Magnetization Transfer Enhanced Vascular-space-occupancy (MT-VASO) MRI with Whole Brain Coverage

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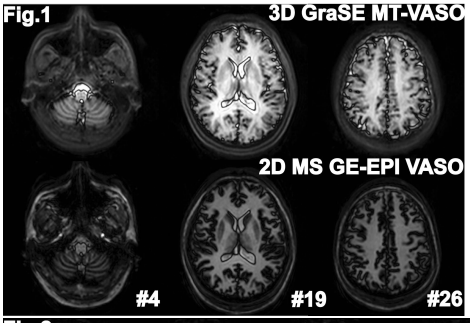
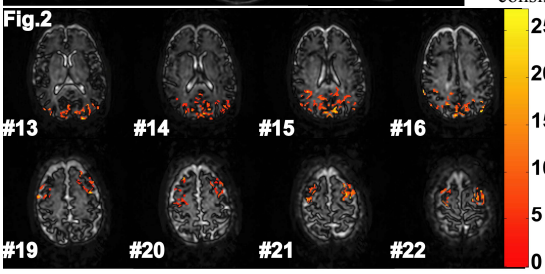
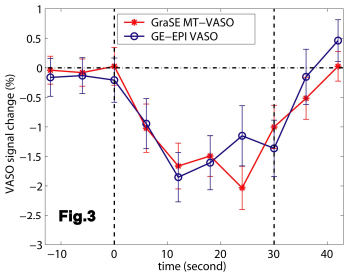
Introduction: Vascular-space-occupancy (VASO) MRI (1) produces cerebral blood volume (CBV)-weighted images by employing inversion recovery to null the blood signal. Depending on the TR used, the residual magnetization in tissue, however, is only about 10-20% of the equilibrium signal intensity at the time of inversion (TI), which yields a relatively low signal-to-noise ratio (SNR). It has been demonstrate that by applying an MT pulse before the VASO inversion pulse (2), we can prepare a smaller tissue magnetization before inversion and accelerate the tissue recovery process after inversion to obtain a higher tissue signal and consequently boost the SNR and contrast-to-noise ratio (CNR), based on the fact that tissue signal can be strongly modulated by the MT pulse while blood has very little MT effect when using medium irradiating power and/or a frequency offset far away from water (>20ppm). Recent work (3,4) has shown that use of the 3D gradient spin echo (GraSE) sequence for the original VASO approach improves slice coverage and SNR/CNR, compared to using echo-planar-imaging (EPI). Here, the MT enhanced VASO (MT-VASO) technique is extended from single-slice to whole-brain coverage using 3D GraSE sequence. The sensitivity (SNR) of this approach is compared to the widely used 2D multi-slice (MS) gradient echo (GE) EPI based conventional VASO protocol (5).

Materials & Methods: Six subjects were scanned on a 3T Philips MRI scanner. A body coil was used for RF transmission and a prototype 32 channel SENSE coil (In Vivo, Corporation, Florida) was used for reception. In the MT-VASO preparation, an MT pulse (block shape, 240ms, 2μT, frequency offset -30ppm) was applied immediately before the VASO inversion pulse. Maxwell gradients were implemented in the 3D GraSE sequence to reduce cross-slice smearing (3). Four scans were performed on each participant. *First*, two regular CBV imaging scans with identical geometry (voxel=2x2x4mm^3, 35 slices) were acquired. *(i)* MT-VASO with 3D GraSE sequence: TR/TE/TI=6s/20ms/1080ms, 17 shots, readout duration=307ms, SENSE=2, total duration=1'54''. *(ii)* Conventional VASO with 2D multi-slice GE-EPI readout: TR/TE/TI=6s/8ms/1088ms, 7 slices acquired after each inversion, TI set on the middle slice, segmented EPI (4 shots), readout duration=104ms, SENSE=2, total duration=2'00'', no gap between slices. *Second*, two functional MRI (fMRI) experiments with identical spatial resolution (voxel=3x3x5mm^3) were carried out. *(iii)* MT-VASO with 3D GraSE sequence: TR/TE/TI=6s/21ms/1064ms, 25 slices, single-shot, readout duration=816ms, SENSE=3. *(iv)* Conventional VASO with 2D GE-EPI readout: TR/TE/TI=6s/10ms/1088ms, single slice, single shot, readout duration=19ms, SENSE=3. The slice was carefully aligned with slice 15 (covering the calcarine fissure) from the previous scan. Visual stimulation with blue/yellow flashing checkerboard (30s off/30s on, 4 repetitions, 1 extra off in the end) was delivered using a projector from the back of magnet, and participants were instructed to perform bilateral finger tapping during the entire flashing period. Each fMRI session took 4'30'' during which 45 image volumes were axquired. Requirements for activation detection were z-score<-2.5, SNR>20 and cluster size≥4. The highest SAR shown on the scanner (3D single-shot GraSE MT-VASO) was less than 1.0W/kg.







