Benefits of Interleaved Continuous Labeling and Background Suppression

W. Dai[1], P. M. Robson[1], A. Shankaranarayanan[2], and D. C. Alsop[1]
[1]Radiology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, United States, [2]Global Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States

Introduction

The arterial spin labeling (ASL) signal suffers from limited signal-to-noise ratio (SNR). Background suppression (BS) has been performed to increase SNR by minimizing errors related to the motion or other stabilities (1). Theoretical perfusion difference signal vs. postlabeling delay curves show that the best signal can be achieved with a long labeling time for any desired postlabeling delay (Fig. 1). The combination of long labeling duration with BS will increase the SNR. Here, we evaluate a method to combine long labeling duration with BS sequence to maximize the SNR.

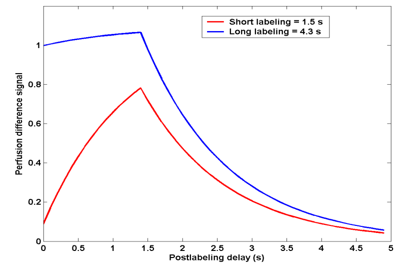

Fig. 1. Theoretical perfusion difference Signals with short labeling period (red) and long labeling period (blue) for the following assumed parameters: transit time 1.4 s, blood T_1 1.65 s, tissue T_1 1.2 s, and perfusion 72 ml/100g.min.

Theory

When combining continuous labeling with BS, the BS pulses are typically applied before and after the labeling period but not during the labeling. When longer labeling durations are used, reasonable background suppression cannot be achieved because inversions before labeling are too far away from the imaging time to be effective. Background suppression pulses must be applied during the labeling. When labeling and BS inversion pulses are interleaved, a special strategy to preserve ASL signal is required. Consider the magnetization after a period of labeling followed by a selective inversion pulse. The tissue has been accumulating negative signal from continuous inversion, but after inversion, this negative signal becomes positive. Switching to control RF after the inversion pulse will continue to accumulate the now positive ASL related signal. More generally, the labeling and control sequences must be modified to switch from label to control, or vice versa, after each selective background suppression pulse.

Methods

The long labeling pulse sequence with interleaved BS is shown in Fig. 2. Labeling was applied from 0.7 s to 5 s before imaging except for short gaps allowed for the BS pulses. The labeling duration and post-labeling delay of the sequence were controlled by turning off the RF and gradients during times when labeling was not desired. The control and label block were comprised of rapidly repeated gradient and RF pulses for pulsed CASL (PCASL) ($B1_{ave}$=14 mG, G_{ave}= 0.07 G/cm, and G_{max}/G_{ave}= 10) (2). BS (1) was achieved using spatially selective saturation and inversion pulses. Saturation of the imaged slab was performed with 4 selective 90° pulses applied with crushers along alternate directions between them. The final pulse was applied at 5s before imaging. Subsequently, four FOCI inversion pulses (3,4) were applied at 3560, 1730, 660, and 150 ms before imaging. The timing of the pulses was optimized to achieve excellent suppression across a broad range of T_1's using a least square optimization algorithm (5). The FOCI pulses were of duration 15.36 ms and bandwidth 1.08 kHz (β = 509 s^{-1}, μ = 6.2).

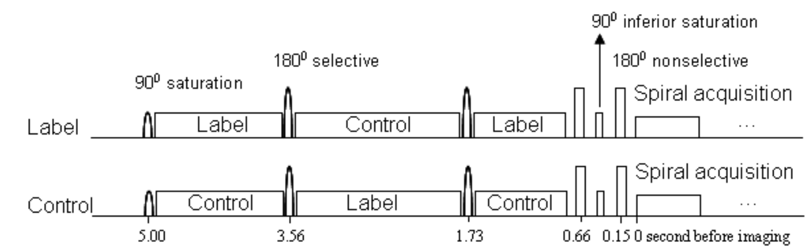

Fig. 2. The interleaved long labeling and background suppression sequence diagram. The selective slab of the 90^0 saturation pulse and two 180^0 selective pulses is the imaging volume up to the labeling plane. The 90^0 inferior saturation pulse is applied to the region below the labeling plane. The control and label block are rapidly repeated gradient and RF pulses for PCASL.

Three subjects were studied on a GE 3Tesla images with a receive-only 8-channel head array coil. Images were acquired with a 3D stack of spirals RARE (FSE) sequence with 8 interleaves and 3 averages. All slice encodes were performed after each ASL preparation. To evaluate the labeling efficiency loss due to the BS pulses applied during the labeling period, we acquired images with conventional background suppression and interleaved background suppression with 1.5 s postlabeling delay and 1.45s labeling duration. Finally images with a long labeling duration (3.5 s), and postlabeling delays of 1.5 s were acquired. The acquisition time for each 3D volume was 5 min.

Results & Discussions

Long labeling duration ASL was successfully combined with BS. The average perfusion difference signals over the whole brain were similar (34.5 vs. 34.8 in arbitrary units) for the conventional and interleaved BS sequences with 1.5s labeling duration (Fig. 3a and 3b). This indicates that the signal loss due to the BS pulses applied in the labeling period is negligible. The average perfusion difference signals for a labeling duration of 3.5 s was 37% higher the labeling duration of 1.45 s.

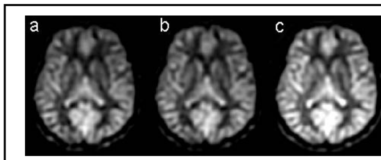

Fig. 3. Perfusion difference images from (a) 1.45 s labeling with conventional BS, (b) 1.45 s labeling with interleaved BS and (c) 3.5 s long labeling with interleaved BS pulses during the labeling period.

In this study, no significant signal loss was detected when BS pulses were performed during the labeling period. In theory, some signal from blood in the transition region of the selective inversion pulses may be lost, thus decreasing efficiency. The small level of this loss in our study probably reflects the high flow velocity through the labeling plane. Interleaved background suppression and labeling permits longer labeling duration of CASL sequence with correspondingly higher signal and robustness to arterial transit kinetics.

References

1. Ye et al, Magn Reson Med 2000;44(1):92-100. 2. Dai et al, Magn Reson Med 2008;60(6):1488-1497. 3. Ordidge et al, Magn Reson Med 1996;36(4):562-566. 4. Yongbi et al, Magn Reson Med 1996;36(4):562-566. 5. Maleki et al, 16th ISMRM 2008: p1929.