3D Cardiac CINE Imaging using 3D Through-Time Radial GRAPPA

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Introduction: Most clinical cardiac MR examinations include the acquisition of several multi-phase CINE images with a short-axis orientation in order to assess the function of the heart. Each of these CINE acquisitions requires the patient to hold his/her breath, and the data collection relies on accurate cardiac gating. In order to image the entire heart, at least 12 separate CINE acquisitions are required, which means that the patient is asked to perform at least 12 breathholds in quick succession. If the patient is unable to hold his/her breath, or the gating fails due to any cardiac irregularity, these datasets must be reacquired. In this work, we seek to drastically reduce the amount of time required to generate these short-axis cardiac CINE datasets by moving to a 3D acquisition augmented with non-Cartesian parallel imaging. In general, whole-heart 3D CINE acquisitions are not feasible because of their long acquisition times. Several groups have reported that 3D CINE imaging is possible using keyhole or sliding-window methods [1,2], a lower resolution scan [3], or free-breathing methods with navigators [4]. Further data acceleration can be performed by using parallel imaging in conjunction with compressed sensing techniques [5]. Based on the success of 2D through-time radial GRAPPA for real-time cardiac imaging [6], we hypothesize that employing 3D through-time radial GRAPPA will allow the use of high acceleration factors and make high spatial and temporal resolution 3D cardiac CINE imaging possible with a relatively simple parallel imaging reconstruction technique. This abstract demonstrates that 3D through-time radial GRAPPA can be used to reconstruct highly undersampled 3D cardiac CINE data acquired in a single breathhold.

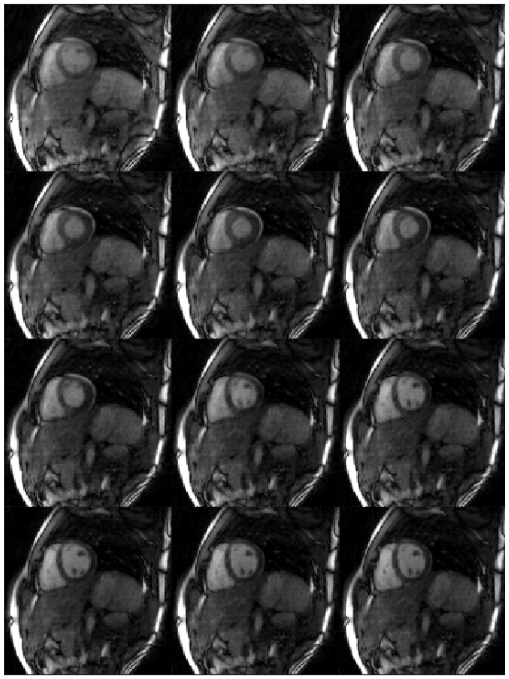

Figure 1: Images showing 12 of the 15 cardiac phases acquired for one of the 16 partitions during the single breathhold 3D CINE acquisition.

Materials: Data were acquired from eight normal volunteers along a short-axis orientation following informed consent. First, a total of 20 fully-sampled 3D stack-of-stars radial datasets were acquired for calibration of the GRAPPA weights during free-breathing with no EKG gating using a 1.5T Siemens Espree and the following parameters: bSSFP sequence, TR=3.04ms, matrix size=128x128x16, projections/partition=128, FOV=300x300x96mm^3, resolution=2.3x2.3x6mm^3, flip Angle=45°, BW=1115Hz/px, 5/8 partial Fourier, 18 receiver channels, 25% slice oversampling. Segmented undersampled data (16 projections/partition, acceleration factor of R=8 with respect to the 128 fully-sampled projections) were acquired with EKG gating during a breathhold for 15 heartbeats, resulting in 15 CINE frames. For the 3D through-time radial GRAPPA, each time frame and partition was employed as a separate source of calibration information. Thus, a total of 300 (20 repetitions x 15 partitions) calibration frames could be used to generate the through-time GRAPPA weight sets for each of the missing points. After reconstruction, the undersampled data yielded fully-sampled 3D CINE images, each with a temporal footprint of 48ms, an in-plane resolution of 2.3mm^2, and a through-plane resolution of 6mm. The total acquisition time was 116 s for the calibration and approximately 15 s for the breathhold CINE acquisition.

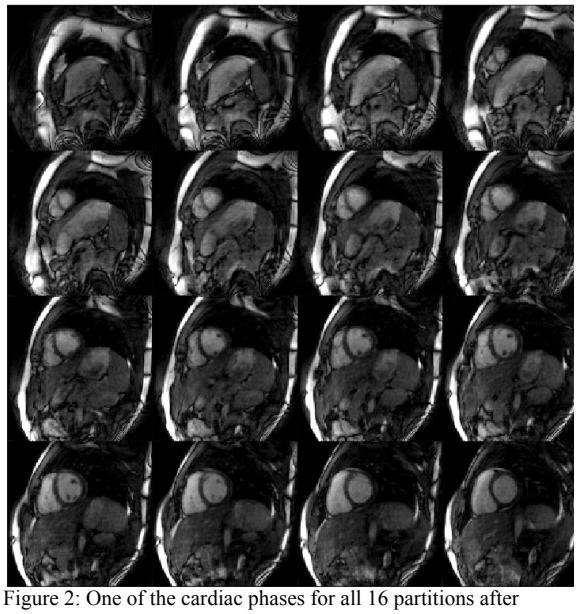

Figure 2: One of the cardiac phases for all 16 partitions after reconstruction with 3D through-time radial GRAPPA.

Results: Figure 1 depicts 12 of the 15 acquired cardiac phases on one volunteer for a single partition after reconstruction with 3D through-time radial GRAPPA. Figure 2 shows all 16 partitions from a single CINE phase in diastole from the same volunteer, demonstrating our ability to cover the entire heart. It is important to note that the images shown in Figures 1 and 2 are from the same dataset, and that synchronous CINE images are available for all 16 partitions.

Discussion: By using a highly undersampled stack-of-stars 3D radial trajectory in conjunction with 3D through-time radial GRAPPA, 3D cardiac CINE images were acquired in a single 15 second breathhold. These images do not use view-sharing or a significantly lower resolution to shorten the acquisition time, but instead rely on the high acceleration factors possible by combining the radial trajectory with through-time non-Cartesian GRAPPA. While the images shown here have a temporal resolution of 48ms per 3D volume, it is anticipated that this time could be reduced by using a more efficient trajectory with through-time GRAPPA [7], or by accelerating in the partition direction in addition to the in-plane direction, as in [8]. Thus, it is expected that further optimizations of the 3D through-time GRAPPA method will lead to even higher spatial and temporal resolutions for 3D cardiac CINE imaging.

References: [1] Rochitte CE, et al. Open Cardiovasc Med J. 2011;5:90-8. Epub 2011 Mar 22. [2] Liu J, et al. J Magn Reson Imaging. 2010 Aug;32(2):434-40. [3] Sievers B, et al. Acta Cardiol. 2011 Jun;66(3):349-57. [4] Spincemaille P, et al. Magn Reson Imaging. 2011 Jul;29(6):861-8. [5] Otazo R et al. Magn Reson Med. 2010;64(3):767-76. [6] Seiberlich, et al. Magn Reson Med. 2011; 65(2):492-505. [7] Seiberlich N, et al. Magn Reson Med. 2011 Apr 26. Epub ahead of print. [8] Jeong HJ, et al. Magn Reson Med. 2010 Jun;63(6):1520-8.

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