GRAPPA estimations using undersampled propeller trajectories

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Introduction GRAPPA weights are typically estimated using a fully sampled central region of k-space. These weights are then used to synthesize the outer parts of k-space. Parallel imaging (PI) techniques such as GRAPPA are of great advantage for sequences using propeller shaped readouts. For example, the echo spacing is long in PROPELLER (1) due to the RF refocused echoes. With PI, however, the readout time becomes R times shorter for a given blade width - which reduces the T2-blurring, SAR, and increases the number of slices/TR. Alternatively, the blades can be widened, which increases navigation capabilities. Recently we proposed a new EPI-based propeller readout design with the readout direction along the short-axis of the blade ("Short-Axis readout Propeller EPI" or "SAP-EPI") in order to reduce the geometric distortions associated with EPI (2). We have also presented the SAP-EPI in combination with GRAPPA using R=3 and R=4 (3), in which it was shown to reduce the geometric distortions by an order of magnitude compared to standard EPI. In that work, we used equally as many EPI interleaves per blades as the R-factor, and estimated the GRAPPA weights using all interleaves of each blade. GRAPPA weights were then applied on *each* (diffusion weighted) interleave separately in order to avoid motion related shot-to-shot ghosting. While SNR-preserving, the drawback of this method is that the scan time becomes $TR{*}N_{blades}{*}R$ instead of just $TR{*}N_{blades}$. The purpose of this study was to explore the possibility of extracting the GRAPPA weight information by capitalizing on the excessively sampled center of k-space, which is well sampled even though each blade itself is undersampled by a factor of R. Scanning only a single interleave per blade rather than R interleaves would substantially minimize scan time without the penalty of an external calibration scan.

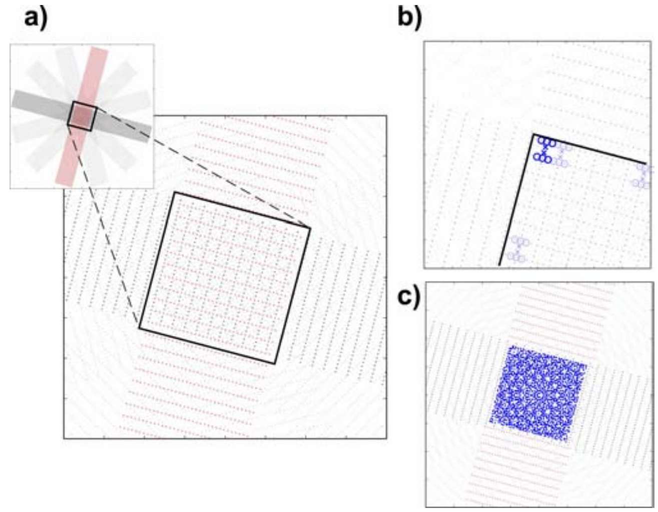

Figure 1. GRAPPA estimation in the intersection between undersampled propeller blades. The two alternative approaches tested in this work are shown in b) and c). (In b label the RO and PE direction and for which blade direction you are determining the weights)

Materials & Methods To calculate the GRAPPA weights on a per-blade basis, two strategies were investigated:

1) Two orthogonal blades to form a Cartesian grid at the center of k-space. The intersecting area is not fully sampled, but samples are bound to a Cartesian grid. The GRAPPA kernel is here shifted over the entire intersecting area by R increments of k_x and k_y, rather than single increments along k_x and k_y, as is typically performed during the weight determination phase. For an R of 2, one ends up with 4 times less locations to train the data, making the system less overdetermined. At R=3, this is even more pronounced (see Fig. 1b) and for that reason, one has to resort to small GRAPPA kernels, e.g. two source lines and three k_x (read) locations.

