Optimized Parallel Imaging for Dynamic PC-MRI with Multi-Directional Velocity Encoding

H-H. Peng[1], S. Bauer[2], H-W. Chung[1], J. Hennig[2], B. Jung[2], and M. Markl[2]

[1]Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, [2]Department of Diagnostic Radiology, Medical Physics, University Hospital Freiburg, Freiburg, Germany

Introduction: Parallel imaging using GRAPPA has been used to accelerate image acquisition via undersampling of k-space in combination with properly-arranged RF coil arrays (1). In GRAPPA, AutoCalibrating Signals (ACS) are acquired for calculating the necessary reconstruction weights (WS). For dynamic phase-contrast (PC) MRI using GRAPPA, several ACS are typically acquired separately for each velocity direction and each cardiac phase. To further accelerate PC-MRI, we developed two methods, which calculated WS with reduced ACS data (2). In this study, we improve the image quality by retaining central part of k-space. The effects on flow velocity measurements were quantitatively investigated and compared to fully acquired data, standard GRAPPA (1), and TGRAPPA (time-interleaved sampling scheme in combination with GRAPPA) (3) reconstruction. In addition, the proposed algorithms were applied to tissue phase mapping data.

Methods and Materials: A full three-directional PC-MRI data set was acquired (3T Trio, Siemens, Germany, FOV=320x200mm, matrix=256x160, TR=40.8msec, VENC=1.5m/sec, 20 cardiac phases). k-lines were removed off-line to simulate GRAPPA with reduction factor (R) of 2, 3, and 4 and 32 central ACS lines (Fig.1(a)). To further accelerate data acquisition Method A computed WS from ACS of the reference image only (V_0), which were applied to other three directionally encoded velocity data (Fig.1a). Method B estimated only the WS of V_0 for the first cardiac phase (t_1), which was then used to reconstruct all remaining images (Fig.1b). To improve the accuracy of flow measurements, images were also reconstructed with retaining 4 (Add4) or 8 (Add8) central k-lines. To evaluate different reconstruction strategies, blood flow velocities within the aorta (white circle in Fig.2a) of standard GRAPPA, TGRAPPA, and the proposed methods A and B were compared with the fully sampled data on a pixel-by-pixel basis. Images were reconstructed with R=[2,3,4] and [0,4,8] retained central k-lines. The new method (R=3, ACS=32, Add4) was also applied to tissue phase mapping data (matrix=256x96, TR=5.8ms, through-plane VENC=25 cm/sec, in-plane VENC=15cm/sec, 11 cardiac phases).

Results: Fig.2 shows magnitude images of fully sampled, standard GRAPPA, and the two proposed algorithms (R=2). Difference images demonstrated only subtle discrepancies for all methods. In Bland-Altman plots (Fig.3), Method A and B (Add8) were comparable with standard GRAPPA. In contrast, TGRAPPA underestimated flow velocity. For all investigated reconstruction algorithms Fig.4 shows the correlation coefficients (r^2) for flow velocities, standard deviation (STD) for Bland-Altman plots, root mean square error (RMSE) for magnitude images, and % of time saving compared to GRAPPA. Methods A and B demonstrated good consistency (r^2 = 0.86~0.98) with fully sampled images (Fig.4(a)), and comparable STD (Fig.4(b)) and RMSE (Fig.4(c)) while providing additional reduction in scan time of 10%~17% (R=2) and 15%~28% (R=3) (Fig.4(d)). The application of Method A and B to tissue phase mapping data (Fig. 5) resulted in myocardium velocities comparable with standard GRAPPA and fully sampled data.

Discussion and Conclusions: The two proposed methods based on reduced ACS data acquisition can improve scan efficiency of dynamic PC-MRI while maintaining image quality and accuracy of measured flow velocities. The usage of retained central k-lines (Add4 and Add8) can improve the accuracy of flow measurements. For R=4, however, the images reconstructed with all reconstructed methods are deteriorated. Compared to TGRAPPA, Method A and Method B have proved to provide more accurate results (smaller STD) in evaluating flow velocity. For Add8, the proposed methods are comparable with standard GRAPPA. In contrast to k-t GRAPPA (4), the proposed methods can be implemented using the standard GRAPPA reconstruction. In conclusion, the two proposed reconstruction provide additional imaging acceleration of up to 25% for dynamic and multi-directional encoded acquisitions for R=2 and R=3.

