A theoretical and experimental investigation of the tagging efficiency of pseudo-continuous arterial spin labeling

W-C. Wu[1], M. Fernandez-Seara[2,3], F. Wehrli[1], J. Detre[2], and J. Wang[4]

[1]Laboratory for Structural NMR Imaging, Department of Radiology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, United States, [2]Department of Neurology, University of Pennsylvania, Philadelphia, Pennsylvania, United States, [3]Center for Applied Medical Research, Department of Neuroscience, University of Navarra, Pamplona, Spain, [4]Department of Radiology, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Introduction

Pseudo-continuous arterial spin labeling (pCASL) is a newly proposed technique, employing repeated RF pulses to mimic continuous ASL (CASL) that is often not available on imagers due to its requirement of continuous mode RF transmit capacity. At present pCASL can be realized in two ways: one referred to as unbalanced pCASL in this study applies gradients whose moment per cycle (i.e. between two consecutive RF pulses) is non-zero in tag session and zero in control (1), the other referred to as balanced pCASL uses an identical gradient waveform with a residual moment for both tag and control sessions (2). In both methods, RF polarity is alternated in control session and constant in tag session. The residual gradient moment in balanced pCASL is adjusted to generate the flow-driven inversion and meanwhile maintain unperturbed M_Z for control state (Fig 1). As a result, the tagging efficiency can be sensitive to the interplay of flow velocity and the gradient applied. In the present study, we implemented balanced pCASL for both transmit/receive coil and array reception. Tagging efficiency was optimized and compared to PASL and CASL techniques. Numerical simulations were conducted to address the effect of flow velocity and off-resonance.

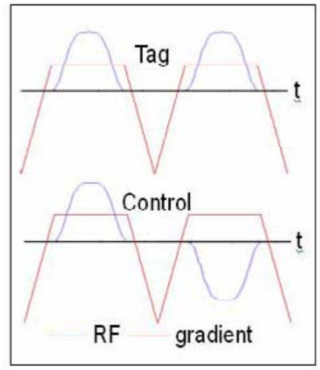


Fig 1

Materials and Methods

Four healthy subjects aged between 24 and 32 years (2 females, 2 males) were imaged following a protocol approved by the institutional review board and informed consent was obtained. All imaging was performed on a 3T Siemens Trio system. Experiments consisted of two parts. 1) ASL signal change ($\Delta M/M_0$, where ΔM was the signal difference of tag and control images and M_0 was the M_Z of arterial blood at equilibrium) was measured for balanced pCASL at multiple residual gradient moments (η) between two consecutive RF pulses. PASL images were acquired for comparison. Body coil was used for transmission and 8-channel head coil for reception. 2) Experiment was then shifted to a Bruker transmit/receive head coil with the capacity of continuous RF for CASL. Finally, pCASL images were acquired using the optimal η determined in Exp 1. Imaging parameters were summarized in the following Table. The effects of flow velocity and off-resonance on tagging efficiency of pCASL was evaluated by computer simulation of Bloch equations (assuming blood T1 and T2* = 1660 and 80ms, respectively).

Generic parameters: FOV = 22cm, in-plane matrix size = 64x64, 9 axial slices, slice thickness = 5mm, inter-slice gap = 1mm, TR/TE = 4000/17ms, 60 acquisitions, gradient-echo echo-planar readout	
pCASL	Hanning window shaped RF pulse with duration/space = 500/920µs, flip angle = 25^0, slice-selective gradient = 6mT/m, post-labeling delay (PLD) = 1000ms, tagging duration (τ) = 1500ms, η = {6,8,…,20}% of the moment in positive cycle
PASL	FAIR (3) and QUIPSS II (4), TI1 = 700ms, TI2 = 1700ms
CASL	Amplitude modulation for control (5), PLD = 1000ms, τ = 2000ms

Results and Discussion

Balanced pCASL was realized with a head array coil of general specifications, providing a ~50% increase of $\Delta M/M_0$ as compared to PASL (Fig 2). The optimal η was 8-10% of the gradient moment of positive cycle and experimental data indicated a tagging efficiency of 80% as referred to the efficiency of amplitude-modulated CASL (68%) after corrected for the different τ used for pCASL and CASL (Fig 3). Quantitative perfusion was 67±5, 59±5 and 61±6 ml/100ml/min in PASL, pCASL and CASL, respectively. Simulations showed an overall efficiency (defined as the M_Z/M_0 difference between tag and control signals divided by 2) of 85% for flow velocity from 10 to 60 cm/s. The efficiency and tag/control states, however, can vary with the extent of off-resonance (Fig 4). In summary, pCASL provides a better compromise between tagging efficiency and signal-to-noise ratio.

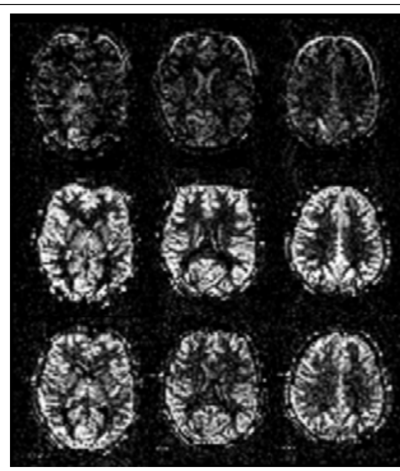
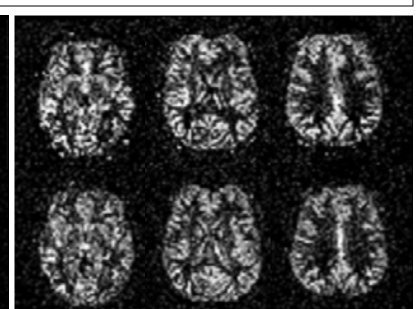


Fig 2. 1st and 2nd rows: pCASL with η = 14 and 10%, respectively. 3rd row: PASL.



Figs 2 (←), 3 (↑) and 4 (↓)

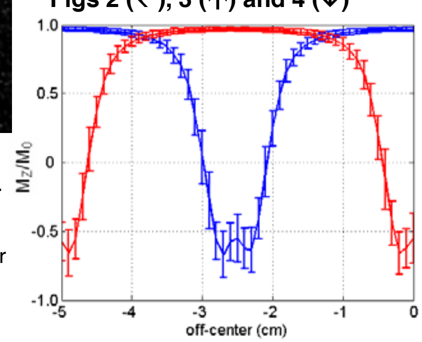


Fig 3. Comparison of pCASL (top, η = 10%) and CASL (bottom).

Fig 4. Profile of tag (red) and control (blue) as a function of off-resonance. Error bars indicate the standard deviation of different flow velocities (10-60cm/s).

References

1. Garcia et al., ISMRM 2005, #37. 2. Wong, ISMRM 2006, #668.
3. Wang, MRM 2002;48:242-254. 4. Wong et al., MRM 1998;39:702-708. 5. Wang et al, Radiology 2005;235:218-228.