Assessing cardiac kinetics using highly accelerated free breathing 2D through-time Radial GRAPPA compared to Cartesian real-time and segmented cine imaging

Jeremy D Collins[1], Bruce Spottiswoode[2], Haris Saybasili[3], Mark Griswold[3,4], Nicole Seiberlich[3], L Cort Sommerville[5], Keyur Parekh[1], Michael Markl[6,7], and James Carr[5]

[1]Radiology, Northwestern University, Chicago, IL, United States, [2]Cardiovascular MR R&D, Siemens Healthcare, Chicago, IL, United States, [3]Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States, [4]Radiology, Case Western Reserve University, Cleveland, OH, United States, [5]Radiology, Northwestern University, Chicago, Il, United States, [6]Radiology, Northwestern University, Chiago, IL, United States, [7]Biomedical Engineering, Northwestern University, Chicago, IL, United States

Target audience: Cardiologists and radiologists who employ MRI to perform cardiac functional studies.

Purpose: Segmented cine imaging using balanced steady state free precession (bSSFP) has been accepted as a gold standard for assessing myocardial systolic function. However, this method requires multiple breathholds to minimize respiratory motion, which may not be possible for very ill or uncooperative patients. Additionally, due to the signal averaging in segmented cine acquisitions, it is difficult to achieve reliable imaging in patients with arrhythmias and assess diastolic dysfunction in patients with regular sinus rhythm. Existing free breathing real time imaging techniques do not offer the spatial and temporal fidelity[1] needed to assess myocardial function. Radial acquisitions are more tolerant to undersampling than Cartesian due to the oversampled central k-space and incoherent aliasing artifacts. As such, high parallel imaging acceleration rates are possible, allowing for real time acquisitions at an appreciable spatio-temporal resolution. The purpose of this study is to assess the clinical utility of highly accelerated real time radial GRAPPA to evaluate cardiac morphology and kinetics comparing to Cartesian real-time and segmented cine imaging.

Methods: 12 patients (6 men, avg 53 years old)were scanned on a 1.5T MR system (MAGNETOM Aera, Siemens Healthcare, Erlangen, Germany) using a body and spine array combination (28 to 32 channels depending on orientation). Radial GRAPPA[2] bSSFP data were obtained during free breathing and without ECG gating, in both mid short axis and four chamber views. Through-plane calibration data[3] were acquired during free breathing over a period of 3.5 seconds and using a segment size of 16 points in the readout direction and 2 points in the projection direction. Two parameter configurations were used: (1) spatial resolution = 1.7 x 1.7 x 8 mm^3, temporal resolution = 36 ms, radial GRAPPA acceleration rate = 16; and (2) spatial resolution = 2.3 x 2.3 x 8 mm^3, temporal resolution = 25 ms, radial GRAPPA acceleration rate = 16. Both standard and high temporal resolution Cartesian segmented cine bSSFP cine images were acquired during breath holding as a reference, with a spatial resolution = 1.7 x 1.7 x 6 mm^3, temporal resolutions of 45 ms and 23 ms, and breath hold durations of 12 and 20 seconds, respectively. Cartesian real time cine bSSFP images were also acquired during free breathing with E-PAT factor 3, temporal resolution = 50 ms, spatial resolution = 3 x 3 x 8 mm^3. A single observer graded trabecular visualization, myocardial-blood pool boundary delineation, and diastolic filling phase separation on a four point Likert scale (0 = Poor, 1 = Adequate, 2= Good, 3=Excellent). The observer also noted the orientation with superior image quality (short vs horizontal long axis) for each acquisition type and the presence of abnormal myocardial relaxation. Myocardial relaxation was evaluated subjectively by assessing left atrial size on the 3-chamber view while noting abnormalities of myocardial filling during early diastole and compared to diastolic assessment at transthoracic echocardiography.

