SNR enhancement of real-time cardiac imaging by respiratory motion corrected averaging

P. Kellman[1], C. Chefd'hotel[2], C. H. Lorenz[3], A. E. Arai[1], and E. R. McVeigh[1]

[1]NHLBI/NIH, Bethesda, MD, United States, [2]Siemens Corporate Research, Princeton, NJ, United States, [3]Siemens Corporate Research, Baltimore, MD, United States

Introduction

Real-time imaging may be used to image cardiac function and flow without breath-holding or ECG triggering, and might be important in patients with congestive heart failure or in pediatric cases. Real-time imaging is also beneficial in cases of arrhythmia which is problematic for conventional gated, segmented cine imaging. However, real-time imaging typically has compromised image quality compared with gated, segmented breath-held studies. The proposed method enhances the SNR of real-time images by means of respiratory motion corrected averaging. The proposed approach provides high quality real-time function using fully automated post-processing.

Methods

Real-time imaging was performed on 1.5T Siemens Avanto and wide-bore Siemens Espree scanners, using an SSFP sequence. Parallel imaging was used to provide rate 4 acceleration using TSENSE [1]. For the Avanto with 200 T/m/sec max slew rate, the temporal resolution was 35 ms for 128x60 matrix, BW=1395 Hz/pixel (TR=2.3 ms), and was 56 ms for 192x80 matrix with BW=1000 Hz/pixel (TR=2.8 ms). For the Espree with 100 T/m/sec max slew rate, the temporal resolution was 44 ms for 128x60 matrix, BW=1150 Hz/pixel (TR=2.9 ms), and was 65 ms for 192x80 matrix with BW=814 Hz/pixel (TR=3.25 ms, asymm echo). Images were reconstructed on-line, and were post processed off-line using MATLAB®. Raw data and ECG log files were saved for analysis of ECG triggering, and for calibrated SNR measurement [2].

A non-rigid registration was performed on the full time series of images and the motion field was extracted to provide an image based navigator derived from a region of interest in the liver. Images and the image-derived navigator signal were retrospectively cardiac gated using ECG triggers embedded in the raw data (Fig. 1). Cardiac self gating could alternatively be used in cases without ECG. For each cardiac phase, the multiple images at various respiratory positions were registered with a reference image of the same cardiac phase which had the most frequent respiratory position, based on histogram analysis of the navigator signal. Registered images were then averaged for each cardiac phase.

Registration was performed pairwise between the original and reference images. For each pair, the algorithm [3] estimates a deformation that maximizes the local cross-correlation between the reference and the uncorrected image. The local cross-correlation criterion was selected for its robustness to intensity changes, signal inhomogeneities, and noise. The resulting algorithm is intensity-based and does not require the extraction and selection of anatomical landmarks. A deformation is modeled as a smooth vector field that gives for each pixel on the reference its corresponding location on the second image. The algorithm recovers the deformation by composition of small displacements, incrementally maximizing the similarity criterion. This process, which can be seen as the numerical implementation of a transport equation, provides a large capture range. The smoothness of the deformation is imposed by applying a low-pass filter to the vector field increments.

Acquisitions were 16sec in duration, allowing for approx. 16 averages depending on the heart rate. To characterize the performance of image registration, the standard deviation of edge positions (4 endo- and 4 epi-cardial edges) in intensity profiles through the LV myocardium was measured for motion corrected images across all heartbeats at both end-diastolic and end-systolic phases (example profiles shown in Fig 2). SNR was compared in images with and without averaging in 4 myocardial ROIs.

Results

Images were acquired & processed for both normal volunteers (N=2) and patients (N=4) with chronic myocardial infarction. Real-time images are shown for end-diastolic and end-systolic phases with and without averaging for comparison (Fig. 3). These images used a matrix size of 192x80. The average myocardial SNR improved with averaging within several percent of the expected $\sqrt{N_{avg}}$ gain. The standard deviation of edge positions was 0.26±0.16 pixels (for all 8 edges x 2 phases x 6 subjects). The regional wall motion abnormalities apparent on the original images were also apparent on the motion corrected averaged images in the 4 patients.

Discussion

Motion corrected averaging of real-time cardiac images provides significant SNR enhancement without apparent loss of resolution on all subjects studied. A similar approach has been validated for delayed enhancement imaging at a single phase [4,5]. The free-breathing acquisition may be extended in duration to gain further SNR.

References

[1] Kellman P, et al., MRM. 2001 May; 45(5):846-52.
[2] Kellman P. et al., MRM 2005 Dec;54(6):1439-47.
[3] Chefd'hotel C, et al., IEEE ISBI 2002.
[4] Kellman P, et al., MRM. 2005; 53(1): 194-200.
[5] Ledesma MJ, et al, SCMR 2007.

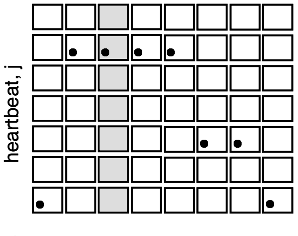

Fig. 1. Schematic diagram illustrating real-time images after retrospective cardiac gating. A reference indicated by ● is selected for each cardiac phase (column) used to register all heartbeats at that phase.

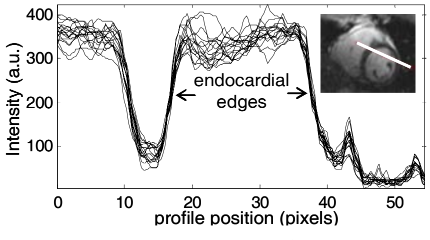

Fig 2. Example intensity profiles across LV of motion corrected images for 16 heartbeats at end-diastole.

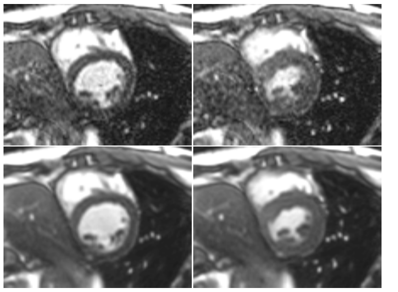

Fig 3. Real-time images for patient with chronic MI with respiratory motion corrected averaging (bottom) and without averaging (top) for end-diastolic (left) and end-systolic (right) phases (N=15 heartbeats averaged).