Quantification and visualization of flow in small vessels of the Circle of Willis: time-resolved three-dimensional phase contrast MRI at 7T compared with 3T

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Introduction: The Circle of Willis (CoW) acts as an essential collateral pathway to maintain blood flow to the cerebral cortex in case of vessel occlusion due to thrombosis, atherosclerosis or vasospasm [1]. Intracranial aneurysms, the most common cause for cerebral stroke, often develop at arterial branch points in the CoW. A risk factor for aneurysm development is the asymmetry and incompleteness of the CoW. For a better understanding of the local hemodynamics in which aneurysms form and develop, the study of blood flow and anatomy of the CoW is necessary. A promising technique to non-invasively measure blood flow is time-resolved three-dimensional phase contrast MRI (PC-MRI). In small structures as the CoW, the resolution of the measurement needs to be high (< 1 mm^3). However, image quality may be compromised since SNR decreases with increasing resolution. A decrease in SNR of PC-MRI data increases blood-flow direction uncertainty and hampers flow quantification [2]. In this study PC-MRI is performed in the CoW of five volunteers at 3T and 7T to investigate the differences in SNR and accuracy of blood flow quantification. Visualization of blood flow in smaller vessels of the CoW is a secondary aim of the study.

Materials & methods: MR examinations were performed on 5 healthy subjects (2 males, 3 females). Age varied between 21 and 55 years old. Retrospectively gated 3D PC-MRI was performed in an 8-channel head coil at 3T (Philips Healthcare, Best, The Netherlands) and in a 7T whole body system (Philips Healthcare, Cleveland, OH, USA) with a 16-channel receive coil and a volume transmit/receive coil for transmission (Nova Medical, Wilmington, MA, USA) at a spatial resolution of 0.5 x 0.5 x 0.5 mm. Imaging parameters were: flip angle: 20°; field of view: 180 x 180 x 20 mm (AP x RL x FH); velocity encoding: 150 cm/s x 150 cm/s x 150 cm/s; SENSE: 3; TE/TR: 4.1/8.6 ms; Temporal resolution averaged over the volunteers was 147±7 ms . Phase images were corrected for background phase offset errors by subtraction of the average phase in a static region of interest (amygdala). The lumen in both scans was semi-automatically segmented at all cardiac phases and in every slice in the fast field echo (FFE) images using a level set evolution algorithm [3]. The postprocessed data was imported in GTFlow (Gyrotools, Zurich, Switzerland) to perform blood flow visualization and quantification in the arteries of the Circle of Willis. To allow for a voxel-wise comparison between the 7T and the 3T results, the 7T velocity information was registered and interpolated to the 3T PC-MRI data. Signal to noise ratios were calculated according to Price et al. [4].

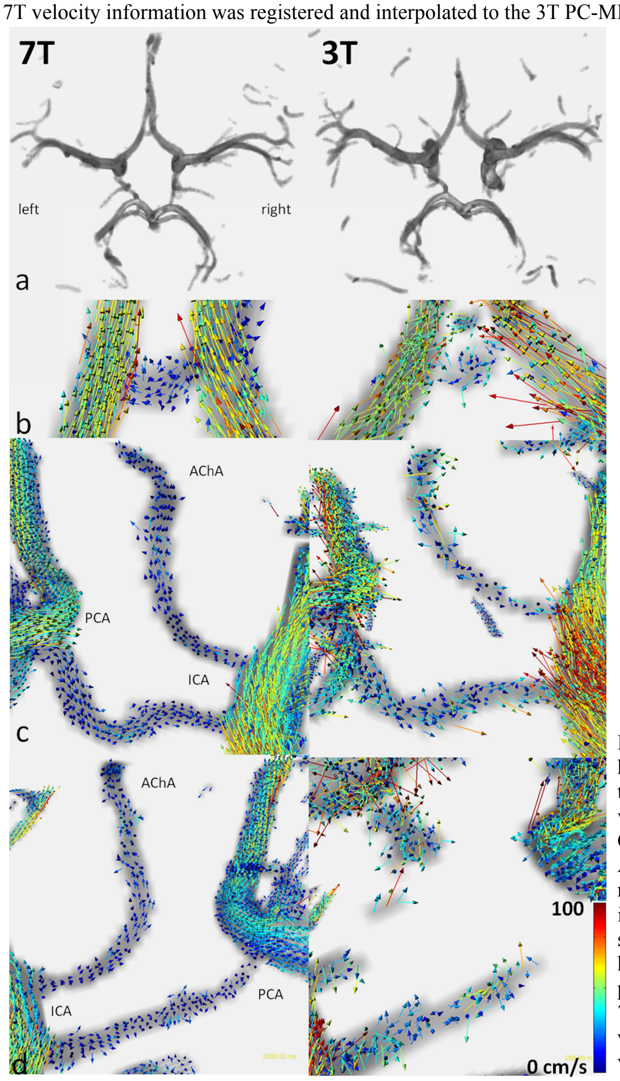

Figure 1: Flow visualization in vessels in the Circle of Willis of volunteer 2. (a) Stack of segmented FFE images. (b) Flow in the ACoA. (c) Flow in the left PCoA. (d) Flow in the right PCoA.

