Multi-slice Delayed Hyperenhancement Imaging of Myocardial Infarction using SENSE Accelerated Phase Sensitive Inversion Recovery True-FISP

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INTRODUCTION

Following administration of Gd-DTPA, infarcted myocardium exhibits delayed hyperenhancement and can be imaged using an inversion-recovery sequence [1]. Using a conventional segmented acquisition requires a number of breath-holds to image the heart. Single-shot phase-sensitive inversion-recovery (PSIR) true-FISP may be combined with parallel imaging using SENSE to achieve multi-slice full heart coverage with high spatial resolution [2,3]. PSIR techniques have demonstrated a number of benefits [4] including consistent contrast and appearance over a relatively wide range of inversion recovery times (TI), improved contrast-to-noise ratio, and consistent size of the hyperenhanced region.

METHODS

The parallel MR SENSE method is applied to 2d multi-slice 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 an entire 2d stack of images in a single breath-hold acquisition. Using a true-FISP imaging sequence with rate R=2 SENSE, the complete set of phase encodes for each slice 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. 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 B_1-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.

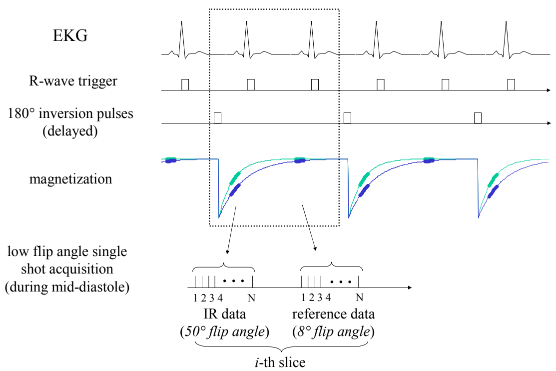

Figure 1. Pulse sequence diagram for ECG triggered single-shot true-FISP acquisition of IR and reference images. Data for IR and reference images are collected every other heartbeat with a single slice acquired each pair of heartbeats.

Infarct imaging was compared using 1) segmented IR-turboFLASH, and 2) multi-slice IR-true-FISP implemented on a Siemens Sonata 1.5T scanner. For both methods, the same spatial resolution (1.4x2.3mm^2), FOV (370x300mm^2), and TI (280ms) were used. A stack of 8 short-axis slices was acquired with 6 mm slice thickness and 3.6 mm gap. The IR-turboFLASH required 16 heart-beat (HB) breath-hold per slice, whereas the IR-true-FISP required a single 16 HB acquisition. Imaging was performed in diastasis with approximately the same acquisition window for both methods.

Typical parameters for the IR-true-FISP sequence were: BW 977 Hz/pixel, TE/TR 1.2/2.7 ms, 50° readout flip angle (8° reference), 256x128 image matrix. Rate=2 SENSE acceleration was used to obtain the full 128 line resolution using 64 phase encodes acquired in a single heartbeat (172 ms window) with 2 R-R intervals between inversions.

Typical parameters for the IR-turboFLASH sequence were: BW 140 Hz/pixel, TE/TR 3.9/8.5 ms, 30° readout flip angle (5° reference), 256x136 image matrix. The phase-encode dimension was slightly oversampled, yielding an effective resolution of 128 lines in this specific example. The 136 phase encodes were acquired in 16 heartbeats collecting 17 lines per heartbeat with 2 R-R intervals between inversions. The segment duration was 145 ms per R-R interval, acquired during diastasis.

A custom 8-element cardiac phased-array (Nova Medical, Inc) was used. A B_1-weighted phased-array combined phase-sensitive reconstruction method was used [4] for all sequences. Images were acquired approximately 20 minutes after administering a double dose (0.2 mmol/kg) of contrast agent (Gd-DTPA, Berlex Magnevist).

Typical imaging parameters are listed in Table 1 for both methods.

