Velocity Selective Arterial Spin Labeling Using an Inversion Pulse Train

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Introduction: Arterial spin labeling (ASL) is a non-invasive imaging technique for quantitative assessment of tissue perfusion rates in which arterial blood is magnetically labeled as a tracer that diffuses freely between vascular and tissue compartments [1]. In classical ASL techniques, blood spins are labeled outside of the region of interest (ROI). A transit delay time (δt) is needed to allow the labeled blood to flow from the labeled region to the ROI. Estimation errors in perfusion values could be caused by this transit delay time. Velocity selective ASL (VSASL) was proposed to overcome this difficulty by labeling blood using velocity selective pulses with no spatial selectivity, resulting in small and uniform δt values [2]. However, the blood spins are labeled by a velocity selective saturation pulse train with a lower labeling efficiency compared to that of an inversion pulse. In addition, the perfusion signal may be contaminated by diffusion because gradients with different strength and therefore different diffusion weightings are applied in label and control scans. The goal of this work is therefore to develop a new velocity selective method to increase the labeling efficiency, and eliminate diffusion contamination in perfusion images.

Methods: The velocity selective pulse train used in this new VSASL scheme is shown in Fig. 1. In the label scan, static spins M_s at t=0 (red arrow) and flowing spins M_v (blue arrow) are both aligned along the z axis. After the -90_x pulse at t=a, both M_s and M_v flip onto the xy plane along y. The bipolar flow gradients in Fig. 1 are chosen so that the zero-th gradient moment m_0 is 0 and the first gradient moment m_1 is $-\pi/2$. Consequently, after the flow gradients and the 180° pulse at t=b, M_s still remains along the y axis ($m_0 = 0$), but M_v rotates along the x axis ($m_1=-\pi/2$). After the 90_y pulse at t=c, M_v flips to the –z axis but M_s remains along the y axis. After the pulse train, the moving spins are labeled by inversion. The static spins along the y axis are then dephased by a spoiler gradient. In a control scan, the same RF pulses are applied with an inverted gradient waveform to ensure $m_0 = 0$ and $m_1=\pi/2$. As shown in Fig. 1, after a flow selective pulse train, M_v is along the +z axis and M_s is along the y axis, which is dephased by a spoiler gradient afterward. As a result, the blood spins are labeled by inversion and static spins can be canceled out in subtraction.

The velocity selective pulse module was integrated with EPI on a 3T MR scanner (Magnetom Trio, Siemens, Erlangen, Germany). For comparison, Q2TIPS [(QUIPSS II) with thin-slice TI1 periodic saturation] [3] was also performed. The measurement parameters were as follows: TE = 26 ms; acquisition bandwidth = 2004 Hz/Pixel; flip angle = 90°; matrix=64 × 52; FOV = 210 × 175 mm; 5 axial slices were acquired with a slice thickness of 5 mm and a gap of 5mm; TR = 3.5 s; measurements = 70 (35 pairs); TI = 1.5 s for VSASL; TI_2 = 1.5 s and TI_1 = 0.7 s for Q2TIPS. A slow slew rate of 4.0T/m/s was used in the bipolar flow gradient to reduce eddy current effects. The cut-off velocity, v_c, was 2 cm/s. A 1.8% agarose gel phantom was used to examine the subtraction error caused by the static signal. The sequence was tested on three healthy volunteers after obtaining informed consent.

Multi-slice T1 weighted FLASH images were acquired with identical slice positions as the ASL images. Gray matter masks were generated with a segmentation tool in FSL (http://www.fmrib.ox.ac.uk/fsl/), and brain cerebral blood flow (CBF) values of gray matters were calculated based on the masks.

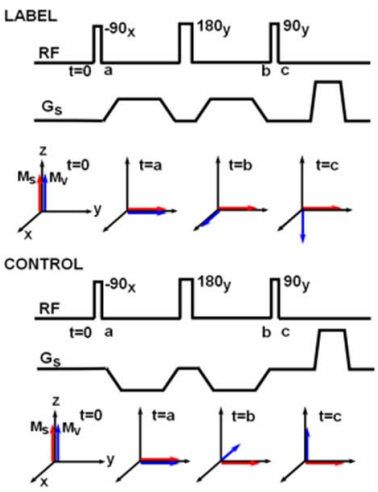

Figure 1: Velocity selective inversion pulse train. Identical pulses are used in both label and control experiments, the gradients, however, are played out in the inverted waveform during control scans.

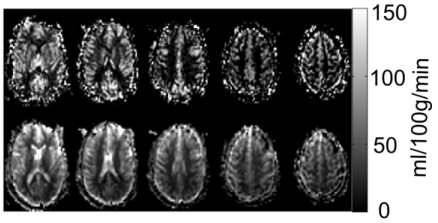

Figure 2: CBF maps obtained with Q2TIPS (top) and VSASL (bottom) of a healthy volunteer.

Results and Discussion: Fig. 2 shows the CBF maps obtained with Q2TIPS (top row) and our new VSASL sequence (bottom row) for a volunteer. The labeled bolus length in the new VSASL (TI, 1.5 s in this study) was longer than that in Q2TIPS (TI_1, 0.7 s in this study), resulting in higher SNR in the VSASL images in Fig. 1. Table 1 summarizes the measured mean gray matter CBF values for the three volunteers. The values obtained by these two methods were close. However, the values obtained by VSASL were in all cases higher than those obtained by Q2TIPS. This may be due to the subtraction error caused by static signals which is about 0.2% of the M_0 image in our phantom test.

Because inversion labeling was achieved with our new VSASL method, the labeling efficiency can be improved by approximately a factor of 2, compared to saturation labeling. The diffusion b value was the same in both label and control scans, therefore diffusion contamination was eliminated in the perfusion images. In this work, we implemented a simple pulse train to demonstrate a new velocity selective labeling scheme. To further reduce the subtraction error from static signals, a more sophisticated pulse train, e.g. one that uses two adiabatic inversion pulses [2] can be used. If desired, background suppression could also be integrated into the sequence to eliminate the static signal as suggested in [2].

Volunteer	Q2TIPS	VSASL
1	50	61
2	49	54
3*	42	50

Table 1: Summary of CBF values, in ml/100ml/min, measured by Q2TIPS and our new VSASL for gray matters.
*Single slice measurement

Conclusion: A new velocity selective ASL method was introduced and tested. The new VSASL method can be easily implemented and yielded relatively high labeling efficiency. This proposed pulse velocity selective inversion pulse scheme can also be implemented with other imaging schemes, e.g. TrueFISP, for a label efficient, SNR optimized ASL experiment.

References: 1. Detre JA et al. MRM 1992; 23:37-45 2. Wong EC. et al. MRM 2006; 55:1334-41 3. Luh et al. MRM 1999;41:1246-54