Image Quality	Trabecular Visibility	Myocardial - Blood Pool Boundary	Phase Separation
Cartesian Real Time Cine	0.89	1.73	1.74
Segmented bSSFP 45 msec	2.66	2.74	2.04
Segmented bSSFP 23 msec	3.00	3.00	2.94
GRAPPA 25 msec	1.65	1.87	2.95
GRAPPA 36 msec	1.92	2.28	2.85

Table 1: Likert Image quality metrics for each cine acquisition type, averaged between short axis and horizontal long axis acquisitions.

Results: Diagnostic GRAPPA acquisitions were acquired in all subjects. Representative images from a patient with ischemic heart disease are provided in Figure 1. Trabecular visualization was superior for segmented bSSFP acquisitions, adequate to good for both GRAPPA acquisitions, and poor to adequate for the real-time cine acquisition (table 1). The myocardial-blood pool boundary was at least good for all acquisitions except the Cartesian real-time and GRAPPA 25 msec acquisitions (table 1). Early and late diastolic phase separation was superior for the 23 msec segmented bSSFP, 36 msec GRAPPA, and 25 msec GRAPPA acquisitions (table 1). Short axis oriented images were preferred for real-time acquisitions, while the horizontal long axis orientation was preferred for segmented acquisitions. Compared to echocardiography, diastolic assessment with both GRAPPA acquisitions was 100% accurate in detecting abnormal left ventricular diastology, while the Cartesian real-time and segmented bSSFP 45 msec acquisitions misclassified one patient and the 23 msec segmented bSSFP acquisition misclassified 2 patients.

Discussion: This pilot study demonstrates the clinical feasibility of real-time highly accelerated GRAPPA cine imaging. GRAPPA acquisitions with temporal resolutions as low as 25 msec were of adequate image quality to identify the blood pool – myocardial boundary, but borderline quality to visualize trabecula. Temporal resolution with accelerated real-time GRAPPA acquisitions approached that of a highly accelerated segmented acquisition, maintaining the ability to visually separate early and late filling patterns in diastole, resulting in superior characterization of diastolic function in our patient cohort.

Conclusion: Highly accelerated GRAPPA cine imaging is clinically feasible and has the potential to improve the MR classification of left ventricular diastology. Integrating ECG-triggering into the acquisition would enable quantification of myocardial function, enabling quantitation of beat-to-beast differences in ventricular function. Work is ongoing to validate our findings in a larger cohort and assess the clinical feasibility of quantitative real-time GRAPPA acquisitions.

References: 1. Kramer et al. JCMR 2008, 10:35. 2. Griswold et al. Proc 12th ISMRM, Kyoto, Japan; 2004:737. 3. Seiberlich et al. MRM 2011;65:492-505.

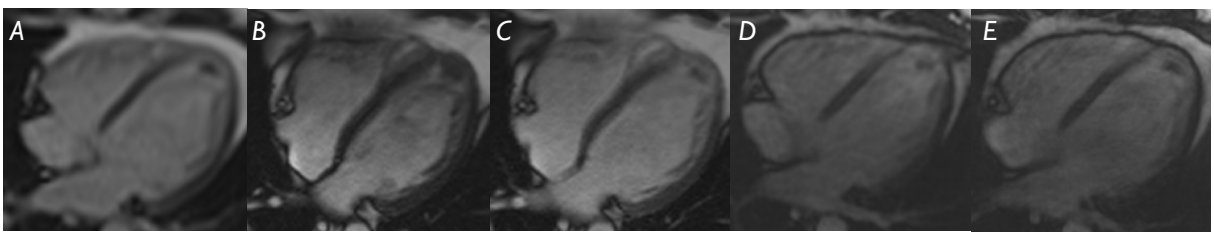

Figure 1: Horizontal long axis orientation cartesian real-time (A), cartesian segmented 45 (B) and 23 (C) msec temporal resolution, radial GRAPPA with 25 and 36 msec temporal resolution cine frames at end-diastole in a patient with apical dyskinesia and an apical thrombus. Note the larger chamber volumes in (A), (D), and (E) due to complete imaging of the cardiac cycle.