Simultaneous MRI acquisition of activation-induced change in blood flow, blood volume and blood exygenation: A human brin study

W-C. Wu[1], E. C. Wong[2]

[1]Radiology, University of California, San Diego, La Jolla, California, United States, [2]Radiology and Psychiatry, University of California, San Diego, La Jolla, CA, United States

Introduction

To date, BOLD contrast is the most commonly used mechanism in fMRI studies. In the brain, BOLD signal is a composite output of cerebral blood flow (CBF), blood volume (CBV) and oxygen consumption ($CMRO_2$) (1). The interaction between these components is still not well understood and usually investigated by collecting data of different contrasts separately. While ASL is capable of detecting CBF and BOLD in a single scan (2), activation-induced CBV change (ΔCBV) can be measured by VASO (3). However, inter-scan variations such as subject motion and physiological status can complicate data interpretation. Yang et al (4) recently proposed a method that combined FAIR (5) and VASO to simultaneously acquire images with contrasts of CBV, CBF and BOLD. The optimal inversion slab thickness, however, could vary with individuals, slice orientation and flow velocity. Besides, low SNR is an inherent disadvantage of current VASO technique because tissue signal is small at blood nulling point. Here we describe a modified sequence for the same purpose by implementing an alternative VASO technique with higher SNR and less sensitivity to inversion efficiency, at the expanse of half temporal resolution.

Materials and Methods

1. VASO imaging without blood suppression. By optimizing the difference of longitudinal magnetization (M_z) between blood and parenchyma, higher SNR can be achieved and the signal is less sensitive to inversion efficiency as M_z reaches a plateau. ΔCBV is calculated with the T_1 of parenchyma measured or assumed. VASO signal change (ΔVASO) is expressed as: $1-(V_{nb,on}\cdot Q_{nb}+V_{b,on}\cdot Q_b)/(V_{nb,off}\cdot Q_{nb}+V_{b,off}\cdot Q_b)$, where $Q_{nb}=M_p(TI)\cdot\xi_p$, $Q_b=M_b(TI)\cdot\xi_b$, $M_i(TI)$ is the normalized M_z at image acquisition, ξ_i is the water density normalized by CSF ($i=b,p$ for blood and parenchyma, respectively). $V_{b,off}$, $V_{nb,off}$ and $V_{b,on}$, $V_{nb,on}$ represent blood and non-blood compartments for "activation-off" and "activation-on" states, respectively. The formulation assumes that TE is very short as compared with the T_2^* of blood and non-blood components. $V_{b,off}=6\%$, $\xi_b=0.75$, $\xi_p=0.82$, $T_{1b}=1627$ms (6), $T_{1p}=1300$ms (7). Detailed comparison with the original VASO technique is currently in journal review process. *2. Simultaneous acquisition of CBF, BOLD and VASO weighted images.* Schematic diagram of the pulse sequence and M_z manipulation are shown in Fig 1 and 2, respectively. Because the VASO-weighted images here are acquired in the presence of blood, a global saturation immediately after data collection (PostSat) is necessary to eliminate inflow effect caused by the different M_z history between inflowing and in-plane blood. *Sinc* pulses are used for excitation and PostSat. An adiabatic inversion pulse is used for alternating non-selective and selective inversion, followed by dual-echo acquisition. *3. MR Experiment.* Experiments were performed on three healthy volunteers on a 3T GE EXCITE scanner, using the standard setup of body coil transmission and head coil reception. A single oblique slice was carefully chosen to encompass the primary visual cortex and an 8 Hz black-white, radial flickering checkerboard was used for stimulation. The paradigm started with 40s off and followed by 4 cycles of 20s on and 40s off. 8s dummy scan was added before each scan to allow the signal to reach a steady state. TR/TI = 2000/1469ms, dual echo with TE1/TE2 = 3/25ms. ASL and BOLD signal were generated from the running difference of the first echo and the running average of the second echo, respectively. VASO signal was generated from the first echo after non-selective inversion. A separate scan was performed using original VASO technique (TR/TE/TI = 2000/3/710ms). Data were fitted to a non-linear function to remove baseline drift before correlation coefficient analysis (c.c. = 0.25 for original VASO imaging, 0.3 for the presented method; $p<0.05$).

