Accelerated carotid imaging using slice GRAPPA (sGRAPPA)

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Introduction Multi-slice 2-dimensional (2D) sequences are routinely used in carotid imaging for accurate depiction of carotid lesions [1]. The narrow slice gap and large coverage results in long acquisition time. To reduce acquisition time, GRAPPA [2] has been used in carotid imaging [3]. Due to the deep location of region of interest (ROI) and the limitation of the coil, the signal to noise ratio (SNR) is often too low for diagnosis if GRAPPA is applied. The objection of this work is to speed up the acquisition of carotid imaging while preserves the SNR better than GRAPPA. Based on the fact that the adjacent slices are very similar because the slice gap is close to 0 in 2D carotid imaging, we adopted the idea in *k-t* GRAPPA [4], and modified the time dimension in *k-t* GRAPPA to be slice dimension. The proposed method is called slice GRAPPA (sGRAPPA). Experimental results demonstrated that the proposed method resulted in better preserved SNR and improved structure similarity than GRAPPA.

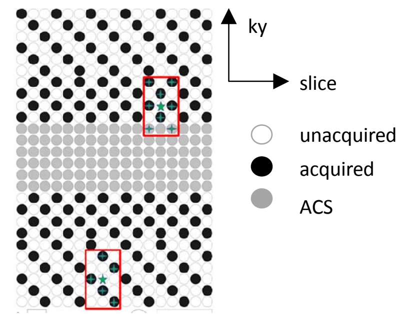

Figure 1. The sampling and interpolation patte of sGRAPPA. Each dot represents a k-spa line, with frequency-encoding direction omitte For every missing k-space line (star), acquired data (cross) in the surrounding (r box) are used for interpolation.

Theory For a multi-slice scan, the sampling and interpolation pattern in the k-s space is shown in *Fig 1*. A variable density, slice interleaved sampling trajectory with fully sampled ACS (auto-calibration signal) lines in all slices is adopted to utilize the high-energy nature of k-space center and promote information sharing between adjacent slices. To interpolate unacquired data at different k-space locations, two examples are given in *Fig 1*, and a general expression is as follows:

$$S_j^s(k_y - m\Delta k_y) = \sum_{l=1}^{L}\left(\sum_{b=0}^{N_b-1} n_b(j,l,m) S_l^s(k_y - bR\Delta k_y) + \sum_{v=s-1,v=s+1} n^v(j,l,m) S_l^v(k_y - m\Delta k_y)\right)$$

where $S_j^s(k_y - m\Delta k_y)$ is the data to be interpolated of coil j and slice s at line $k_y - m\Delta k_y$. R represents reduction factor. N_b is the number of acquired lines used in the reconstruction. L is the number of coils. The index v denotes adjacent slice. After coil by coil reconstruction, images of different coils can be combined by means of square root of sum-of-squares reconstruction (SOS) method.

Method Phantom and volunteer scans were performed on a Philips Achieva 3.0T scanner system (Philips Healthcare, Best, Netherland) using a standard turbo spin echo (TSE) sequence and an 8-channel SENSE carotid coil. Fully sampled data were acquired in all experiments and manually undersampled to net reduction factor of 1.78 for GRAPPA and 2 for sGRAPPA reconstruction. A water phantom designed for carotid imaging was used in phantom scans, and scan parameters are: TE=10msec, TR=800msec, flip angle=90°, number of slice=8, slice thickness=2mm, FOV=160mm*160mm, acquisition matrix=260*260. Volunteer data were acquired on one patient of carotid atherosclerotic plaque with the following parameters: TE=10msec, TR=800msec, flip angle=90°, number of slice=9, slice thickness=3mm, FOV=140mm×140mm, acquisition matrix=238×238. To quantitively evaluate the performance of reconstruction, structural similarity (SSIM) [5], root-mean-square error (RMSE) and signal to noise ratio (SNR) are calculated for the reconstruction results.

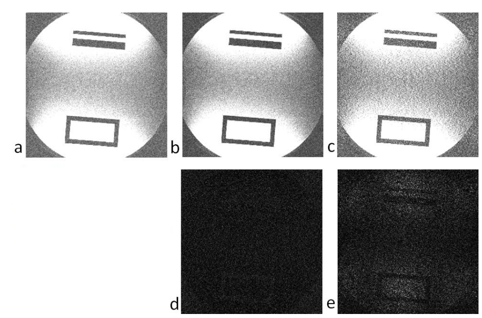

Figure 2. **a)** Reference image; **b)** sGRAPPA R=2; **c)** GRAPPA at R = 1.78; Error maps(×4): **d)** sGRAPPA; **e)** GRAPPA

Result and Discussion Results of phantom experiment are shown in Table 1 and Figure 2. Both subjective visual evaluation and quantification index indicate that sGRAPPA is superior to GRAPPA in several aspects including noise suppression, similarity in structural information with reference image. Results of *in-vivo* experiment are shown in Table 1 and Figure 3. We zoom in the carotid region when comparing images reconstructed by the two methods, and the image quality indexes are also calculated for this area, since this is the most important region for assessing carotid atherosclerotic plaque. While GRAPPA introduces more severe noise at carotid arteries, sGRAPPA performs better with lower noise level.

Conclusion sGRAPPA provides better SNR and enhanced preservation of structural information, especially at the ROI and thus it is more prospective in accelerating carotid imaging.

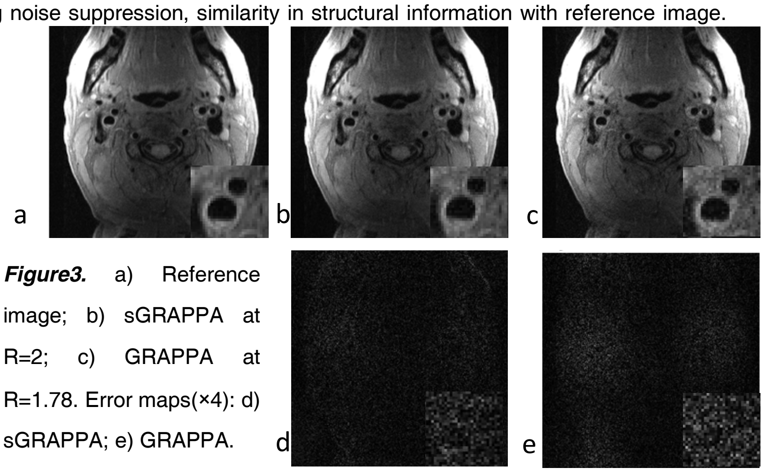

Figure3. a) Reference image; b) sGRAPPA at R=2; c) GRAPPA at R=1.78. Error maps(×4): d) sGRAPPA; e) GRAPPA.

Table 1. Quantitive comparison of sGRAPPA and GRAPPA

	Phantom result			Patient result		
	RMSE	SSIM (mean)	SNR	RMSE	SSIM (mean)	SNR
SGRAPPA	0. 23%	0.91	38.54	4.39%	0.94	7.60
GRAPPA	0. 32%	0.86	27.85	5.83%	0.90	5.67

Reference [1] Yuan et al.,Circulation 2001; 104:2051-2056.[2] Griswold et al, MRM 2002;47:1202–1210.[3] Saam et al.J CMR 2009; 11:41.[4] Huang et al., MRM 2005; 54:1172-1184.[5] Wang et al, IEEE TIP, 2004; 600-612