Tagging Efficiency Corrected Pseudo-Continuous Arterial Spin Labeling – A New Approach for Correction of Phase Tracking Errors

D. D. Shin[1], H-L. Liu[2], A. Shankaranarayanan[3], and T. T. Liu[1]
[1]Center for Functional MRI, University of California, San Diego, La Jolla, CA, United States, [2]Department of Medical Imaging and Radiological Sciences, Chang Gung University, Taiwan, [3]GE Healthcare, Waukesha, Wisconsin, United States

Introduction: Pseudo continuous arterial spin labeling (PCASL) has emerged as a valuable research and clinical tool for the measurement of cerebral blood flow (CBF). However the acquisition of accurate and reliable CBF estimates can be complicated by variations in tagging efficiency (α) caused by phase tracking errors [1]. Optimized PCASL (OptPCASL) has been proposed as a method to measure and minimize the phase tracking errors [2], and several variants of this technique [3-5] have been recently presented. One drawback of the OptPCASL technique is the need to iteratively acquire and analyze calibration scans until the phase tracking errors are sufficiently minimized. Here we propose an alternate approach, which is more time efficient and simpler to implement. This new technique, named α-corrected PCASL, compensates for tagging efficiency variations on a per voxel basis. The key component of this technique is the accurate estimation of the phase errors and the associated tagging efficiency map. The feasibility of this technique is demonstrated and the performance is compared to that of OptPCASL and conventional PCASL.

Methods: For the direct conversion of phase error to tagging efficiency, the dependence of tagging efficiency on phase tracking error (0°-180°) and velocity (10-50cm/s) was determined with a numerical simulation of the Bloch equations using the PCASL tagging parameters described below. A healthy 28-year old female subject was scanned on a 3T GE MR750 scanner using an 8-channel head coil. For a quick and robust estimation of the phase tracking errors, a 2-minute multiphase PCASL (MP-PCASL) sequence with 8 RF offsets was used with a short post labeling delay (400ms) [1,4]. A tagging duration of 2000ms was used to obtain the maximum SNR efficiency based on calculations with the General Kinetic Model [6]. Two PCASL experiments (conventional PCASL and OptPCASL) were performed with: TR=4200ms, TE=3.3ms, tag duration=2000ms, post labeling delay=1600ms, reps=60, and scan time=252s. The images were acquired with a 2D spiral readout for twenty 5mm thick axial slices with 1mm gap, achieving whole brain coverage. The balanced PCASL tagging scheme was implemented with: Hanning-shaped RF pulses of 375us duration, $B1_{max}$=0.1G, G_{max}=1.6G/cm, G_{mean}=0.09G/cm, and a RF-to-RF spacing of 998us. Velocity encoded phase contrast MRI (VE-PC-MRI) sequence was used to measure the velocity of blood in major arteries at the tagging plane. A 3D high resolution T1-weighted structural scan was acquired, which was used to define a gray matter (GM) mask. Using the results from the Bloch simulation study, the tagging efficiency map was generated from the acquired phase error map. The perfusion signal from the conventional PCASL was then converted into calibrated CBF units (ml blood/100 ml tissue-min) using the tagging efficiency map.

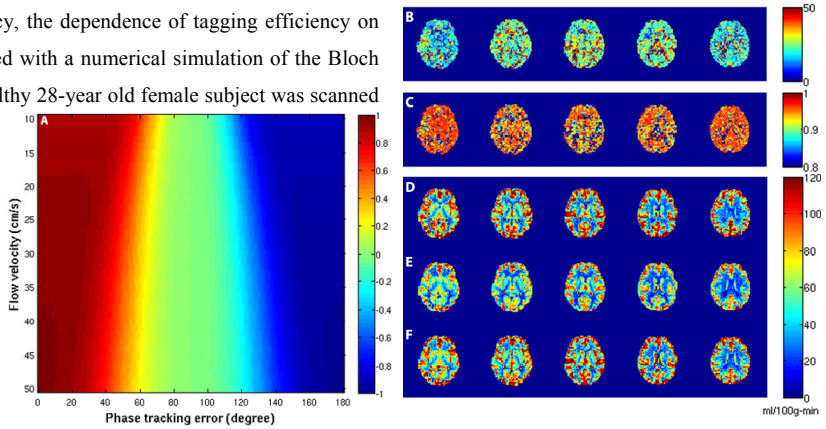

Fig. 1. A) Tagging efficiency as a function of phase tracking error and velocity. B) Phase error map. C) Tagging efficiency (α) map. Quantified CBF maps for OptPCASL (D), conventional PCASL (E) and α-corrected PCASL (F).

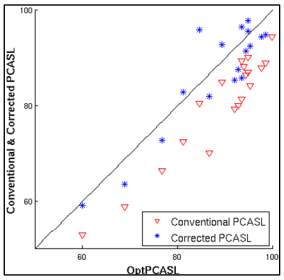

Fig. 2. CBF with conventional (red) and corrected PCASL(blue) vs. OptPCASL.

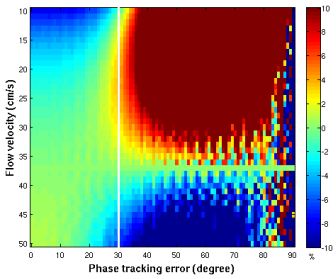

Fig. 3. Percent tracking error in quantification (referenced to velocity of 37 cm/s) as a function of velocity and phase error.

Results & Conclusion: Fig. 1A shows tagging efficiency as a function of phase tracking error and blood velocity for the tagging parameters described above. Note that tagged spins are more susceptible to phase error at higher velocity. The average velocity for the two internal carotid arteries at the tagging plane was 37 cm/s over the cardiac cycle. The estimated phase error map for 5 representative slices and the associated tagging efficiency (α) map assuming a velocity of 37 cm/s are shown in Figs 1B and 1C, respectively. CBF estimates obtained with OptPCASL and α-corrected PCASL are qualitatively similar (Figs. 1D and 1F), while conventional PCASL estimates are visibly lower (Fig. 1E). The mean whole brain GM CBF was 87.7, 78.4, and 86.0 ml/100ml-min for OptPCASL, conventional PCASL, and α-corrected PCASL, respectively. Scatter plots of per-slice GM CBF from OptPCASL versus that from conventional (red markers) and α-corrected PCASL (blue markers) are shown in Fig. 2 for all 20 slices. OptPCASL and conventional PCASL CBF estimates were found to be significantly different ($p<1e-6$), while OptPCASL and α-corrected PCASL estimates were not significantly different ($p = 0.5$). In this study, we used the measured blood velocity to calculate the tagging efficiency as a function of phase error. Fig. 3 shows that the relative error (referenced to zero error at 37 cm/s) in quantified CBF measures is relatively insensitive to blood velocity for phase tracking errors less than 30 degrees (white line), suggesting that it may not be necessary to acquire an additional VE-PC-MRI scan to measure blood velocity. Indeed, with the MRI system and tagging parameters described above, the vast majority of subjects have phase errors that are less than 30° [3], implying that CBF quantification error should be less than 2.85±1.51% over the range of velocities that are physiologically relevant.

References: 1. Jung Y et al. MRM 64:799-810. **2.** Jung Y et al. 17th ISMRM (Abstract 1578). **3.** Shin D et al. 18th ISMRM (Abstract 1744). **4.** Luh W-M et al. 18th ISMRM (Abstract 520). **5.** Jahanian et al. 18th ISMRM (Abstract 519). **6.** Buxton et al. MRM 40:383-396.