Improved cardiac motion self-gating

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Purpose: Cardiac motion self-gating is a technique where MRI signal, instead of ECG, is used to trigger the segmented K-space acquisition. It is especially important in cardiac MRI applications where ECG is unreliable (e.g. high field) or even inaccessible (e.g. fetal cardiac imaging). However, the existing cardiac self-gating approaches have not yet enabled clinical utility. We propose and evaluate a novel cardiac self-gating method, aiming to improve the cardiac trigger detection accuracy and reliability.

Methods: Conventional cardiac self-gating uses the k-space center from a radial acquisition to represent the cardiac motion[1]. However, the acquired motion signal by this method suffers from drifting and distortion shown in Fig.2a, making it difficult to derive reliable cardiac triggers. The hypothesis is that since the cardiac motion signal acquisition was combined with the imaging acquisition, it is modulated by the eddy currents from the varying phase-encoding (PE) or radial acquisition gradients during imaging.

To reduce the signal interference associated with existing self-gating techniques, we propose a self-gating approach where the data acquisition switches between imaging mode and self-gating mode as shown in Fig. 1. We implemented a custom prospectively ECG triggered cardiac cine pulse sequence by adding multiple dedicated self-gating acquisitions at the end of each imaging window. During the self-gating mode, the pulse sequence is the same as the imaging mode except the phase-encoding gradient is turned off so that the center k-space line is repeatedly acquired. To validate our self-gating approach and compare with the ground truth ECG triggers, the sequence is prospectively triggered by ECG for every two heartbeats and the self-gating mode duration was set long enough to cover the ECG R wave of every other heartbeat so that the calculated self-gating triggers can be verified against the corresponding ECG R wave (Fig.1). Our custom cardiac cine sequence was performed on 4 healthy volunteers with 22 total breath-held cine scans to cover different slice orientations. The self-gating raw data was exported offline for processing and real-time ECG signal and trigger was recorded as the ground truth. We use Principle Component Analysis (PCA) to extract the cardiac motion signal from the acquired data. Trigger is then detected by finding the local maximum with an adaptive threshold. As a comparison, the k-space center point (instead of the full k-space center line) from the acquired self-gating data was used to generate a self-gating trigger signal based on previously described method[1].

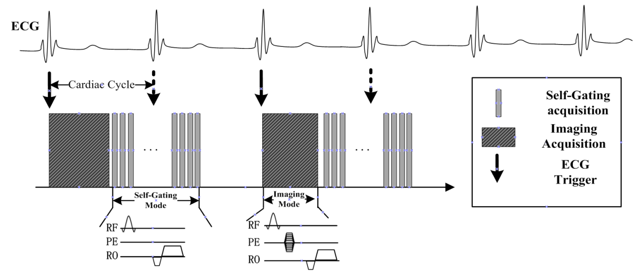

Fig. 1 Modified cardiac CINE sequence with multiple dedicated self-gating acquisitions (center k-space line with PE off) added at the end of each imaging window. For validating the proposed method, the sequence is prospectively triggered by every other ECG triggers. We are working on implementing a ECG-free, self-triggered sequence using the same framework.

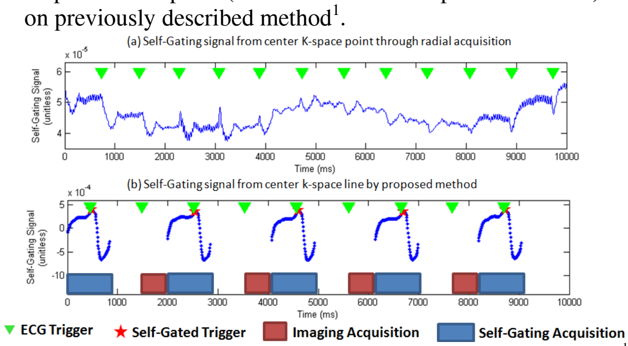

Fig. 2 (a) self-gating signal using center k-space point from radial acquisition[1] shows significant signal drifting and distortion even after a band-pass filter. (b) self-gating signal using the proposed method (i.e. sequence shown in Fig.1) without any frequency filtering is capable of offer accurate and stable cardiac triggers compared with ECG triggers.

Result: Fig.2b shows that the cardiac self-gating triggers generated by the proposed method matches the corresponding ECG R wave. Based on data from all 22 scans, a total number of 122 self-gating triggers were detected with 100% trigger detection rate. Quantitative evaluation result in Table.1 including mean *trigger delay*[1] (i.e. the delay between the ECG R wave trigger and the self-gating triggers) and mean *temporal variability*[1] (i.e. standard deviation of trigger delay for each acquisition) indicates the proposed method offers accurate and robust cardiac triggers. However, using previous methods on the k-space center point only, we were only able to detect 65% of the triggers in all 12 scans from the same 4 subjects.

Discussion:
The purpose of our study is to verify that a self-gating acquisition using non-phase-encoded center k-space lines that is separate from the imaging data acquisition is capable of deriving more precise and robust cardiac motion triggers. We are currently working on implementing a ECG-free, completely self-triggered sequence using the same sequence framework and algorithm. The sequence switches from self-gating mode, where the PE gradients are turned off, to imaging mode as soon as a new self-gating trigger is detected and switches back after imaging acquisition to detect the next trigger. Such implementation requires real-time trigger detection with minimum processing delay. The PCA technique we used is a powerful tool to extract the cardiac motion while suppressing other non-cardiac motion and noises. Using such technique, the trigger could be detected without a high-order frequency filter which is often required by other self-gating method[2] and causing inevitable and significant processing delay. To summarize, our method differs from other cardiac self-gating techniques in four aspects: 1)The entire k-space centerline is used instead of the center point; 2)Coil arrays were used instead of a single coil[3]; 3)The self-gating signal is derived from repeatedly acquired non-phase-encoded k-space centerline and is therefore free of aforementioned signal interference. 4)PCA is used to further reduce any residual interference and enabled real-time trigger detection. Our technique is able to achieve 100% detection rate with <5ms temporal variability. Furthermore, it ensures a reliably detection of the onset of the ventricular contraction 20-50ms after ECG R wave, which has not been achieved using previous methods.

Conclusion: Our data demonstrates that the proposed method can offer cardiac motion self-gating signal that is free of distortion or artifacts usually seen in traditional method and therefore improve cardiac trigger detection accuracy and reliability. Future work will be focused on implementing it in a sequence for real time prospectively cardiac self-gated MRI.

Table 1 Quantitative evaluation of the detected self-gating triggers using ECG as reference

	Short Axis	Vertical Long Axis	Horizontal Long Axis
Mean Delay	17.9ms	29.1ms	58.1ms
Temporal Variability	±4.3ms	±4.7ms	±3.8ms

Reference: 1. Larson et al. *MRM* 51(1):93-102 (2004); 2. Nijm et al. JMRI 28:767-772 (2008); 3. Hu et al. MRM 66:467-475 (2011)