Flow sensitive 4D MRI at 1.5T and 3T

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Introduction: The intrinsic sensitivity of MRI to motion offers the opportunity to analyze blood flow in-vivo. In recent studies, time-resolved 3D CINE phase contrast MRI with three-directional velocity encoding (flow-sensitive 4D MRI) has been applied for the visualization of 3D hemodynamics and quantitative analysis of flow inside the entire aorta and other vascular systems. Although initial reports have shown the advantage of higher magnetic fields for phase contrast applications [1], no detailed in-vivo comparison of flow-sensitive 4D MRI at different field strengths has been presented to date. It was therefore the aim of this study to directly compare the performance of flow-sensitive 4D MRI regarding noise, 3D flow visualization, and quantitative flow analysis at 1.5T and 3T. Thoracic aortic hemodynamics was evaluated in a study with 10 normal volunteers who were examined at both field strengths. A region-of-interest analysis was used to quantify velocity noise and regional velocity-time curves at both field strengths.

Methods: Flow-sensitive 4D-MRI was evaluated in a cohort of 10 normal volunteers (mean age = 26 ± 2 years). All measurements were performed on both a 1.5T system (Avanto, Siemens, Germany) and a 3T system (TRIO, Siemens, Germany) with identical 12 element body coils for signal reception (time difference of scans = 6.6 ± 5.8 days). To ensure comparability of the results, all volunteers underwent MR imaging with an identical flow-sensitive 4D MRI pulse sequence for both field strengths: rf-spoiled gradient echo with three-directional velocity encoding (*venc* = 150cm/s), sagittal oblique 3D volume covering the entire thoracic, TE/TR = 2.6ms/5.1ms, flip angle = 7°, temporal resolution = 40.8ms, spatial resolution = 1.7x2.0x2.2mm^3. Respiration and wall motion artifacts were minimized by ECG and respiratory gating [2].

Data processing included noise filtering, correction for eddy currents and velocity aliasing. A 3D phase contrast (PC) MR angiography was calculated from the 4D MR data and was used to position two analysis planes at defined anatomical landmarks normal to the aorta (Ensight, CEI, USA, figure 1). 3D flow visualization included the calculation of 3D stream-lines and time-resolved particle traces emitted for the two analysis planes. Further, data in two analysis planes in the ascending and descending aorta at the level of the pulmonary artery were imported into a home built analysis tool (Matlab, The Mathworks, USA) which was used to quantify time resolved blood flow velocities as described previously [3]. For each volunteer and both field strengths, regional velocity noise σ_V in these analysis planes was estimated by calculating the standard deviation of all three measured velocity components for the last acquired time frame based on the assumption that blood was mostly static during late diastole.

Results: The quality of 3D visualization and depiction of aortic lumen geometry by 3D PC-MRA was generally superior at 3T compared to 1.5T as exemplary shown in figure 1. Improved depiction of vascular geometry and reduced noise for 3T can clearly be appreciated. Flow visualization resulted in smoother appearance of stream-line traces and improved visualization of flow in small vessels as shown for the supra-aortic branches in figures 1 which could only be partly visualized at 1.5T (open white arrow). Similar results were obtained for other volunteers. As expected, velocity noise was significantly (2-sided paired t-test, p=0.007) higher for 1.5T (σ_V = 3.6% ± 0.6% of *venc*) compared to 3T (σ_V = 2.9% ± 0.6% of *venc*) corresponding to a 23% improvement for data acquired at 3T. Flow analysis revealed generally good agreement between velocity-time curves at both filed strengths. Interestingly, flow quantification at 1.5T resulted in a systematic small underestimation of peak velocities (0.05m/s) as shown by the Bland Altman analysis in figure 2 despite higher heart rates (65±12 vs. 61±11) and significantly (p=0.002) increased systolic blood pressure (134±14mmHg vs. 124±13mmHg) during examinations at 1.5T compared to 3T.