*Table 1: Mean, standard deviation (SDp) of the paired difference (3T minus 7T), median of the angles between velocity vectors at 7T and 3T and SNR; * indicates significant*

	Vol 1		Vol 2		Vol 3		Vol 4		Vol 5	
Field strength	3T	7T	3T	7T	3T	7T	3T	7T	3T	7T
Mean (cm/s)	0.4* (p<.01)		1.2* (p<.01)		0.3* (p<.01)		0.2* (p<.01)		0.0 (p=0.6)	
SDp (cm/s)	10.1		16.3		17.2		17.8		14.4	
Med angle (°)	21.6		27.6		26.0		35.3		31.3	
SNR	12.6	34.3	12.4	38.9	11.2	29.8	10.9	28.1	12.1	27.4

Table 2: The mean velocity, area, and flow of vessels in the Circle of Willis averaged over all cardiac phases and volunteers. Standard deviations are calculated over the 5 volunteers.

Resolution	Mean velocity (cm/s)		Mean area (mm^2)		Mean flow (ml/s)	
Field strength	3T	7T	3T	7T	3T	7T
ICA	34.6±5.9	29.7±6.3	11.8±2.0	13.2±1.1	3.5±0.5	3.5±0.6
MCA	30.9±7.2	28.6±5.8	9.7+2.5	9.5±2.1	2.4±0.3	2.4±0.4
BA	24.8±3.8	21.9±5.8	9.3±1.9	10.5±0.8	2.1±0.4	2.2±0.6
ACA1	30.7±8.0	24.9±5.9	4.9±0.8	6.4±1.3	1.2±0.4	1.5±0.4
ACA2	29.8±7.4[a]	24.0±6.7	4.9±1.2[a]	5.4±1.6	1.1±0.1[a]	1.1±0.3
ACoA	12.3±1.4[b]	12.0±8.3[c]	2.1±0.9[b]	3.3±1.6[c]	0.1±0.1[b]	0.1±0.0[c]
PCA	20.5 ±2.1	17.5±3.6	5.1±1.4	6.1±1.2	0.9±0.3	1.0±0.3
PCoA left	19.7±7.6[b]	8.95[f]	2.6±0.3[b]	2.8[f]	0.4±0.3[b]	0.2[f]
PCoA right	8.5[d]	8.4±2.4[e]	2.2[d]	3.1±1.7[e]	0.1[d]	0.2±0.2[e]

[a]Measured in 4 volunteers, FOV placed too low in one volunteer
[b]Measured in 2 volunteers: hypoplastic, not present or not segmented in others
[c]Measured in 3 volunteers: hypoplastic, not present or not segmented in others
[d]Measured in 1 volunteer: hypoplastic, not present or not segmented in others
[e] Measured in 4 volunteers: hypoplastic, not present or not segmented in the other
[f] Measured in 1 volunteer, not in the other volunteer due to movement in between sequences

Results/Discussion: From table 1 it can be deduced that the SNR is an average factor of 2.7 higher in the 7T data. This gain in SNR allowed for better segmentation and reduced noise in the velocity data, as can be seen in figure 1. At 7T the direction of the flow in small vessels was visible. For the subject shown in figure 1, the direction of the flow in the Anterior Communicating Artery (ACoA) was from right to left, in the left Posterior Communicating Artery (PCoA) from Posterior Carotid Artery (PCA) to Internal Carotid Artery (ICA) and in the right PCoA from ICA to PCA. Note the upward flow in the Anterior Choroidal Artery (AChA) in figures 1c and d at 7T. Directions of flow were less obvious in the 3T data. Furthermore, segmentation failed where signal was low, see figure 1d. The noise in the 3T data resulted in a higher mean velocity in all vessels as shown in table 2, resulting in a positive mean of the paired differences in table 1. In table 2 the mean flow values corresponded well between 3T and 7T. However, due to increased SNR the areas of the vessels were larger and the mean velocities were lower at 7T. Thus, lower mean areas in the 3T data were compensated by a higher mean velocity due to increased noise, resulting in similar flow values for 3T as for 7T. As a result of the use of a 16-channel head coil at 7T and an 8-channel head coil at 3T, the gain in SNR at 7T, calculated from table 1, was slightly higher than expected, namely 2.7 instead of 2.3.

Conclusion: Increased signal and decreased noise levels at 7T compared to 3T enhance segmentation and allow for better quantification and visualization of flow in small vessels of the Circle of Willis.

References:
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