Artifact Suppression in Delayed Hyperenhancement Imaging of Myocardial Infarction using B1-weighted Phased Array Combined Phase Sensitive Inversion Recovery

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INTRODUCTION

Myocardial viability assessment using Gd-DTPA hyperenhancement MRI is gaining clinical acceptance [1-2]. Using recent MRI methods [3] myocardial infarction may be imaged with high spatial resolution and good contrast. Following administration of Gd-DTPA, infarcted myocardium exhibits delayed hyperenhancement and can be imaged using an inversion recovery sequence.

Oscillations in the transient approach to steady state for regions such as CSF with long T_1 may cause artifacts in breath-held, segmented imaging. B_1-weighted phased-array combining [4] provides an inherent suppression of ghost artifacts. Image reconstruction uses phase sensitive detection with B_1-weighted phased-array combining to optimize SNR. Phase sensitive inversion recovery (PSIR) techniques have demonstrated a number of benefits [5] 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

A B_1-weighted phased array combined phase sensitive reconstruction method was used [5]. 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 field maps. The pulse sequence is illustrated in Figure 1.

The sequence was implemented on a GE Signa 1.5T scanner using the following typical parameters: BW ±31.25 kHz, TE/TR 3.4/7.8 ms, 20° readout flip angle (5° reference), FOV 360x270mm^2, 256x96 image matrix. The 96 phase encodes were acquired in 12 heartbeats collecting 16 lines per heartbeat with 2 R-R intervals between inversions. The segment duration was 125 ms per R-R interval, acquired during diastasis. A standard 4-element cardiac phased-array was used. Images are usually acquired between 10 and 30 minutes after administering a double dose (0.2 mmol/kg) of contrast agent (Gd-DTPA, Berlex Magnevist).

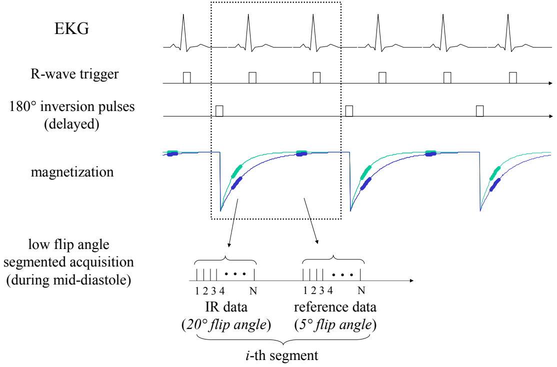

Figure 1. Pulse sequence diagram for ECG triggered, segmented *k*-space acquisition of IR and reference images using low flip angle readouts. Data for IR and reference images are collected alternately every other heartbeat.

A simplified block diagram of the image reconstruction process is shown in Fig. 2. The B_1-maps derived from the reference images were used for optimal B_1-weighted combining [4] to form complex IR and reference images, and for calculating the background phase map for phase sensitive detection.

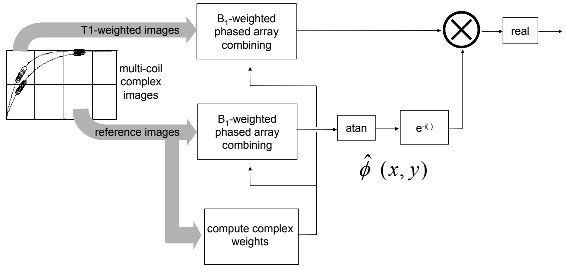

Figure 2. Block diagram showing the B_1-weighted phased-array combined phase-sensitive reconstruction of IR image using a separate reference image acquired after magnetization recovery.

Artifacts due to oscillatory approach to steady state for regions with long T_1 were characterized by calculating a simulated point spread function (PSF). The transverse magnetization vector for each RF readout during the transient approach to steady state was calculated for the IR sequence shown in Fig. 1. The effective *k*-space weighting was calculated from the magnetization for each pulse after accounting for the interleaved order of the segmented acquisition, as well as a single segment discarded acquisition. The point spread function (PSF) was then calculated by FFT of the *k*-space weighting. Normal and infarcted myocardium were simulated as well as CSF. The TI was set to null the normal myocardium. Simulated data are shown in Fig. 3.

