K-t-GRAPPA accelerated Phase Contrast MRI: Improved assessment of blood flow and 3-directional myocardial motion during breath-hold

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Introduction: Functional cardiovascular MRI applications such as phase contrast (PC) MRI provide established tools for the quantification of blood flow and left ventricular tissue motion. The additional scans needed to encode the functional information increase total scan time and limit the spatial and/or temporal resolution that can be achieved during breath-holding [1]. Acquisitions are thus often performed during free breathing using respiration control such as navigator gating in order to overcome such limitations. However, respiratory gating often results in image blurring and motion artifacts which may severely impair image quality and flow or motion quantification. Conventional parallel imaging (e.g. GRAPPA) can reduce scan time but typical reduction factors of ~2 are often not sufficient to reduce scan time to breath hold duration, particularly for 3-directional flow or motion encoding. Spatiotemporal parallel imaging such as k-t-SENSE or k-t-GRAPPA offers a higher potential to further accelerate data acquisition. It has been shown that k-t-GRAPPA allows for a net speed-up in data acquisition in phase contrast imaging up to a factor of 5 while preserving the temporal dynamics [2]. However, previous studies mostly acquired full k-space data while removing data retrospectively. In this study, high temporal resolution flow (2D PC in the aorta) and motion encoded (myocardial velocities, Tissue Phase Mapping, TPM) scans were acquired during breath-hold using spatiotemporal acceleration with PEAK-GRAPPA [3] (as an extension of k-t-GRAPPA) and compared to conventional protocols using standard GRAPPA and navigator respiration gating.

Methods: Imaging was performed on a 3T system (Trio, Siemens, Germany) using a 12-channel thorax coil. In five healthy volunteers 2D PC (through plane velocity encoding) measurements were performed in the ascending aorta and TPM (3-directional motion encoding) measurements in a midventricular short axis location. Three different scans were performed for the 2D PC and TPM measurements:

	Flow		TPM	
	BH	FB	BH	FB
Matrix size (75% RecFov)	256 x 160		128 x 70	
Voxel size [mm]	1.3 x 1.5		2.2 x 3.0	
Venc [m/s]	1.5 (through)		0.2(in) x 0.3(through)	
TR [ms]	4.7		5.1	
Temp. res. [ms]	28.2		20.4	
ACS lines	10	24	10	24
R (R_{net})	5 (4)	2 (1.74)	5 (3.33)	2 (1.49)
Scan time [s]	12	55	19	85

Table 1: Scan parameters for flow and TPM measurements. Scan times are given for a navigator efficiency of 50% and an RR-interval of 0.9s.

1) A breath-hold (BH) scan using PEAK-GRAPPA with R=5.
2) A free-breathing (FB) scan using conventional GRAPPA with R=2.
3) A free-breathing scan using PEAK-GRAPPA with R=5.

The free-breathing scans were acquired using adaptive navigator gating [4] with an acceptance window of 6 mm All acquisitions were performed using a slice thickness of 8 mm and a 15° flip angle. Further imaging parameters are itemized in table 1. The PEAK-Grappa reconstruction was directly implemented into the Siemens image reconstruction environment. Reference (ACS) lines were copied back into the data matrix after reconstruction to preserve the temporal dynamics. Data analysis included the quantification of aortic blood flow and myocardial velocities. For 2D-PC, the ascending aortic lumen was manually segmented and the mean and peak through-plane velocity time course was measured. For TPM, after segmentation of the myocardial contours mean and peak radial, rotational and longitudinal myocardial velocity components (describing myocardial motion) were calculated.

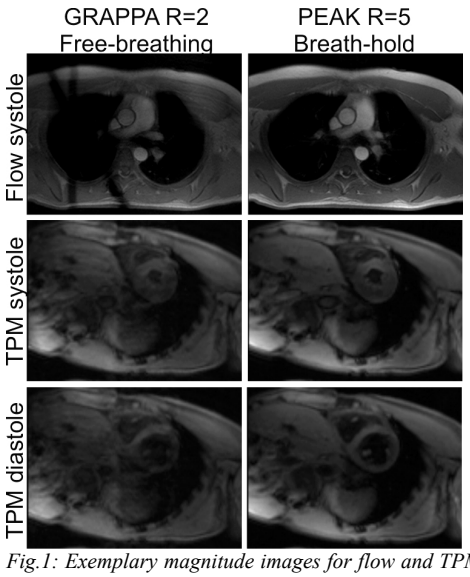

Fig.1: Exemplary magnitude images for flow and TPM scans acquired with conventional GRAPPA with R=2 and PEAK-GRAPPA with R=5.

