Phase Sensitive Inversion Recovery for Detecting Myocardial Infarction using Gd-DTPA Delayed Hyper-Enhancement

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Introduction

Infarcted myocardium exhibits Gd-DTPA delayed hyper-enhancement [1-3], and may be imaged using an inversion recovery (IR) sequence, typically 10-30 minutes after administration of the contrast agent. Using normal magnitude reconstruction, the contrast is maximized by using an inversion recovery time (TI) which nulls the signal of the normal myocardium.

We present experimental results that demonstrate the utility of phase sensitive inversion recovery image acquisition and reconstruction for detecting myocardial infarction. Phase sensitive detection may be used to remove the background phase while preserving the sign of the desired magnetization during inversion recovery. The use of phase sensitive detection avoids the need to precisely null the normal tissue as is common practice with IR using normal magnitude detection. This obviates the need to make additional measurements in order to determine the precise null time for normal myocardium. This also decreases the sensitivity to changes in the tissue T1 value with increasing delay from injection, which will occur during multi-slice imaging (short axis stack) that may take several minutes to acquire.

Methods

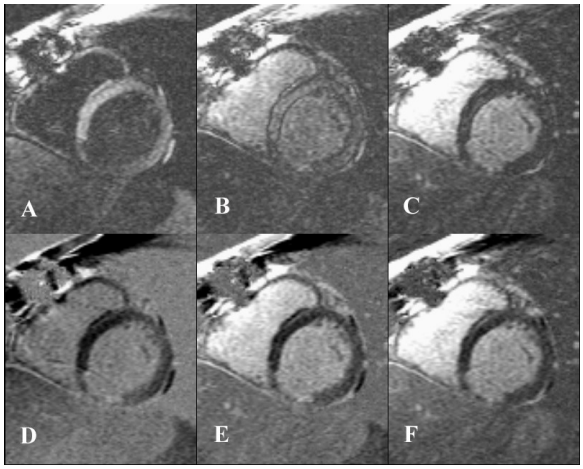
All experiments were conducted using a GE Signa CV 1.5T MR imaging system. For each slice, imaging was performed at late diastole (prior to atrial filling) using a prospectively gated segmented acquisition of *k*-space over several heartbeats during a single breath-hold. Inversion recovery pulses were applied every other heartbeat to permit full recovery of magnetization in the presence of Gd-DTPA. A reference phase map was aquired during the same breath-hold in alternate heartbeats using a reduced flip angle readout. The overall imaging time was not increased by the reference acquisition, and the reference acquisition resulted in only a small loss of magnetization. This reference image was acquired at the same cardiac phase as the IR image after the magnetization had virtually recovered. Therefore, the reference exhibited negligible T1-contrast.

Images were acquired using a 4-element cardiac phased array. A fast gradient recalled echo pulse sequence was used with interleaved phase encode ordering. Imaging of a single short axis slice was performed during each breath-hold using the following parameters: bandwidth ±31.25 kHz, TE=3.4 msec, TR=7.8 msec. The FOV was 360mm x 270mm with an image matrix of 256 x 96, thus the in-plane spatial resolution was approximately 1.4 mm x 2.8 mm. The 96 phase encodes were acquired in 12 heartbeats using 16 views per segment with 2 R-R intervals between inversion pulses. The T1-weighted IR image was acquired using a 20° flip angle, while the reference used a 5° flip angle. Images were acquired at late diastole (delayed approx 600 msec from R-wave ECG trigger). A short axis slice was imaged repetitively using a sequence of TI times (160, 210, 260 msec) starting at 10 minutes after administering a double dose (0.2 mmol/kg) of contrast agent (Gadopentetate Dimeglumine, Berlex Magnevist). The series was repeated 3 times at approx. 5 minute intervals.

Images were reconstructed offline using MATLAB. The complex images for each coil were optimally combined (weighted sum), prior to phase sensitive detection. This resulted in a slight improvement in SNR, as well as in a more accurate estimate of the background phase. The phase of the reference image was removed from the T1-weighted IR image, and, as a result, the real part of the resultant image preserved the polarity of the inversion recovery signal. The complex weights were an estimate of the relative coil sensitivities normalized by the noise standard deviation that was measured during pre-scan. The complex coil sensitivities were estimated using the reference image.

Results

Example single slice, short axis images of the heart reconstructed using both magnitude (top row) and phase sensitive (bottom row) detection are shown in Figure 1, from a single TI series, with TI=160, 210, and 260 msec for columns from left to right. The images for columns from left to right were acquired at approx. 14, 16, and 17 minutes after administering the contrast agent, respectively. Both magnitude and phase sensitive images were acquired using the same data. In this case the normal myocardium is nulled at approx. 260 msec as may be observed in the upper right magnitude image (C). A myocardial infarct in the inferior wall is clearly hyper–enhanced in this image. With TI=160 msec, the blood and infarct are approximately nulled, and the normal myocardium is negative which appears bright in the magnitude image (A). At TI=210 msec, the normal myocardium is still negative, while the blood and the infarct are positive, resulting in similar magnitudes with virtually no contrast between normal and infarcted tissue (B). Phase sensitive reconstructed images (D,E,F), which preserve the signal polarity, maintain excellent contrast over a wide range of TI´s. Using the phase sensitive reconstruction, the contrast was consistently good over a wide range of delays (10-20 minutes) from initial injection.



The magnetization of the desired inversion recovery image is reduced a small amount due to the reference image acquisition. This loss in magnetization was measured using a phantom with T1 values corresponding to both normal and infarcted myocardial tissue. The loss was less than 2% using a 5° flip angle for the reference image. The SNR of the reference image was approximately 8-10 in the myocardial region which corresponds to a rms error of 4-6° in the phase estimate. While this phase noise degrades the SNR slightly, the SNR of the phase sensitive reconstructed images actually has a net gain of 10-15% due to coherent array combining at this low value of SNR.

Discussion

Phase sensitive reconstruction of inversion recovery images provides images with uniformly good contrast between normal and infarcted myocardial tissue over a wider range of inversion recovery times than using conventional magnitude detection. Nominal values of TI may be used, thus avoiding the need to perform additional scans to accurately determine the null point for normal myocardium. The null point is in fact increasing with elapsed time from injection of contrast agent. This increased tolerance has value in a clinical environment, where a stack of 6-8 short axis slices may take 4-5 minutes duration. The same uniformly good contrast was achieved using phase sensitive reconstruction at a nominal value of TI over a wide range of delays from initial injection. With the imaging parameters described above, conventional magnitude images were obtained in the same breathhold which is useful for comparison.

References

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