Comparison of kt-SENSE and kt-GRAPPA applied to Cardiac Cine and Phase Contrast Imaging

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Introduction: To reduce scan time in time-resolved imaging, advanced parallel imaging techniques have been introduced such as kt-SENSE [1], kt-GRAPPA [2], and PEAK-GRAPPA [3] as an extension of kt-GRAPPA. In this work, kt-SENSE was compared to PEAK-GRAPPA (below referred as kt-GRAPPA) in terms of error, noise behavior and temporal fidelity for cardiac Cine and phase contrast (PC) data.

Methods: Measurements were performed on a 3T Trio system (Siemens) with a 12-channel thorax coil. In vivo time-resolved cardiac measurements in a healthy volunteer were performed using a bSSFP sequence (TR=3 ms) with 26 time frames (temporal res. 36 ms) and a matrix size of 192 x 256 acquired during breath-hold in a short axis orientation. Subsequently, an additional noise-only data set with zero flip angle was measured to allow for SNR analysis. The PC measurement was performed (TR=4 ms) with 16 cardiac time frames (temporal res. 64 ms) and a matrix size of 192 x 256 acquired during breath-hold in the aortic outflow tract with one-directional velocity encoding (through-plane venc=1.5 m/s).
To compare the full data to kt-SENSE and kt-GRAPPA, k-space lines were removed retrospectively from the fully acquired data sets. Cardiac bSSFP and phase contrast data sets were reconstructed with a reduction factor of R=6 and 12 reference lines for both k-t-SENSE and kt-GRAPPA yielding a net acceleration factor of R_{net}=4.6. Global and regional (encompassing LV for cardiac and aorta for PC) root-mean-square errors between the accelerated and full data averaged over all time frames were determined. The distribution of noise in the kt-SENSE and kt-GRAPPA images was determined by feeding noise samples into reconstruction while still using the reference lines from the Cine scan. Phased array image combination was performed as described by Roemer [4] with coil sensitivities calculated as temporal average derived from the fully acquired k-space data. For the cardiac data set SNR was estimated in a ROI within the myocardium (1 in Fig.2) and in static muscle tissue (2 in Fig.2) Velocity time courses were evaluated for PC data in the ascending aorta. Furthermore, a correlation analysis of pixel-wise velocity values for the peak velocity frame of the segmented ascending aorta was performed between the fully acquired k-space reconstruction and kt-SENSE / kt-GRAPPA.

Results: kt-SENSE and kt-GRAPPA in Fig.1 show similar image quality compared to the full k-space reconstruction. The kt-SENSE noise image in Fig.2 demonstrates distinct noise amplification in the myocardial region with motion while static tissue regions exhibit considerably less noise. In contrast, kt-GRAPPA shows only minor noise amplification in the myocardial region but increased noise in the static regions compared to kt-SENSE. These finding are also supported by the calculated SNR in the two ROIs (Table 1). Phase difference images of kt-SENSE and kt-GRAPPA in Fig.3 show similar artifact behavior if compared to the reference (see arrows). Fig. 4 and 5 demonstrate the excellent quantitative agreement of both acceleration techniques compared to the fully acquired k-space. Regional RMSE in the LV of kt-GRAPPA was slightly superior compared to kt-SENSE due to less noise in this region.

R=6, 12 reference lines R_{net}=4.6	RMSE global [%]	RMSE regional	SNR myocard (Ref=42.2)	SNR muscle (Ref=42.5)	r^2
Cardiac kt-SENSE	3.1	9.5	20.8	75.5	-
Cardiac kt-GRAPPA	2.7	5.6	32.6	48.7	-
PC kt-SENSE	6.5	9.3	-	-	0.95
PC kt-GRAPPA	6.2	6.6	-	-	0.93

Table 1: Global and regional root-mean-square error of the different reconstruction types. SNR in a myocardial and a static region (muscle) was calculated for the cardiac data with the noise-only data. For PC data the correlation coefficient (r^2) of pixel-wise systolic velocities is given.

Discussion: The results demonstrate that both reconstruction methods, kt-SENSE and kt-GRAPPA, provide excellent image quality and temporal fidelity for net acceleration factors > 4. Interestingly, the methods exhibit marked differences in the noise characteristics which have not been described before. While noise amplification due to image acceleration in kt-SENSE is mostly confined to regions with motion, kt-GRAPPA demonstrated less spatially varying noise. A comparison with Compressed Sensing as a further method to speed up data acquisition might be also of interest.

