Optimizing the Net Acceleration of GRAPPA and PEAK-GRAPPA

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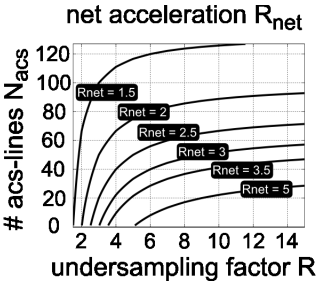

Fig. 1: Isolines of net acceleration factor for N_y = 200.

Introduction: Parallel imaging methods require calibration to coil sensitivities. The autocalibration approach acquires the calibration data along with the normal data acquisition while sampling the full k-space center with a certain number autocalibration lines N_{acs} [1]. Thus, the net acceleration of such an experiment depends on the undersampling factor R, the number of autocalibration lines N_{acs} and the number of phase encoding steps N_y. Different combinations of R/N_{acs} can result in the same net acceleration (Fig.1). The aim of this work was to systematically investigate different autocalibrating methods (standard spatial acceleration GRAPPA [2], spatio-temporal acceleration PEAK-GRAPPA[3]) with respect to their reconstruction performance depending on different R/N_{acs} combinations for the same net acceleration.

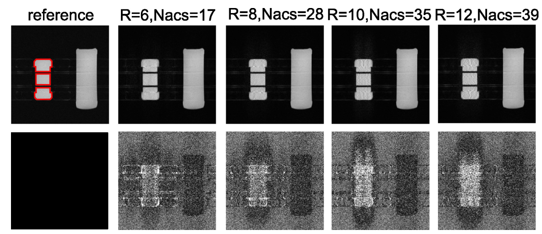

Fig. 2 Three PEAK-GRAPPA reconstructions of the phantom measurement for R_{net} = 4.5 and the difference images to the reference image.

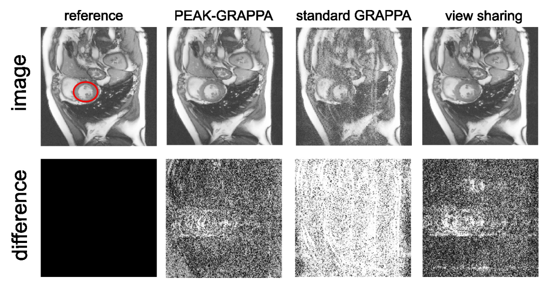

Fig. 3 Reconstruction of the in-vivo measurement with R_{net} = 4 (R=5, N_{acs}=12). Additionally the reference and the difference maps are shown.

Materials and Methods: All measurements were performed on a 3T system (Trio, Siemens) with full k-space sampling. To obtain undersampled data, phase encoding lines were subsequently removed and set to zero according to the sampling scheme. Each measurement was repeated without rf-excitation (flip angel = 0) for noise analysis. Phantom measurements were performed with a 12 channel body coil using an rf-spoiled CINE gradient echo sequence (matrix size = 256 x 256, spatial resolution = 0.94 x 0.94 mm, temporal resolution 16.8 ms (68 time frames)). The phantom consisted of a moving part filled with agarose gel and a static water bottle. The moving phantom oscillated with a frequency of approximately 1Hz. Additionally, in-vivo short axis cardiac images were acquired during breathold with 15 coil elements. A 2D bSSFP sequence was used with matrix size = 202 x 198, spatial resolution = 1.4 x 1.4 mm and temporal resolution = 33 ms (26 time frames). Three different reconstruction algorithms were evaluated: PEAK-GRAPPA (kernel size: $b_y = b_t =$ R+d with d=2 for R=2,3 and d = 4 for R>3 and b_x =3, [3]), GRAPPA (kernel size: b_x x b_y = 5x2), and view sharing. The autocalibration lines were copied back into k-space after reconstruction. To estimate image quality root mean square error (RMSE) and Noise in different regions (red lines in Fig. 2 and Fig. 3) was calculated. Image noise was estimated from the 'noise only' data, which underwent the same reconstruction chain as the measurements with rf-excitation, using the GRAPPA-weights obtained from the acquisition with excitation. Noise quantification was based on histograms of regional pixel intensities in the noise images [4].

