On the use of k-t accelerated 4D Flow MRI in the Portal System

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Target audience: Radiologists interested in hymodynamics of the portal system.

Purpose: 4D flow MRI is a powerful tool to assess cardiovascular hemodynamics in-vivo and can provide valuable information of the portal system in patients with chronic liver disease such as cirrhosis [1]. Total imaging time, however, is still a limiting factor of this method and one of the reasons why it is often difficult to add 4D flow MRI as a standard method in clinical routine. Advanced acceleration methods for dynamic imaging such as k-t GRAPPA have high potential to substantially accelerate 4D flow MRI [2]. However, it is known that k-t acceleration can induce temporal and spatial blurring and thus may impact quantitative accuracy of the velocity data. The purpose of this study was to evaluate the utility of k-t parallel imaging for the acceleration of 4D flow MRI in the portal system by systematically investigating the impact of different acceleration factors and temporal resolution on the flow quantification.

Methods: Time-resolved 3D MR velocity mapping of the arterial and venous portal hemodynamic system was performed in a group of 16 volunteers (age=25±3 years) at a 3T Siemens Trio system using a 12-channel thorax coil. An axial oblique 3D volume was acquired with respiratory gating, using a navigator at the spleen-lung interface and ECG gating [1], with a spatial resolution = 2.0 × 2.5 × 2.4 mm, velocity sensitivity *venc*=100 cm/s, flip angle=7°, TR=5.1 ms, bandwidth = 450 Hz/pixel.

For each volunteer, five 4D flow MR scans were acquired during the same session: (i) standard GRAPPA with R=2; k-t-GRAPPA with (ii) R=3, (iii) R=5, and (iv) R=8; all of these scans with a temporal resolution of 41 ms. Additionally, one k-t-GRAPPA scan with (v) R=5 was acquired with a temporal resolution of 82 ms. The k-t-GRAPPA accelerated scans (i.e. undersampling along ky, kz and t dimensions) were performed as described previously [2]. The number of autocalibration (ACS) lines and the resulting nominal acceleration R_{net} are summarized in Table 1. The k-t algorithm was integrated into the scanner's data reconstruction workflow and all undersampled data were acquired and reconstructed directly on the MR system.

Table 1	GRAPPA	k-t-GRAPPA			
R	2	3	5	5	8
Tres	82	82	82	41	82
ACS lines (ky × kz)	24 × Nz	18 × 6	20 × 7	20 × 7	16 × 7
R_{net}	1.6	2.8	4.2	4.2	6.3
Scan time	13:56	8:12	7:06	11:02	4:00

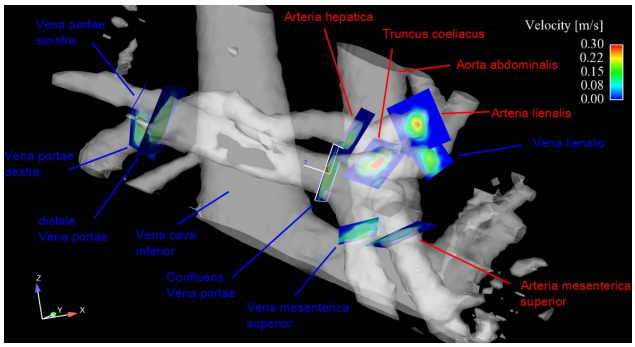

Fig.1: Veins (blue) and arteries (red) used for quantification of hemodynamic parameters (vena cava and aorta are displayed but not quantified)

Data preprocessing included a correction for aliasing, eddy currents and background noise and the calculation of a 3D phase contrast MR angiogram. Data analysis consisted of a time-resolved pathlines 3D visualization (ENSIGHT 8.2, CEI, USA) of aortic blood flow and the positioning of six 2D planes in the portal venous system (Vena mesenterica superior, Vena lienalis, Confluens Vena portae, distale Vena portae, Vena portae dextra, Vena portae sinistra) and four planes in the arterial system (Arteria mesenterica superior, Arteria lienalis, Arteria hepatica propria, Truncus coeliacus), see Fig. 1. For each plane, the vessel lumen boundaries were manually segmented for each time frame using a home-built Matlab tool. Flow quantification included the extraction of pixel-wise peak systolic velocity and net flow over the cardiac cycle. For each plane peak systolic WSS was calculated as described previously [3]. The differences between means of all parameters were statistically compared to the standard method GRAPPA R=2 using paired two-tailed t-tests.

