Image-based self-navigator using cardiac functional parameters for cine imaging

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INTRODUCTION: MR cine imaging can provide important functional cardiac information such as ventricular volume or ejection fraction [1]. Commonly CINE data is acquired with a segmented retrospectively gated approach using an external ECG signal. Nevertheless, the ECG signal can be negatively impaired due to the MR environment or patient's pathology [2]. Cardiac self-navigators have been proposed to overcome this problem [3]. They mainly rely on the amplitude changes of k-space data due to flow or volume changes of the blood. All of these approaches derive a gating signal from signal changes which are correlated with cardiac motion but do not measure the movements of the ventricle directly.

Here we propose a new technique which uses real-time imaging data to derive a gating signal directly from cardiac function. This signal allows for the retrospective combination of data from different cardiac cycles. In contrast to standard cine imaging, data acquisition with this approach is highly flexible and does not require a prospective setting of cardiac phases or arrhythmia rejection techniques.

METHODS: Image acquisition: A Golden angle 2D radial trajectory was implemented on a 1.5T MRI scanner (Philips Healthcare) allowing for retrospective reconstruction with different temporal and spatial resolution (Fig 1a) [4]. Short axis images at 3 different positions in the left ventricle (LV) were acquired in five healthy volunteers: balanced SSFP sequence, FOV: 320mm^2, 2mm in plane resolution, flip angle: 60^o, TR/TE = 3.0/1.49ms. Real-time images and retrospective gated cine images were reconstructed using a non-Cartesian iterative SENSE reconstruction [5] by estimating the coil sensitivity maps from the image data itself.

Gating signal: The cardiac gating signal was determined as the maximum of the systolic contraction, i.e. the smallest LV blood pool diameter. For this, real-time images (I_n) were reconstructed with a temporal resolution of 24ms (16 radial lines) using a sliding window approach (window shift of 8 radial lines) (Fig 1b). In these images the mean diameter of the blood pool in the LV is determined by calculating the full width at half maximum (FWHM) along radial lines through the LV blood pool (Fig 1c). From this signal the maximum point of systolic contraction (S_n) is determined by fitting a polynomial to each systole separately and determining the minimum of this fit (Fig 1d).

In order to compare the accuracy of the gating signal obtained from the blood pool to standard ECG data, each slice was acquired over a 18s breathhold. The standard deviation between S_n and the R-peaks determined by the MR scanner from a standard ECG signal were used as a quality measure. In contrast to Winkelmann et al. [4] the obtained cardiac signal was used to retrospectively reorder the obtained data, i.e. data from different cardiac cycles but the same cardiac phase are retrospectively combined (Fig 1e) for the final image reconstruction. This allowed the reconstruction of 50 cardiac phases each from 120 radial lines (sliding window approach, window shift of 60 radial lines) which have the same high temporal resolution as the real-time images but without noticeable undersampling artefacts. Due to the sampling properties of the Golden Angle acquisition, the number of cardiac phases can be set arbitrarily.

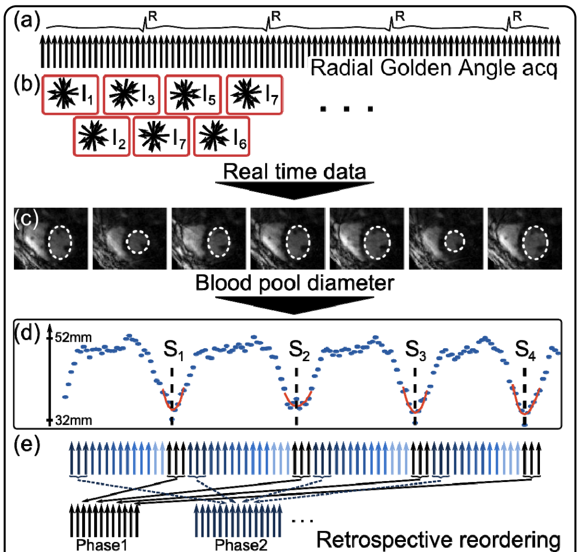

Fig. 1(a) 2D radial Golden Angle data is acquired continuously over several heart beats. (b) A sliding window reconstruction is used to obtain real time data. (c) The diameter of the blood pool in the left ventricle (white line) is determined in each image. (d) The change of the diameter over time is used as a cardiac gating signal and the maximum of systolic contraction (S_i) is used as reference points (blue dots: measured blood pool diameter, red line: polynomial fit to systolic minima). (e) The acquired profiles are reordered based on the blood pool signal and images with both high temporal and spatial resolution are reconstructed.

RESULTS: The blood pool signal in Fig. 1d shows clearly fast systolic contraction and a flattening of diastolic expansion towards end-diastole. The standard deviation between S_n and the R-peaks from the ECG signal over all subjects was 16.5ms, which is below the temporal resolution of the blood pool signal. Retrospectively gated CINE images using the blood pool signal are shown in Fig. 2.

CONCLUSION: We have presented a method which derives a cardiac image-based navigator directly from the motion of the left ventricle with accuracies below the temporal resolution of the real-time data. The obtained gating signal would allow not just for the detection of cardiac arrhythmias but also for their quantification. Furthermore, the highly flexible data acquisition yields not just retrospectively gated cine images from data acquired in regular cardiac cycles but also high quality real time images showing irregular heartbeats could be obtained. This could yield further information to characterise the heart functionality of arrhythmia patients. A reliable gating signal can only be obtained if the blood pool is visible throughout the cardiac cycle. To overcome this limitation a multislice radial CAIPIRINHA acquisition [6] is being investigated to excite one slice for data acquisition and one slice as a cardiac navigator slice simultaneously.

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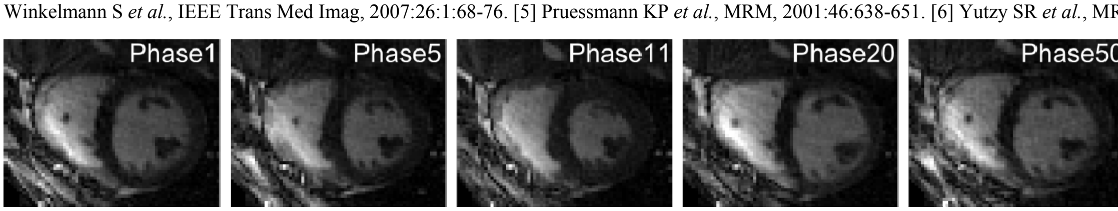

Fig. 2: 5 Selected cardiac phases of the retrospectively gated cine images reconstructed using a cardiac navigator signal obtained from the blood pool of real time images. Temp resolution: 24ms.