Hypercapnia-Induced Vessel Size Imaging at 3 Tesla using PROPELLER-EPI

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Introduction

Vessel size imaging (VSI) [1] allows quantitative mapping of the microvasculature by measuring changes in the transverse *gradient-echo* (GE) and *spin-echo* (SE) relaxation rates, ΔR_2^* and ΔR_2, respectively. Recently, the hypercapnia-induced *blood oxygenation level depending* (BOLD) effect has been successfully demonstrated for VSI with the benefit of avoiding application of exogenous contrast agents in humans [2]. This so called BOLD-VSI method, however, requires sensitive mapping of ΔR_2^* and ΔR with sufficient *contrast-to-noise ratio* (CNR), which can be problematic at lower clinical field strengths. In the present work we demonstrate that the *periodically rotated overlapping parallel lines with enhanced reconstruction – echo planar imaging* (PROPELLER-EPI) [3] technique can be applied for robust multi-echo acquisition to map both ΔR_2^* and ΔR at 3 T.

Methods

With PROPELLER-EPI a narrow blade, centered in *k*-space, is acquired with each *rf*-excitation. Subsequently, this blade is rotated until the entire *k*-space has been covered. Recently, it was shown that sliding-window reconstruction can be used with PROPELLER-EPI data, making the technique also suitable for fMRI application [4, 5]. Here, we combined a *long-axis PROPELLER-EPI* (LAP) sequence with multi-echo gradient- and spin-echo readout to acquire ΔR_2^* and ΔR data. Four gradient-echoes with echo times of 7.9, 16.1, 24.3 and 32.5 ms as well as the spin echo at 79.8 ms were sampled after a single excitation for each blade orientation. To cover *k*-space completely 10 blades were acquired with TR of 2 s per blade. Measurements were performed on a 3 T system (TIM Trio Siemens Healthcare, Erlangen, Germany) with 192 mm radial field-of-view, 64x64 acquisition matrix size, 18 slices with 3 mm slice thickness and a gap between slices of 1.5 mm. The receiver bandwidth was 100 kHz. To correct geometric distortions multi-frequency reconstruction [6] was applied on the blade level, i.e., blades were individually corrected prior to full *k*-space combination based on a field map that was acquired first by using a multi-echo reference scan [7].

Five subjects were scanned after informed consent was obtained. Subjects were breathing room air and carbogen (5% CO_2, 95% O_2) in an alternating fashion using a facial mask with a three-way valve. Each stimulation block lasted 3 min resulting in a breathing pattern of *air – carbogen – air – carbogen – air*. Total scan duration was 15 min. For each subject an additional T_1-weighted MP-RAGE scan was acquired as an anatomical reference and for creating gray matter *(GM)* and white matter *(WM)* masks.

Calculation of CNR, ΔR_2^* and ΔR_2 was performed as described in [2]. Maps of the average venous vessel radius r_v were obtained from the ratio $q=\Delta R_2^*/\Delta R$ using a Monte-Carlo model [8]. In addition, maps of the venous blood volume β and the vessel density N_v were also calculated.

