White Matter Perfusion Measurement using Velocity-Selective Arterial Spin Labeling – A Comparison with Pulsed ASL and Pseudo-Continuous ASL

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Target Audience: Researchers who are interested in white matter (WM) blood flow measurement and Arterial Spin Labeling (ASL).

Purpose: There are two major challenges for measuring WM CBF using ASL: 1) the intrinsic local CBF is low, resulting in low Signal to Noise Ratio (SNR); and 2) the transit delays from typical tagging locations to the target tissue are heterogeneous and long, requiring long post-labeling delays (PLD), which also leads to reduced SNR due to T_1 relaxation. Recent research efforts have been devoted to implementing a high SNR tagging method, pseudo-continuous ASL[1] (PCASL), in WM perfusion measurement[2, 3] or conducting WM perfusion measurement at an ultra-high field, where the prolonged T_1 improves the SNR[4]. Velocity Selective ASL (VSASL) is inherently insensitive to transit delays[5], but for typical parameters it has a lower SNR than conventional ASL methods such as PCASL. However, in applications where transit delays can be long, such as cerebrovascular disease and WM, the need for long post-labeling delays in conventional ASL lowers the SNR of those methods to levels that are similar to, or lower than VSASL. We report here the results of WM perfusion measurements using conventional VSASL and improved VSASL using two Velocity Selective Saturation (VSS) modules[6] (VSASL-2VSS), and compare these with pulsed ASL (PASL) and PCASL.

Methods: Seven healthy subjects (6M, 1F) were studied on a GE 3T MR750 scanner with an 8-channel head coil under an IRB approved protocol. The tagging parameters were: PASL: PICORE QUIPSS II[7], hyperbolic secant inversion pulse, TI/TI_1=2.4/0.8s, PLD=1.6s; PCASL: tagging duration=2s, PLD=2s; VSASL: one BIR-8 based VSS module with a cutoff velocity (V_c)=2cm/s, along S/I direction, TI=1.3s; VSASL-2VSS: two BIR-8 based VSS modules, V_c=2cm/s, TI/TI_1=1.97/1.15 s. Other parameters included: two background suppression pulses, flow-crushing gradients in the imaging with V_c=2cm/s along S/I direction, FOV=220×220mm, 7 slices with 6mm slice thickness and 6mm gaps, fat saturation, spin echo with matched phase RF[8], TR/TE=4.5s/14.7ms, a spiral-out readout with a 64^2 matrix, 30 pairs of tag and control images after 2 dummy repetitions. The scan time was 4min 39s each. To minimize the partial voluming between WM and gray matter[9] (GM), high-resolution anatomical images were acquired and segmented in AFNI[10] to generate GM and WM ROIs (Fig. 1). The ASL scans for each subject were conducted under the same pre-scan settings (transmit/receive gains, etc.), so the thermal noise should be at the same level and the ASL signal intensities should be indicators of SNR. To perform the group analysis, the ASL signals were normalized to a CSF reference signal from each subject. The artifacts due to diffusion attenuation in the two VSASL scans, $M_t e^{(-b*D_t)}$, were corrected with the segmented tissue maps and fully relaxed reference images, where M_t is the tissue magnetization at the time of applying the VSS modules, b the b-value of the VSS module, 0.37s/mm^2, D_t the diffusion coefficient of the tissue. Assumed tagging efficiencies were 0.97, 0.8 and 0.5 for PASL, PCASL and each of the VSS modules in the VSASL scans respectively.

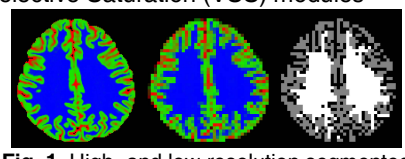

Fig. 1. High- and low-resolution segmented tissue images (red: CSF, green: GM, blue: WM); GM (gray), WM (white) ROIs.

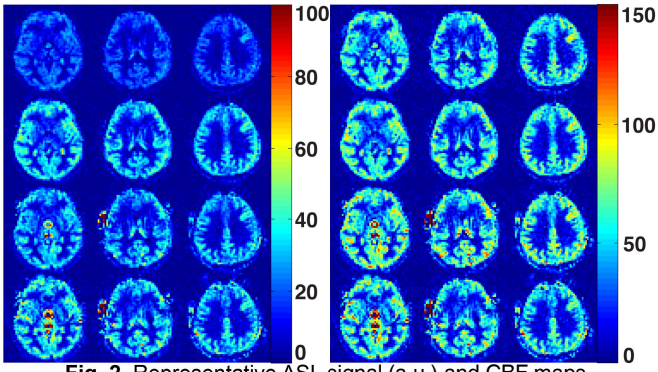

Fig. 2. Representative ASL signal (a.u.) and CBF maps (ml/100g/min) of 3 slices, top to bottom: PICORE, PCASL, VSASL and VSASL-2VSS.

Results: The ASL and CBF maps of three representative slices are shown in Fig. 2. The ASL signals and CBF values are given in **Table 1**. The CBF values and the Gray/White Ratios were consistent with published data[2, 4]. Relative to PCASL, the WM SNR using PASL and VSASL were significantly lower (P=2.4×10^{-7} and P=5.5×10^{-4}), with that using PASL being the lowest among all the sequences tested. 2VSS-VSASL had a comparable SNR to PCASL (P=0.52). 2VSS-VSASL had a significantly improved SNR over VSASL (P=1.8×10^{-4}). For WM CBF quantification, PASL provided significantly lower WM CBF values than PCASL (P=0.013). The WM CBF values were comparable between PCASL and VSASL (P=0.98), between PCASL and 2VSS-VSASL (P=0.61), and between VSASL and 2VSS-VSASL (P=0.54). The averaged Gray/White ratio was 2.39. The SNR in GM with VSASL-2VSS exceeded that with PCASL (P<0.01) at current settings.

Discussion: For the PCASL scan, the post labeling delay of 2s was long enough that we expect accurate values for both WM and GM[2]. The consistency between the CBF values with PCASL and two VSASL scans also indicated that the VSASL signal model is valid.

Conclusions: With the SNR improvement from using two VSS modules, VSASL may provide higher SNR than other tagging methods in applications where the possibility of long transit delays requires long PLDs.

Sequence	PASL		PCASL		VSASL		VSASL-2VSS	
ROI	GM	WM	GM	WM	GM	WM	GM	WM
ASL (a.u.)	14.6±2.6	6.4±1.3	24.6±3.0	10.9±1.4	22.8±3.3	9.0±1.4	26.8±3.5	11.2±1.5
CBF (ml/100g/min)	45.1±6.5	19.4±3.2	50.0±5.1	21.6±2.1	54.7±7.7	21.6±3.2	50.8±7.1	21.2±3.0
CBF_{GM}/CBF_{WM}	2.32		2.31		2.53		2.39	

Table 1. Averaged ASL, CBF values and Gray/White ratios.

References: 1. Dai. MRM. 2008; 2. van Osch. MRM, 2009; 3. Lu. ISMRM, 2009; 4. Gardener. ISMRM, 2013; 5. Wong. MRM, 2006; 6. Guo. ISMRM, 2011; 7. Wong. MRM, 1998; 8. Zun. MRM 2013; 9. van Gelderen. MRM, 2008; 10. Cox. Comput Biomed Res,1996.

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