Results & Discussions: First, we compare the image quality from GraSE-MT-VASO and EPI-VASO sequences with the same total scan time and spatial resolution. Fig. 1 displays representative images (slices 4, 19 and 26 from left to right) from GraSE-MT-VASO (top) and EPI-VASO (bottom). Regions of interest (ROI) of gray matter (GM) and white matter (WM) were generated using the Medical Image Processing, Analysis, and Visualization (MIPAV) application developed by NIH (http://mipav.cit.nih.gov/). The average SNRs over all subjects (n=6) from GraSE-MT-VASO and EPI-VASO sequences were 38.4±22.1 and 14.1±9.5 in GM, 122±13 and 72.8±6.3 in WM, respectively. Compared with EPI-VASO, SNR in GraSE-MT-VASO was boosted by 151±81% and 65±22% in GM and WM regions, respectively. This SNR improvement is the combined result of accelerated signal recovery powered by the pre-inversion MT pulse, as well as less signal loss in spin echo based sequence (GraSE) compared to gradient echo sequence (GE-EPI) as discussed in (3). Both effects contribute in GM, whereas in WM, which has larger MT effects but lower iron concentration, enhancement from the MT pulse may play the major role for the SNR increase, the amount of which is consistent with that reported in previous work (2). The WM SNR in both sequences was higher than that in GM, mainly because WM has a longer T_1 and a shorter T_2^*. The T_1 effect dominates in GraSE sequence while both effects have significant influence in GE-EPI sequence, which results in an even higher SNR in WM. Notice that the signal void artifact seen in the frontal area in slice 4 of EPI-VASO, caused by different magnetic susceptibility between tissue and air, was suppressed in the GraSE sequence. Second, we demonstrate that single-shot GraSE-MT-VASO protocol can be designed for fMRI with whole brain coverage. Fig. 2 illustrates representative activation maps with overlapping z-scores from scan (iii) of one subject. Robust activations were found in both visual and motor cortex for all subjects. For VASO fMRI, single-slice GE-EPI sequence is now the most commonly used readout scheme that has been applied in a number of studies (1,6). Using it as the standard, the average time courses from common voxels meeting activation criteria in slice 15 of scan (iii) and the single slice in scan (iv) (identical location) were compared in Fig. 3, in order to verify the temporal response of CBV change detected by GraSE-MT-VASO. The two time courses, which were averaged over all functional blocks and subjects, matched well. The average VASO signal changes were -1.55±0.37% in GraSE-MT-VASO and -1.49±0.47% in EPI-VASO, which are not statistically different (P>0.1). Thus, the CNR for fMRI, which is defined as the product of SNR and relative signal change, is enhanced for similar amount as SNR in the GraSE-MT-VASO approach, when the geometry and total scan time are kept identical.

Conclusions: We demonstrated in this study that 3D GraSE sequence can be combined with the previously proposed MT-VASO method for whole-brain CBV imaging, with which the SNR and CNR can be drastically improved by 60-150%, as compared to the conventional 2D multi-slice GE-EPI VASO approach.

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