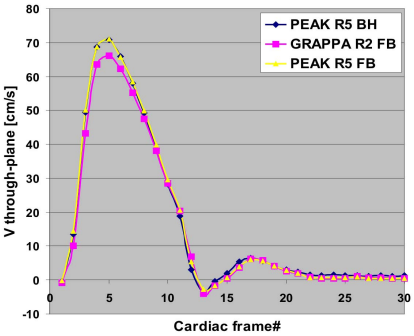

Fig.2: Velocity time course for the flow scan averaged over 5 volunteers.

V_Peak [cm/s]	Flow	TPM			
	V_{max}	Vr_{max}	Vr_{min}	Vz_{max}	Vz_{min}
R5 BH	72±14	2.6±0.2	-3.9±0.3	4.9±1.4	-8.5±2.2
R2 FB	68±12	2.2±0.9	-2.9±1.4	3.6±1.4	-6.3±2.2
R5 FB	72±15	2.5±0.1	-3.5±0.2	4.1±0.6	-7.6±2.1

Table 2: Mean peak velocities (±SD) for flow (systole) and TPM scans of 5 volunteers (systole and diastole).

Results: The magnitude images shown in figure 1 clearly demonstrate the advantage of the breath-hold scans compared to data acquired during free-breathing. Clearly improved image quality was provided by the breath-held PEAK-GRAPPA reconstruction. In addition, the velocity time courses of the aortic flow measurements averaged over all 5 volunteers in figure 2 show good agreement between PEAK Grappa and conventional 2D-PC. Further, a slight underestimation of peak velocities by the conventional GRAPPA data can be seen whereas both PEAK-GRAPPA scans demonstrated an excellent agreement and less low pass filtering. A similar behaviour can be observed for the TPM measurements for all three velocity components as shown in figure 3. These results are corroborated by the mean peak velocities given in table 2 where the conventional GRAPPA scans yielded the lowest peak velocities.

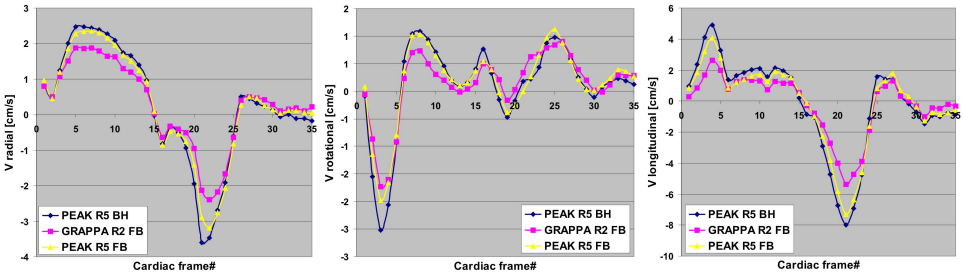

Fig.3: Velocity time courses for the different velocity components for the TPM scan averaged over 5 volunteers.

Discussion: The results of this feasibility study indicate that the use of high accelerations factor with PEAK-GRAPPA which cannot be achieved with conventional parallel imaging can provide scan time reductions that allows data acquisition during breath-hold while maintaining a high temporal resolution. This enhances the image quality while avoiding breathing related artifacts that can occur with navigator gating in combination with CINE imaging. Noticeably, the lowest peak velocities were observed for the conventional GRAPPA protocol. A slight decrease can also be observed for the TPM scans acquired with PEAK-GRAPPA during free-breathing due to motion-induced artifacts. However, both PEAK-GRAPPA accelerated TPM scans provided an improved temporal dynamics of myocardial velocities compared to the conventional GRAPPA accelerated scan. Additional measurements should be performed to allow for a statistical analysis of the observed results and patient studies are needed to evaluate the achievable improvement within a clinical workflow.

References: [1] Jung et al. *JMRI* 2006;24:1033. [2] Jung et al. *MRM* 2008; 60:1169. [3] Jung et al. *JMRI* 2008; 28:1226. [4] Markl et al. *JMRI* 2007; 25:824.