Highly k-t-space accelerated Tissue Phase Mapping

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Introduction: Tissue Phase Mapping (TPM) enables a quantitative analysis of myocardial wall motion [1]. A major drawback is related to long scan times in order to achieve a temporal resolution comparable to echocardiography measurements. In order to increase spatiotemporal resolution or reduce total acquisition time, parallel imaging techniques such as kt-SENSE, kt-BLAST [2] and kt-Grappa [3] have been introduced. For kt-BLAST/ kt-SENSE it has been shown that high reduction factors of the order of R=8 may introduce discrepancies in the measured velocities in phase contrast MRI [4]. Generally, all techniques suffer from decreased SNR and/or increased temporal blurring with increasing acceleration factors. In this study, a method called PEAK-Grappa (Parallel MRI with Extended and Averaged Grappa Kernels) was applied to time-resolved TPM measurements of the left ventricle. PEAK-Grappa is based on an extended spatiotemporal Grappa kernel in combination with temporal averaging. Qualitative and quantitative results of in-vivo experiments illustrate that the temporal fidelity of time-resolved TPM measurements are preserved while SNR was considerable improved compared to conventional Grappa.

Methods: A uniform spatiotemporal 3D Grappa kernel (kx, ky direction and time dimension) was defined for every reduction factor as shown in Fig.1 for R=3. For each spatiotemporal kernel location, spatial and temporal Grappa weights were estimated using the fully acquired central *k-t*-space. Subsequent averaging of weights resulted in a single unique 3D Grappa kernel for the reconstruction of the entire k-t space. For the reconstruction this kernel is shifted by an increment of R in *ky*- and *t*-direction over *k-t*-space, with a kernel size in kx-direction of *bx*=5. Such a uniform kernel was chosen since different kernels for different *k-t*-data points might lead to systematic errors and hence artifacts in image reconstruction. All reconstructions were performed with 24 reference lines, such that the true acceleration factor is smaller than the reduction factor (e.g. for R=8, 96 ky-lines and 24 reference lines the acceleration factor is 2.91). After reconstruction of the missing k-space lines the reference lines were copied back into the data matrix. For conventional Grappa, a border with zeros is typically placed around the kx-ky-space to permit the reconstruction of outer k-space lines. For PEAK-Grappa, the border also includes the time direction where central k-space lines contribute to the weight calculation and hence generate image artifacts for the first and last time frames. To compensate for these effects, the last time frames were copied to the beginning and vice versa. To account for the spatial dependency in parallel imaging, SNR was calculated by averaging and subtracting two adjacent time frames (end-diastolic frames) and by dividing the mean signal intensity in a ROI of the averaged image by the standard deviation in the identical ROI in the subtracted image.
TPM measurements were performed on a 3T Trio (Siemens, Germany) in a healthy volunteer using an 8 channel thorax coil and a black blood prepared k-space segmented gradient echo phase contrast sequence (TR=5.8ms) with a temporal resolution of 70 ms (11 cardiac frames) acquired during breath-hold. Full k-space data was acquired (32 heartbeats breath-hold) and PEAK-Grappa data with reduction factors R2-R4 with shorter breath-hold periods (14 heartbeats for R=4). The matrix size was 96 x 256, velocity encoding was performed with a *venc* of 25 cm/s through-plane and 15 cm/s in-plane. Data processing was performed in Matlab (The Mathworks). To evaluate the performance of different reconstruction methods, fully acquired k-space data sets were used to compare the following algorithms: standard (full k-space), conventional Grappa and PEAK-Grappa with reduction factors from R2-R6.

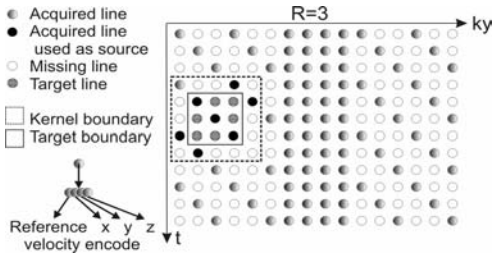

Fig.1: Data acquisition in ky-t space with reference lines and the PEAK-Grappa kernel with its source and target lines for R=3.

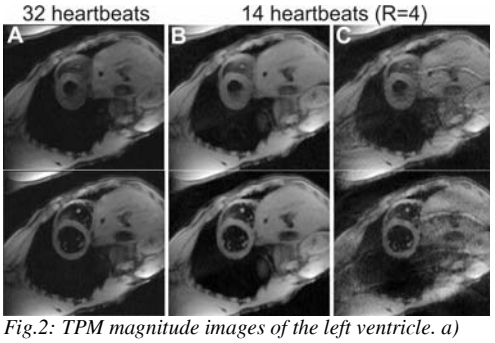

Fig.2: TPM magnitude images of the left ventricle. a) full k-space, b) PEAK-Grappa R6, c) conventional Grappa R6; upper row –systole, lower row – diastole.

