Image Quality Evaluation of Real-Time Cardiac Images Reconstructed using Linear and Golden Angle Through-Time Radial GRAPPA

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

Purpose: To compare the performances of standard and golden angle through-time radial GRAPPA for *in vivo* functional cardiac imaging through radiologist review. Previous research has shown that through-time radial GRAPPA[1] can be modified to reconstruct data acquired with an undersampled golden angle radial trajectory[2], which permits retrospective selection of the acceleration factor without acquiring additional data[3]. That work demonstrated in simulation that the selection of a low acceleration factor can lead to a loss in dynamic information, but the selection of an acceleration factor that is too high can lead to poor image quality. Thus, retrospective selection of temporal resolution could be beneficial when the optimal acceleration factor for a dynamic scan is not known *a priori*. In this work, volunteers and patients were imaged using three reconstruction methods: golden angle, self-calibrated golden angle, and linear radial through-time GRAPPA, in order to determine if image quality was compromised when using the more flexible golden angle trajectory. Images reconstructed at different acceleration factors using all three techniques were rated by a cardiothoracic radiologist for artifacts, motion visibility, and anatomical visibility, and a statistical analysis was performed to compare the performance of each method.

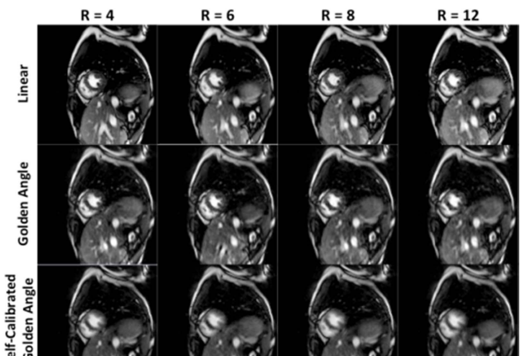

Figure 1*. Images during systole from a patient with pericardial constriction reconstructed with linear, golden angle, and self-calibrated golden angle through-time radial GRAPPA.*

Methods: In this HIPAA compliant and IRB approved study, real-time cardiac MRI was performed on twelve asymptomatic volunteers on a Siemens 3T Skyra scanner with 30 coils. Short-axis cardiac data were acquired during free breathing with no EKG gating. Undersampled radial data were acquired along both linear and golden angle trajectories, and fully-sampled calibration scans were collected along both linear and sorted golden angle trajectories, as suggested by Han et al[3]. A bSSFP sequence was used with the following parameters: TR/TE=2.94/1.74ms, FoV=300mm^2, slice thickness=8mm, matrix=128^2, BW=1115Hz/pixel, flip angle=70°. All calibration datasets used 144 projections and 26 temporal repetitions (scan time 11s). Undersampled linear radial data were acquired at acceleration factors of 2, 4, 6, 8, and 12 (72, 36, 24, 18 and 12 projections and temporal resolutions of 212, 106, 71, 53 and 35 ms/frame, respectively). Projections from a single golden angle dataset were grouped to yield the same acceleration factors for comparison. Images were reconstructed using three variations of through-time radial GRAPPA: (1) linear radial with separate calibration, (2) golden angle with separate calibration, and (3) self-calibrating golden angle. All GRAPPA reconstructions employed 8x4 (read x projection) k-space segmentation and 26 temporal repetitions, and images were gridded after reconstruction using the NUFFT[4]. In addition, three cardiac patients were imaged on a Siemens 1.5T Avanto with 15 channels using a bSSFP sequence with the same parameters as 3T except TR/TE=2.62/1.31ms. Linear radial and golden angle datasets were reconstructed using the same acceleration factors as above. After reconstruction, the images were presented in a random order to a cardiothoracic radiologist. The following image features were rated on a scale of one (non-diagnostic) to five (excellent): epicardial and endocardial border definition, papillary muscle visualization, myocardial wall visualization, blood pool contrast, and cardiac motion. Images were also assessed for radial streaking, noise enhancement, spatial blurring, and temporal blurring. A Wilcoxon test was performed to assess the equality of the scores' distributions across reconstruction methods and at different acceleration factors.

