Tagging Efficiency Improvement Using Velocity-matched Pseudo-continuous Arterial Spin Labeling and VERSE

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Introduction

Pseudo-continuous arterial spin labeling (PCASL) (1,2) provides for direct control of tag duration as in continuous ASL allowing for whole brain coverage. However, unlike continuous ASL, it can be performed with standard commercial scanners without special hardware. In addition, several characteristics of the RF and gradient pulses, such as RF pulse width and inter-pulse interval as well as maximum and mean gradient amplitudes, can be adjusted for optimal performance. However, changes in velocity through the cardiac cycle can compromise tagging efficiency especially during systolic phases with high velocity and volume throughput. It is possible to improve tagging efficiency for high velocity spins by increasing RF amplitude at the cost of SAR and maintain better adiabatic conditions than reducing gradient amplitude for slow velocity spins. Fortunately, the increase in SAR can be mitigated with VERSE (3) transformation if needed. Here we examined the efficacy of dynamically raising PCASL RF amplitude according to the measured velocity profile at labeling location with cardiac gating and VERSE modification.

Methods

Typical PCASL tagging pulse train designed for 40 cm/s target velocity consists of Hanning-shaped RF of 800 μs duration and 0.05 G amplitude, and gradient amplitude of 0.8 G/cm during RF with refocusing lobes to achieve a mean gradient of 0.06 G/cm over the inter-pulse interval of 1.7 ms. The labeling period is 2.5 sec with 1.4 sec post-labeling delay and 4.5 sec TR. Nine 5 mm axial slices with 4.5 or 4.6 mm gap were acquired using EPI with TE=25 ms for a 4 min scan. The tagging efficiency as a function of B1 amplitude and spin velocity is simulated through Bloch equation as shown in Fig. 1. The velocity profiles within the carotid and vertebral arteries at the tagging location were obtained with CINE phase contrast imaging to provide the template of velocity changes over a cardiac cycle. From the Bloch equation simulations, for fixed B1 amplitude, the tagging efficiency deteriorates when velocity is higher than the target velocity, but improves with higher B1. Therefore the averaged velocity profiles were scaled to the maximum velocity and converted to corresponding velocity-matched B1 amplitudes for velocities over target velocity through an empirical linear relationship (red line in **Fig.1**), and applied dynamically to the PCASL tagging train every RF pulse pair together with cardiac gating. Two extra in-slab pre-saturation pulses were applied for cardiac gating experiments using peripheral gating. Experiments were conducted on a GE 3T Excite scanner with a 16 channel receiver coil. Gray matter ROIs were selected based on T1 values estimated from EPI-based inversion-recovery experiments to arrive at 50% of the masked brain area. VERSE RF and gradient waveforms were designed relative to a target Fermi function.

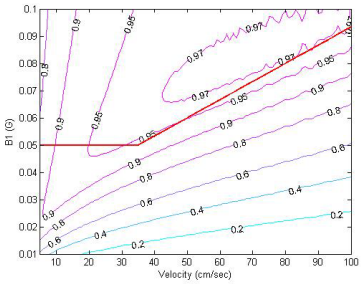

Fig. 1. Calculated PCASL tagging efficiency vs. B1 and velocity from Bloch equation simulation (T1=inf, T2=200ms), and the relationship between velocity and B1 amplitude.

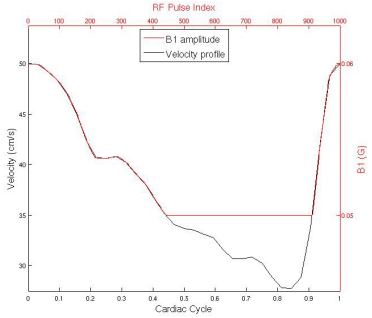

Fig. 2. Measured velocity profile (black line) over a cardiac cycle from one subject and converted B1 amplitude waveform (red line) applied to PCASL tagging pulse train.

Results

Fig. 2 shows the measured mean velocity profile scaled to the maximum velocity at the tagging location and the converted B1 amplitude modulation waveforms over a cardiac cycle from one subject. In this example, the SAR increases by 12%. **Fig. 3** shows the original and VERSE waveforms resulting in 20% reduction in SAR. **Fig. 4** shows the ΔM_0 ((control-tag)/control) perfusion images with default PCASL tagging (top row), velocity-matched B1 modulation (middle row), and VERSE modification (bottom row). The increase in ΔM_0 perfusion signal with velocity-matched B1 modulation is 11.9±10.4% (P<0.001, n=15, paired t-test). The perfusion signal with and without VERSE modification did not show significant differences (P=0.039, n=9, paired t-test).

Discussion and Conclusion

The increase in perfusion signal with cardiac-gated velocity-matched B1 modulation indicated improved tagging efficiency despite the fact that the TR is over several cardiac cycles and the heart rate typically fluctuates over 4 min period. Since the blood volume passing through during systolic phases represent a large amount of tag, a more accurate real time cardiac tracking may further improve the tagging efficiency. The increase in SAR may be reduced by lowering B1 during diastolic phases; however, unless velocity tracking is precise, it may relinquish the gain from elevating B1. Similar modulation should be possible with continuous ASL but the increase in SAR may not be reduced by VERSE. Due to individual differences, the increase in SAR with velocity-matched modulation PCASL varies from subjects to subjects (2%-38%) and can be alleviated with VERSE modification when needed. This method may provide a means to compensate for variation in tagging efficiency due to differences in blood velocity among individuals and pathological conditions (4). In summary, velocity-matched B1 modulation improves PCASL signal by 12% and VERSE transformation can be applied to reduce SAR by 20%.

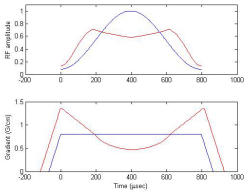

Fig. 3. PCASL RF/gradient original waveforms (blue) and with VERSE (red).

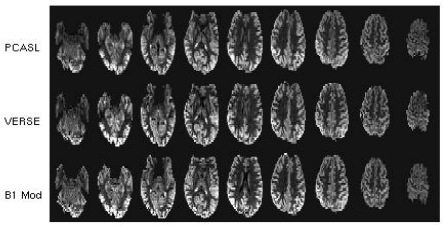

Fig. 4. PCASL images with default setting (top), VERSE (middle), and B1 modulation (bottom).

References

1. Garcia et al., *ISMRM*: 37 (2005). 2. Wong, *ISMRM*: 668 (2006). 3. Conolly et al., *JMR* 78: 440 (1988). 4. O'Gorman et al., *MRM* **55**: 1291 (2006).