Comparison of CBF measured with velocity selective ASL and pulsed ASL in pediatric patients with prolonged arterial transit times due to Moymoya Disease

Divya S Bolar[1,2], Borjan Gagoski[3], Richard L Robertson[4], Elfar Adalsteinsson[5], Bruce R Rosen[1,2], and P Ellen Grant[3]

[1]*Department of Radiology, Massachusetts General Hospital, Boston, MA, United States,* [2]*MGH/HST Martinos Center for Biomedical Imaging, Charlestown, MA, United States,* [3]*Fetal Neonatal Neuroimaging and Developmental Science Center, Boston Children's Hospital, MA, United States,* [4]*Department of Radiology, Boston Children's Hospital, MA, United States,* [5]*Department of Electrical Engineering & Computer Science, Massachusetts Institute of Technology, MA, United States*

INTRODUCTION: Arterial spin labeling (ASL) MRI has become a standard technique to quantify cerebral blood flow (CBF). Traditional pulsed ASL (PASL) and pseudo-continuous ASL (PCASL) techniques create a spatially-defined magnetic bolus (or "tag") that flows from proximal arteries into distal target microvasculature. Due to spatial separation between these regions, a delay arises between time of arterial tagging and time of microvascular delivery, the so-called transit delay (TD). As TD gets long, these ASL techniques become less accurate, yielding large-vessel artifacts and perfusion deficits, since the tag fails to reach target microvasculature by imaging time. This is especially problematic in pathologies with significantly increased arterial transit times (and thus TDs), including ischemic stroke and moyamoya (a disease in which there is progressive large artery stenosis, often with extensive collateral formation). Recently, a velocity-selective ASL (VSASL) technique was introduced to address these issues by creating a tag within the imaging slab itself, allowing immediate delivery to target microvasculature [1]. As such, VSASL is theoretically insensitive to TD and should be free from the aforementioned artifacts. In this study, VSASL and PASL were used to assess perfusion and TD sensitivity in pediatric moyamoya patients, with comparison and correlation to cerebral angiography,

METHODS: Three pediatric moyamoya patients (2 females, 1 male, ages 7-9) were imaged; the first with symptomatic left-sided disease recently diagnosed by angiography, the second with stable bilateral disease post bilateral synangiosis, and the third with stable right-sided disease post right synangiosis. These patients were scanned at 3T (Siemens Trio/ Skyra) using VSASL and PASL MRI with an EPI readout. VSASL parameters include V_C=2.1 cm/s and TI=1300ms to center slice. PASL (Q2tips variant) parameters include TI1= 700 ms, TI2=2000-2400 ms to center slice, tag width=100 mm, and PASL gap=21-25 mm. Common EPI parameters include TE/TR=13/3000 ms, voxel size=3.5x3.5x5 mm^3, 20 slices, BW=2300-2700 Hz/pixel, and scan time=4.5m. A standard EPI scan acquired the calibration image used for both absolute quantification and brain segmentation. Perfusion time-series data for both PASL and VSASL were generated by performing pairwise subtractions between tag and control images. Relative CBF maps were generated by averaging voxels across the perfusion time series; temporal SNR (tSNR) maps were calculated by dividing these average values by the temporal standard deviation. Relative CBF maps were calibrated to absolute CBF by incorporating the calibration scan and using the ASL signal equations [1,2]. Gray matter (GM) masks were created by processing the calibration scan using FSL-FAST (FMRIB, Oxford, UK) and subdivided into left and right hemispheres. These masks were overlaid on the absolute CBF maps and tSNR maps to calculate GM CBF and tSNR, respectively. Of note, due to significant macrovascular artifact seen on PASL images (e.g. fig 1), voxels with measured CBF over 90 ml/100mg-min were excluded from calculations; this threshold was felt to be above physiologic microvascular perfusion.

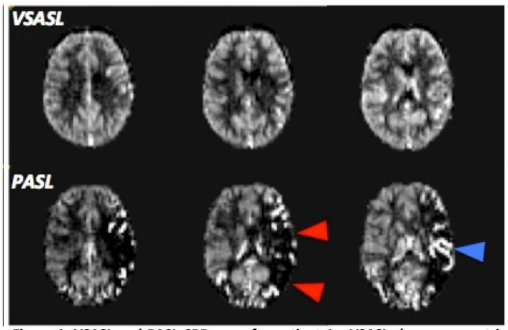

Figure 1. VSASL and PASL CBF maps for patient 1. VSASL shows symmetric bilateral perfusion. PASL shows left-sided perfusion deficits (e.g. red arrowheads) and macrovascular flow artifacts (e.g. blue arrowhead).

