Whole-brain Perfusion Measurements at 7T using Pulsed Arterial Spin Labelling and Simultaneous Multi-slice Multi-echo Echo Planar Imaging

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Target audience: Researchers and clinicians interested in perfusion imaging and/or working in ultra-high field MRI

Purpose: Implementation and evaluation of 7T whole-brain perfusion protocols with simultaneous multi-slice EPI

Introduction: Arterial spin labeling (ASL) at ultra-high field (7 Tesla and higher) is very attractive due to the higher image signal-to-noise ratio (SNR) and the longer T_1 relaxation time of tissue and blood [1] as compared to clinical field strengths. However, ASL at 7T has not been widely used in humans, owing to the significant technical challenges its successful implementation presents. While B_0- and B_1-inhomogeneities may significantly reduce the spatial homogeneity and efficiency of the labeling [2,3], the increased specific absorption rate (SAR) renders spin-echo-based acquisition methods impractical. All these issues have led to previous implementations of ASL at 7T having only partial brain coverage and/or poor temporal resolution [3-7]. In this work we propose the combination of the SAR-efficient flow alternating inversion recovery (FAIR) [8] pulsed ASL scheme with a simultaneous multi-slice echo planar imaging (SMS-EPI) readout to achieve perfusion measurements with whole-brain coverage at temporal resolutions comparable to recently proposed SMS-EPI ASL protocols at 3T [9,10] and to minimize the inversion time variability of the slices in one volume.

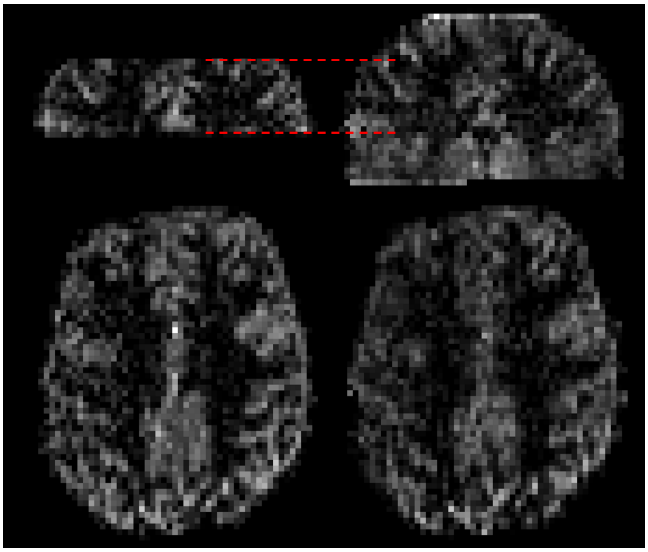
Methods: Experiments were performed on a 7 T Siemens scanner with a 32-channel NOVA Medical head coil. Two subjects participated in the study after giving informed consent. The FAIR scheme was combined with QUIPSSII [9] and TI_1/TI_2 = 700/1800ms. Slab-selective or non-selective inversion was done using an optimized 10ms tr-FOCI pulse [11], which achieves high inversion efficiency at 7T despite B_1-inhomogeneities and SAR constraints. The readout strategy combined simultaneous multi-slice excitation with a 2D blipped-CAIPI [12] and multi-echo EPI readout. The nominal voxel size was 2.5 mm isotropic without slice gap. Scans at four different SMS-factors were compared with a conventional 2D dual-echo EPI scan, using the following parameters: 15 slices, in-plane GRAPPA-2, partial Fourier (PF) 6/8, $TR/TE_1/TE_2$ = 2438/11/27ms. The acquisition parameters of the four SMS scans varied slightly, but the total acquisition time was kept constant at 7 min and 35 sec for each protocol. SMS-scans doubled the volume coverage to 30 slices (32 for the SMS-4 scan). The other parameters were, using CAIPIRINHA notation ($AF_{in\text{-}plane}$ x SMS-factor_caipi-shift): 1) CAIPI 2 x 2_z3, PF=6/8, $TR/TE_1/TE_2$ = 2388/9/25ms; 2) CAIPI 2 x 3_z3, PF=6/8, $TR/TE_1/TE_2$ = 2216/9/26ms; 3) CAIPI 1 x 3_z2, PF=5/8, TR/TE = 2143/9ms; 4) CAIPI 1 x 4_z3, PF=5/8, TR/TE = 2098/10ms. All data were reconstructed offline in MATLAB using 4x3 slice-GRAPPA kernels for slice separation [13] and 4x3 in-plane GRAPPA kernels, followed by motion correction and coregistration with SPM 8. Voxel-wise maps of the temporal SNR and the mean perfusion-weighted signal were generated from the early echo of each scan (the second TE was not used for this analysis).

Results:

The table lists the mean voxel-wise tSNR of perfusion in grey matter of the region covered by all the scans i.e. the volume defined by the non-slice-accelerated scan.

CAIPI parameters	2 x 1	2 x 2_z3	2 x 3_z3	1 x 3_z2	1 x 4_z3
tSNR	0.46	0.50	0.39	0.49	0.35

The figure shows the comparison between the mean perfusion-weighted signal of the conventional PASL acquisition on the left and the SMS acquisition with the highest tSNR on the right.



Discussion: Due to the optimized inversion pulses fast imaging within SAR constraints was possible. Whole-brain coverage as offered by SMS-EPI sampling is an important asset for both neuroscientific and clinical application of ASL at 7T. Furthermore, the simultaneous acquisition of multiple slices provides significantly reduced variability of inversion times across the brain counteracting the SNR decrease along the slice direction due to T_1 decay of labeled blood. The proposed approach allows concurrent whole-brain CBF and BOLD measurements with reduced acquisition time to be performed which finds immediate application for (calibrated) fMRI studies at 7T. In conclusion, we have presented a simultaneous multi-slice PASL approach that offers whole-brain coverage at 7T with comparable SNR to a conventional 2D PASL partial volume acquisition.

References: [1] Gardener et al. MRM, 2009. 61:874-82; [2] Teeuwisse et al. Int J Imaging Syst Technol, 2010. 20:62–70; [3] Luh et al. MRM, 2013. 69:402-10; [4] Ghariq et al. MAGMA, 2012. 25:83-93; [5] Hall et al. Proc. 18th ISMRM, 2010. 517; [6] Pfeuffer et al. MRM, 2002. 47:903-11; [7] Zuo et al. PloS One, 2013. 8:e66612; [8] Kim SG MRM, 1995. 34:293-301; [9] Kim et al. MRM, 2013. 10.1002/mrm.24880; [10] Feinberg et al. MRM, 2013. doi: 10.1002/mrm.24994; [11] Wong et al. MRM, 1998. 39:702-8; [12] Hurley et al. MRM, 2010. 63:51-8; [13] Setsompop et al. MRM, 2012, 67:1210-24;