2) The inclusion of all blade data in the central region will provide sufficiently dense k-space coverage (blue dots in Fig. 1c) that for each blade, data can be regridded to Cartesian k-space locations. This intersecting central area (Fig. 1a and c) will allow the estimation of GRAPPA weights using the conventional 2D sliding scheme of the GRAPPA kernel. This reconstruction requires extra computation due to the gridding of blade data around the origin of k-space for each blade (with up to $N_{RO}^2/R{\times}N_{blades}$ k-space samples for each blade). Experimental data were acquired using 256-shot SAP-EPI scans on a resolution phantom. The scan parameters were as follows: 28cm FOV, 5mm slice thickness, 12 blades of 32×256 (freq×phase), blade sweep=0°-165°. Here, a larger number of interleaves were used to avoid confounding effects from ghosting, susceptibility distortions or other artifacts. From these measurements, R=2 and R=3 scans were simulated by using only every R^{th} phase encoding line for each blade.

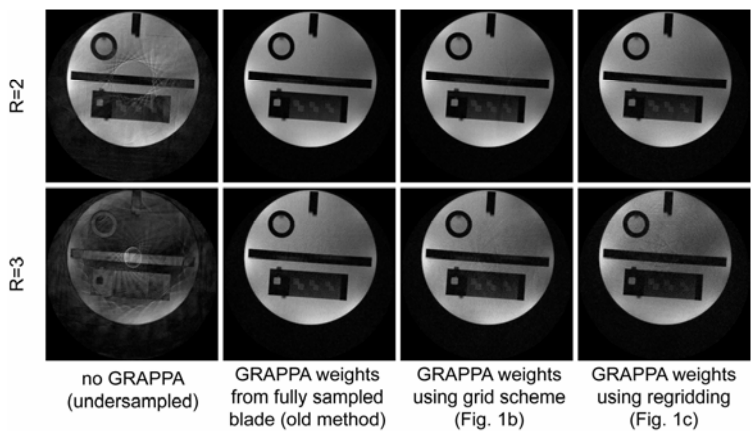

Figure 2. Reconstruction of undersampled blades using (from left to right) i) regridded as acquired (without GRAPPA), ii) GRAPPA weights from fully sampled blades (reference, not proposed here), iii) GRAPPA weights derived on a sparse grid from two orthogonal blades (Fig. 1b), iv) GRAPPA weights derived from per-blade regridded locations from all blades (Fig. 1c)..

Results Figure 2 shows the regridded reconstructions of R=2 and R=3 scans using different calibration methods. While the ideal situation is to acquire R interleaves for each blade (column 2), columns 3 and 4 show that adequate reconstructions can be made using a single interleave by employing the calibration methods proposed in this work. For both R=2 and R=3 the blade-regridding technique generated fewer reconstruction artifacts than the orthogonal blade approach. Due to the increasing sparsity of the calibration data reconstructions become less accurate with increasing R. Since (R-1) fewer interleaves were acquired, images computed with the new calibration methods are certainly noisier than the full reconstruction (column 2). However, the time savings are quite substantial. If deemed necessary, the extra time savings afforded by this calibration can be invested in more (thinner) blades to reduce distortions even further than with GRAPPA alone.

Discussion & Conclusion This work has shown the possibility of reconstructing undersampled propeller data using GRAPPA without the need for external calibration or the acquisition of all interleaves once. Although the specific k-space trajectory corresponds to our SAP-EPI sequence, the results also hold for PROPELLER (1), Turbo-PROP (4), or Long-axis Propeller EPI (5). In this study, we have removed other confounders of image quality - such as motion, susceptibility artifacts as well as amplitude oscillations from FSE train instabilities or FOV/2R ghosts in order to isolate the PI reconstruction behavior. The impact of these artifacts on the two methods proposed here remains to be investigated.

References 1) Pipe JG. Magn Reson Med 1999;42(5):963-969. 2) Andersson JL *et al.* Neuroimage 2003;20(2):870-888. 3) Skare S. 2006; Seattle. ISMRM. p 857. 4) Pipe J. 2002; Honolulu. ISMRM. p 425. 5) Wang FN *et al.*; 2004; Kyoto. ISMRM. p 2462.

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