Results: Representative images during systole from one patient with pericardial constriction are shown in Figure 1. Average results from the radiologist image rating are presented for the three reconstruction methods in Figure 2. Most anatomical features were most highly rated for R=4 for the linear trajectory, despite the relatively low temporal resolution (~100ms), while the golden angle scores generally were highest for R=2. Per radiologist review, all techniques showed increased streaking and noise enhancement as the acceleration factor increased. Based on the Wilcoxon test, no significant differences ($p<0.05$) in anatomical or motion visibility were seen between the linear and golden angle reconstructions up to R=8. However, there were increased streak and blurring in the golden angle images at R=4 and higher. The self-calibrated golden angle reconstructions displayed increased noise and streak artifacts compared to linear radial GRAPPA at all acceleration factors. The self-calibrated method also had difficulty capturing rapid cardiac dynamics, as evidenced by the lower motion ratings at R=4 and R=6 and the poor wall definition at R=8 and above. No significant difference was observed between the two golden angle reconstructions in any category ($p>0.05$ in all cases). Results from the radiologist rating study also indicate that the optimal acceleration factor can vary widely across subjects (data not shown).

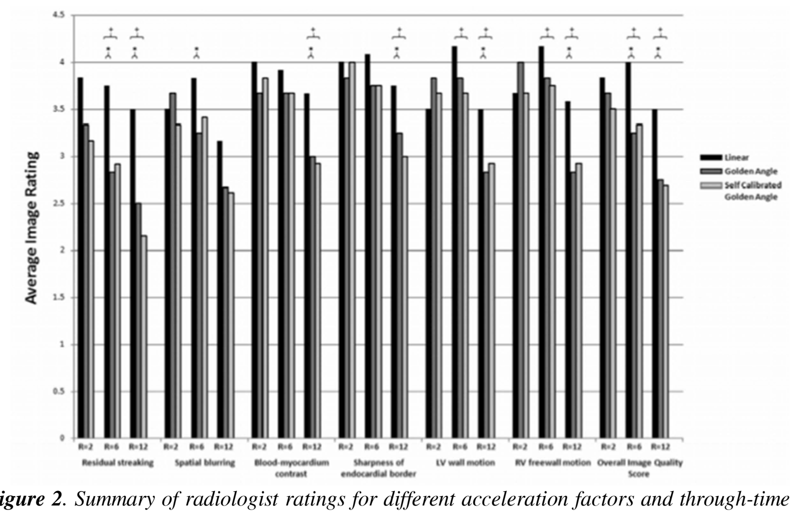

Figure 2*. Summary of radiologist ratings for different acceleration factors and through-time radial GRAPPA methods. Only the results for R=2, 6, and 12 are shown, although the results for R=4 and R=8 show the same trends for statistical significance as R=6. Significant differences as determined using the Wilcoxon test ($p<0.05$) are denoted with brackets and a star (linear vs. golden angle techniques) and a plus sign (linear vs. self-calibrated golden angle techniques).*

Discussion: The radiologist image rating suggests that golden angle radial GRAPPA with a separate calibration scan offers similar image quality to linear through-time radial GRAPPA, with the advantage of retrospective selection of temporal resolution. This is beneficial since an acceleration factor that is too low or high may lead to spatial blurring or residual aliasing, respectively, and thus the golden angle through-time GRAPPA approach can offer the optimal balance between these two extremes. Self-calibrated golden angle through-time radial GRAPPA leads to significantly lower scores for motion and border definition categories, indicating that this method may not be preferred when rapid dynamics are encountered.

Conclusion: Golden angle and linear through-time radial GRAPPA demonstrated similar image quality in real-time cardiac MRI and showed no significant differences in anatomy or motion scores when rated by a radiologist, indicating that the golden angle trajectory may be preferred by physicians over the linear approach when the optimal acceleration factor and temporal resolution are not known *a priori*. The self-calibrated golden angle approach showed significant differences when compared to the linear method, with a drop in image quality in the presence of rapid motion. **Acknowledgements:** Funding for the project was received from 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]Winkelmann S, et al. *IEEE Trans. Med. Imaging*. 26(1):68–76. [3]Han X, et al. *Proc ISMRM* 2013:3834. [4]Fessler JA. *J Magn Reson*. 2007;188(2):191–195.