Results: Fig 2 shows the PEAK-GRAPPA reconstruction results for an exemplary net acceleration factor of R_{net} = 4.5 for the phantom measurement. The difference images (full data versus PEAK-GRAPPA) demonstrate stronger deviations for increased R and N_{acs} but identical net acceleration. Fig 3 shows in-vivo images of all three reconstruction methods for R_{net} = 4 (R = 5, Nacs = 12). Fig 4 shows the RMSE (a) and the noise (b) averaged over all time points for the moving phantom and the left ventricle for all three methods depending on R and R_{net} The black vertical bars represent the standard deviation of the different time frames. Note that the scaling of the graphs of the GRAPPA results is different from the other due to the higher maximum values of the RMSE and the noise.

Discussion: Results of the phantom data and the in-vivo data reconstructed with varying R/N_{acs} combinations demonstrate PEAK-GRAPPA shows the best performance with respect of RMSE and noise amplification. Generally, for optimal results with a desired net acceleration, R and N_{acs} should be selected as small as possible. The only exception was the standard GRAPPA reconstruction at high net acceleration of R_{net} = 4.5 (figure 4, arrow) due to a poor determination of the set of linear equations for calculating the coil weights. Note that the RMSE values of PEAK-GRAPPA and view sharing show higher temporal standard deviations. While in standard GRAPPA each time frame is reconstructed independently, PEAK-GRAPPA and view sharing can suffer from motion induced blurring due to the inclusion of data from adjacent time-fremes in the reconstruction process. The results underline that the benefit of acquiring more calibration data in the center of k-space is smaller than the penalty induced by higher undersampling factors. Further studies are necessary to investigate if different objects and coil configuratons show the same behaviour. Moreover, an investigation of optimal reduction factors and number of autocalibration lines for 3D data with 2D accelerated GRAPPA is of high interest.

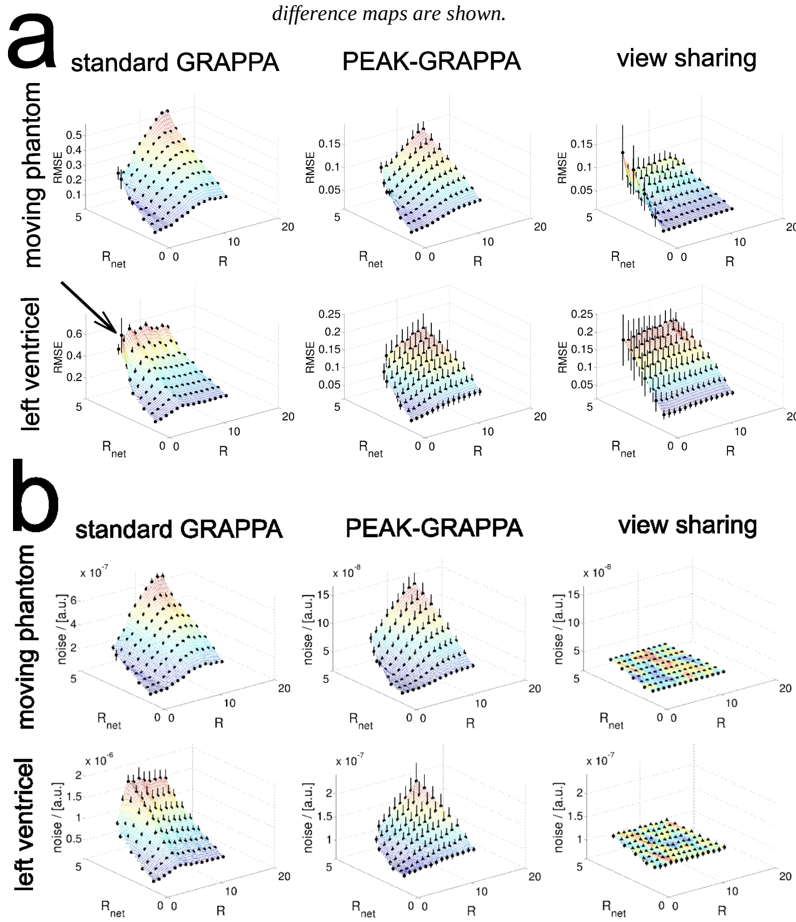

Fig. 4 Root mean square error(a) and estimation of noise (b) results for reconstructions at different R/R_{net} positions .

References: [1]Heidemann et al. MRM 2001; 45:1066-74 [2]Griswold et al. MRM 2002; 47:1202-10 [3]Jung et al. JMRI; in press. [4]Bauer et al. ISMRM 2008:1290
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