Simultaneous acquisition of cerebral blood volume, blood flow and blood oxygenation weighted MRI signals at 7T

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Target Audience: Researchers and users interested in brain physiology, hemodynamics and fMRI; MRI sequence developers

Purpose: Blood oxygenation level dependent (BOLD) contrast emerges from a complicated interaction of changes in cerebral blood flow (CBF), cerebral blood volume (CBV) and cerebral metabolic rate of oxygen ($CMRO_2$) which is not yet fully understood [1-3]. Yang et al. proposed a technique for simultaneous acquisition of CBV, CBF and BOLD which enables one to accurately compare the temporal characteristics of these physiological quantities [4-5]. However, especially due to the limited signal-to-noise (SNR) of the classical vascular space occupancy (VASO) technique, the flow contamination of the BOLD images, and the low static magnetic field strength used, the practicability of this technique is limited. We introduce a modified version of the Yang sequence at 7T which involves slab-selective ss-VASO [6], double EPI readouts for arterial spin labeling (ASL) and VASO in order to correct for BOLD contamination, and a separate BOLD acquisition to minimize inversion effects on the BOLD signal.

Methods: A single-slice inversion recovery sequence with three excitations within one TR was chosen in order to acquire CBV-based, CBF-based and BOLD images (fig. 1). CBV-based images are acquired via the recently introduced ss-VASO technique, based on a slab-selective inversion instead of the global inversion used by classical VASO [7]. A double EPI readout is used to exponentially extrapolate to an echo time of 0ms in order to correct for BOLD signal contamination. CBF-weighted images are acquired via the PASL-FAIR inversion scheme. Slab-selective and non-selective inversions are played out alternately, and a double EPI readout is performed after the slice-selective excitation at time TI_2. BOLD images are acquired at TI_3 via a third excitation and a single EPI readout. A very late time point has been chosen for BOLD signal acquisition in order to minimize the effects of the inversion on the BOLD images.

Experiments were performed with five subjects on a 7T Siemens Magnetom whole-body scanner with a 24 channel head-coil. Visual stimulation with an 8-Hz checkerboard were presented on a screen inside the magnet with a block design of 30s rest – 30s activation periods. The following imaging parameters were used: FOV=192mmx192mm, nominal isotropic resolution = 1.5mm, $TE_{VASO,1}$=14ms, $TE_{VASO,2}$=37ms, $TE_{ASL,1}$=14ms, $TE_{ASL,2}$=37ms, TE_{BOLD}=22ms, TR=3s, GRAPPA factor = 3, partial Fourier factor = 6/8, TI_1=1100ms, TI_2=1650ms, TI_3=2250ms.

Results: Fig. 3 shows a typical set of VASO, ASL and BOLD activation maps. Fig. 4 shows the VASO, ASL and BOLD time courses averaged over all five subjects. The largest signal change during visual stimulation can be seen in BOLD (4.1%). ASL and VASO signal changes are 3.2% and 3.4%, respectively. The average change in CBV was measured as 51%. Our technique has an average SNR of 21.

Discussion: Slab-selective VASO provides a much larger grey matter signal than traditional VASO, resulting in higher SNR values than classical VASO techniques [7,8]. Additionally, T_1 of blood at 7T is longer than at lower field strengths, which gives the inverted blood more time to flow into the microvasculature within the imaging slice. Consequently, ss-VASO and PASL at 7T show better spatial specificity than the same methods at lower field strengths. The characteristics of ASL and BOLD signals are comparable to those of separate acquisition techniques at 7T. However, due to the long TI_3 the BOLD signal has only minor flow contamination whereas for shorter TI (such as Yang proposed) flow effects could lead to an overestimation of the BOLD response. VASO, ASL and BOLD time courses show an expected temporal behavior.

Conclusion: We have shown that combining slab-selective VASO with PASL FAIR and BOLD within one TR at 7T provides signal characteristics which are good enough to be used for high-resolution functional MRI studies in the human brain.