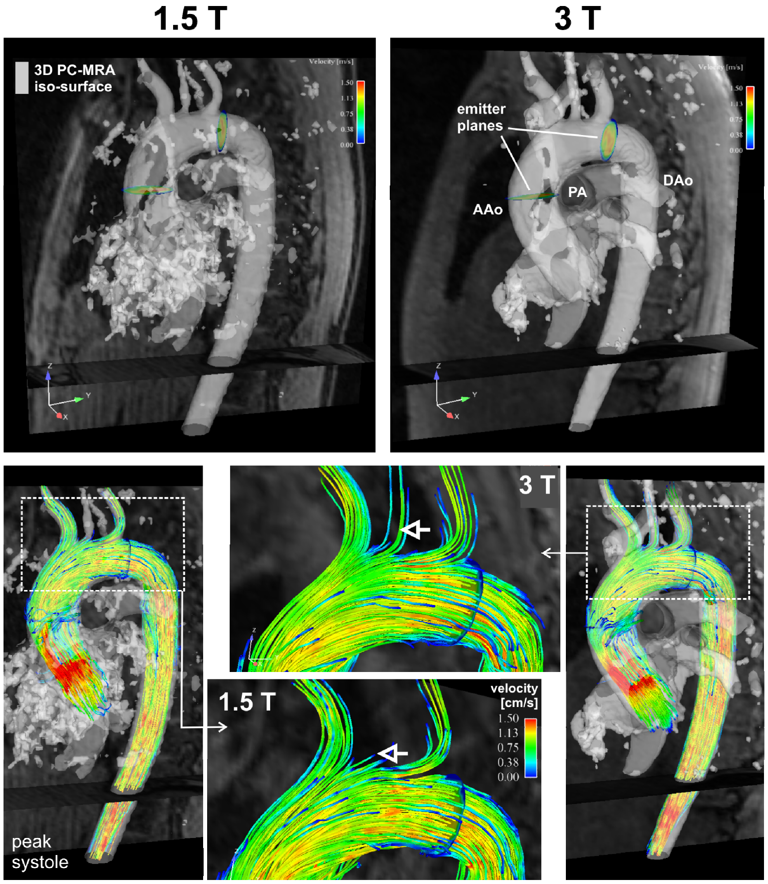
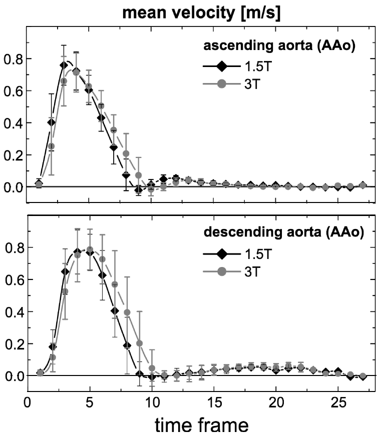


Fig. 1: Direct comparison of phase contrast MR angiography (PC-MRA) and 3D blood flow visualization for the same volunteer examined at 1.5T (left) and 3T (right). **Top:** Time-average 3D PC-MRA was calculated from the 4D data and displayed as gray shaded semi transparent iso-surface. **Bottom:** Two emitter plane (top right) were used to generate systolic 3D steam-lines by forward / backward tracing of the measured three-directional velocity vector field. Flow quantification was performed in the ascending (AAo) and descending (DAo) aorta at the height of the pulmonary artery (PA).



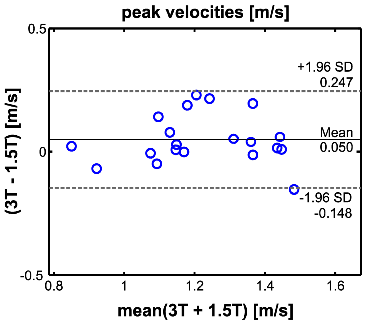


Fig. 3: Bland-Altman analysis of peak velocities in the ascending and descending aorta for volunteers (n=10) examined at 1.5T and 3T.

Fig. 2: Mean velocity-time curves at.1.5T (back diamonds) and 3T (gray circles). For both field strengths, data points reflect average values over 10 volunteers while standard deviations represent inter-individual variations.

Discussion: Results of this volunteer study demonstrated that flow-sensitive 4D MRI at 3T was superior to imaging at 1.5T and provided reduced velocity noise and clearly improved quality of phase contrast angiography and 3D flow visualization. Reduced peak velocities at 1.5T despite increased heart rates indicate the value of reduced velocity noise at 3T for improved flow quantification accuracy. Nevertheless, flow-sensitive 4D MRI at both 1.5T and 3T was feasible and provided comprehensive information of aortic geometry, 3D hemodynamics and quantitative flow velocities without the use of contrast agents.

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References: **1.** Lotz J, et al. J Magn Reson Imaging 2005;21:604-610. **2.** Markl M, et al. J Magn Reson Imaging 2007;25(4):824-831. **3.** Stalder AF, et al. Magn Reson Med 2008;60(5):1218-1231.