Vascular-space-occupancy (VASO) MRI in human brain at 7T

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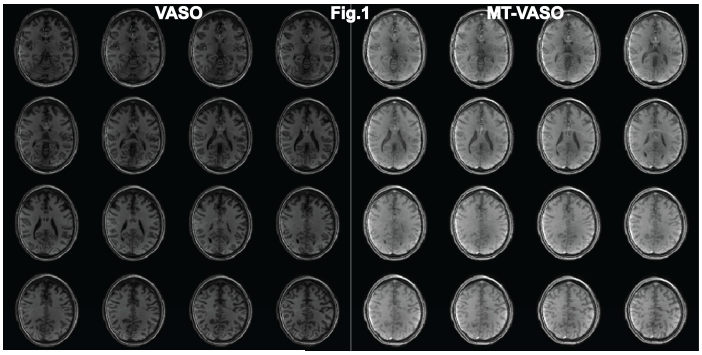
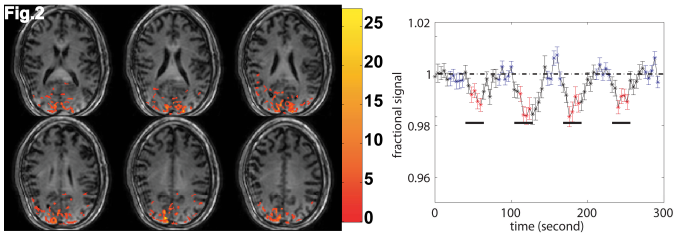
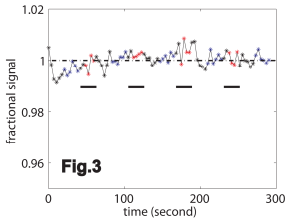
Introduction: Vascular-space-occupancy (VASO) MRI (1) measures cerebral blood volume (CBV) changes through extravascular tissue signal changes. During neuronal activation, a negative signal change is expected, which is attributed to the vasodilation. Based on the difference between blood and tissue T1, inversion recovery is employed to null blood signal while keeping substantial tissue signal for detection. At 3T, this T1 difference is sufficiently large (about 35% (2)), so that about 20% tissue signal is available at the blood nulling point. At 7T, however, the T1 difference becomes smaller (about 15% (3)), leaving only about 5% tissue signal at blood nulling time, which significantly negates the sensitivity gain at higher field for VASO MRI. Off-resonance magnetization transfer (MT) effects are large in tissue but minimal in blood when saturating far from water resonance (>20ppm). We have shown previously at 3T that by incorporating MT with VASO (MT-VASO), the recovery process after inversion can be accelerated, which produces higher tissue signal at the same blood nulling time (4). At 7T, Bloch equation simulations show that MT-VASO can enhance tissue signal, and thus signal-to-noise ratio (SNR), by up to 160% compared to conventional VASO. Another challenge that hampers the application of VASO fMRI at 7T is that the BOLD effect during neural activity is greater, which counteracts with the negative VASO signal change. Here, we demonstrate our initial results for high resolution whole brain single shot MT-VASO fMRI during a visual task.

Materials & Methods: Five subjects were scanned on a 7T Philips MRI scanner. A 32 channel SENSE head coil was used for RF reception. fMRI sessions were performed using visual stimulation with blue/yellow flashing checkerboard (42s off/21s on, 4 repetitions, 1 extra off in the end) delivered using a projector from the back of magnet. Common parameters in all scans: TR/TI = 3500/1162 ms, voxel = 2 mm isotropic. Importantly, to alleviate the signal contamination in VASO due to fresh inflow blood when no body coil is available for RF transmission, a non-selective saturation (90^{O} RF pulse followed by spoiler gradients) was applied after each readout (5). Four pseudo-randomized fMRI experiments were done on each subject: **(a)** Single slice VASO with gradient echo echo-planar-imging (GE-EPI) readout (single shot, 4 echoes, TE/echo spacing (ES) = 12/23 ms). **(b)** VASO with 3D turbo-field-echo (TFE) readout (single shot, 30 slices, TE = 1.77ms, turbo direction = radial, profile = CENTRA (k = 0 first), SENSE = 3x2). **(c)** MT-VASO with the same 3D TFE readout. An MT pulse (block shape, 400ms, 2.5μT, frequency offset -30ppm) was applied immediately before the VASO inversion pulse. **(d)** The same 3D TFE readout as in (b,c) without inversion and MT pulses. Each fMRI session took 4'54'' during which 84 image volumes were acquired. Requirements for activation detection were z-score<-2.5, SNR>20 and cluster size≥4. The highest SAR shown on the scanner (MT-VASO 3D TFE) was less than 1.8W/kg.

Results & Discussions: Fig. 1 shows the typical images from VASO (left, Experiment (b)) and MT-VASO (right, Experiment (c)) with the same 3D TFE readout (30 slices acquired, 16 slices shown). The two sets of images are displayed at identical intensity scale. The tissue signal in MT-VASO is clearly higher than in VASO, with SNR in grey matter (GM) improved by 112+/-33% (n=6). The contamination from the BOLD effect was investigated in Experiment (a) (VASO with GE-EPI). Even with a relatively short TE (12 ms), few GM voxel in visual cortex has negative signal change, while most of them show significant positive signal changes (1.8+/-0.4%). When the original images were extrapolated to effective TE of 0 with four acquired echoes, the same GM voxels in visual cortex that showed positive changes had an average negative signal change of -2.1+/-0.6%. This indicates that the positive signal change observed in GE-EPI VASO is mainly due to T2* alterations during neural activity, i.e. the BOLD effect. At 7T, this BOLD contamination becomes overwhelming, which may offset the negative CBV based VASO signal change and lead to a substantial underestimate of vasodilation upon neuronal activation. The 3D TFE sequence allows using very short TE (1.77ms) to alleviate the BOLD contamination. Fig. 2 illustrates representative activation maps with overlapping z-scores and the average time courses (blue dots: baseline; red dots: activation) from voxels meeting activation criteria in Experiment (c), MT-VASO with 3D TFE readout (TE = 1.77 ms, 30 slices acquired, 6 shown). It can be seen that the activated voxels are well localized in GM in visual cortex, with an average negative signal change of -1.1+/-0.3%, the magnitude of which is in line with the theoretical CBV based VASO signal change predicted at 7T (6). To estimate the residual BOLD effect, Experiment (d) was performed using the same 3D TFE readout but without the inversion and MT pulses in VASO. Fig. 3 shows the average time course from the same activated voxels as in Fig. 2. No significant positive or negative signal changes (0.1+/-0.3%, P > 0.5) were detected, which confirms that the residual BOLD contamination in the 3D TFE MT-VASO scan (TE = 1.77 ms) is negligible.







Conclusions: We demonstrated in this study the feasibility of performing VASO MRI in human brain at 7T. The MT-VAO technique, originally proposed at 3T, magnifies the difference between tissue and blood signals during inversion recovery, thereby boosts SNR for about 110% compared to conventional VASO at 7T. The contrast-to-noise ratio (CNR), which is defined as the product of SNR and relative signal change, will be improved by a similar amount. A 3D TFE sequence is used to mitigate the positive BOLD contamination and provide whole brain coverage (2mm isotropic) with temporal resolution of 3-5 seconds. This sequence will be useful for non-invasive high resolution CBV based fMRI in human brain at 7T.

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