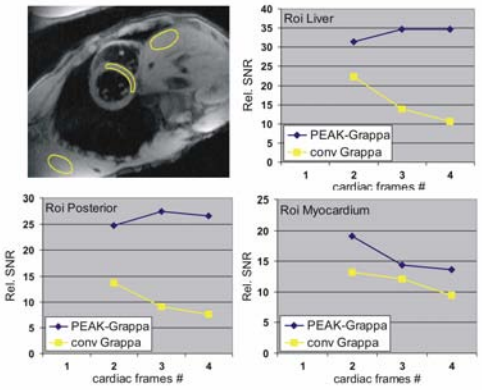

Fig.3: SNR behavior in three different ROI's for conventional Grappa and PEAK-Grappa.

Results: Fig.2 shows the TPM magnitude images for systolic and diastolic cardiac frames acquired with full k-space data (a), PEAK-Grappa R=4 (b), and conventional Grappa R=4 (c). The conventional Grappa reconstruction leads to strong image artifacts whereas the PEAK-Grappa reconstruction exhibits excellent image quality for R=4. The graphs in Fig.3 show the SNR variation as a function of the reduction factor in three ROI's. As expected, the SNR for the conventional Grappa reconstruction decreases with higher reduction factors, whereas the SNR for PEAK-Grappa increases in static tissue for higher reduction factors and slightly decreases for the ROI in the myocardium. To further analyze the effect of high reduction factors on the temporal dynamics of the myocardial velocities, mean velocities of the left ventricle were evaluated. Fig.4 shows color-coded maps of radial velocities (red=contraction; blue= expansion) in systolic and diastolic time frames for full k-space data (a), PEAK-Grappa R=6 (b), and conventional Grappa R=6 (c) demonstrating high SNR (reflecting a low standard deviation of the signal phase) in the PEAK-Grappa maps compared to conventional Grappa. The left graph in Fig.5 shows the time courses of global longitudinal velocities for full k-space data (blue), conventional Grappa R=6 (yellow), and PEAK-Grappa R=6 (pink) with a good agreement of the two latter compared to the full k-space velocities. In contrast, regional velocities e.g. in the anteroseptal area shown in the right graph demonstrate discrepancies in the time course of the conventional Grappa reconstruction.

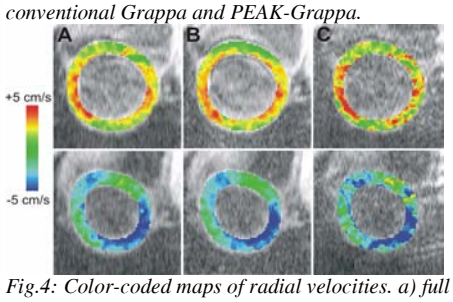

Fig.4: Color-coded maps of radial velocities. a) full k-space, b) PEAK-Grappa R6, c) conventional Grappa R6; upper row - systole, lower row – diastole.

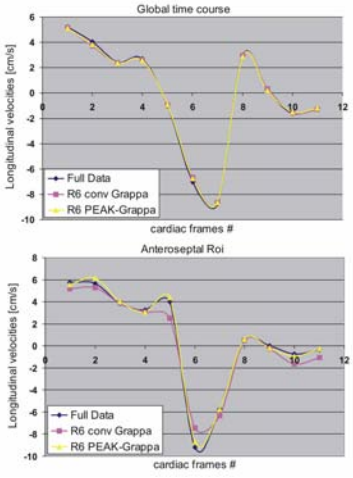

Fig.5 (left): Global (left) and regional (right) time courses of longitudinal velocities for full k-space (blue), conventional (pink) and PEAK-Grappa (yellow) with R=6.

Discussion: PEAK-Grappa in combination with time-resolved TPM provides robust image quality for high reduction factors while maintaining high SNR compared to conventional Grappa. The observed SNR optimization is a result of the averaging process included in the weight estimation used to define a single Grappa kernel for the entire k-t-space. Grappa weight averaging effectively exploits temporally uncorrelated noise in different time frames and results in considerably optimized SNR performance compared to other parallel imaging techniques while minimizing temporal blurring. Moreover, the integration of the temporal domain into the 3D PEAK-Grappa kernel helps preserving the myocardial velocities in TPM.

References: [1] Jung et al. *JMRI* 2006;24:1033-39. [2] Tsao *MRM* 2003;50:1031-42. [3] Huang et al. *MRM* 2005;54:1172-84. [4] Baltes et al. *MRM* 2005;54:1430-38.