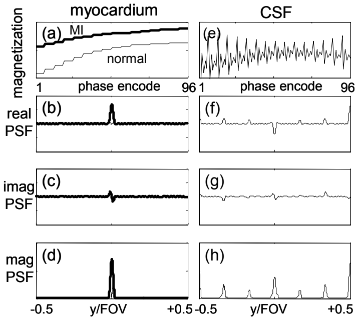

Figure 3. Magnetization amplitude versus phase encode line number after re-ordering and the corresponding PSF for several cases. The left column is for infarcted (bold line) and normal (light line) showing (a) magnetization recovery, and (b-d) the real, imaginary, and magnitude PSF, respectively. The right column is for CSF showing (e) oscillatory approach to steady state which causes substantial artifacts (ghost images equal to the number of segments and evenly distributed across the FOV) as evident in the PSFs (f)-(h). The asymmetric *k*-space weighting due to IR during the segment leads to an imaginary component in the PSF. This imaginary component can cause an edge artifact in magnitude reconstructed images, however, phase sensitive reconstruction which uses the real part will not have this artifact [5].

RESULTS

Long axis images of the heart are shown to illustrate the artifact suppression using B_1-weighted phased-array combining. There is a greater prevalence for this artifact with the 4-chamber view. Root-sum-of-squares magnitude combined and B_1-weighted phased-array combined phase sensitive reconstructions are shown in Figures 4 (a) and (b), respectively. Both magnitude and phase sensitive images were acquired using the same breath-hold data. An artifact may be observed in the magnitude image that is not present in the B_1-weighted phased-array combined phase sensitive image which is reconstructed using the same data. The magnitude images for the individual coils are shown in Figure 5. The artifact is clearly caused by ghosting of the CSF in the spinal cord, and is only evident in the back coils, Fig. 5 (c) and (d). In vivo estimates of the B_1-maps derived from the reference images after almost complete magnetization recovery are shown in Fig. 6. The CSF artifact is suppressed by the B_1-weighting. The suppression was calculated to be approximately 4:1 at D=FOV/2.

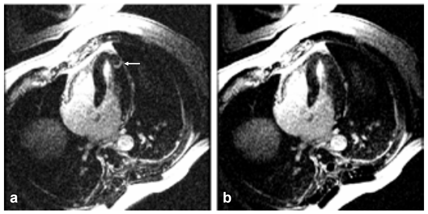

Figure 4. Example long axis delayed hyperenhancement images illustrating (a) artifact in root-sum-of-squares magnitude combined IR image, and (b) suppressed artifact in B_1-weighted phased array combined phase sensitive IR image.

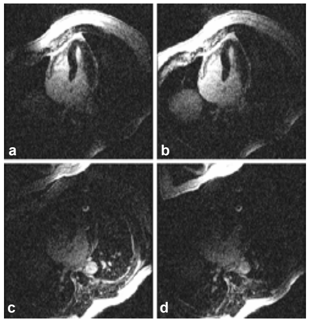

Figure 5. Magnitude images for individual coils illustrating B_1-weighting of ghost artifacts. The artifact from CSF in spinal cord is evident in images from the back coils (c),(d), and is suppressed in chest coil images (a),(b).

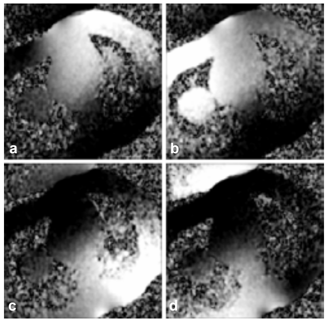

Figure 6. Magnitude of in vivo estimates of B_1-maps for 4-element cardiac phased array.

CONCLUSIONS

Hyperenhancement imaging of myocardial infarction using inversion recovery sequences with breath-held, segmented acquisition may lead to an artifact in regions with long T_1 such as CSF. The CSF artifact is rather small, unlike larger breathing or motion related artifacts, and is less well recognized as an artifact. B_1-weighted phased-array combined phase sensitive reconstruction provides an inherent degree of artifact suppression that is shown to effectively mitigate this artifact.

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