Increased Tagging Efficiency in Velocity Selective ASL using Multiple Velocity Selective Saturation Modules

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Introduction: In VSASL, arterial blood is tagged by velocity selective saturation (VSS) (1). This method is intrinsically insensitive to transit delays and may be useful in applications where transit delay can be long, such as perfusion imaging in white matter, and in stroke. However, conventional VSASL suffers from relatively low tagging efficiency because it saturates, rather than inverts, arterial blood. Efforts have been put into improving tagging efficiency by approaching arterial inversion, but with limited success. In this work, we introduce a new tagging strategy that uses two or more VSS modules to improve the tagging efficiency and hence the SNR of VSASL.

Methods: The ideal ASL experiment is one in which the tagging is: 1) continuously 2) inverting blood and 3) occurring right at the arterioles before the blood enters the capillary bed and tissue. In conventional VSASL, the tagging is applied once before imaging, and the tagged blood undergoes uniform T1 decay prior to image acquisition. We note here that if two or more VSS modules are used, some of the tagged blood will be closer to saturation at the time of image acquisition, and the overall tagging efficiency can be improved. To illustrate this method, the evolution of the Mz of blood is shown schematically in **Figure 1** for the case using 2 VSS pulses, where the blue curve represents blood in the control condition; red - blood in the tag condition; and the dashed line - blood that is delivered to tissue (e.g. its velocity decelerates to below vcut before the later VSS pulses are applied). The total ASL signal is described by:

$$M_{Z,ASL} = M_{0B} CBF\left[\left(1-e^{-(TR-TI_1-TI_2)/T_{1B}}\right)TI_1 e^{-(TI_1+TI_2)/T_{1B}} + \left(1-e^{-(TR-TI_2)/T_{1B}}\right)TI_2 e^{-TI_2/T_{1B}}\right]$$

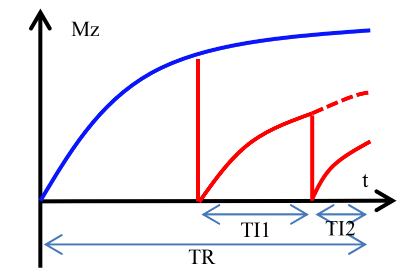


Figure 1 Mz evolution with 2 VS pulses

A good metric of the temporal efficiency in ASL experiment is the SNR per unit time, defined by signal/sqrt(TR). The theoretical SNR per unit time vs. TR was simulated using 1, 2 and 3 VSS modules and is shown in **Figure 2**, with the numbers normalized to the single VSS module with TR=1s. The image acquisition time, as well as T2 decay during the VSS pulses, were neglected in this simulation, and a global saturation was assumed at the end the imaging acquisition. The theoretical SNR per unit time peaks around TR=4.3/4.5/4.6s for 1/2/3 VSS modules, and the ratio is 1.00:1.42:1.65 with TI: [1.35s], [0.85s, 1.25s], [0.6s, 1.15s, 0.6s].

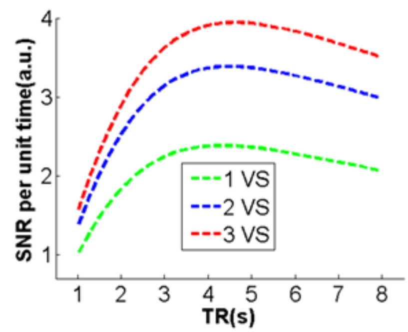


Figure 2 Theoretical SNR per unit time vs. TR

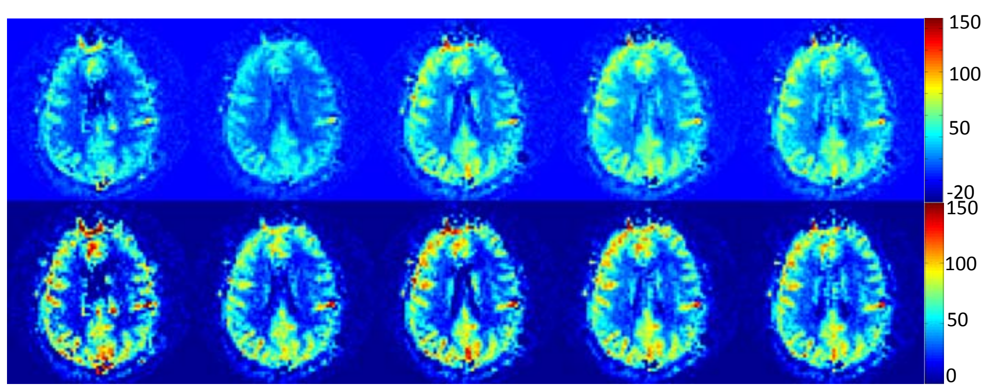
The imaging sequence was implemented using BIR4-based VSS modules (2) and tested on healthy human volunteers on a GE 3T MR750 scanner. Other imaging parameters were: spatial spectral excitation, spin echo spiral, dual echo acquisition, TR=4.5s with minimum TE1 and TE2 500ms to correct for CSF signal (3). Two global inversion pulses were applied after the VSS pulses for background suppression; except in one experiment, where the phase of the last portion of the BIR-4 was altered by 180° to tip down the static spins, and thereby replace one of the BGS pulses. Two reference scans were also collected to correct for the B1 sensitivity of the coil and to calculate the absolute M_0 of blood from the CSF signal. Raw ASL images were generated by pair-wise subtraction and CSF correction, and absolute CBF values were calculated using the equation above. In addition, the ASL signal was corrected for the small diffusion weighting (0.97s/mm^2 per VSS module) that is present in the tag condition but not the control condition, assuming the ADC of gray matter.

Results: The results are shown in **Figure 3**, the imaging parameters and the averaged raw ASL signal and CBF values in the brain tissue were listed below the figure. The theoretical raw ASL signal using two VSS pulses is 41.6% higher than using one VSS pulse using the parameters in this experiment, in a good agreement with the experimental results, 47.4% and 40.3% with and without using BGS.

Discussion: The measured ASL signal was higher using 2 VSS modules, and was in good agreement with theory. This improvement makes VSASL SNR competitive with other ASL methods, while maintaining the inherent insensitivity to transit delays. An example of applying this method in White Matter measurement is shown in ref.4. **Acknowledgement:** NIH R01 EB002096

References: 1. Wong et al, MRM 55:1334-41 (2006). 2. Wong et al, ISMRM p. 2853, 2010. 3. Guo et al, "Removal of CSF Contamination in VSASL and QUIXOTIC using a long TE CSF Scan", ISMRM, submitted. 4. Guo et al, "Measurement of White Matter CBF using Velocity Selective ASL", ISMRM, submitted.

Figure 3
Top: Raw ASL signal
Bottom: quantitative CBF maps using 1 and 2 VSS pules



	1 VSS, BGS off	1 VSS, 2 BGS	2 VSS, BGS off	2 VSS, 2 BGS	2VSS, 1 BGS
TI (ms)	1250	1250	1150, 800	1150, 800	1150, 800
mASL sig (a.u.)	35.5	35.3	49.8	52.2	51.5
mCBF (ml/min*100g)	53.9	53.6	56.5	58.4	56.0