A Self-Calibrated Through-time radial GRAPPA Method

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Target Audience: Scientists and clinicians interested in highly accelerated cardiac imaging.

Purpose: High acceleration factors with undersampled radial trajectories have previously been demonstrated in cardiac MRI with through-time radial GRAPPA (tt-rGRAPPA).[1] This method estimates the radial GRAPPA (rGRAPPA) weights from a calibration pre-scan, consisting of multiple fully sampled reference frames, with a separate scan required per imaging plane.[2-4] This work aims to remove the need for a calibration scan. Several self-calibrating methods for radial GRAPPA have previously been proposed,[5-8] however, none have realized acceleration factors high enough to enable real-time acquisition with good image quality. An alternative self-calibration scheme for undersampled radial trajectories is proposed and demonstrated including quantitative comparison to the reference gold standard of through-time radial GRAPPA.[1]

Theory: Self-calibrated rGRAPPA (SC-tt-rGRAPPA) is derived from the original rGRAPPA formulation,[9] which uses a unique GRAPPA kernel for each missing k-space sample, and calibration for weight calculation is derived from multiple kernel occurrences with similar geometries over small segments of a fully sampled k-space (i.e. through-k-space calibration) (Fig. 1a). tt-rGRAPPA increases kernel occurrences by also using data from additional fully sampled frames.[1] Here, we use a one-sided kernel instead of a standard two-sided kernel (i.e.3x1 instead of 3x2), which we refer to as "half-block" (HB) rGRAPPA (Fig. 1b). Finally, kernel occurrences with matching geometries are collected from the undersampled k-space (Fig. 1). Choosing the most geometrically similar $N_{similar}$ kernel occurrences from N_{frames_acc} consecutive undersampled frames, yields $N_{similar} \times N_{frames\_acc}$ kernels for calibration. To obtain kernel occurrences with better geometric similarity, the azimuthal indices of the N_{proj}/R acquired projections were shifted by $floor(R/2)$ on alternating frames where N_{proj} is the number of projections and R is the undersampling factor.

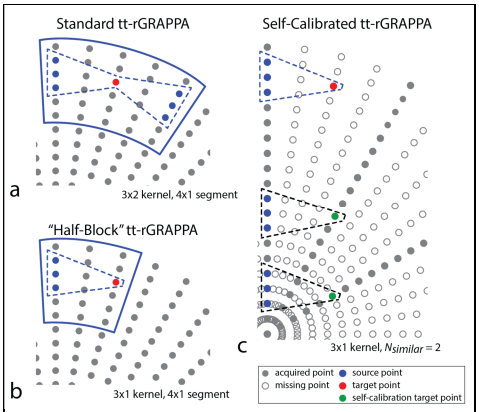

Figure 1: Depiction of the through-k-space portion of various radial GRAPPA calibration methods. The solid blue lines in **a** and **b** show segment size for calibration.

Methods: One swine and two healthy subjects were imaged with ACUC and IRB approval, at 1.5T (Avanto, Siemens Medical Systems, Erlangen, Germany) using standard coils (15 channels). Imaging included a free-breathing balanced steady-state free precession sequence (BW=1184 Hz/pixel, FoV=250 mm^2) at two resolutions with varying acceleration rates. *Standard:* N_{proj}=144, matrix=128x128, TE/TR=1.4/2.8 ms, R=[6, 9,12]. *High-Res:* N_{proj}=192, matrix=192x192, TE/TR=1.5/3.1 ms, R=[8,12]. Slice thickness was 7.0 and 8.0 mm for animal and human scans, respectively. Since rGRAPPA calibration requires motion, the animal study was carried out to serve as a comprehensive "phantom" experiment during which gold standard reference images were reconstructed with 400 fully sampled calibration frames with a 1 x 1 segment (i.e. no through-k-space calibration).[1] RMSE values were computed for both tt-rGRAPPA and SC-tt-rGRAPPA for 3 short axis slices (SAX) and one long axis (LAX) slice. The effects of of N_{frames_acc} and $N_{similar}$ on image quality were explored. In humans a complete stack of 12 SAX was acquired with each slice imaged for 5-10 sec, yielding 200 undersampled frames. SC-tt-rGRAPPA was compared to tt-rGRAPPA with 80 fully sampled frames per slice with a 4x1 segment.

Results: Figure 2 shows the performance of the self-calibrated reconstructions. As either $N_{similar}$ or N_{frames_acc} increased, RMSE decreased. $N_{similar}$=6 demonstrated optimal results though with some variation with imaging resolution. Increasing $N_{similar}$ too much (>8) lead to an increase in RMSE. Figure 3 displays images from a healthy subject reconstructed with both tt-rGRAPPA and SC-tt-rGRAPPA at various resolutions. High acceleration rates (R=12) were supported and achieved acquisitions speeds of ~20 frames/second.

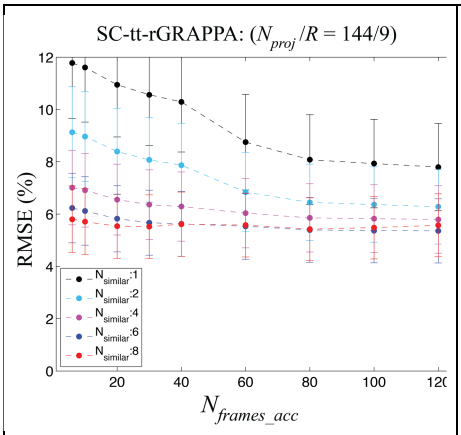

Figure 2: RMSE for self-calibrated reconstructions from a swine SAX slice.

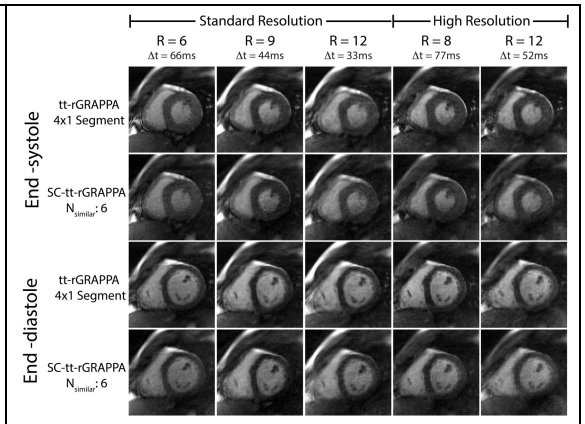

Figure 3: Example images from a human SAX slice reconstructed with tt-rGRAPPA and SC-tt-rGRAPPA.

Discussion/Conclusion: A novel self-calibrated rGRAPPA technique is proposed. Image quality is comparable to that of the state-of-the-art tt-rGRAPPA techniques as shown by RMSE. The performance of this method may enable more efficient clinical imaging by removing the need of pre-scan calibration. Eliminating a calibration in non-Cartesian scans may also increase flexibility in image-guided procedures where slice orientation may need to be altered on the fly. **References:**[1] Seiberlich et al., *MRM* 2011. [2] Sayin et al., *ISMRM 2013.* [3] Sayin et al., *SCMR 2014.* [4] Saybasili et al., *Magn Reson Imaging 2014.* [5] Arunachalam et al., *MRM 2007.* [6] Huang et al., *MRM 2007.* [7] Codella et al., *NMR in Biomed 2011.* [8] Hamilton et al., *ISMRM 2013.* [9] Griswold et al., *ISMRM* 2003. **Funding**: AHA11SDG5280025, R00EB011527, R01EB018108, 1RO1HL094557.