Observations on the tagging time and velocity cutoff dependence in velocity selective ASL

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Introduction: In VSASL, arterial blood is tagged by velocity selective (VS) pulses [1,2 norris, wong]. The tagging pulses are applied globally. Theoretically the VSASL signal can be modeled by: $S_{VSASL}(TI) \propto CBF \cdot TI \cdot \exp(-TI/T_{1b})$ (**Eq.1**), where the CBF is cerebral blood flow, TI is the post labeling delay between the tag pulse and the image acquisition, and T_{1b} is the T_1 of blood. A maximum ASL signal can be reached at $TI = T_{1b}$, given a sufficient bolus of supplying blood. However, in practice, the length of the tagged bolus may be limited by limited RF transmit coil coverage, i.e., when the head is centered at the isocenter, the whole-body RF transmit coil does not fully cover the lung and the heart. Therefore a maximum ASL signal may be reached at a shorter TI. The CBF estimate may also be more accurate at shorter TI, where it is less likely to overestimate the bolus length. In addition, the theoretical overall tagging efficiency of VSASL is 0.5 which is derived under the assumptions that 1) the velocity of arterial blood has a laminar distribution which gives a sinc-shaped velocity excitation profile after tagging; and 2) the TI is long enough so the side lobes of the sinc will cancel out, leaving the tagged in-flow blood bolus close to a step-function shape (**Figure 1**). It may be possible that at very short TI's and lower cutoff velocities (V_{cut}), the tagging efficiency could be higher than 0.5, depending on how fast the blood decelerates. Another interesting hypothesis is that by applying lower V_{cut}, the tagging site is down the vascular tree and closer to the destination tissue, as one can see from **Figure 1**. Thus one would expect that the blood reaches tissue earlier, and spend more time for the water to exchange. Therefore the apparent T_1 will be moving towards that of the tissue, and this will be reflected on the timing for VSASL signal to reach its maximum. Though previous studies [3,4] has probed the VSASL signal dependence on TI at various V_{cut}, such data at even lower cutoff velocity (e.g., 1 cm/s) has not been reported. In this study, we explored the three questions mentioned above: 1) whether limited RF coil coverage reduces the available tagged bolus; 2) if the velocity excitation profile will affect the VSASL signal and be reflected in early TI data; 3) if one can observe that the water exchange between blood and tissue occurs earlier by using lower V_{cut}.

Methods: Seven healthy volunteers (5M, 2F) were scanned on a GE MR750 3T scanner with an 8-channel head coil. The imaging parameters were: FOV=220*8mm, 32*32 original resolution reconstructed into 64*64 matrix, single slice prescribed just above corpus callosum, spin echo with spiral readout, TR=4s, TE=18ms for $V_{cut} = 2cm/s$ and 20ms for $V_{cut} = 1cm/s$, TI ranged from 400ms (except for one of the scan on subject 1, it was 600ms) to 2000ms with 200ms step size, no background suppression and global post saturation pulses, 20 pairs of tag and control images with 4 dummy scans before actual data acquisition. Other scan parameters are listed in **Table 1**. For each scan, a double inversion image ($TI1/2$ =4060/460ms) was also collected to generate a GM ROI. Diffusion attenuation correction for gray matter was applied on the GM ROI by $S - S \cdot (1 - \exp(-(TR - TI)/T_{1GM}))/(1 - \exp(-TR/T_{1GM})) \cdot (1 - \exp(-bD_{GM}))$, , with b=0.39 and 1.52 s/mm^2 for V_{cut}=2 and 1 cm/s accordingly, and D_{GM}=0.0008mm^2/s [5] was used. Mean ASL signal from GM ROI and standard error of the mean (SEM) were calculated from the 20 temporal points for each TI. The mean GM ASL signal was then normalized to its maximum across TI's for each subject, then they were pooled together to give the group mean and SEM. The same processing was applied to give "CBF" estimates through **Eq.1**, except that a constant to convert the numbers to absolute CBF numbers was not used.

