Segmented Spiral Parallel Imaging Using GRAPPA

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Introduction: Efficient and robust parallel imaging reconstruction techniques for Cartesian k-space sampling have been developed [1-2]. For non-Cartesian sampling, such as spiral trajectories, only image domain reconstruction, which is computationally very expensive, has been described [3]. Parallel imaging with spiral k-space coverage is attractive because it allows the use of fewer spiral segments, improving imaging speed and lessening required gradient performance, particularly slew rates. For parallel spiral imaging to be routinely applicable, it is desirable to have a computationally efficient method. A possible approach is to estimate missing spiral segments from weighted averages of neighboring segments in a similar manner as missing lines are recovered in Cartesian sampling by fitting measured data to calibration lines, as in GRAPPA [2]. The essence of this approach is illustrated in Fig. 1, where spirals are viewed as horizontal lines in a pseudo-rectilinear data space. In the original GRAPPA developed for rectilinear sampling, the weights for the averaging are the same for the calculation of every missing line. For non-Cartesian sampling, the weights will depend on the orientation of the spiral and the location along the trajectory. A similar situation occurs when applying GRAPPA to projection reconstruction [4]. To derive the weights, the data space is divided into smaller sections, as shown by alternating gray areas in Fig. 1, and a set of weights are generated for each section. This paper describes the implementation of and demonstrates this reconstruction approach using an eight channel phased array head coil with reduction factors up to 8.

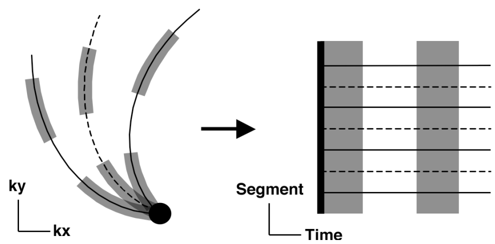

Figure 1. Depiction of spiral segments in a pseudo-rectilinear space. Dashed lines represent missing segments to be reconstructed using GRAPPA. The gray sections indicate sub-segments of the data over which the fitting is performed.

Methods: A phantom experiment was performed on a 3 Tesla Siemens Trio scanner using an eight channel phased array heal coil. A spin echo (TR/TE=1000/15 ms) spiral pulse sequence is utilized using a 16 segment spiral designed to acquire a 256 matrix in a 256 mm FOV. Gradient design limits included a maximum gradient strength of 40 mT/m, and a maximum risetime of 500 microseconds. The spiral gradient readout has duration of 13 ms per segment, is sampled at 200 kHz, and reaches a maximum gradient switching corresponding to 83% of stimulation threshold. All sixteen segments are acquired and are used as either measured data or calibration data to test reduction factors of 2, 4 and 8. Each spiral segment is evenly divided into 59 sub-segments for GRAPPA fitting, where the block size is equal to the number of measured segments. For all reduction factors each missing segment is calibrated using a full calibration pre-scan of all segments. Single coil images are reconstructed using standard gridding and combined by square root sum of squares, forming a multi-coil composite image.

Results and Discussion: Fig. 2 displays a panel of images showing segmented spiral images reconstructed with several reduction factors. The degree of aliasing caused by the missing segments is quite significant, especially at high reduction factors. The reconstructed phantom images for rate 2 and 4 show no residual aliasing artifacts, while the rate 8 image shows some small residual. Also apparent is the loss of SNR when moving to higher reduction factors, which is commonly encountered in parallel imaging. Results indicate that fitted weights are dependent on the orientation of spiral segments (results not shown), necessitating calibration of each missing segment individually. This work demonstrates that k-space based parallel imaging reconstruction is possible with spiral imaging, and that the images are relatively free of residual aliasing. The computation time for spiral GRAPPA is on the order of the duration needed to grid a single image, hence the benefits of using k-space based reconstruction include faster reconstruction time and availability of single coil images.

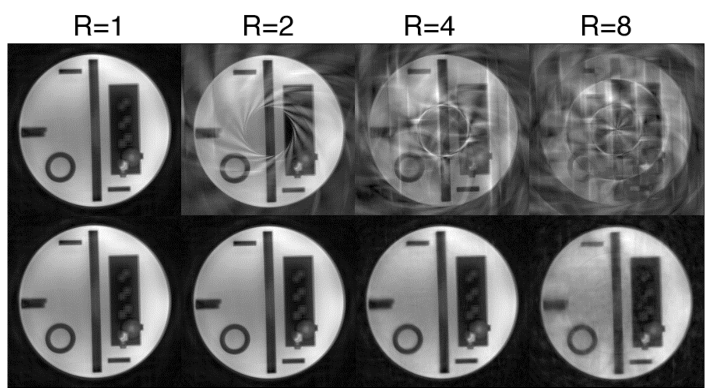

Figure 2. Spiral GRAPPA results for reduction factors 1, 2, 4, and 8. The top row show the aliasing caused by the missing spiral segments, and the bottom row shows the GRAPPA reconstruction.

Acknowledgment: The authors would like to acknowledge support for this work by NIH grant EB002009, the Georgia Research Alliance and the Whitaker Foundation.

References: 1. Pruessman, et al, MRM 42:952, 1999. 2. Griswold, et al, MRM 47:1202, 2002. 3. Pruessman, et al, MRM 46:638, 2001. 4. Griswold ISMRM, 2003.