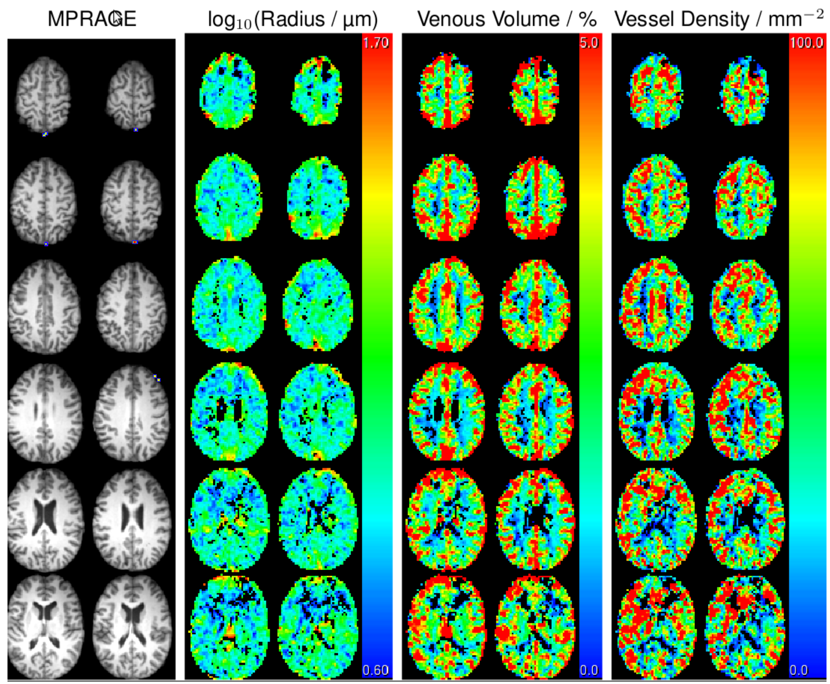

Fig. 1. Maps of venous vessel size (r_v), blood volume fraction (β) and vessel density N_v in several slices of subject 3. For comparison anatomical data obtained with an MPRAGE scan is shown in column one.

Results

Table 1 shows the calculated parameters ΔR_2^* and ΔR_2 as well as the CNR for both the PROPELLER-EPI experiment at 3 T and a previously performed comparable EPI study at 7 T [2]. The CNR of the present PROPELLER-EPI study at 3 T was slightly superior compared to the CNR achieved at 7 T. Figure 1 shows representative maps of r_v, β and N_v at 3 T. The corresponding averages of these parameters are shown in Table 2 together with the results of the 7 T study [2]. As is evident from the table the values of r_v and β are comparable, whereas, however, the inter-subject variability of r_v is greatly reduced at 3 T. Reliable estimates of r_v with an error less than 5% were obtained for 88 ± 3 % of the voxels in GM and for 80 ± 3 % in WM. These results are in very good agreement with the 7 T study (91 ± 3% in GM and 77 ± 5 % in WM).

Discussion

Our work demonstrates that BOLD-VSI is possible at clinical field strength of 3 T within scan durations of 15 min by using multi-echo PROPELLER-EPI. The high signal stability achieved by oversampling the *k*-space center and using sliding-window reconstruction is highly advantageous for robust estimations of ΔR_2^* and ΔR. The averaged parameters r_v and β are similar to those obtained at 7 T, whereas slight deviations between 3T and 7T could originate from too simplistic or incorrect assumptions made in the Monte-Carlo simulation [8] used in both studies. In conclusion, our experiments demonstrate that PROPELLER-EPI in combination with a sliding-window reconstruction can be used for a reliable estimation of ΔR_2^* and ΔR at *3 T*.

	GM (3T)	WM (3T)	GM (7T) [2]	WM (7T) [2]
r_v / µm	11.9 ± 0.7	10.1 ± 0.5	13.4 ± 1.7	13.7 ± 2.1
β / %	3.45 ± 0.66	1.89 ± 0.20	2.58 ± 0.25	1.26 ± 0.19
N_v / mm^{-2}	74.2 ± 20.6	65.9 ± 10.3	33.7 ± 5.6	18.9 ± 4.6

Tab. 2. Mean parameters averaged over all subjects for *gray matter* (GM) and *white matter* (WM) for the current experiment and a comparable 7 T study [2].

Sequence	ΔR_2^* / s^{-1}	$\sigma(\Delta R_2^*)$ / s^{-1}	CNR(ΔR_2^*)	ΔR_2 / s^{-1}	$\sigma(\Delta R_2)$ / s^{-1}	CNR(ΔR_2)
EPI (7T) [2]	5.02 ± 0.21	0.92 ± 0.12	5.46 ± 0.94	0.80 ± 0.03	0.34 ± 0.07	2.35 ± 0.57
PROPELLER(3T)	2.24 ± 0.23	0.36 ± 0.03	6.22 ± 1.16	0.54 ± 1.16	0.14 ± 0.01	3.86 ± 0.63

Tab. 1. Comparison of CNR, ΔR_2^* and ΔR_2 between PROPELLER-EPI at 3 Tesla and a comparable EPI measurement at 7 T [6]. Temporal noise σ was calculated from the standard deviation over time during baseline.

References [1] Prinster A et al., NeuroImage 1997, [2] Jochimsen TH et al., NeuroImage 2010, [3] Wang FN et al., MRM 2005, [4] Krämer M et al., MRM, *in press*, [5] Nordell A et al., Proc. ISMRM 2008, [6] Man LC et al., MRM 1997, [7] Schmitthorst VJ, et al., IEEE Trans Med Imaging, 2001, [8] Jochimsen TH et al. NeuroImage 2008