Coronary Endothelial Function Assessment Using Self-Gated Cardiac Cine MRI with golden angle acquisition and k-t Sparse SENSE

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PURPOSE: The endothelium plays a major role in maintaining homeostasis and regulating vascular tone by responding to various hormones, neurotransmitters, and vasoactive factors.[1] Disruption of this normal vascular function, known as endothelial dysfunction, can lead to pathological inflammatory processes and cardiovascular disease. Recent studies have demonstrated that the coronary endothelial function (CEF) can be assessed non-invasively and with excellent reproducibility by measuring the vasoreactivity of the coronary arteries in response to isometric handgrip exercise using bright blood cine magnetic resonance imaging (MRI).[2,3] However, bright blood cine MRI generally requires the use of an external electrocardiography (ECG) signal to synchronize the data acquisition with the cardiac cycle; a limitation which has several drawbacks: a) the ECG signal is susceptible to the magnetohydrodynamic effect, RF interference and to the rapid switching of magnetic field gradients, b) the detection of the R-wave in patients with arrhythmias is challenging due to different wave heights and RR intervals, and c) the number of cardiac phases is commonly pre-defined at the time of acquisition. To address these shortcomings, we propose a cardiac self-gated technique that combines golden angle radial data acquisition with compressed sensing and parallel imaging (sparse SENSE[4]) to reconstruct cardiac cine MR images without the need of an external ECG signal. We hypothesize that our proposed framework can accurately assess CEF and provide results equivalent to those of the standard ECG-gated technique, while also being robust against the ECG fluctuations caused by arrhythmia.

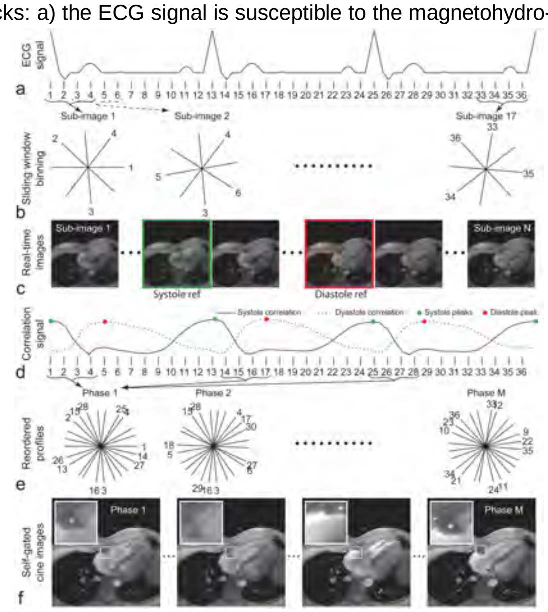

Fig. 1: *Conceptual illustration of the key steps of the proposed framework. See main text for details.*

METHODS: ***Data acquisition:*** Data were acquired from 16 healthy adult volunteers (age 26 ± 4 years, 8 males) on a 3T clinical scanner (MAGNETOM Prisma, Siemens Healthcare) using a free running 2D golden angle radial trajectory (Fig. 1a) with an 18-channel chest coil and a 32-channel spine coil. The imaging plane was placed perpendicular to a proximal linear segment of the right coronary artery (RCA) identified by a double oblique scout scan.[5] The relevant imaging parameters include: FOV=260×260 mm^2, 416 readout points for each radial line, reconstructed pixel size = 0.6×0.6 mm^2, slice thickness = 6.5 mm, TE/TR = 2.7/5.9 ms, radiofrequency excitation angle = 22°, and breath-hold duration ~ 20 s. As a standard of reference and for quantitative comparison, a conventional 2D radial retrospective ECG-gated sequence was also acquired with the same parameters. ***Cardiac self-gating signal estimation:*** Non-ECG triggered real-time images (Fig. 1c) with 37 ms temporal resolution were first reconstructed using a sliding window approach (Fig. 1b). These highly undersampled sub-images were reconstructed with a k-t sparse SENSE model using the wavelet transform and total variation for spatial and temporal regularization.[6] From these sub-images, a systolic and diastolic reference frame (Fig. 1c) were selected to compute the Pearson correlation coefficient (Fig. 1d), with all other sub-images chosen from a user selected region of interest around the heart. An in-house arrhythmia detection and rejection algorithm ensured that each systole peak was followed by a diastole peak. ***Reconstruction of self-gated cine images:*** The self-gating signal was derived from the systole correlation signal and used to retrospectively reorder the radial profiles into cardiac phases (Fig. 1e). Self-gated cardiac cine images with high-spatial and high-temporal (23 ms) resolution were reconstructed using the above mentioned k-t sparse SENSE model (Fig. 1f). ***Functional assessment:*** Self-gated and standard ECG-gated cine images were acquired both at rest (baseline) and during isometric handgrip exercise, and analyzed to measure the cross-sectional area changes of the RCA. In volunteers where electromagnetic field interference did not corrupt ECG triggering, the heartbeat-to-heartbeat trigger variation was correlated between the proposed self-gating technique and the conventional ECG-gating approach.

