First-pass Contrast-Enhanced Cardiac Perfusion with 3D Coverage Per Heartbeat with 3D Through-Time Radial GRAPPA

Kestutis Barkauskas[1], Jesse Hamilton[1], Bruce Spottiswoode[2], Sven Zuehlsdorff[2], Mark Griswold[1,3], and Nicole Seiberlich[1]

[1]*Biomedical Engineering, Case Western Reserve University, Cleveland, Ohio, United States,* [2]*Cardiovascular MR R&D, Siemens Medical Solutions, Chicago, Illinois, United States,* [3]*Radiology, Case Western Reserve University, Cleveland, Ohio, United States*

TARGET AUDIENCE: Clinicians and researchers who desire volumetric coverage during contrast enhanced cardiac perfusion studies

PURPOSE: To demonstrate feasibility of volumetric coverage within a single heartbeat for first-pass contrast-enhanced cardiac perfusion imaging using the consecutive application of Cartesian GRAPPA [1] followed by 3D Through-time Radial GRAPPA [2] to reconstruct ECG-gated data acquired with an undersampled (in both the angular and partition directions) 3D radial stack-of-stars trajectory.

METHODS: Seven healthy volunteers were recruited to participate in this IRB approved study. All scans were performed on a clinical 1.5T MR scanner (MAGNETOM Espree, Siemens Healthcare, Erlangen, Germany) using a body and spine array combination (15-18 channels). The perfusion scan parameters were: ECG-gated 3D Radial FLASH (TR 3.32ms, TE 1.5ms, flip angle 15°); reconstructed matrix size 128x128x16; 16 radial projections (R=8 with respect to Cartesian sampling); R=2, 6/8 partial Fourier and 33% oversampling in partition direction. This yields 2.3x2.3x8mm^3 resolution and whole-heart coverage with the central 12 partitions from just 96 echoes per cardiac cycle. The trigger delay was set to acquire data in diastole, where the magnetization was first prepared with a non-selective composite saturation pulse with TI 185ms (N=3) or 250ms (N=4). Acceleration was applied in both the angular (radial, R=8) and partition (Cartesian, R=2) directions, yielding a total acceleration of R=16 and a per heartbeat acquisition time of 341ms which can still fit within a typical diastole. Two minutes of imaging was performed, where volunteers held their breath as long as possible, and contrast was injected at the second cardiac cycle (Optimark, 0.5mmol/kg at 2-3mL/sec followed by 25mL saline flush).

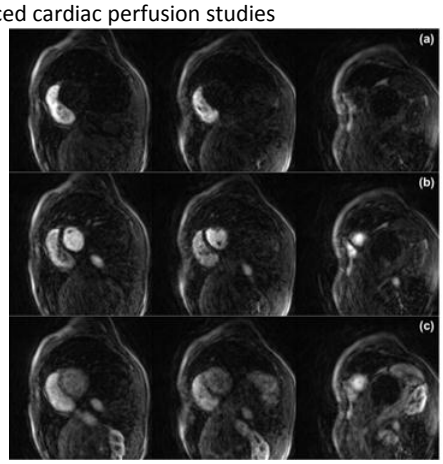

Fig. 1: Key timeframes. Basal (left), medial (center) and apical (right) partitions are shown at peak RV (a, RR 14), peak LV (b, RR 24) and peak myocardium enhancement (c, RR 35) at TI 250ms.

Two different calibration data sets were needed to reconstruct the perfusion scan. First, the missing partitions for each projection angle were reconstructed using Cartesian GRAPPA [1]. The centermost cardiac phase of a breathheld ECG-gated 3D radial cine FLASH sequence (same basic parameters as the perfusion scan with a fully-sampled partition direction acquired for each cardiac phase in each heartbeat) served as the calibration reference. Secondly, missing projections for each partition were reconstructed with 3D Through-time Radial GRAPPA (segmentation: radial 4, angular 1) [2]. The calibration reference for this second step included 10 repetitions of an ungated, free-breathing, 3D Radial FLASH sequence (same basic parameters as the perfusion scan, but fully-sampled in both the partition and radial direction). Both reference datasets were acquired prior to the contrast injection. Zero-filling prior to inverse FFT in the partition direction yielded 16 reconstructed partitions, where each was gridded using the IRT toolbox [3] in Matlab (R2011b, The Mathworks, Natick, MA). Temporal uptake in the anterior segment was expressed as the mean of ROI value normalized to the value that was obtained in the first cardiac cycle for the given partition.

