Optimization of Tagging Efficiency Using ECG-gated Velocity-matched B1-increased Pseudo-continuous Arterial Spin Labeling

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Introduction

In conventional pseudo-continuous arterial spin labeling (PCASL) (1,2) techniques, a train of short RF pulses with constant amplitude are played out over entire labeling period. The RF pulse width and inter-pulse interval as well as maximum and mean gradient amplitudes are designed to achieve an optimal tagging efficiency at a certain spin velocity range such as 5-40 cm/s. However, changes in velocity throughout the cardiac cycle can compromise tagging efficiency especially during systolic phases with high velocity and volume throughput. It has been shown that there is potential to improve PCASL tagging efficiency for high velocity spins by increasing RF amplitude (3,4). However, the previous approach may not well synchronize to immediate systolic phase using peripheral gating and long labeling period spanning several cardiac cycles. To minimize mismatch between RF amplitude increase and systolic phase, here we employed ECG triggering and short labeling period to be within a typical cardiac cycle. Moreover, RF modulation was implemented in a pair-wise interleaved fashion to minimize run-to-run differences.

Methods

Experiments were conducted on a GE 3T HDx scanner with a 16 channel receiver coil on 6 healthy subjects. The velocity profiles within the carotid and vertebral arteries at the tagging location were obtained with CINE phase contrast imaging and ECG triggering to provide the template of velocity changes over a cardiac cycle. PCASL tagging pulse train designed for 5-40 cm/s target velocity consists of a 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 was 700 ms with 1400 ms post-labeling delay and 2700 ms TR. Thirteen 5 mm axial slices with 1 mm gap were acquired using GE-EPI with SENSE x2 for two 9 min scans. The tagging efficiency as a function of B1 amplitude and spin velocity was simulated through Bloch equation as shown in **Fig. 1**. It showed that for fixed B1 amplitude, the tagging efficiency deteriorates when velocity is higher than the target velocity, but improves with higher B1. Therefore, the amplitudes of the PCASL RF pulse train were increased to derive maximum tagging efficiency for a given averaged velocity from the simulated velocity-B1 relationship in Fig. 1. To compare the effects of elevating versus constant B1 amplitude, minimum B1 amplitude was set to 0.05 G as the constant B1. The resulted B1 waveforms were dynamically applied to the PCASL tagging trains every other sequential tag-control pairs of the time series in an interleaved fashion so the first tag-control pair was modulated B1 and the second pair was constant B1, etc. Two extra in-slab pre-saturation pulses were applied after the cardiac gating and before the PCASL pulse trains to compensate for non-constant TR. PCASL images from both runs were split into two separate time series according to two PCASL labeling conditions after image registration. ASL percent signal change ((control-tag)/control) was averaged from the gray matter ROIs based on T1 values, estimated from EPI-based inversion-recovery experiments to arrive at 50% of the masked brain area.

Results

Fig. 2 shows an example of a measured mean velocity profile (black line) at the tagging location and the corresponding B1 amplitude modulation waveforms over a cardiac cycle from one subject. **Fig. 3** shows the ΔM_0 ((control-tag)/control) perfusion images with velocity-matched B1 modulation (top row) and default constant B1 PCASL tagging (bottom row) from the same run. The increase in ΔM_0 perfusion signal with velocity-matched B1 modulation was 5.0±12.2%. Large variance was observed among subjects.

Discussion and Conclusion

Both tagging conditions have the same in-plane pre-saturation and similar slow changes in heart rate over the course of scan duration. With ECG gating and 700ms labeling period, the systolic phase should synchronize better with the increase in B1 amplitude in the PCASL RF pulse trains opposed to peripheral gating and long labeling duration. However, large improvement in ΔM_0 ~ 25% was observed in one subject but minimal improvement from some other subjects. The large variance indicates the sensitivity of B1 changes relative to the cardiac cycle. Even with ECG gating, current implementation assumes a fixed heart rate and R-R interval. Any mismatch between B1 increase and velocity due to fluctuation in heart rate and the reduction in average heart rate after the subjects settled down in the scanner environment can lead to diminishing or even deteriorating return. The measured velocity profiles may shift nonlinearly when the heart rate deviates from the average heart rate during velocity profile measurement. It may be possible to account for the changes in average heart rate by properly scaling the measured velocity profiles and by optimally extending the window of B1 modulation to allow for more tolerance. Since the blood volume passing through during systolic phases represents a large amount of tag, a more accurate real time cardiac tracking and gating is necessary to realize long labeling duration for SNR gains. The increase in SAR may be reduced with variable-rate selective-excitation (VERSE) modification when needed (3). This method may provide a means to compensate for variation in tagging efficiency due to differences in blood velocity among individuals and pathological conditions (5).

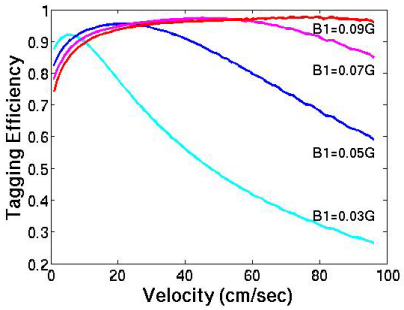

Fig. 1. Calculated PCASL tagging efficiency vs. B1 and velocity from Bloch equation simulation (T1=inf, T2=200ms).

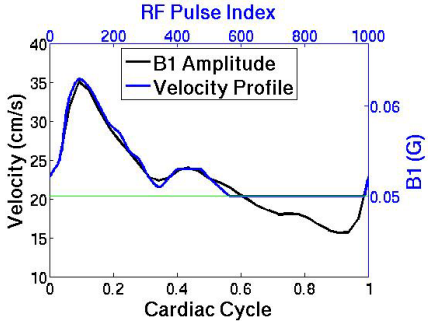

Fig. 2. Measured velocity profile (black), optimized B1 amplitude waveform (blue) and constant B1 level (green) over a cardiac cycle from one subject.

References

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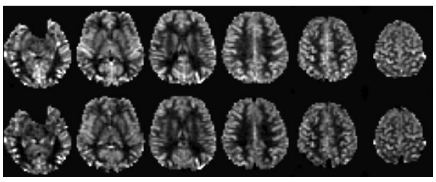

Fig. 3. PCASL ΔM_0 images with B1 modulation (top) and constant B1 (bottom).