Table 1. Typical Imaging Parameters

pulse sequence:	turbo-FLASH	true FISP
k-space acquisition:	ECG gated, segmented	ECG gated, single-shot
resolution:	256 x 136	256 x 128
TE/TR:	3.9/8.5 ms	1.2/2.7 ms
bandwidth:	140 Hz/pixel	977 Hz/pixel
imaging window:	145 ms	172 ms
	17 views per segment	64 views using R=2 SENSE
breath-hold duration:	16 heart beats/slice	2 heart beats/slice
		16 heart beats/ 8 slice stack
slice thickness:	6 mm	6 mm
RF flip angle:	30° IR image (5° reference)	50° IR image (8° reference)

A simplified block diagram of the phase sensitive SENSE reconstruction is shown in Fig. 2. The T_1-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 B_1-maps derived from the reference images were used for optimal B_1-weighted combining [4] to form a complex reference image, and for SENSE processing [3] to form the full FOV IR image.

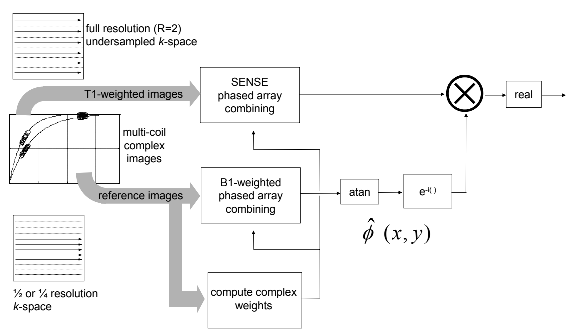

Figure 2. Block diagram showing the phased array phase sensitive SENSE accelerated reconstruction of IR image using a separate reference image acquired after magnetization recovery.

CNR between MI and normal myocardium was calculated using measured signal intensities and pre-scan noise measurement. Measured CNR was compared with values predicted based on simulation of the magnetization during inversion-recovery for both methods.

RESULTS

A stack of short-axis images of the heart for 2 patients with chronic MI are shown in Figures 3 and 4, respectively, acquired using both methods. The measured CNR for the segmented turbo-FLASH method was approximately 2.7 times that of the true-FISP with SENSE which was close to predicted.

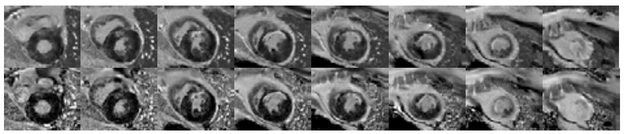

Figure 3. Example delayed hyperenhancement images from 1st patient with chronic MI acquired using single breath-hold per slice 2d turboFLASH (top row) and single breath-hold per stack using multi-slice2d trueFISP IR sequence (bottom row).

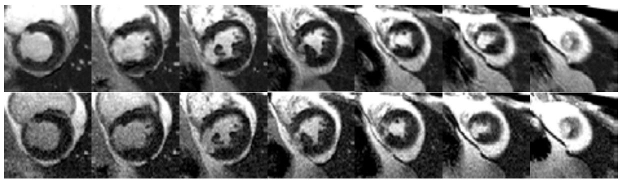

Figure 4. Example delayed hyperenhancement images from 2nd patient with chronic MI acquired using single breath-hold per slice 2d turboFLASH (top row) and single breath-hold per stack using multi-slice2d trueFISP IR sequence (bottom row).

CONCLUSIONS

Multi-slice coverage of the entire heart in a single breath-hold acquisition is possible using SENSE accelerated phase sensitive inversion recovery true-FISP. Using SENSE acceleration, it is possible to use single-shot true-FISP without compromising spatial resolution. Since the single-shot method is insensitive to breathing, the multi-slice acquisition, achieved by catenating several single-shot acquisitions, may be either breath-held for better slice registration, or free-breathing in cases where patients have difficulty holding their breath.

REFERENCES

1. Simonetti OP, et al. Radiology. 2001; 218:215-23.
2. Chung, YC, et al. JCMR 2003; 5(1) ; 40-1.
3. Pruessmann KP, et al. MRM 1999; 42:952-62.
4. Kellman P, et al. MRM. 2002; 47:372-83.