Motion Corrected Free-Breathing Delayed Hyperenhancement Imaging of Myocardial Infarction

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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 high spatial resolution [2,3]. Enhanced SNR may be achieved by averaging multiple motion corrected images acquired during free-breathing. 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

Free-breathing infarct images were acquired for multiple repetitions of a single shot IR trueFISP sequence and averaged to enhance SNR following registration to correct motion. Averaged, free-breathing images were compared with images acquired using a breath-held segmented IR turboFLASH sequence which has become a “standard” approach at our site. Both methods were implemented on a Siemens Sonata 1.5T scanner and used phase sensitive reconstruction [4]. Multiple free-breathing images were motion corrected using a multi-scale, subpixel, intensity based image registration method [5,6]. Image registration was constrained to rigid motion.

For both methods, the same FOV, spatial resolution, and TI were used. The IR-turboFLASH required a 16 heart-beat breath-hold per slice, whereas the PSIR true-FISP required a 2 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. This previously described approach acquires a reference image at the same cardiac phase, during the same breath-hold during alternate heart beats to estimate both the background phase and surface coil B_1-maps. Images were acquired approximately 20 minutes after administering a double dose (0.2 mmol/kg) of contrast agent (Gd-DTPA, Berlex Magnevist).

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

Short-axis images of the heart for a patient with inferior and inferolateral MI and a smaller anterolateral MI is shown in Figure 1 comparing : (a) the “standard” breath-held, segmented IR-turboFLASH, (b) a single free-breathing, single shot IR-trueFISP image, (c) average of 8 repetitions free-breathing without motion correction, (d) average of 8 repetitions free-breathing with motion correction using automatic image registration, and (e) average of 30 repetitions free-breathing with motion correction. The acquisition time was the same (16 HB) for cases in Fig. (a)-(d). In the example of Fig 1, the spatial resolution was 1.4x2.7x6 mm^3 with FOV 350x350mm^2, and TI = 300ms.

Based on simulation, the CNR (MI to normal) for the segmented turbo-FLASH method is predicted to be 2.7 times that of the true-FISP with SENSE for a single frame without averaging. The CNR for the averaged image with 8 avg. (Fig 1d) is improved by $\sqrt{8} \approx 2.8$ yielding approximately the same CNR as the breath-held turboFLASH acquired in the same time. Averaging was extended for 30 images (Fig 2e) acquired in 60 HB to further increase CNR (approx. double that of IR-turboFLASH case) with no visible motion blurring or loss of detail after registration. CNR between MI and normal myocardium was measured for both methods for n=4 patients with chronic MI. The CNR for free-breathing motion corrected IR-true FISP with 8 averages was 0.98±0.16 (mean±SD) times that for breath-held IR-turboFLASH.

Discussion

In the same imaging time as required for a conventional breath-held segmented imaging approach, the new free-breathing method achieves approximately the same spatial resolution and CNR. Using SENSE acceleration, it is possible to use single-shot true-FISP without compromising spatial resolution. Multiple images may be registered and averaged to enhance SNR without discernible motion blurring. This approach overcomes the prior limitation of single shot FISP in detecting smaller infarcts [7]. The smaller anterolateral MI which is difficult to detect without averaging (Fig 1b) is readily discernible after averaging with motion correction (Fig 1d,e).

This method is particularly attractive in cases where patients have difficulty holding their breath. Improved CNR through extended averaging will improve discimination between LV blood pool and subendocardial MI as well as be important at lower contrast doses, reduced slice thickness, or improved in-plane resolution. In the case of long-axis image orientations which have substantial thru-plane motion the method has been modified to automatically discard frames that have large registration error in a similar fashion as retrospective respiratory gating. Preliminary experience with long axis orientation has used approximately 25-30% of the frames. Further improvement in SNR may be achieved by averaging an increased number of frames (beyond the limit of breath-holding).

References

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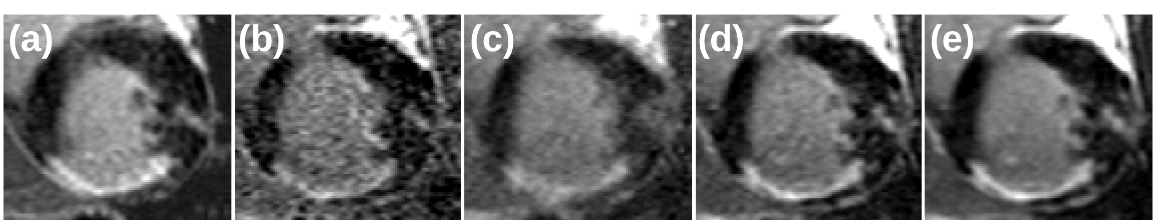

Figure 1. Example images of single SAX slice with inferior and inferolateral MI and a smaller anterolateral MI: (a) “standard” breath-held, segmented IR-turboFLASH, (b) single frame of free-breathing, single shot IR-trueFISP, (c) average of 8 repetitions free-breathing without motion correction, (d) average of 8 repetitions free-breathing with motion correction using automatic image registration, and (e) average of 30 repetitions free-breathing with motion correction.