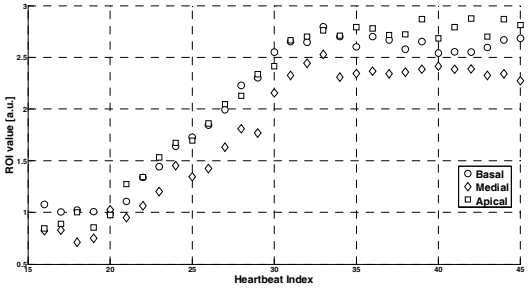

Fig. 2: Uptake vs. heartbeat index. Note the synchrony of the upslope and plateau of myocardial uptake for the basal (circle), medial (diamond) and apical (square) partitions.

RESULTS: Figure 1 shows a subset of three locations (basal, medial and apical) that would have been acquired with a conventional 2D approach. The elapsed time is denoted as the acquired cardiac cycle (RR) index. Note the following features: physiologically-correct temporal enhancement pattern, good delineation between the myocardium and blood pool, and uniform myocardial uptake. Figure 2 shows the effects of synchronous uptake of contrast in the anterior myocardial segment for the same volunteer and partitions as Figure 1. Figure 3 demonstrates whole heart coverage for a different volunteer, where uptake analysis could be performed for any standard cardiac segment at any given partition.

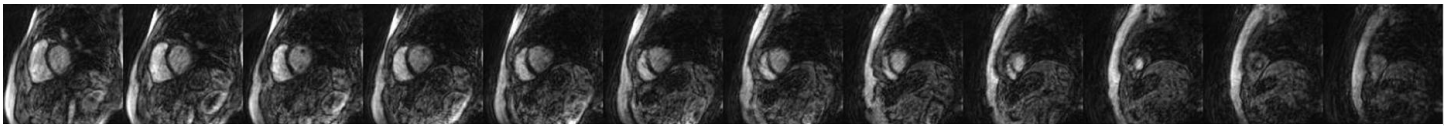

Fig. 3: Whole heart coverage. All non-oversampled partitions are shown at the peak of myocardial enhancement (RR 32) for a different volunteer at TI 250ms.

DISCUSSION: Due to the 16-fold acceleration relative to Cartesian, the proposed combination (3D FLASH with an undersampled 3D radial trajectory and a two-part, non-iterative GRAPPA-based reconstruction) was able to achieve volumetric coverage of the whole heart within each cardiac cycle with clinically-relevant resolution during a first-pass contrast-enhanced cardiac perfusion study. Unlike a comparable 2D method that may be restricted to minimum TI in order to acquire all slices within diastole, the 3D approach demonstrated in this work allows flexibility in controlling the amount of T1 relaxation prior data encoding. Note that a 16-fold acceleration (R=8 and R=2 in the radial and partition directions, respectively) was possible using parallel imaging alone; no view-sharing, spatial or temporal regularization, explicit knowledge of the coil sensitivity map, or iterative reconstruction were required to generate these images. This high acceleration factor is made possible by dividing the undersampling into all three spatial dimensions and fully utilizing the 3D coil sensitivity variations. Further acceleration may be possible by employing a 32-channel cardiac array, which could even further reduce the current acquisition time per heartbeat of 341ms, and make perfusion mapping of the entire 3D volume of the heart possible.

REFERENCES: [1] Griswold, et al. MRM 2002. 47:1202-10, [2] Seiberlich, et al. ISMRM 2012, Pg. 3838, [3] http://web.eecs.umich.edu/~fessler/code

ACKNOWLEDGEMENTS: Siemens Medical Solutions, NIH/NIBIB R00EB011527, CWRU CTSC Annual Pilot Grant 2012, NIH 1RO1HL094557.