved by the IRB of the NHLBI, with prior informed consent. For the results shown, images were acquired using an 8-element surface coil array (Nova Medical, Inc., Wakefield, MA). Images are shown for 2 patients. The first patient with acute MI was imaged using a 340x340 mm^2 FOV with 256x128 matrix, corresponding to an in-plane resolution of 1.3x2.5 mm^2. The second patient with chronic MI was imaged using a 320x280 mm^2 FOV with 256x150 matrix, corresponding to an in-plane resolution of 1.3x1.9 mm^2. For the second patient, a stack of 2d images acquired using an IR turboFLASH sequence with phase sensitive reconstruction are shown for comparison. The 2d stack are acquired using a breath-hold per slice. For both examples, in the partition encode dimension, 8 slices spaced 8mm were reconstructed from 10 partition encodes, which may be 2x interpolated to 16 slices with 4mm spacing. Images were acquired between 10 and 20 minutes after administering a double dose (0.2 mmol/kg) of contrast agent (Gadopentetate Dimeglumine, Berlex Magnevist). The TI time was set to approximately null the normal myocardium. The use of phase sensitive detection avoids the need to precisely null the normal tissue as is common practice with IR using magnitude detection.

RESULTS

Example images are shown in Figures 3 and 4 for patient with acute MI and chronic MI (microinfarct), respectively. The acquisitions were 15s, corresponding to 20 heartbeats at a heart rate of 80 bpm for Fig. 3, and 19s (HR~63 bpm) for Fig. 4. The SENSE reconstruction is effective in suppressing aliasing with no evident artifacts, and phase sensitive reconstruction has restored the correct polarity of the myocardial signal.

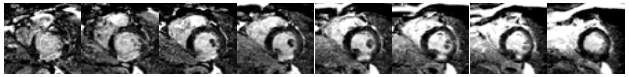

Figure 3. Example delayed hyperenhancement images from patient with inferior MI acquired in single breath-hold using 3d trueFISP IR sequence.

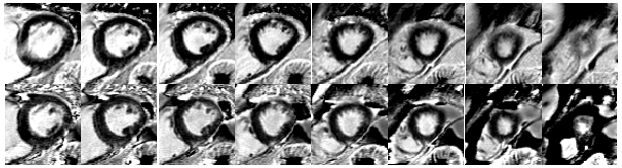

Figure 4. Example delayed hyperenhancement images from patient with chronic MI (microinfarct) acquired using (a) single breath-hold per slice 2d turboFLASH (top row) and (b) single breath-hold per stack using 3d trueFISP IR sequence (bottom row).

CONCLUSIONS

Parallel imaging using SENSE has been used for single breath-hold 3d phase sensitive IR imaging of myocardial infarction. Using SENSE with true-FISP imaging, the 3d acquisition is accomplished with 2 R-R between inversion pulses, as well as using full-Fourier acquisition. Using 2 R-R between inversions leads to almost full magnetization recovery thus improving CNR and reducing sensitivity to R-R timing variation. Full-Fourier phase sensitive IR has an improved point spread function [2] as compared with methods using partial-Fourier acquisition [4] that lead to artifacts. Phase sensitive reconstruction has the additional benefit of TI insensitivity.

REFERENCES

1. Pruessmann P, Weiger M, Scheidegger MB, Boesiger P, SENSE: Sensitivity Encoding for Fast MRI. *Magn. Reson. Med.*, 42(5), 952–62, 1999.
2. Kellman P, et al., *MRM.* 2002 Feb; 47(2):372-83.
3. Roemer, PB, et al., *MRM.* 16, 192-225, 1990.
4. Foo TKF, et al., *ISMRM 10th Annual Meeting* 2002, 1624.