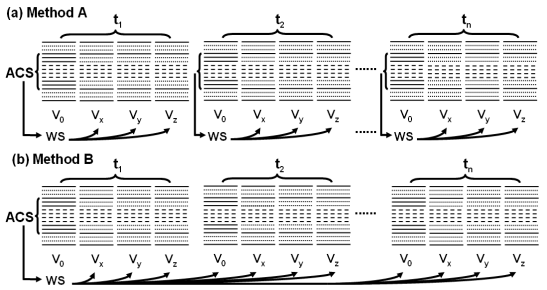

Fig.1. Method A (a) & B (b) with R=3. Solid line: acquired line. Dotted line: missing line. Dashed-line: retained central k-line. ACS: auto-calibrating signal. WS: coil weight estimation.

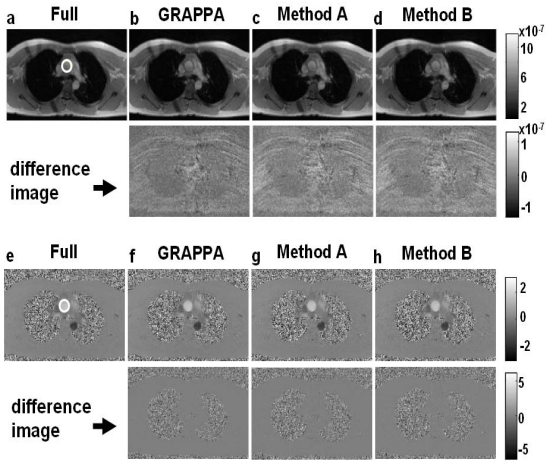

Fig.2. Magnitude images (a-d) and flow images (e-h) reconstructed with different strategies. The difference images (compare to fully sampled data) are shown in lower rows.

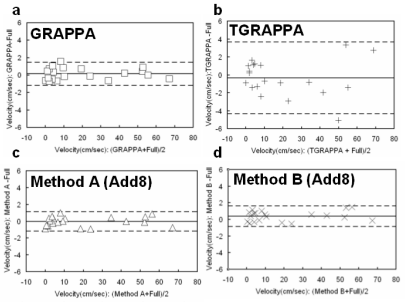

Fig.3. Bland-Altman plots reflecting the accuracy of flow measurements. Method A and B are comparable with GRAPPA. Without additional central k-lines TGRAPPA underestimates velocity.

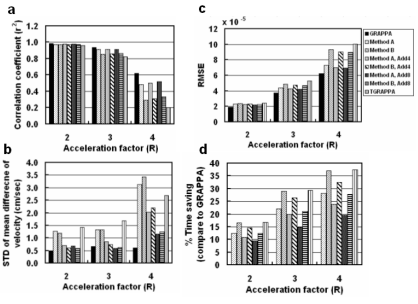

Fig.4. r^2 (a), STD (Bland-Altman plot) (b), and RMSE (c) for all methods for R=2,3,4 and added central k-lines. The results of Method A and B (with R=3, ACS=32, Add4 or Add 8) are comparable with GRAPPA.

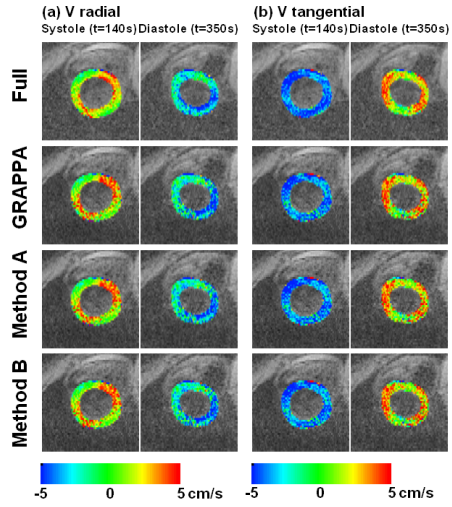

Fig.5. Myocardial motion velocities in radial (a) and circumferential (b) directions. Results of Methods A and B are comparable to standard GRAPPA and fully sampled data.

References: **1.** Griswold MA et al, 2002, MRM, 47(6):1202-1210. **2.** Peng HH et al, 2008, ESMRMB, No. 760. **3.** Beuer FA et al, 2005, MRM, 53(4):981-5. **4.** Huang F et al, 2005, MRM, 54(5):1172-84.