References: [1] Ogawa et al (1990) *PNAS* 9868-9872; [2] Aguirre et al (1998) *Neuroimage* 360-369; [3] Buxton (2010) *Front Neuroenerg* 1-16; [4] Yang et al (2004) *MRM* 1407-1417; [5] Gu et al (2005) *MRM* 921-928; [6] Huber et al (2012) *Proc. ISMRM*; [7] Lu et al (2003) *MRM* 263-274; [8] Hua et al (2012) *MRM*

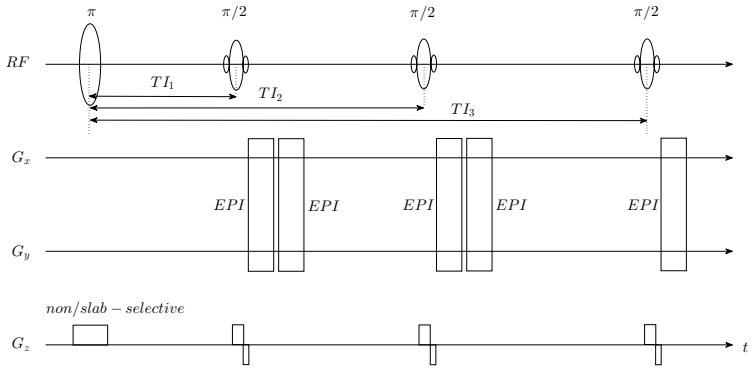

Fig. 1: Sequence diagram of simultaneous ss-VASO, PASL-FAIR and BOLD acquisition.

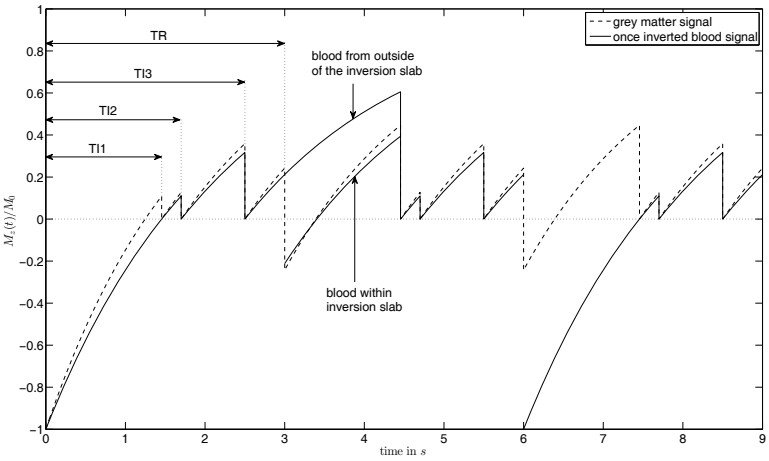

Fig. 2: Longitudinal magnetization diagrams of grey matter and blood during three TRs.

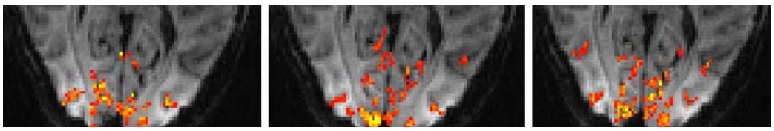

Fig. 3: An example of VASO (left), ASL (middle) and BOLD (right) activation maps.

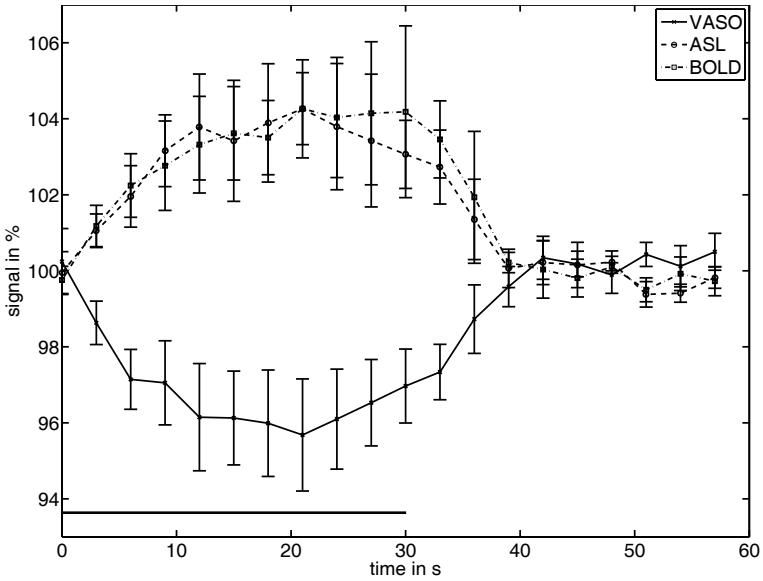

Fig. 4: Averaged timecourses of VASO, ASL and BOLD signals in the activated areas.