Extending GRAPPA kernels to 4D: application on time-resolved 3D phase contrast imaging

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Introduction: Improved scanner performance (gradients, CPU, RAM) and recent methodological development enable multi-dimensional data acquisition such as time-resolved 3D phase contrast imaging with three-directional velocity encoding [1]. However, these methods suffer from long acquisition times while aiming for high temporal / spatial resolution and thus hampering their use in clinical routine. To speed up acquisition times for 3D data acquisition, parallel imaging techniques have been introduced [2]. To further reduce scan time in time-resolved imaging, dynamic parallel imaging techniques have been developed such as k-tSENSE and k-tBLAST [3], kt-GRAPPA [4], and PEAK-GRAPPA [5]. Previous applications of these methods focused on time-resolved 2D imaging. It was the aim of this work was to extend spatio-temporal PEAK-GRAPPA acceleration to reconstruction for time-resolved 3D phase contrast data acquisition to fully exploit data redundancy along all spatial and temporal directions.

Methods: Time resolved three-directional, three-dimensional phase contrast measurements of the aorta were performed in a healthy volunteer on a 3 T Siemens Trio system using a 12 channel thorax coil. Imaging parameters were as follow: matrix 160 x 120 x 48 (spatial resolution 1.6 mm isotropic), flip angle = 7°, TR = 4.9 ms, temporal resolution = 50 ms, venc = 150 cm/s. Acquisition duration was about 45 min during free breathing using navigator gated respiratory control. PEAK-GRAPPA as an extension of kt-GRAPPA is characterized by a uniform kernel geometry. Previous conversions of k-tSENSE and k-tBLAST 

Results: Magnitude and phase difference images encoded along the foot-head direction (vx) for a systolic time frame in Fig.3 show the strongly enhanced quality of PEAK reconstruction (Rnet=7.2) compared to conventional GRAPPA (Rnet=2.4). Velocity time courses in Fig.4 show the excellent agreement of the PEAK recon types compared to the full k-space data. Note that the use of true 4D kernels provide improved results compared to the 3D-kernel reconstruction (yellow) which showed increased deviations in peak velocities. Pixel-wise correlation of systolic velocities is plotted in Fig.5 for the PEAK reconstruction with a 4D-kernel for Rnet=7.2. RMSE and correlation analysis of velocity values are summarized in Table 1.

Discussion: By including additional dimension such as kz and t in the PEAK-GRAPPA reconstruction process, considerably improved image quality and quantitative accuracy of functional data can be obtained compared to conventional GRAPPA even for net acceleration factors of up to 10 as indicated by the velocity time course and correlation coefficients. Furthermore, the results clearly demonstrate the importance of including all available dimensions for fitting the missing k-space lines and illustrate the high potential to accelerate multi-dimensional data acquisition such as 7D flow measurements for the investigation of vascular hemodynamics. More detailed investigations are necessary in order to determine optimized acquisition and kernel configurations in multi-dimensional acquisition space.