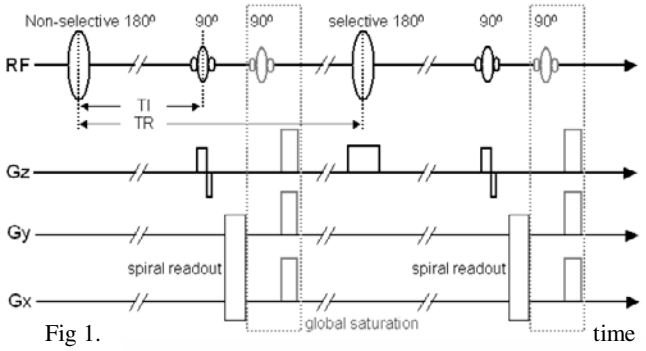

Fig 1.

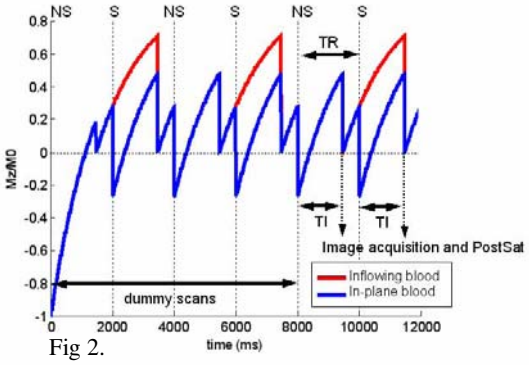

Fig 2.

Results and Discussion

Fig 3 shows a typical set of ASL, BOLD and VASO activation maps as well as the separately acquired VASO data with blood suppression. For comparison, they are all overlaid on the average of blood suppressed VASO images. As compared with original VASO imaging, the presented method provides 1.7-fold higher SNR, compatible activation maps and signal time curves, and complementary information of ASL and BOLD in a single scan (Fig 4). For BOLD data, flow effect can be minimized by calculation of T2* from both echoes (the second echo in non-selective inversion period is free from flow effect). The calculated ΔCBV is ~41% and baseline perfusion is ~62ml/100ml/min.

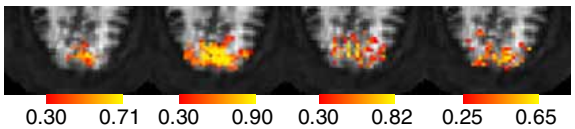

Fig 3. From left to right: concurrently acquired ASL, BOLD, VASO and separately collected VASO with blood suppression.

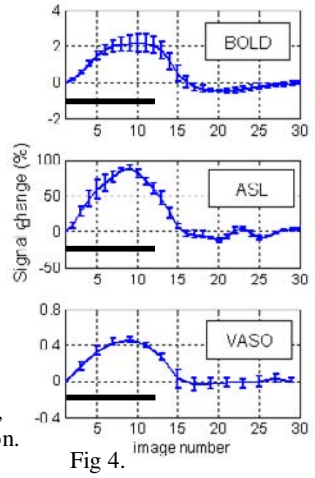

Fig 4.

References

1. Kwong et al, Proc Natl Acad Sci USA 1992;89:5675.
2. Wong et al, NMR Biomed 1997;10:237.
3. Lu et al, Magn Reson Med 2003;50:263.
4. Yang et al, Magn Reson Med 2004;52:1407.
5. Kim et al, Magn Reson Med 1995;34:293.
6. Lu et al, Magn Reson Med 2004;52:679.
7. Wansapura et al, J Magn Reson Imaging 1999;9:531.