Self-Calibrating Interleaved Reconstruction for Through-Time Non-Cartesian GRAPPA

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Target Audience: Those interested in non-Cartesian parallel imaging and its application to cardiac imaging.

Purpose: To demonstrate the use of through-time non-Cartesian GRAPPA with a self-calibrating acquisition. Previous research has demonstrated that a hybrid through-k-space/through-time calibration improves the estimation of GRAPPA weights for undersampled non-Cartesian trajectories [1]. However, one disadvantage is the need for multiple fully-sampled reference datasets. Often this is not a problem since the reference scans may be acquired under free-breathing conditions. Nonetheless, this is not acceptable for some applications, such as those where slice orientation is frequently changed. Here we introduce a self-calibrating interleaved non-Cartesian acquisition that estimates GRAPPA weights directly from the undersampled data. This approach is conceptually similar to TGRAPPA [2], which merges temporally adjacent frames in undersampled rectilinear data to build up a fully sampled autocalibration signal. The proposed method aims to combine a major benefit of TGRAPPA—namely, dynamic updating of coil coefficients—with the advantages of non-Cartesian trajectories and through-time calibration.

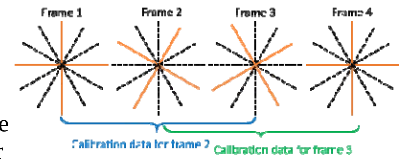

Fig 1. *Interleaved acquisition scheme.*

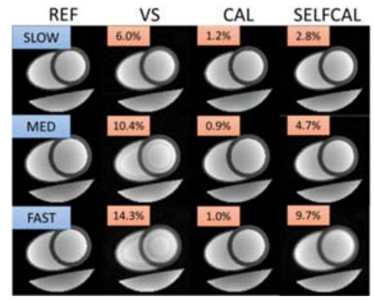

Fig 2. *Simulations with average RMSE values as insets for different reconstructions of a cardiac phantom moving at slow, medium, and fast speeds. REF=Reference, VS=view-sharing, CAL=through-time non-Cartesian GRAPPA with calibration; SELFCAL=self-calibrating through-time non-Cartesian GRAPPA.*

Methods: Undersampled data were simulated and acquired using both interleaved radial and spiral acquisitions. As shown in Fig 1 for a radial trajectory, calibration data for a particular frame were accumulated by merging temporally neighboring undersampled frames in a symmetric manner. All through-time radial GRAPPA reconstructions were performed with a 3x2 (read x projection) kernel, 8x4 k-space segment, and 16 frames, while spiral GRAPPA reconstructions were done with a 3x2 kernel, 4x1 k-space segment, and 80 frames. Regridding was performed after reconstruction using the non-uniform fast Fourier Transform [3]. Simulations were conducted using a cardiac numerical phantom moving at three different speeds and undersampled along a radial trajectory with R=6 (24 projections), a 128^2 grid, and an eight-channel coil sensitivity profile. The self-calibrating method was compared to (1) a through-time radial GRAPPA reconstruction using the same interleaved undersampled data but with an additional calibration scan, and (2) view-sharing where temporally adjacent frames were merged without parallel imaging reconstruction. To test the method *in vivo*, free-breathing non-gated cardiac data were acquired on a 1.5T Siemens Espree using a bSSFP sequence along both radial (8 interleaved groups of 16 projections) and spiral trajectories (6 interleaved groups of 8 arms) with an 18 channel cardiac array. The radial acquisition had a 128^2 grid, TR/TE = 2.64ms/1.32ms, FOV 300mm^2, spatial res 2.3x2.3x8 mm, temporal res 42.2 ms/frame, and the spiral had 48 arms, 128^2 grid, TR/TE = 4.48ms/2.24ms, FOV 300mm^2, spatial res 2.3x2.3x8 mm, and temporal res 35.8 ms/frame. Note that the acquisition of the calibration frames took 5.4s and 17s for the radial and spiral reconstructions, respectively, a time penalty that is removed when using the self-calibrated method.

