Retrospective Self-Gated Free-Breathing Radial 3D Cine SSFP CMR using Self-Calibrated GRAPPA: A Feasibility Study

N. C. Codella[1], P. Spincemaille[2], J. Liu[2], M. Prince[2], and Y. Wang[2]
[1]Physiology, Cornell Weill Medical College, New York, NY, United States, [2]Radiology, Cornell Weill Medical College

INTRODUCTION: Current clinical cardiac MRI uses a series of 2D cine-SSFP and may suffer from slice misregistration due to inconsistent breath-holding positions. Some severely ill or pediatric patients may be unable to perform satisfactory breath-holds. In this study, a 3D free-breathing self-calibrated radial GRAPPA cine-SSFP pulse sequence was developed to overcome these 2D limitations. The radial k-space sampling was employed to provide z-profile self-navigator to monitor respiratory motion.

MATERIALS AND METHODS: Data were acquired using a "stack-of-stars" k-space radial trajectory [1]. Gradient delay errors were corrected by shifting the center of the readout trajectory using additional compensation gradients [2]. Each cardiac phase consisted of a complete set of slice encodes kz that was repeatedly sampled within a cardiac cycle, and this is further repeated over a number of heartbeats (3 in this study) determined by an oversampling parameter of the retrospective gating algorithm. Partial slice encoding of 65% was employed to improve temporal resolution. Respiratory positions were determined from the center-of-mass of the image volume projection onto the z-axis, which is the Fourier transformation of the kz-axis points acquired during each cardiac phase. A sliding window over the acquired sets of slice encodes was used to generate additional temporal frames. Results were band-pass filtered to suppress noise and cardiac motion. The respiratory position corresponding to end-expiration was chosen as the reconstruction position. Each readout contributed to a weighted average signal at its corresponding projection angle and slice encode position, based on a weight that was determined by a 2D Gaussian apodized sinc window function in the 2D plane of the respiratory position and cardiac phase. Radial projections were reconstructed using a self-calibrated radial GRAPPA method at an acceleration factor of 4 [3]. GRAPPA kernel coefficients are calculated by fitting kernels to the undersampled data as if it were the calibration data itself. Resultant coefficients are associated with relative k-space shifts. Because these shifts for a radial trajectory vary, kernel coefficients for a wide range of k-space shifts are sampled, and can be resampled to generate new kernels for arbitrary shifts. New GRAPPA kernels are then directly interpolated for unacquired points between acquired projections such that new radial projections at those positions can be generated [3].

The study population included 5 healthy volunteers (IRB approved). MR scans were performed on the left ventricle in the short-axis using a GE Signa 1.5T scanner. Typical 2D cine SSFP imaging parameters were as follows: TR 3.3-4.5ms, flip angle 55-60, matrix size 256 readout points and 128 phase encodes, image dimensions 256x256, receiver bandwidth 125 kHz, FOV 290-400 x 240-360, slice thickness and slice gap 6mm & 4mm, respectively (total 10mm). The left-ventricle (LV) in each patient was imaged in 6-10 slices, 20-28 cardiac phases, 24 views per segment. 3D free-breathing cine SSFP scan parameters were as follows: TR 3.7-4ms, flip-angle 50, matrix size 512 readout points and 100 projections, reconstructed image dimensions 256 x 256, receiver bandwidth 250 kHz, FOV 640mm acquired (reconstructed to 320mm), and 6mm slice thickness. 15-16 partial slice encodes were acquired out of 22-24, yielding the same number of views-per-segment. Overscan factors of 3 were used yielding scanning efficiencies of 33%. 20 cardiac phases were reconstructed. Acquired temporal resolution was 67.5 ms. LV volumes were quantified using the LV-METRIC automated ventricular segmentation software [4], and compared between 3D and 2D datasets.

RESULTS: An example 3D dataset at end-diastole is depicted in Figures 1 and 2. Averaged over all volunteers, resultant measurements from the retrospective 3D self-gated free-breathing cine SSFP sequence were 135 mL for diastolic volume, 45.4 mL for systolic volume, and 66.1% for ejection fraction. 2D cines yielded 135, 43.8, and and 67.6%, respectively. The differences between techniques were 0.4 mL ± 5.4, -1.5 mL ± 7.6, and 1.5% ± 5.7, respectively.

DISCUSSION: In summary, a free-breathing 3D projection cine-SSFP pulse sequence was implemented and demonstrated in a group of 5 volunteers. Good image quality was obtained, and scan times were 5 minutes on average. Further study in a larger cohort of clinical patients is necessary to validate the success rate of the respiratory navigator and to assess the differences, if any, in quantification of functional cardiac parameters, such as ejection fraction, stroke volume, and left-ventricular mass, as compared to 2D breath-hold cine. Limitations of the sequence include RF profile imperfections at the edge of the prescribed slab, and loss of inflow enhancement as in comparison to 2D scans. The first may be address by longer RF pulses or larger slabs at a cost of reduced temporal or spatial resolution. The latter is an inherent property of 3D imaging; the effects of such on functional quantitation will need to be studied in further detail.

References: [1] Peters D.C., et al. JMRI 20:411-416 (2004) [2] Peters D.C., et al. MRM 50:1-6 (2003) [3] Codella et al. ISMRM Third Workshop on Parallel Imaging. (2009) [4] Codella et al. Radiology 248:3 (2008)

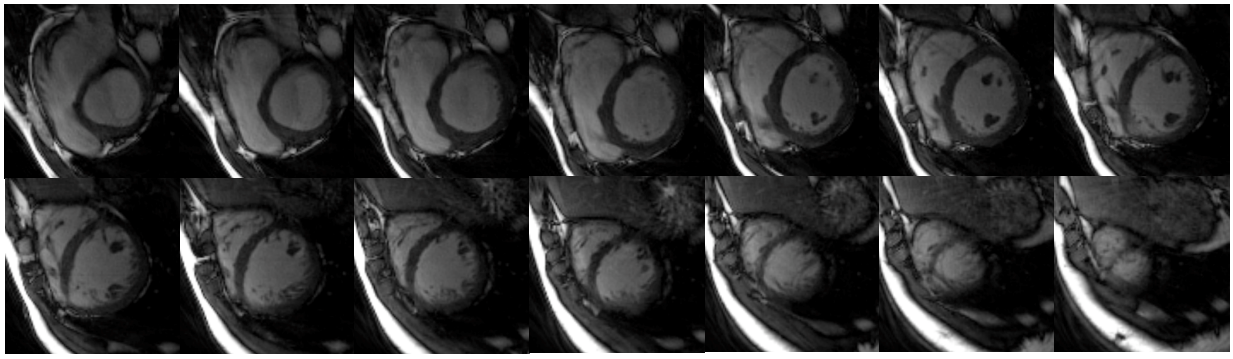

Figure 1: Representative full 3D free-breathing dataset at end-diastole.

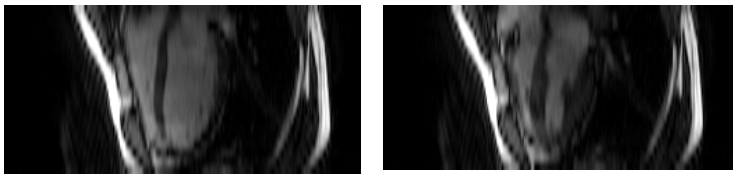

Figure 2: Reformatted 4-chamber view at end-diastole and end-systole.