Results and Discussion: The normalized ASL signals measured at different TI's are shown in **Figure 2**. Both of their maximums were not observed around predicted $TI = T_{1b}$.This could be explained by limited RF coil coverage, and/or water exchange between blood and tissue. It is notable that the VSASL signal raised earlier and the maximum appeared at shorter TI for $V_{cut} = 1cm/s$ than for $V_{cut} = 2cm/s$, which suggested a lower apparent T_1 was observed to give the maximum ASL signal predicted by Eq.1. This supported the hypothesis that the water exchange occurs earlier when lower V_{cut} is used. In addition, the observed peak appeared even at TI shorter than $T_{1GM} = 1430ms$ [ref], which can be explained by limited coverage of RF coil. The normalized CBF vs. TI at V_{cut}=1 cm/s and 2 cm/s are shown in **Figure 2**, the decreasing CBF estimated from **Eq.1** could be explained by the fact that the higher tagging efficiency at lower velocity range. And if the population of arterial blood is skewed towards these lower velocities than predicted by a laminar flow model, this effect will be amplified as suggested by **Figure 3**. Another interesting observation was that on a repeated scanned subject, the ASL signal showed a repeated fluctuation pattern, this might be explained by the fluctuation of the velocity excitation shown in **Figure 1**. It probably could provide some information on the decelerating rate of arterial blood as it traveled down the vasculature. Further experiments are needed to explore these possibilities. The data collected here were from single slice acquisition, similar experiments should be done with slab acquisition to validate these finding.

Conclusion: Multi-TI VSASL experiments at low cutoff velocities (1 and 2 cm/s) suggested that lower TI to use in practice to get higher VSASL signal, both due to limited RF coil coverage and water exchange between blood and tissue, especially a low V_{cut} (e.g., 1 cm/s) is used. Lower TI also allows shorter TR to use, therefore also increases SNR efficiency. The results in this study here supported that low V_{cut} brings the tagging location closer to tissue, and the apparent T_1 was reduced due to the exchange. The multi-TI VSASL experiments may also provide some useful information which may help better understanding of blood flow dynamics.

Acknowledgement: NIH R01 EB002096 **References:** [1]. Norris et al, JMR, 137:231, 1999; [2].Wong et al, ISMRM 2002, P621, 2002; [3]. Duhamel et al, MRM, 50:145, 2003; [4]. Wu et al, Neuro Im, 32:122, 2006; [5]. Kuroiwa, et al, Stroke, 29: 859, 1998; [6] Ethofer, et al. MRM 50:1296, 2003.

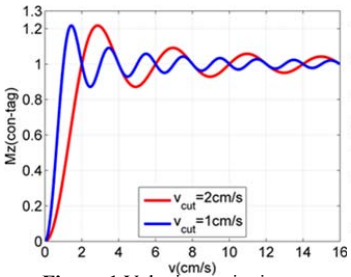

Figure 1 Velocity excitation profile at v_{cut} =1,2cm/s.

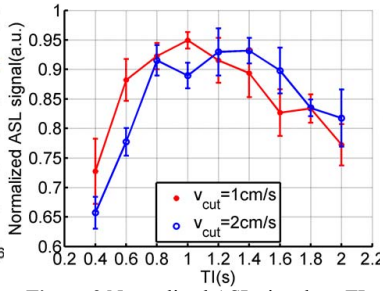

Figure 2 Normalized ASL signal vs. TI, the error bars are SEMs across subjects.

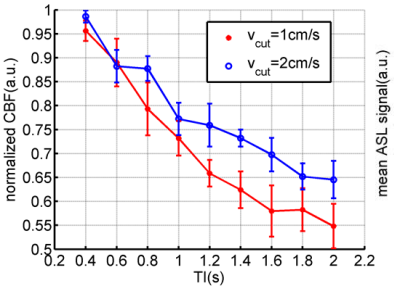

Figure 3 Normalized CBF vs. TI, the error bars are SEM across subjects.

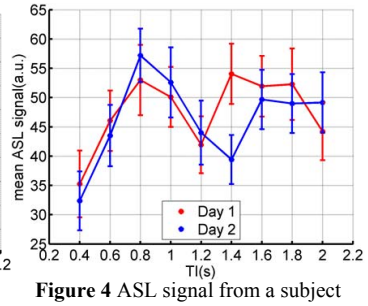

Figure 4 ASL signal from a subject on different days, v_{cut}= 1cm/s, the error bars are SEMs across reps.