Results: The differences for peak velocities, flow rates, and wall shear stress for all five scans and all ten vessels are summarized in Fig. 2. Only minor differences are observed for venous peak velocities, two significant values for the smallest vessels, vena portea dextra and sinistra. For all arteries an underestimation of peak velocities occurs for an acceleration factor of R=8. However, significant differences observed in peak velocities disappear in the flow rate values where only differences occur in venous vessels for R=3 and 5 revealing somewhat higher flow rates compared to standard GRAPPA. The comparison of venous peak WSS revealed a slight underestimation for R=5, whereas significantly higher values could be observed for R=5 with the higher temporal resolution in two veins. Clearly underestimated values of arterial WSS can be seen for R=8.

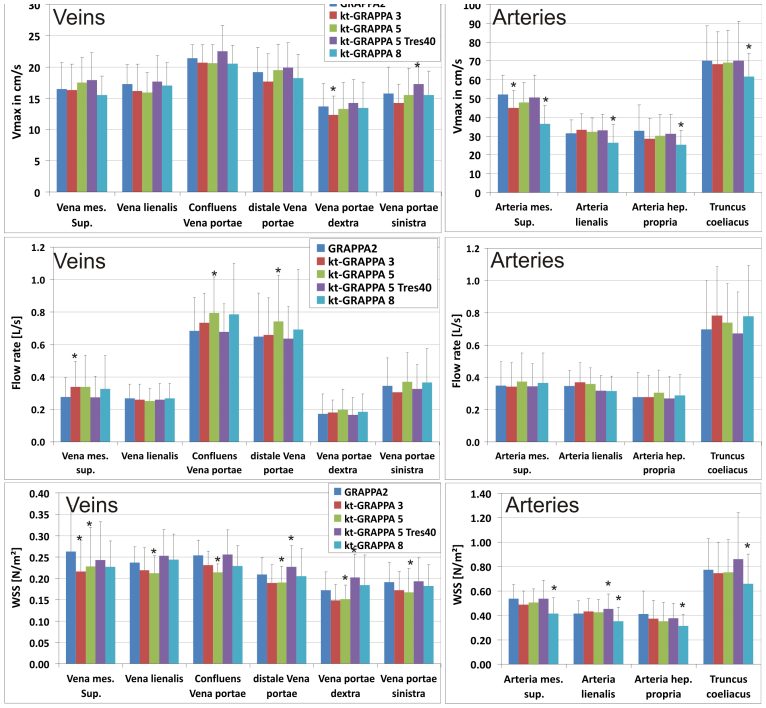

Fig. 2: Comparison of peak velocities, flow rates and peak WSS averaged over all volunteers for the five different scan protocols.

Discussion: The results revealed overall good image appearance except for an acceleration factor of R=8 where the noise enhancement made the segmentation more difficult. However, all acceleration factors allowed a robust pathlines visualization (not shown) as well as a reliable determination of flow rates. Most differences in the venous system could be observed for peak WSS, which may be caused by the higher velocity noise (compared to arteries) and the more difficult vessel segmentation. Furthermore, a tendency particularly in the veins could be observed revealing somewhat higher peak velocities and WSS for R=5 with a higher temporal resolution indicating a slight low-pass filter effect using a temporal resolution of 82 ms despite the low pulsatility in the veins.

In conclusion, the results demonstrate the feasibility (i.e. improved scan efficiency) of using k-t-GRAPPA for 4D flow measurements in the portal system. The results suggest the use of acceleration factors of up to R=5. R=8 clearly yielded an underestimation of peak velocities and WSS and therefore is not recommended to speed up data acquisition. The presented study focused on flow measurements in the portal system. However, the performance may vary in other applications, i.e. other vascular territories, due to different volume locations in different coil configurations.

References: [1] Stankovic Z et al. *J Magn Reson Imaging* 2010;32:466–475. [2] Jung B et al. *Magn Reson Med* 2011;66:966-975. [3] Stalder AF et al. *Magn Reson Med* 2008; 60:1218-1231.