SLAB-SELECTIVE, BOLD-CORRECTED VASO (SS-VASO) IN HUMAN BRAIN AT 7T

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Introduction: Functional changes in cerebral blood volume (CBV) may localize changes in neural activity better than other MRI-accessible physiological variables [1]. Vascular space occupancy (VASO) measures CBV changes non-invasively through extravascular tissue signal change [2]. The contrast, relying on the difference in T1 between tissue and blood, is generated by applying an inversion pulse prior to acquisition that nulls blood water magnetization, while keeping substantial tissue signal for detection. At high magnetic field strengths, the remaining tissue signal at the blood nulling point is reduced, due to convergence of tissue and blood T1 values [3]. This results in a contrast-to-noise-ratio (CNR) for VASO which is disappointingly small. However, VASO CNR at the blood nulling time can be dramatically improved by applying a slab-selective gradient during inversion [4], such that proton spins in stationary tissue are in steady-state, while flowing blood is inverted only once. There are different methods to correct for the counteracting extravascular BOLD effect in VASO, e.g. small TE or multi-echo readout [5]. To assess and eliminate residual BOLD effect contamination here, we acquire BOLD data interleaved with VASO. We present results using slab-selective, BOLD-corrected VASO (SS-VASO) in human brain at 7T during a visual task.

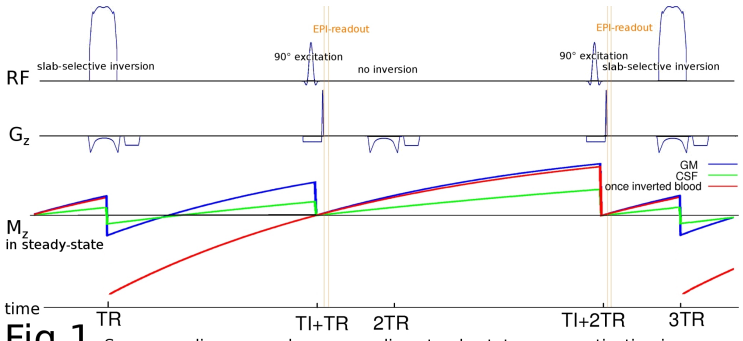

Fig.1 Sequence diagram and corresponding steady-state z-magnetization in the slab-selective, BOLD-corrected VASO sequence

Methods: The slab-selective, BOLD-corrected pulse sequence was implemented on a Siemens 7T MRI scanner. Fig.1 shows the sequence diagram and corresponding spin magnetization. The study was approved by the local ethics committee and all subjects gave informed consent. The scan parameters were: voxel size = 1.5 mm isotropic, TE/TI/TR=19/1330/1500ms. We acquired data with 2D multi-slice single-shot GRE EPI without slice gaps. We implemented a tr-FOCI pulse [6] to achieve proper slab-selective inversion despite B_1 inhomogeneities and SAR constraints. A 6 min. high-contrast moving star-field paradigm (block design: 30s rest vs. 30s stimulation) was used to induce neural activation in the visual cortex of ten subjects. In four sessions, the rest period was increased to 90s, in order to investigate the signal behavior after cessation of the stimulus. To eliminate false positive voxels, a statistical analysis with a z-threshold of 2.3 and a cluster significance threshold of p=0.05 was performed (FEAT ver. 5.98) [7]. In order to ensure that all blood in the imaging slice has been inverted once and only once, we adjusted inversion slab thickness and TR with the help of pilot experiments. We validated BOLD the correction scheme in pilot scans by means of a hyperoxia experiments.