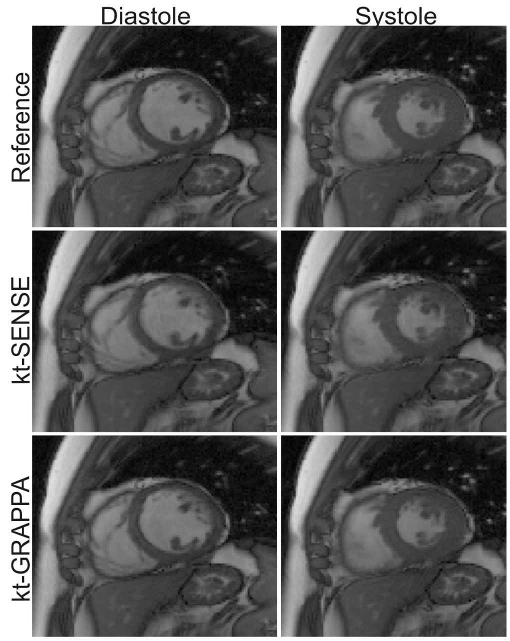

Fig.1: Zoomed diastolic and systolic cardiac images for R=6 and 12 reference lines (R_{net}=4.6).

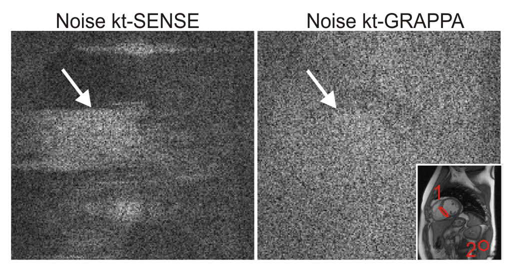

Fig.2: Noise images for one cardiac frame: where kt-SENSE shows a distinct noise amplification in the myocardial region only a slight noise amplification can be observed for kt-GRAPPA (see arrows) – in static tissue this behavior is contrary.

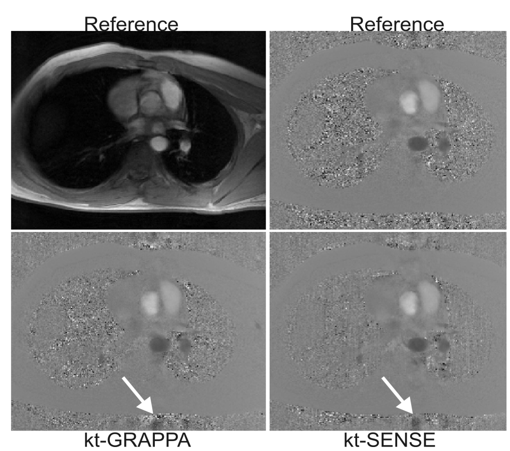

Fig.2: Magnitude and phase images for the fully acquired k-space and phase images for kt-GRAPPA and kt-SENSE reconstruction for R=6 (R_{net}=4.6).

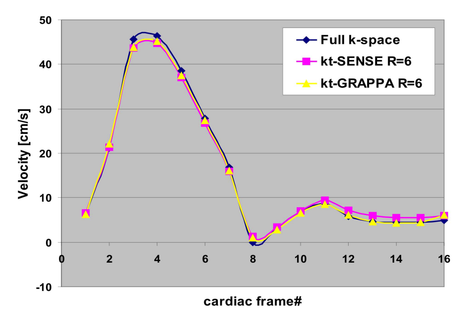

Fig.3: Velocity time courses for the reference and the kt-GRAPPA and kt-SENSE reconstruction.

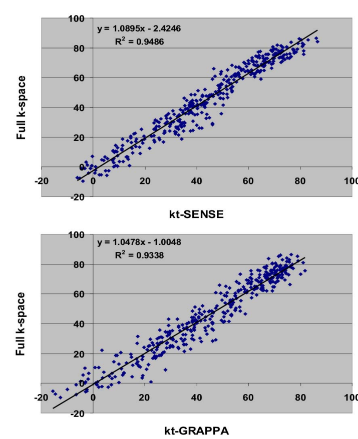

Fig.4: Pixel-wise correlation of ascending aorta for the peak systolic cardiac frame.

References:
[1] Tsao et al. *MRM* 2003;50:1031-42. [2] Huang et al. *MRM* 2005;54:1172-84. [3] Jung et al. *JMRI* 2008;28:1226-32. [4] Roemer et al. *MRM* 1990;16:192-225.