High resolution retrospective reconstruction from real-time acquired cine MR images

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Introduction

Real-time cardiac cine imaging typically has compromised image quality compared with gated, segmented breath-held studies. The proposed approach produces high quality cine images with high spatial and temporal resolution matching that of conventional segmented cine using fully automated retrospective reconstruction with real-time acquired image data.

Methods

High temporal resolution retrospective reconstruction of cine MRI was performed using data acquired in real-time over multiple heartbeats during free-breathing. High spatial resolution images with a temporal resolution of approx. 110 ms were acquired in real-time. Over multiple heartbeats, the cardiac cycle fills in with phase encode samples (Fig 1) to allow higher temporal sampling. The k-space samples were re-binned retrospectively after respiratory motion correction to enable true high temporal resolution reconstruction without view sharing. In the results presented, images were reconstructed with a temporal resolution of 33 ms with a heart rate of 60 bpm. An image based respiratory navigator signal [1] derived from the low resolution real-time acquired images was used for respiratory gating with an acceptance window of 25% of the full scale image based navigator signal. The lower temporal resolution real-time acquired images were also used to calculate the motion field for sub-pixel in-plane respiratory motion correction. In the proposed scheme (Fig 2), in-plane warping is performed and the resulting images are transformed back to k-space for temporal re-binning and respiratory gating. The image based navigator calculation and respiratory motion correction used a non-rigid registration algorithm [3] to correct the full-FOV automatically.

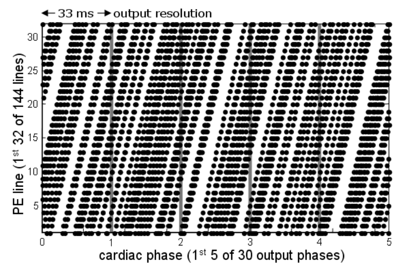

Fig 1. Illustration of k-space filling showing k-space samples (zoomed to show 1st 32 of 144 PE lines, and 1st 5 of 30 output cardiac phases) acquired over 60 s with initial temporal resolution of 110 ms and final resolution of 33 ms (at 60 bpm).

Real-time imaging was performed on 1.5T Siemens Avanto and wide-bore Espree scanners, using an SSFP sequence. Parallel imaging was used to provide rate 4 acceleration using TSENSE [2]. For the Espree with 100 T/m/sec max slew rate, the initial temporal resolution was 110 ms for 256x144 matrix, BW=977 Hz/pixel (TR=3.1 ms). Images were acquired continuously without ECG gating for 60s during free-breathing. Retrospective images reconstruction from raw data with embedded ECG timing data was performed off-line using MATLAB®. Conventional breath-held segmented SSFP cine imaging with the following parameters was used for comparison: matrix=256x156, views-per-segment=10, TR=3 ms, BW=930 Hz/pixel, temporal resolution=30 ms, with 30 phases calculated retrospectively, rate 2 parallel imaging, and 11 heartbeat breath-hold duration.

Image quality was assessed using a 5 point scale with conventional and new methods presented in a blinded, randomized manner. The rating was based on (a) SNR and image artifacts, (b) readability of global function, (c) readability of regional function, and (d) ability to discern fine details. A score of 5 corresponded to excellent and 1 to non-diagnostic.

Results

Images were acquired and processed for N=10 patients. Images (Fig 3) are shown for end-diastolic and end-systolic phases comparing conventional and proposed methods. The maximum increment in cardiac phase between k-space samples was 0.02±0.008 cardiac cycles (m±SD, N=10) for 60 sec acquisition, with and average of 7.9±2.4 PE lines per output phase bin after respiratory gating. The average SNR improvement is $\sqrt{7.9} \approx 2.8$. The proposed free-breathing method was compared with conventional breath-held cine images in 10 subjects. The resultant image quality for the proposed method (4.2±0.4) was comparable to the conventional cine (4.45±0.5) on a 5 point scale (p = n.s.).

Discussion

The proposed method provides a means of attaining high quality cine images with many of the clinically important benefits of real-time imaging, such as free-breathing acquisition and tolerance to arrhythmias. The proposed method was validated at ~30 ms temporal resolution but could be implemented at higher effective temporal resolution.

References

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[3] Chefd'hotel C, et al., IEEE ISBI 2002.

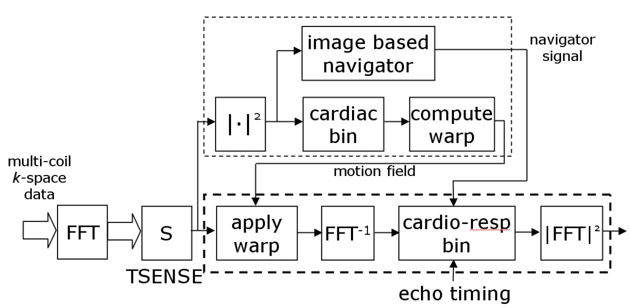

Fig 2. Simplified processing diagram for high resolution retrospective reconstruction of real-time acquired cine MR images.

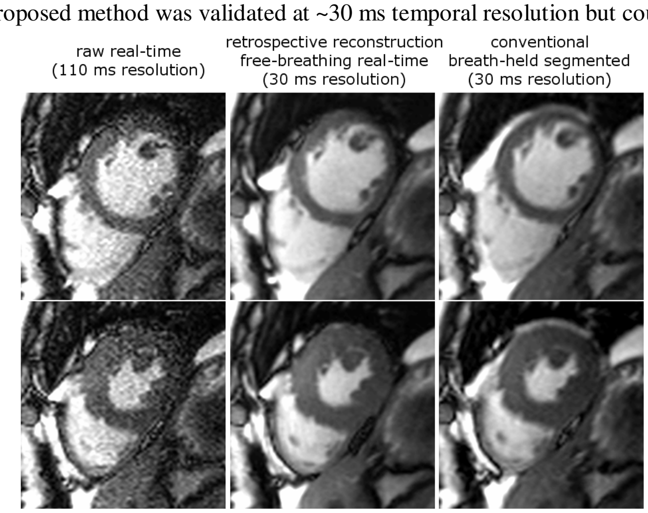

Fig 3. Comparison of raw real-time acquired images (left), retrospective reconstructed (center), and conventional (right) cine images.