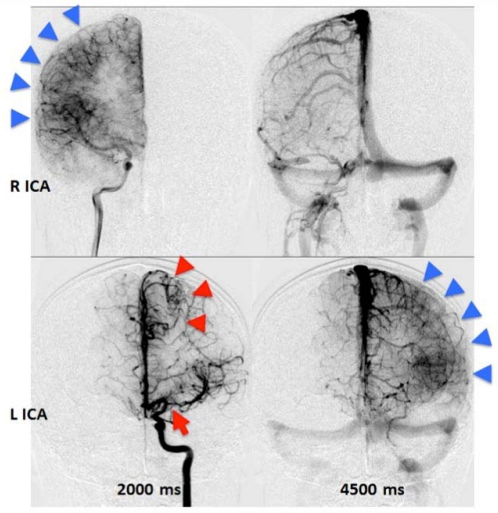

Figure 2. Angiograms for patient 1 from left and right ICA injections at two post-injection times. Right-sided capillary perfusion is seen at 2000 ms and left-sided capillary perfusion is seen at 4500 ms (blue arrowheads). Left M1 MCA stenosis and MCA-ACA collaterals are depicted by red arrow and red arrowheads, respectively.

RESULTS and DISCUSSION: Figure 1 shows representative VSASL and PASL CBF maps for patient 1 (left-sided disease). PASL maps demonstrate grossly normal right-sided flow, but severely abnormal left-sided flow, including perfusion defects in an MCA distribution and curvilinear hyperintensity consistent with macrovascular flow. In contrast, VSASL shows symmetric parenchymal perfusion, without focal deficit or hyperintensity. Angiographic data from the same patient (figure 2) correlate these findings; right-sided capillary perfusion is seen at 2000 ms post injection, whereas left-sided perfusion is seen only much later at 4500 ms post injection. Additionally, a stenotic left M1 MCA branch is noted, along with ACA-MCA collaterals. The PASL acquisition is analogous to cerebral angiography in that the bolus is created in arteries inferior to the brain, with TI2 analogous to post injection time. With a TI2 of 2000 ms, PASL similarly demonstrates parenchymal perfusion on the right side, with bolus still remaining in the macrovasculature on the left side, presumably within the collaterals and slow-flowing, stenotic vessels. VS-ASL, on the other hand, demonstrates symmetric bilateral perfusion despite the different angiographic arrival times, as theoretically predicted. VSASL and PASL data from patients 2 and 3 (not shown) also demonstrate near-symmetric perfusion with VSASL, and focal perfusion deficits/ macrovascular arterial artifacts with PASL.

Table 1 depicts quantitative PASL and VSASL GM CBF for all three patients. VSASL GM CBF is within the physiologic range, whereas PASL GM CBF is significantly lower in patients 2 and 3, possibly related to globally prolonged transit times leading to CBF underestimation. VSASL CBF is nearly identical in both hemispheres for all patients, with low coefficients of variation (CV), confirming the symmetric and fairly homogeneous perfusion seen qualitatively. Unexpectedly, PASL CBF is similar in both hemispheres in patients 1 and 3. However, high CVs in the affected hemisphere suggest that low flow in perfusion-deficient regions is being compensated by high flow in macrovascular regions when calculating average CBF within the mask. This suggests that our threshold is not sufficient to adequately eliminate macrovascular flow artifact in PASL. Finally, VSASL tSNR (5.7 ± 1.5) is increased compared to PASL tSNR (4.6 ± 1.4), despite PASL having a theoretical SNR advantage over VSASL. This is likely due to decreased tag delivery, possibly secondary to globally prolonged transit delays and increased tag decay from long TI2s.

Subject	Region	PASL CBF (ml/100mg-min)		VSASL CBF (ml/100mg-min)	
		Mean	CV	Mean	CV
1	LH GM	34.6	0.81	39.2	0.57
Left-sided disease	RH GM	37.4	0.47	38.9	0.50
2	LH GM	28.7	0.83	48.1	0.35
Bilateral disease	RH GM	40.9	0.59	49.5	0.28
3	LH GM	28.2	0.50	48.8	0.34
Right-sided disease	RH GM	26.6	0.78	47.7	0.35

Table 1. VSASL and PASL GM CBF results. CV = coefficients of variation.

CONCLUSION: VSASL and PASL MRI show promise in imaging CBF when there are prolonged arterial transit times such as with pediatric moyamoya patients, and correlate with angiographic findings. True to theory, VSASL appears unaffected by TD and successfully images parenchymal perfusion. In contrast, PASL is sensitive to TD, resulting in apparent perfusion deficits and macrovascular signal. While PASL may not be useful for imaging microvascular perfusion, it may be useful in detecting or confirming collateral circulation and/or post stenotic slow-flow.

1) Wong et al MRM (2006) 2) Cavusoglu et al, MRI (2009)