Single Coil Amplitude Modulated Continuous Arterial Spin Labeling Perfusion MR at 3.0 Tesla

J. Wang[1], Y. Zhang[1], R. L. Wolf[1], A. C. Roc[2], D. C. Alsop[3], J. A. Detre[2]

[1]Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States, [2]Department of Neurology, University of Pennsylvania, Philadelphia, PA, United States, [3]Department of Radiology, Harvard Medical School, Boston, MA, United States

Introduction Recently technical developments demonstrated a greater than 2-fold SNR gain by performing pulsed ASL (PASL) at 3.0 and 4.0T as compared to PASL methods at 1.5T (1, 2). The implementation of continuous ASL (CASL) at high magnetic field is expected to provide even greater perfusion contrast and SNR gain. Two important challenges of using continuous labeling, however, are controlling for the off-resonance effects and achieving adequate labeling efficiency within the safety constraints for RF power deposition. Use of a separate small RF coil for labeling can minimize the off-resonance effects and reduce the total RF power (3, 4). However, special hardware requirement, the added distance for arterial transit from the carotid tagging region and the relatively poor labeling of the vertebral arteries limit the practical usage of this dual-coil approach. Alternatively, the off-resonance effects of the labeling pulses can be mimicked by applying a control RF irradiation that produces equal off-resonance saturation in the brain tissue, e.g., a sinusoid modulated control (5). In this study, we tested the feasibility of performing the amplitude modulated CASL method at 3.0T using a single coil through parameter optimization of the continuous labeling RF pulses and gradients.

Methods Thirteen healthy subjects underwent scanning on a Siemens 3.0T Trio whole-body MR system, using the product quadrature (T/R) head coil. One patient with moyamoya syndrome and one brain tumor patient were also scanned. In CASL, the labeling plane was placed 8cm beneath the center of the imaging slices. The control pulse was an amplitude modulated (sinusoidal function) version of the labeling pulse. The total duration of the labeling/control pulses was 2sec (10 blocks of 200ms RF pulses), followed by a post-labeling delay of 1sec. A gradient-echo EPI sequence was used for image acquisition (FOV=22cm, 64x64 matrix, TR/TE=4000/17ms, bandwidth=3kHz/pixel, slice thickness 6mm, inter-slice space 1.5mm). 12 slices were acquired from inferior to superior in a sequential order. Each CASL scan with 80 acquisitions took 5min 20sec. Two RF levels (1.50 and 2.25 μT) and three levels of gradient strength (0.8, 1.6 and 2.4 mT/m) were tested on 5 subjects (with control modulation frequency of 100Hz), in order to find the optimal labeling parameters within SAR limit. The effect of modulation frequency on the CASL perfusion signal was examined in 6 subjects using 5 frequency values (50, 80, 100, 160 and 200 Hz). A CASL scan was carried out in one volunteer with the labeling plane placed distal to (8cm above the center of) the imaging slices, and a fractional signal change of 0.004% was observed which confirmed well balanced off-resonance effects in the control and label acquisitions. The labeling efficiency of the multi-slice CASL sequence was estimated through comparison with the single-slice version of CASL technique, in which the label and control were proximal and distal to the imaging slice respectively. The SNR of the optimized CASL method was also compared with a PASL technique (modified FAIR) (1) in 9 subjects. The SAR level of the 3.0T CASL sequence was estimated using an analytical solution to a homogeneous sphere model for the human head, which yielded a SAR level of 1 W/kg (with 2.25 μT RF) on an adult head with a radius of 10cm. This SAR estimation was further confirmed by integrated product software which yielded a mean percentage SAR level of 54.5±15.6% (based on IEC 60601-2-33 guideline, normal operation mode) in the 13 healthy volunteers.

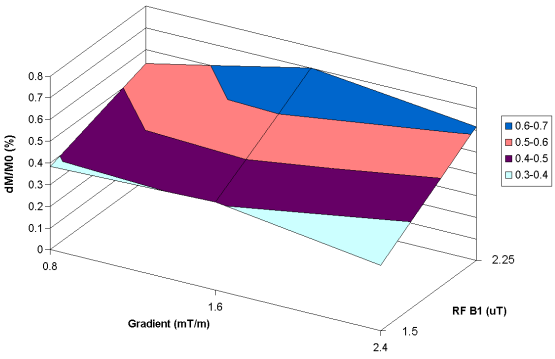

Fig. 1 Mean fractional CASL signal ($\Delta M/M_0$) acquired at different gradient strength and RF irradiation.

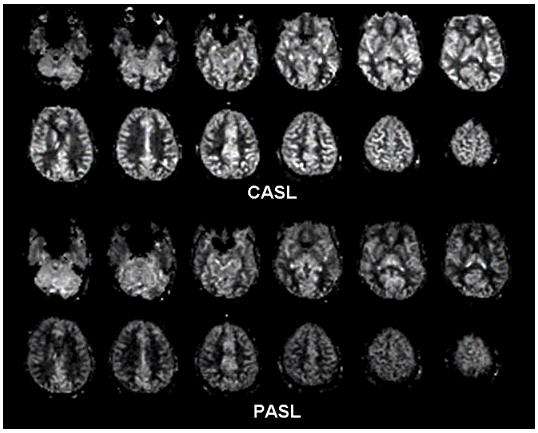

Fig. 2 Comparison of CASL and PASL perfusion images (ΔM) of a representative subject at 3.0T.

Results and Discussion As displayed in Fig. 1, the peak fractional CASL signal (0.70±0.10%) was obtained with 1.6 mT/m gradient and 2.25 μT RF irradiation. The optimal ratio between the gradient strength and RF magnitude at 3.0T is the same as that at 1.5T, consistent with previous finding that the labeling efficiency can be preserved by simultaneously reducing the strengths of gradient and labeling pulses (6). The frequency of the amplitude modulation was found not to significantly affect the CASL signal. Though a frequency of 100Hz yielded the highest mean perfusion signal in the whole brain. The ratio of the mean CASL signals obtained with the amplitude modulated and single-slice approach was 0.74±0.12. Assuming a labeling efficiency of 92% in the single-slice CASL mode based on numerical simulation (6), the labeling efficiency in the 3.0T amplitude modulated CASL method is calculated to be 68% (92%×0.74). This value is comparable with reported continuous labeling efficiency of 71% at 1.5T (5). Comparison of the CASL and PASL methods at 3.0T showed a 33% improvement in the SNR by using CASL (see Fig. 2). Due to improved SNR, CASL perfusion images of the moyamoya patient could be acquired at a longer delay time (1.8s) which showed reduced transit effects compared to those obtained at 1.5s delay. Heterogeneous perfusion pattern was observed in the tumor patient, consistent with clinical diagnosis (glioblastoma multiforme, grade IV).

References (1) Wang J et al. *MRM* **48**: 242-254; 2002. (2) Yongbi MN et al. *Radiology* **222**:569-575; 2002. (3) Zaharchuk G et al. *MRM* **41**:1093-1098; 1999. (4) Mildner T et al. *MRM* **49**:791-795; 2003. (5) Alsop DC&Detre JA *Radiology* **208**: 410-6; 1998. (6) Maccotta L et al. *NMR Biomed* **10**:216-221; 1997.