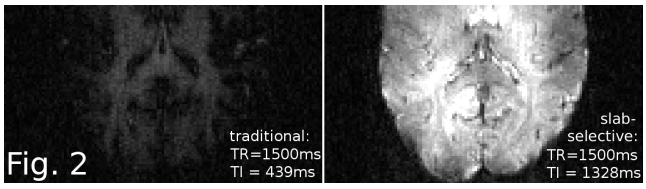

Fig. 2

Results: Slab-selective VASO provides a much larger grey matter signal than traditional VASO (Fig. 2). This increase results from the longer nulling time (TI) for once-inverted blood, compared with steady-state blood. Fig. 3 shows the ΔCBV map for a single representative subject. Fig. 4 shows the time course of BOLD and VASO signals averaged across all ten subjects. The measured average change in CBV of 28 % ± 5% is in good agreement with the literature [8]. The VASO signal change appears to vary less than BOLD across subjects, giving smaller error bars as shown. This may be due to the reduced signal drift resulting from the pair-wise subtraction that corrects for BOLD contamination. The post-stimulus return to baseline has a similar time constant for VASO and BOLD signals, contrasting with [9] but in agreement with [10]. This result may be due to the absence of significant changes in venous CBV with short stimulus durations [11]. Fig. 5 shows the time course for rest periods of 90s. A significant VASO undershoot can be seen. In voxels containing more than 10% CSF partial volume, the BOLD signal change is larger than the mean (p=0.026). By contrast, VASO signal change is significantly (p=0.0018) smaller in such voxels (Fig. 6). This is consistent with results showing that CBV change is smaller in voxels closer to the pial surface, in contrast with BOLD [1,4]. Because the steady-state can be controlled separately in stationary tissue and in blood, both blood and CSF can be nulled independently, thus avoiding partial volume effects of dynamic changes in CSF that can be problematic in VASO [12].

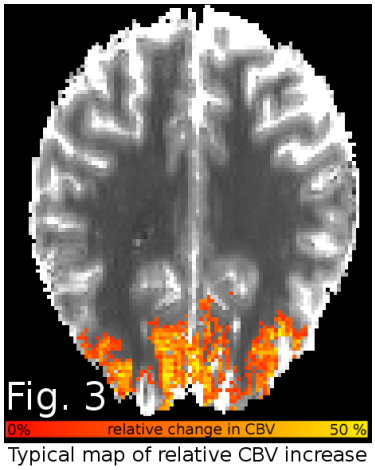

Fig. 3 Typical map of relative CBV increase overlayed on a T1 map

Conclusion: We have shown that VASO can give reliable and consistent CBV changes at 7T [4]. Here blood arrival and transit times are comparable to the blood nulling time after inversion, which is used in the slab-selective approach. With these improvements, SS-VASO becomes a useful tool for high resolution functional brain mapping in humans at high fields.

References: [1] Kim T, Kim SG 2010 [2] Lu, H, et al., 2003 [3] Rooney, WD, et al., 2007 [4] Jin, T, et al., 2008 [5] Hua, J, et al., 2011, Proc. ISMRM [6] Hurley, AC, et al., 2010 [7] Smith, SM, 2002 [8] Belliveau JW, et al., 1991 [9] Mandeville, JB, et al., 1999 [10] Dechent, P, et al. 2010 [11] Hillman, EMC, et al., 2007 [12] Donahue, MJ, et al. 2006

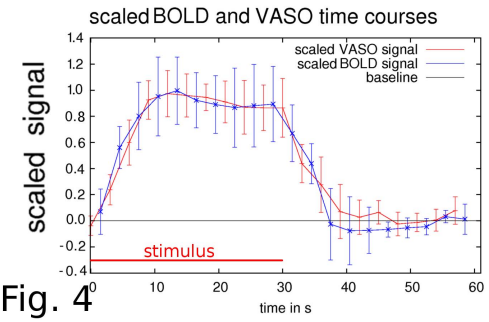

Fig. 4

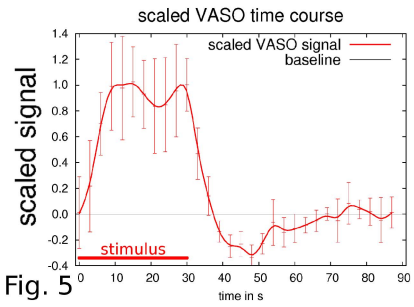

Fig. 5

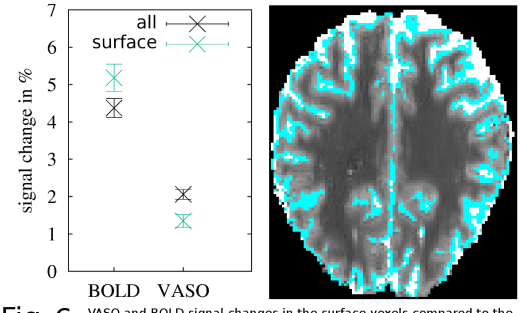

Fig. 6 VASO and BOLD signal changes in the surface voxels compared to the mean signal change and a representative image of the surface voxels