Retrospective Reconstruction of Cardiac Cine Images from Golden-Ratio-Radial MRI using 1D Navigators

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Target Audience – Researchers using radial trajectories for cardiac imaging.

Purpose – Recent advances using radial trajectories for retrospectively gated cardiac imaging[1,2] have demonstrated the advantage of motion robust radial *k*-space center oversampling for the acquisition of dynamic images. However, a reliable trigger signal is always required for cardiac gating in order to ascribe the radially acquired data to the phases of the cardiac cycle. In this work, we describe a continuous radial data acquisition using rotation angles based on the golden-ratio. Retrospective gating was performed based on 1D navigator data that periodically acquire a projection of the measurement slice[3].

Methods – A single slice sequence with radial readouts and rotation angles based on the golden-ratio[4] was implemented in ODIN[5]. To ensure an optimal distribution of the radial readouts during *k*-space filling the number of radial readouts corresponded to a Fibonacci number. 1D navigator readouts acquired with a fixed rotation angle of 0° in the same measurement slice were interspersed with the continuous radial data acquisition, using the same repetition time (TR) as the golden-angle data. Navigators were interspersed with a frequency of 35.7 Hz.

For retrospective gating each navigator was 1D-Fast-Fourier-Transformed along the readout direction, obtaining a projection of the measurement slice. Following coil channel combination correlation analysis was performed between all navigator readouts, obtaining a 2D correlation matrix $r_{k,j}$. Each row of the correlation matrix can theoretically be used for retrospective gating; however, for a high gating accuracy a correlation function $r_k(j)$ featuring distinct peaks was found to be advantageous. Therefore, the correlation function with the highest power spectrum of the non-zero frequency components was automatically selected. Finally, peaks in this selected correlation function were identified by using first order difference information to detect rising edges. Detected peaks were used as synthetic trigger to synchronize data windows with the cardiac phases.

All images were acquired on a 3T clinical scanner (TIM Trio, Siemens Healthcare) using the vendor supplied body and spine coils. Experiments were performed on healthy volunteers aged between 25 and 35 during breath-hold periods of up to 26 seconds. Cardiac short axis measurements were performed using the following parameters: FOV 245 x 245 mm², matrix 144 x 144, radial readouts 233, TE 1.5 ms, TR 2.7 ms, 12° FA, Bandwidth 140 kHz, 6 mm slice thickness, 69 readouts per data window, 23 TR data window shifts for each frame. Breath-hold durations were artificially reduced by omitting data at the end of the measurement. Parameters for an aortic valve measurement were identical except for a reduced FOV of 216 x 216 mm², data window width of 36 readouts per window and a data window shift of 12 TR per frame. For comparison vendor supplied ECG electrodes were attached logging the ECG together with a synchronization time signal of the sequence.

Results – Based on the correlation of the navigator projections a stable cardiac trigger signal could be successfully extracted (Fig. 2). Even by reducing the navigator frequency to 8.9 Hz a reliable trigger signal was still obtained. Compared to ECG (Fig. 3a) the correlation peaks were broader and shifted in time. Nevertheless, stable data window positions could be defined without noticeable differences in the final image quality between ECG and navigator based reconstructions (Fig. 3b and Fig. 3c). Images of the systolic motion of the aortic valve were acquired with a high in-plane resolution of 1.5 x 1.5 mm² and temporal resolution of 33 ms (Fig. 4a). For a cardiac short axis acquisition (Fig. 4b) with resolution of 1.7 x 1.7 mm² acquisition time could be shortened to 8 seconds with sufficient CNR of 25 between myocardium and the left ventricular cavity.

Discussion & Conclusion – The proposed navigator acquisition and correlation analysis between projections of the measurement slice enable a reliable estimation of data window positions for retrospective triggering of continuously acquired golden-angle radial data. Although comparison with ECG showed slightly different waveforms with reduced temporal resolution, synchronization with any particular ECG segment is not necessary for cine reconstruction. The continuous golden-angle based data acquisition as well as the TR preserving navigator acquisition enables high flexibility in parameter selection, such as acquisition time, navigator frequency and data window width, enabling parameter adjustment tailored to individual measurement challenges. Finally, navigator analysis was performed fully automated without any user interaction using computationally efficient and fast 1D FFT and correlation analysis.

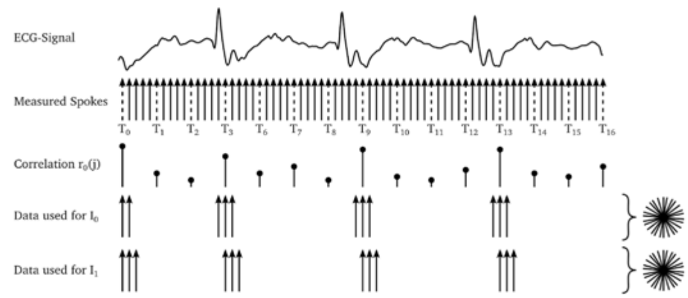

Fig. 1. Data and navigator acquisition scheme showing the periodically acquired navigator projections T_j which are used for correlation analysis $r_0(j)$ and data windowing for reconstruction of images I_n.

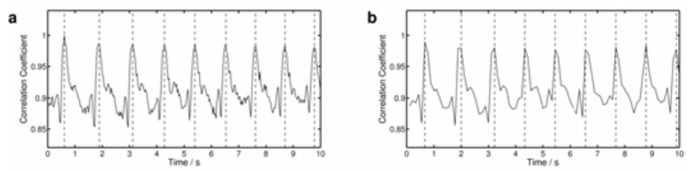

Fig. 2. Correlation functions for a navigator spoke showing the first 10 seconds of an aortic valve cross section. The correlation functions were obtained using the measured navigator frequency of (a) 35.7 Hz and an artificially reduced frequency of (b) 8.9 Hz.

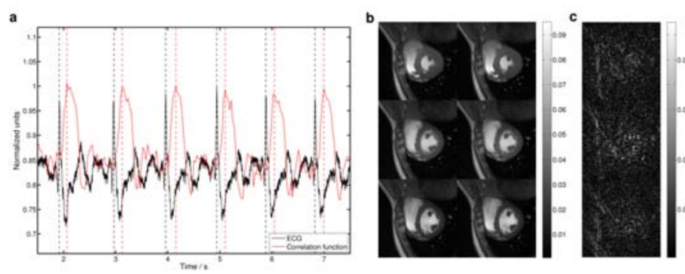

Fig. 3. Calculated correlation function (red curve in a) overlaid with timely synchronized ECG data (black curve in a) together with 3 frames reconstructed based on the 1D navigators (left column in b) and the ECG data (right column in b). Also displayed are the difference images between ECG and 1D navigator based image reconstruction

Fig. 4. Cardiac images showing (a) 7 consecutive frames (left to right) of the closing motion of an aortic valve cross section and (b) a short axis view showing 6 out of 20 reconstructed images for breath hold durations of 8, 14 and 26 seconds.

References – [1] Kolbitsch C, et.al., Magn Reson Med, 2013;Epub ahead of print [2] Usman M, et.al., Magn Reson Med, 2013;70:504-516; [3] Krämer M, et.al., J Magn Reson Imaging, 2013;Epub ehad of print [4] Winkelmann S, et.al., IEEE T Med Imaging 2007;26:68 –76. [5] Jochimson TH, et.al., J Magn Reson, 2004;170:76-7