

# Pseudo-Continuous Arterial Spin Labeling with Optimized Tagging Efficiency for Quantitative ASL fMRI

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## INTRODUCTION

Arterial spin labeling (ASL) fMRI can provide quantitative measurements of functional changes in cerebral blood flow (CBF) that can be used either on their own or in conjunction with BOLD measures. The continuous arterial spin labeling (CASL) or the pseudo-continuous arterial spin labeling (PCASL) method [1] offers higher SNR and therefore the potential for improved detection of activation compared to pulsed ASL (PASL). However, a prior study has reported differences in the functional CBF activation measured by CASL versus PASL [2]. PCASL can be implemented without the need for a special RF system, which is often required for continuous ASL (CASL). The quantification of CBF activation with PCASL has not yet been examined in detail, and may be sensitive to phase errors. Here we optimized the PCASL method by estimating and compensating the phase errors at the tagging vessels. Our result shows good agreement in quantitative CBF measures between PICORE ASL [3] (a PASL method) and our optimized PCASL method.

## THEORY

The tagging efficiency of PCASL can be significantly modulated by both gradient imperfections and the presence of off-resonance fields at the tagged vessels [2] because the tagging mechanism is highly sensitive to the accurate specification of phase between successive RF pulses. The conventional PCASL method uses two phase offsets:  $0^\circ$  for tag and  $180^\circ$  for control. We estimated the phase errors between RF pulses using a novel PCASL method with multiple phase offsets (i.e.  $-90^\circ$ ,  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ ) which is less sensitive to those factors because it allows the acquired data to be fitted to a predefined inversion response function. This enables the estimation of the phase errors as well as the perfusion signal on a per-voxel basis. The estimated phase error which is global through a tagging plane can then be compensated by adding a constant phase offset to the labeling RF pulses ( $\Delta\theta$  in Fig. 1). However, the labeling plane typically contains several blood vessels, each of which may have a different phase error due to the local field frequency offset, causing non-uniform tagging efficiency across blood vessels. This asymmetric tagging efficiency can be compensated by adding gradients in x and y plane (shaded gradient area in Fig. 1). A uniform and near-optimal tagging efficiency across all tagged vessels can be achievable.

## METHOD

We compared the visual activation in one female subject across 3 different ASL methods : PICORE ASL, PCASL, and the optimized PCASL. The experiment was executed on a 3T Signa HDx scanner with an 8-channel head coil (GE Healthcare, Waukesha, WI). The PICORE ASL scan was performed with QUIPSS II post-inversion saturation pulses [4] and scan parameters were  $T1/T2 = 600\text{ms}/1900\text{ms}$ , 10cm tag width, 1cm tag-slice gap, TR 2 sec. PCASL scan parameters were 1600 msec tag duration, 1200ms post labeling delay, 5cm tag-slice gap TR 3 sec. All methods have 240mm FOV, 6 slices (5 mm thick, no gap), single-shot spiral acquisition ( $TE = 3\text{ms}$ ). Each method had two scans: one scan to measure baseline CBF (3min) and a block design scans (30s off, 4 cycles of 30s on/30s off; 8-Hz flickering checkerboard visual stimulus). All the CBF data were calibrated to physiological units of (ml/100g/min).

## RESULTS AND CONCLUSION

As shown in Fig 2, both the PCASL and the optimized PCASL provide higher tSNR (mean divided by standard deviation over time) than PICORE ASL method but PCASL gave lower tSNR than optimized PCASL due to the non-optimal tagging efficiency. The time course in quantified CBF unit (ml/100g/min) (Fig. 3) shows there was good agreement in quantitative CBF measures between PICORE and PCASL. Measured baseline CBF and the change in CBF are shown in Fig. 4. The change in CBF from the optimized PCASL method is comparable to that from the PICORE ASL method.

The compensation or correction of the phase errors at tagging plane in PCASL acquisition is essential for higher SNR and accurate CBF quantification.

## REFERENCES

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2. Luh et al, 8<sup>th</sup> ISMRM: 243, 2000.
3. Wong et al, NMRB 10: 237-249, 1997.
4. Wong et al, MRM 39: 702-708, 1998.

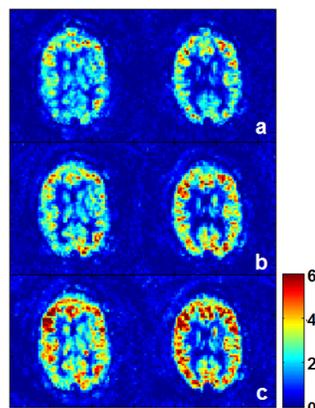


FIG. 2. tSNR maps from (a) PICORE ASL, (b) PCASL, and (c) the optimized PCASL

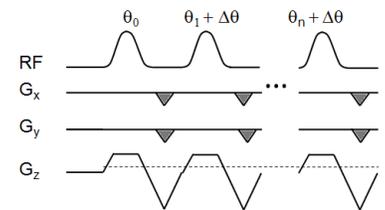


Fig. 1. Diagram of tagging modulation with the additional phase offset ( $\Delta\theta$ ) and compensation gradients expressed by the shaded area in  $G_x$  and  $G_y$

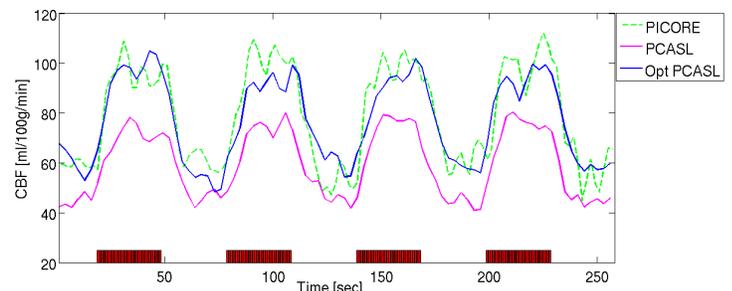


FIG. 3. Averaged time courses from the common activated ROI (total 89 voxels) expressed in the physiological unit of perfusion.

	PICORE ASL	PCASL	Optimized PCASL
$CBF_0$	58.6	44.9	56.5
$\Delta CBF$	40	29.5	39.1

FIG. 4. Baseline CBF ( $CBF_0$ ) and the changes of CBF ( $\Delta CBF$ ) from three ASL fMRI methods