Respiratory Resolved Cardiac Cine Imaging using Self-Gated Golden Angle Radial Acquisition

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Target audience Physicists/engineers, physicians, basic scientists and technologists with an interest in cardiovascular MRI and pulse sequence development for cine imaging.

Purpose Breath holding during imaging can be challenging for patients with heart disease. Furthermore, the volume and function of the left and right ventricles of the heart are affected by pressure changes during respiration. This so called ventricular coupling can be affected by diseases that change the stiffness of the ventricles or the pericardium[1]. The purpose of this study was to develop a free breathing cardiac magnetic resonance (CMR) technique for left ventricular function assessments in all possible combinations of cardiac and respiratory phases. The technique was evaluated by measuring respiratory induced variation in end-diastolic left ventricular (LV) area.

Methods

Acquisition A balanced steady-state free precession (bSSFP) sequence using golden angle (GA) radial acquisition order was implemented at 1.5T (Siemens Aera). One mid-ventricular short-axis slice was acquired in 8 healthy volunteers during free breathing with GA and a standard radial real time (RT) cine bSSFP sequence for comparison. GA parameters were: FOV 375 mm, slice 8 mm, TR/TE 3.2/1.6 ms, radial matrix 208, flip angle 67°, 90000 radial spokes. RT parameters were: FOV 375 mm, slice 8 mm, TR/TE 2.3/1.2 ms, radial matrix 128, flip angle 64°, 50 radial spokes per image, 60 cardiac cycles, 8-17 images per cycle. ECG and respiratory motion from bellows were recorded simultaneously by the scanner.

Retrospective SG signals Image-derived respiratory and cardiac self-gating (SG) signals from the GA data were extracted retrospectively by summing all pixel intensities from sliding window reconstruction of the center 20 *k*-space points. Respiratory SG signals were extracted by smoothing this curve with a 0.9 s wide boxcar filter. Cardiac SG signals were extracted from the image-intensity curve subtracted the respiratory SG signal and smoothed with a 0.3 s wide boxcar filter. Representative SG signals are shown in Figure 1. Each cycle duration in the image-derived SG signal was compared to the equivalent cycle duration in the signal from the scanner.

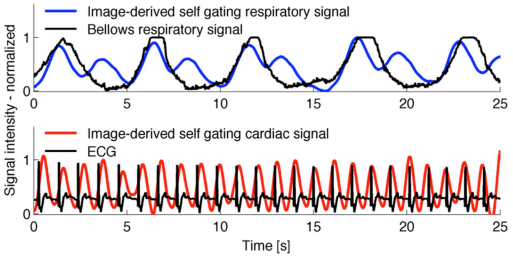

Figure 1 Self-gating signals extracted from the sliding-reconstruction images compared to respiratory bellows and ECG curves measured by the scanner.

Image reconstruction The SG signals were used to bin each radial spoke into 10 respiratory phases and 25 cardiac phases. 10 by 25 images were reconstructed from the spokes assigned to each unique phase combination, as illustrated in Figure 2 (Upper). The range in end-diastolic LV area over 10 respiratory phases from GA was compared to the range of end-diastolic LV area from the RT images over 10 respiratory phases approximately equally spaced with respect to a normalized respiratory cycle. The measured ECG and respiratory bellows signals were used to find these 10 images from the RT data. LV endocardial border was manually segmented to calculate the area. Data are given as mean±SD unless otherwise noted.

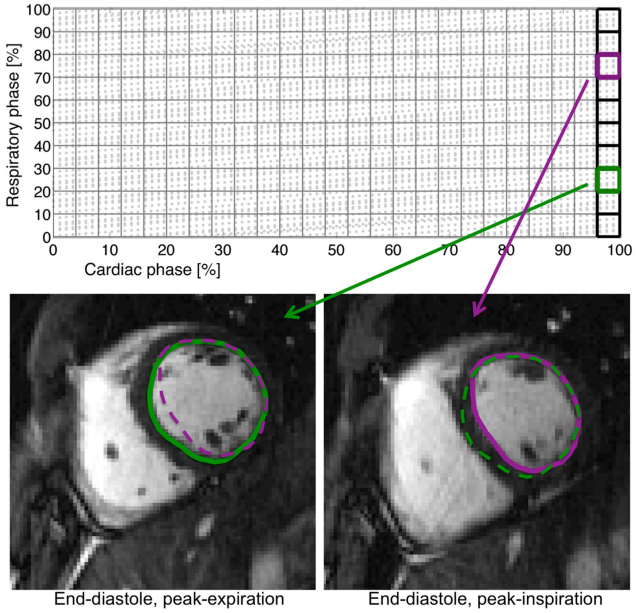

Figure 2 Upper: All measured spokes (dots) were assigned a bin (boxes) out of 25 by 10 cardiac and respiratory phases. Each bin then contains enough spokes distributed using golden angle to reconstruct images in any combination of cardiac and respiratory phases. **Lower:** end-diastolic images in peak-expiration and peak-inspiration respiratory phases. The endocardial contours indicate the change of LV shape due to respiration.

Results The average SG respiratory cycle duration (n=42 cycles per subject) was 4356±1633 ms, and the difference between SG and bellows cycle duration was 50±544 ms (p=0.09). The SG cardiac cycle duration (n=243 cycles per subject) was median 957 ms (interquartile range (IQR) 768 to 1104 ms) and the difference between SG and the ECG duration was median 13 ms (IQR -44 to 22 ms). The number of radial spokes in each unique cardiac and respiratory phase combination over all subjects was 326±103. The end-diastolic LV area was 3.09±0.72 cm^2 and the difference between GA and RT was -0.19±0.39 cm^2 (p=0.21). Figure 3 shows mean±SD of LV area from GA for all subjects with average LV area normalized to 100%. Representative images from peak expiration and peak inspiration are shown in Figure 2 (Lower).

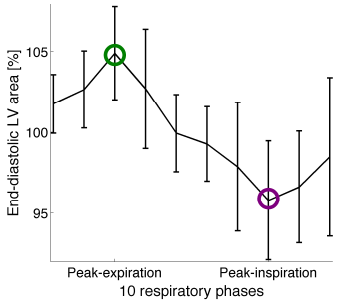

Figure 3 Variation of end-diastolic LV area during the respiratory cycle. Centerline indicates average and bars indicate standard deviation across the 8 volunteers.

Discussion The proposed method is able to reconstruct images of excellent image quality in nearly all 250 phase combinations, owing to the high number of golden angle distributed radial spokes in each phase combination. The use of several cardiac and respiratory cycles of acquisition allows for higher spatial resolution and less streaking artifacts compared to real time techniques. Cardiac and respiratory SG signals showed good correspondence with and no difference compared to ECG and bellows measurements, respectively. GA and RT acquisition did not differ in end-diastolic LV area, but the GA method gave a higher resolution and flexibility.

Conclusion Golden angle radial acquisition during free breathing enabled retrospective sorting of the data from image derived SG signals for both the cardiac and respiratory cycles, and detection of respiratory induced variations in LV end-diastolic area.

References 1. Weber KT, Janicki JS, Shroff S, Fishman AP. Contractile mechanics and interaction of the right and left ventricles. Am J Cardiol; 1981;47(3):686–95.