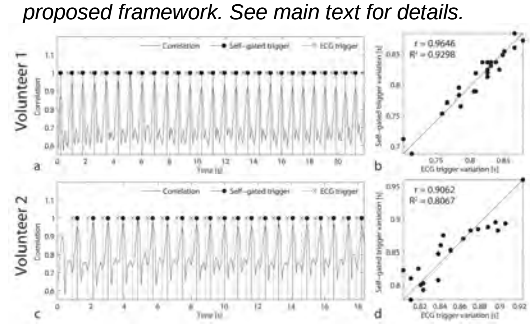

Fig. 2: *(a,c) Systole correlation signal with the detected self-gated and ECG triggers for two different volunteers. (b,d) Correlation of the heartbeat-to-heartbeat trigger variation between both approaches.*

RESULTS: Data acquisition, reconstruction, and endothelial functional assessment were successfully carried out in all volunteers. Comparison of the trigger variation between self-gating and ECG-gating demonstrated a high correlation (average R^2=0.84). Fig. 2 shows an example of the best (a,b) and worse (c,d) correlations. As depicted in Fig. 3, our self-gated approach yielded high-quality cine images with excellent depiction of the cardiac phases and the RCA. Unlike the standard ECG-gated approach, our technique was also robust against arrhythmias and permitted measurements of the cross-sectional area of the RCA (arrows in Fig. 3b). Furthermore, the vasoreactivity measurements from the self-gated cine images were in good agreement (R^2=0.83) with the standard ECG-gated imaging approach (Fig. 3c).

DISCUSSION: The proposed framework takes advantage of the golden angle trajectory and k-t sparse SENSE reconstruction to enable flexible retrospective selection of cardiac phases and to eliminate the need of an external ECG signal. In addition, the technique enables robust detection of arrhythmia and rejection of the corrupted radial profiles to improve the final image quality. We also demonstrated that our framework provides reliable measurement of coronary endothelial function equivalent to the standard ECG approach without the need for an external ECG signal.

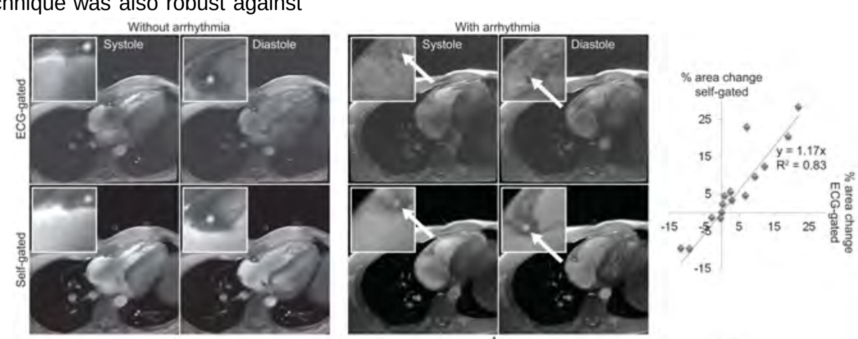

Fig. 3: *Comparison of ECG-gated and self-gated cine images for data (a) without and (b) with arrhythmias. Area change measurements in % are shown in (c).*

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