Quantitative Assessment of Highly Accelerated Real Time Cardiac Cine MRI Using Compressed Sensing and Parallel Imaging

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Introduction: Non-invasive imaging of cardiac function plays an important role in diagnosis of various types of heart diseases. Breath-hold cine MRI with balanced steady-steady free precession (b-SSFP) readout [1] is considered the gold standard for imaging myocardial function. However, in patients with impaired breath-hold capacity or arrhythmias, breath-hold cine MRI may yield non diagnostic image quality, and thus real-time cine MRI might be more useful. Recently, highly-accelerated real-time cine imaging using a combined compressed sensing [2] and parallel imaging approach (k-t SPARSE-SENSE [3]) has been proposed to achieve good temporal resolution with eight-fold acceleration [4-5]. While this technique is promising for clinical applications, it has not been validated for quantification of global function measurements. Therefore, the purpose of this study was to validate the accuracy of global function measurements from 8-fold accelerated real-time cine data against those from the breath-hold cine data.

Methods: Both breath-hold cine MRI and 8-fold accelerated real-time cine MRI pulse sequences were implemented on a 3T whole-body MR scanner (Siemens, Tim-Trio) equipped with a 12-element body matrix receive coil. Relevant imaging parameters for breath-hold cine with retrospective electrocardiogram (ECG) triggering are: spatial resolution = 1.78mm x 1.78mm, slice thickness = 8 mm, TR/TE = 37.5/1.2 ms, reconstructed cardiac phases =25, FA =40°, BW = 1300 Hz/pixel. Relevant imaging parameters for real-time cine MRI with prospective ECG triggering include: spatial resolution = 2.66mm x 2.66mm, slice thickness = 8 mm, TR/TE = 2.7/1.37 ms, temporal resolution = 43.2 ms, FA =40°, BW = 1184 Hz/pixel. Twelve healthy human volunteers with no prior known cardiac disease (11 males and 1 female; mean age = 26.2 ± 2.7 years) were imaged using both pulse sequences. Images were acquired in a stack of 12 short axis planes covering apex to base of the entire left ventricle (LV). For breath-hold cine MRI, two slices were acquired per 20s breath-hold. For real-time cine MRI, 12 slices were acquired during free breathing, with each slice acquisition time = 2 s (1 s dummy scan to achieve steady state of magnetization; 1 s to acquire data). Breath-hold cine reconstruction was performed on-line by the scanner, and k-t SPARSE-SENSE reconstruction was performed off-line using customized software developed in MATLAB (MathWorks, MA). Coil sensitivity maps were self calibrated by averaging undersampled k-space data over time and computed using the adaptive array combination method [4]. The l1-norm inverse problem was solved iteratively using a non-linear conjugate gradient algorithm. Both temporal fast Fourier transform (FFT) and temporal total variation (TV) were chosen as sparsifying transforms, where the weight for the temporal TV is ten times larger than that for the temporal FFT, based on our preliminary analysis, which showed that this combination produced less temporal blurring than our previously published method [5-6] (data not shown). For more details on the k-t SPARSE-SENSE reconstruction, please see reference [3]. The pooled short-axis stacks of cine data (n=24, including both breath-hold cine and real-time cine) were randomized and blinded for quantitative evaluation. Specifically, two cardiologists from one institution, and one cardiologist and one radiologist from another institution independently calculated the end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV) and ejection fraction (EF) for each dataset. The inter-observer variability within each pulse sequence type and global function measurements was assessed by inter-class correlation (ICC). Global function measurements between real-time and breath-hold cine MRI pulse sequences were compared using the Bland-Altman and coefficient of variation (CV) analyses.

Results: Fig 1 shows representative sets of end-diastolic and end-systolic frames in the apical, mid, and basal ventricular short axis planes from one volunteer. As previously reported [4-5], 8-fold accelerated real-time cine MRI produces clinically acceptable image quality. The interclass correlation (Table 1) showed that the inter-observer variability in calculating global function measurements for the two pulse sequences was similar. According to the Bland-Altman and CV analyses (Table 2), all four global function measurements, averaged over 4 readers, were in good agreement, with CV less than 10%.

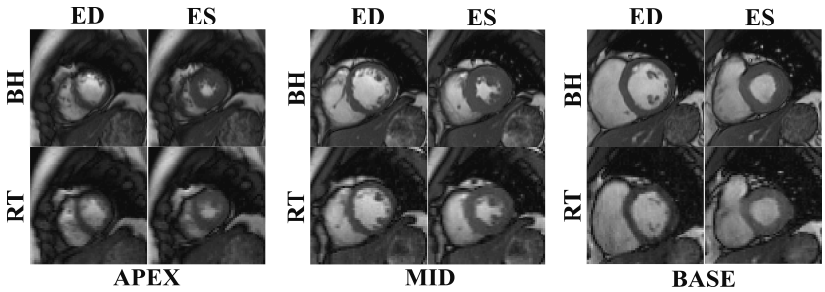

Fig 1. Representative sets of end-diastolic and end-systolic frames in apical (left), mid (middle) and basal (right) ventricular short axis planes. ED: end diastole; ES: end systole; RT: real-time; BH: breath-hold

Discussion: This study demonstrated that the proposed 8-fold accelerated real-time cine MRI produces relatively accurate global function measurements in healthy human volunteers. Compared with the retrospectively ECG triggered breath-hold cine, our prospectively ECG triggered real-time cine underestimated EDV, SV, and EF, because in prospective ECG triggered acquisition it is difficult to image at true end diastole. One approach to overcome this limitation is to acquire real-time cine data without ECG triggering over multiple heart beats and visually identify a frame that best represents end diastole. Future work includes clinical studies in patients with arrhythmias.

Table 1. ICC analysis of inter-observer variability of EDV, ESV, SV and EF within each pulse sequence type. BH: breath-hold; RT: real-time;

Measurement	ICC (BH)	ICC (RT)
EDV	0.88	0.78
ESV	0.76	0.77
SV	0.76	0.64
EF	0.64	0.64

Table 2. Bland-Altman and coefficient of variation (CV) analyses of 4 global function measurements between real-time and breath-hold cine MRI pulse sequences.

Measurement	Mean	Mean Difference	Upper 95% Limit	Lower 95% Limit	CV (%)
EDV (ml)	143	-15.2	-2.8	-27.6	6.22
ESV (ml)	55.7	2.1	8.9	-4.7	4.42
SV (ml)	87.3	-17.3	-3.3	-31.3	8.19
EF	0.61	-0.06	0	-0.11	4.68

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Reference: [1]. Carr, JC, et al. Radiology 2001; 219:828-34. [2]. Lustig M, et al. MRM 2007; 58:1182-1195. [3]. Otazo R et al. MRM 2010; 64:767-776. [4] Walsh et al. MRM. 2000; 43(5):682-90. [5]. Feng L et al. ISMRM 2010; 4044. [6]. Feng L et al. ISMRM 2011; 748.