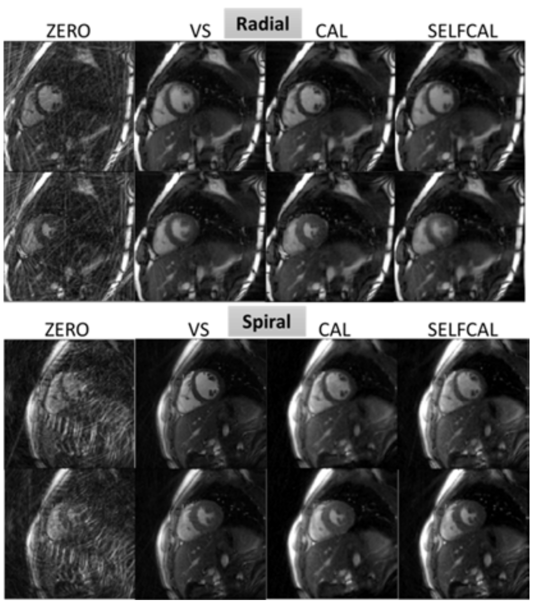

Fig 3. *Images generated using interleaved radial and variable density spiral trajectories in systole and diastole. ZERO=zero-filled; VS=view-sharing; CAL=through-time non-Cartesian GRAPPA with calibration; SELFCAL=self-calibrating through-time non-Cartesian GRAPPA*

Results: Results from the phantom study (Fig 2) suggested that the self-calibrating method accurately reconstructed images with slow to moderate motion but deteriorated with rapid movement. At all speeds, the self-calibrating method outperformed view-sharing but had higher errors than through-time radial GRAPPA calibrated with a separate fully-sampled dataset. Representative radial and spiral cardiac images are shown in diastole and systole (Fig 3). Both self-calibrating reconstructions had higher image quality and less blurring than view-sharing. The self-calibrating images showed minor blurring during systole compared to images generated with calibration data; this was less severe with the spiral trajectory and than when using view-sharing for both trajectories.

Discussion: We have demonstrated that self-calibrating through-time non-Cartesian GRAPPA can be used to reconstruct highly undersampled data along interleaved non-Cartesian trajectories without additional calibration data. While the calibration data required for through-time non-Cartesian GRAPPA can be acquired rapidly (these examples used 5.4s and 17s of radial and spiral calibration data, respectively), these calibration times can be long and potentially clinically infeasible when scanning multiple 2D slices or rapidly changing scan planes. Unlike other self-calibrating methods such as CG SENSE [4] or CS techniques, self-calibrating through-time non-Cartesian GRAPPA is not iterative, does not require coil sensitivities maps or assumptions about image properties or dynamics, and can be used to generate images in real-time[5]. When merging frames to build the calibration data, projections that are adjacent in k-space are not necessarily acquired close in time, and the through-time GRAPPA weights may be inaccurate if significant motion occurs over the merged frames. Because the spiral-based calibration had a shorter temporal footprint than the radial trajectory (215ms vs. 338ms), less blurring due to more accurate weights was observed.

Conclusion: The self-calibrating through-time non-Cartesian GRAPPA method introduced here may be useful for applications where collecting a separate reference scan is inconvenient or impossible. In certain applications such as interventional MRI, the benefits of having a self-calibrating scan may outweigh the appearance of slight temporal blurring in cases of rapid motion.

Acknowledgements: Siemens Medical Solutions, Case Western Reserve University/Cleveland Clinic CTSA UL1 RR024989 and NIH/NIBIB R00EB011527.***References***: [1]Seiberlich N, et al. *Magn ResMed*. 2011;65(2):492–505. [2]Breuer FA, et al. *Magnetic Resonance in Medicine*. 2005;53(4):981 – 985. [3]Fessler JA. *J Magn Reson*. 2007;188(2):191–195. [4]Pruessmann, et al. Magn Reson Med. 2001;46:638-651. [5] Saybasili, et al. ISMRM 20 (2012), Pg. 2554.