Golden Angle Through-Time Radial GRAPPA for Real-time Cardiac MRI

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Target audience: Clinicians and scientists interested in fast MRI for dynamic imaging, especially real-time cardiac MRI.

Purpose: To demonstrate that through-time radial GRAPPA can be used to reconstruct images from data acquired using an undersampled golden angle radial trajectory. The standard linear radial trajectory can be combined with a parallel imaging reconstruction in the form of through-time radial GRAPPA (TT radial GRAPPA) to accelerate data acquisition in cardiac imaging, leading to temporal resolutions of less than 50ms/image[1]. However, when working with linearly acquired radial data, the desired acceleration factor must be known before the acquisition so that the appropriate projections can be acquired. When using the golden angle (GA) radial trajectory[2], the extent of undersampling can be selected after acquisition, which may be advantageous when imaging patients whose breath-holding abilities are unpredictable, or who may have pathologies such as arrhythmias which might be better assessed if there an ability to retrospectively adjust the spatio-temporal resolution. One possibility for reconstructing undersampled GA data with TT radial GRAPPA is to generate the necessary weights using fully-sampled GA data in a self-calibrating approach. However, GA data is not naturally compatible with TT radial GRAPPA, as the GA projections that are adjacent in k-space are not temporally adjacent, which can lead to errors when estimating GRAPPA weights. Another possibility for the TT radial GRAPPA calibration is to acquire a calibration dataset with sequentially ordered GA projections. While the sequential GA calibration increases the total scan time, it may provide more accurate GRAPPA weights in comparison to a self-calibrated approach. Here these two TT radial GRAPPA calibration methods for GA data are described and compared via simulation and also *in vivo* volunteer experiments.
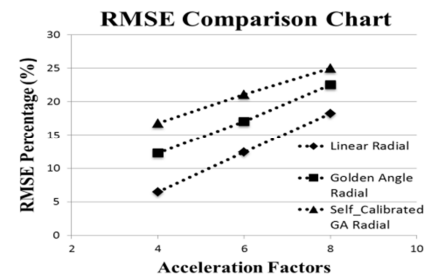

Fig 1: RMSE comparison of reconstructed images using through-time radial GRAPPA and a linear radial data, the golden angle data with sorted golden angle calibration data, and self-calibrating golden angle at different acceleration factors

Methods: Continuously and randomly moving phantom images were created in MATLAB using a simulated 8-coil sensitivity map. Data consisting of 20 repetitions were sampled using both GA and linear radial trajectories. For each repetition, 144 GA projections were sampled with both GA (for acceleration) and sequential ordering (for calibration). The GA data were grouped into sets of 36, 24, and 18 projections and reconstructed using the self-calibrated approach (TT GRAPPA weights calculated using the GA data without a separate calibration scan) as well as by using the sequentially sorted GA data as calibration data. For comparison, a linearly-ordered radial acquisition was also implemented (36, 24 and 18 projections/frame for undersampled data and 144 linear radial projections for calibration), and data were reconstructed using standard TT radial GRAPPA[1]. The same calibration parameters were used for all methods (8×4 segment in the read x projection directions and 20 calibration frames[1]). The reconstructed data were gridded using the Image Reconstruction toolbox[3]. The RMSEs of reconstructed images were calculated using gold-standard images (144 fully sampled linear radial images). To test these methods *in vivo*, short axis cardiac data were acquired on healthy volunteers (N=15) on a 1.5T Siemens Espree (Siemens Medical Solutions) with a 15-channel receiver coil. The entire exam was free-breathing, and no EKG gating was used during data acquisition. As in simulations, GA and linear radial data were acquired. GA data was reconstructed using both the self-calibration and the sequentially sorted calibration, and linear data was reconstructed using the standard method[1]. The following acquisition parameters were used for both scans: bSSFP sequence, TR/TE=2.64ms/1.32ms, FoV=300mm^2, slice thickness=8mm, matrix size=128^2, BW=1115Hz/px, flip angle=70°.
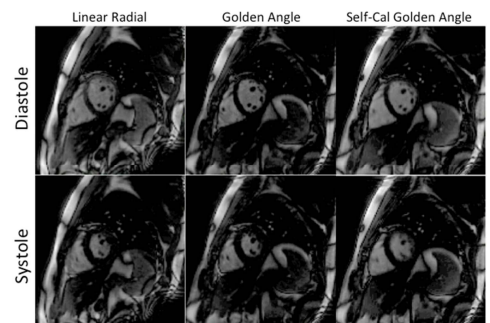

Fig 2: Examples of R=8 (47.5ms/image) real-time cardiac images at diastole and systole using different through-time radial GRAPPA methods

Results: The simulation results showing relative errors from the different trajectories and reconstruction methods are shown in Fig 1. The self-calibrated GA TT radial GRAPPA method has a higher error level than the reconstruction using a separate sequential GA calibration dataset. The reconstruction using the linear radial trajectory has the lowest RMSE, although these datasets would have to be acquired independently, unlike the GA data where all images can be generated using one dataset. *In vivo* cardiac results in Fig 2 show that GA data can yield similar image quality at a temporal resolution of 47.5 ms/frame (R=8). The in vivo images reconstructed using GA data and TT radial GRAPPA with a separate calibration dataset demonstrate quality comparable to that from the linear radial data; the self-calibrated GA images, which did not use a separate calibration dataset, are similar in diastole but show considerable artifacts in systole due to the rapid cardiac motion.

Discussion: Images reconstructed using TT radial GRAPPA and the GA trajectory have a higher RMSE than similar reconstructions with linear radial data due to the non-uniform projection coverage. The self-calibrated GA through-time radial GRAPPA method has the highest RMSE as projections adjacent in k-space are distant temporally, leading to suboptimal calibration data for TT radial GRAPPA. Given the trade-off in image quality between quality between linear and GA trajectories appear small in these experiments, the GA techniques are worth exploring further due to the important advantage of the retrospective ability to choose the degree of acceleration.

Conclusion: Data collected along the GA trajectory can be used with TT radial GRAPPA to select an appropriate acceleration factors after data acquisition with a minor loss in image quality compared to linear radial data. While self-calibrating GA TT radial GRAPPA is also possible, the image quality is lower due to inaccurate GRAPPA weights generated from temporally distant projections.

References: 1. Seiberlich N, et al. *Magn. Reson. Med.* 2010;65(2):492–505. 2. Winkelmann S, et al. *IEEE Trans. Med. Imaging*. 26(1):68–76. 3. http://www.eecs.umich.edu /~fessler/code/.