Multiple Acquisitions with Global Inversion Cycling (MAGIC): A multi-slice technique for Vascular-Space-Occupancy dependent fMRI

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INTRODUCTION: Recently we introduced a new fMRI technique that is sensitive to cerebral blood volume (CBV) changes during neuronal activity (1). Such Vascular-Space-Occupancy (VASO) dependent fMRI uses a non-selective inversion pulse in combination with an optimal inversion time (TI) to eliminate blood signals. The remaining tissue magnetization is determined by the amount of extravascular water protons in a voxel. Upon stimulation, the VASO-fMRI signal shows a signal decrease, consistent with a blood volume increase that results in more signal nulling. In line with brain physiology observations that only small vessels (diameter<100-200 microns) are equipped with smooth muscle and are capable of dilating or constricting (2-3), VASO-fMRI was shown to have minimal contamination from large draining veins, and high spatial localization to brain tissue (1). Therefore, it would be very useful to apply this method to routine human brain fMRI. However, the present VASO approach is limited to a single slice due to the fact that there is only one zero-crossing point on the T1 relaxation curve. We here introduce a new multi-slice blood-nulling approach, named Multiple Acquisition with Global Inversion Cycling (MAGIC), which uses non-selective inversion pulses to keep the blood magnetization around the zero-point, while acquiring images between the inversion pulses.

METHODS Pulse Sequence (Fig. 1): After a non-selective 180º pulse to invert the magnetization, the longitudinal magnetization relaxes back towards equilibrium. At the optimal TI for complete blood signal elimination, the first slice is excited and an image is acquired using single-shot EPI. At the end of the first acquisition, blood magnetization has crossed the zero point and is in the positive range, after which a second non-selective 180º pulse is applied to re-invert the longitudinal magnetization. Following a small interval (TS/2), the blood signal becomes zero again, and a second slice can be acquired. Such interleaving of excitation and inversion pulses can be repeated multiple times. The gradual signal decay as a function of slice number (black dots in Fig. 1b) was corrected by performing two complementary experiments: one with ascending slice acquisition order, and a second with descending slice acquisition order. **Experiment***:* Studies were performed on a 1.5 T MR scanner (Philips Medical Systems) using body coil transmission and head coil reception. Phantom experiments, using CuSO4 solution and agarose gel, were performed to test magnetization transfer effects and to compare to simulations. A visual stimulation study was also performed (n=4, with written consent, block design, checkerboard, visual angle=25º, frequency=8Hz) with the parameters below: TR=6000ms, TI=898ms, TE=6ms, FA=90º, matrix=64x64, FOV=240mm, 60% half Fourier acquisition, number of slices=9. 3D MPRAGE images (1x1x1mm3) were acquired for anatomical reference. BrainVoyager (Brain Innovation, the Netherlands) was used for data processing. Activation detection: cross-correlation, t>2.7, cluster>6, p<0.005.

RESULTS and DISCUSSION: Solution phantom experiments showed excellent agreement with simulation results. On the other hand, gel phantom signals showed a faster signal decay as a function of slice number compared to simulation, indicating magnetization transfer effects due to the application of a series of inversion pulses, resulting in a shorter T1app. Figs. 2a-c show multi-slice VASO-fMRI images for the ascending-slice, descending-slice and combined functional data, respectively. It can be seen that the VASO contrast, i.e. the blood nulling effect, was achieved in all slices. The ascending and descending slices have opposite signal decay patterns, while the combined images have comparable intensity in all slices. Fig. 2d shows the SNR of different slices in the three data sets. Fig. 3 shows sagittal (a), coronal (b), and axial (c) activation maps for multi-slice VASO-fMRI overlaid on high-resolution MPRAGE images. Bilateral activations can be seen in the occipital region corresponding to visual cortex.

REFERENCES: 1) Lu et al. MRM 50: 263-274 2003; 2) Harrison et al. Cereb Cortex 12: 225-233 2002; 3) Lee et al. MRM 45: 791-800 2001.

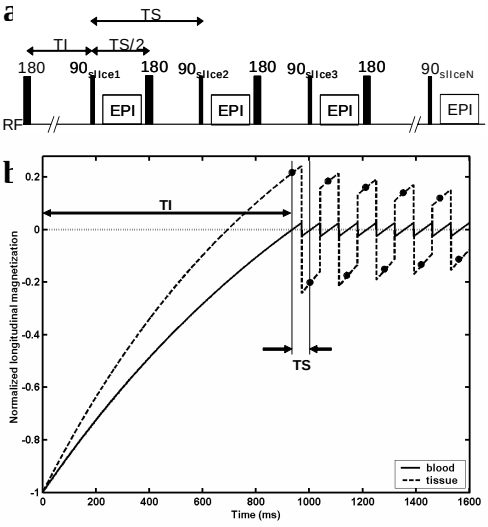

Fig. 1: (a) Pulse sequence for multi-slice VASO using MAGIC. (b) Simulation of longitudinal magnetization of blood and tissue.

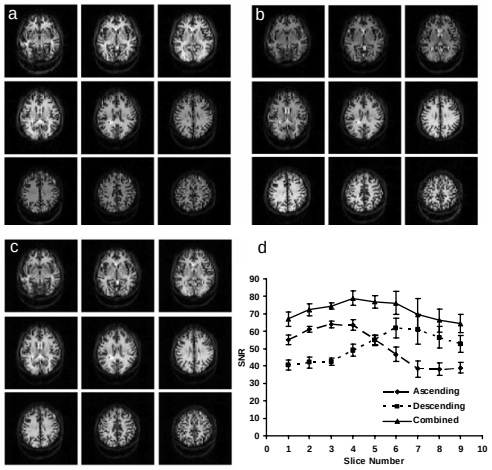

Fig. 2: Multi-slice VASO images using ascending (a) and descending (b) slice acquisition order show opposite signal decay patterns. The combined images (c) appear to have the same signal intensity in all slices. (d) SNR (mean ± standard deviation, n=4) as a function of slice number.

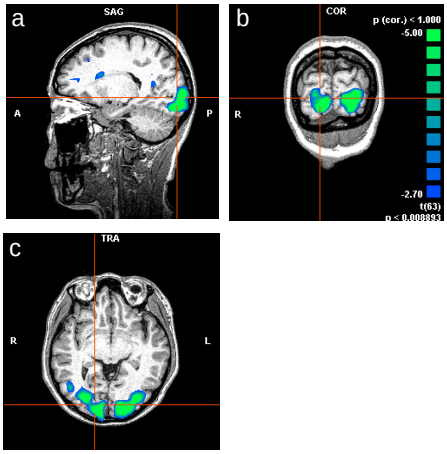

Fig. 3: Sagittal (a), coronal (b) and axial (c) activation maps (t>2.7, cluster>6, p<0.005), overlaid on high-resolution (1x1x1mm3) MPRAGE cross-sections. Blue-green colors are used instead of red-yellow to indicate a negative signal change in VASO fMRI.