Single-Artery Pseudo-Continuous Arterial Spin Labeling with Off-Resonance Correction

Cheng Ouyang[1], Aiming Lu[1], Xiangzhi Zhou[1], and Mitsue Miyazaki[1]
[1]*Toshiba Medical Research Institute USA, Vernon Hills, IL, United States*

Target Audience: Researchers and clinicians who are interested in single-artery pCASL.

Introduction: The single-artery, or vessel-selective, pCASL sequence has demonstrated to provide regional perfusion maps non-invasively[1]. However, similar to the original pCASL labeling, vessel-selective pCASL is also sensitive to off-resonance effects, which introduce phase errors in the labeling RF train and thus compromise in tagging efficiency. In this work, we propose to restore the signal loss due to off-resonance effects by applying a modified multiple phase correction method in the vessel-selective labeling sequence.

Methods and Materials: Numerical Bloch simulations were carried out to explore the inversion responses (control-tag) of the vessel-selective pCASL labeling at the target vessel as a function of phase offset ($\Delta\Psi$ as shown in Fig. 1). The simulated inversion efficiency curve was first fitted to a 12th order polynomial $P(\Delta\Psi)$. Then, the polynomial was utilized as the signal model, and the perfusion signal can be estimated by fitting the measured perfusion-weighted data ($m_{i,n}$) at multiple phase offsets to the expected inversion efficiency function in a voxel-by-voxel manner: $m_{i,n} = CBF_i \times P(\Delta\Psi_n - \varepsilon_i)$ [1], where n is the phase offset index, CBF is the perfusion-weighted map, and ε is the phase error map. Different from previous correction method[2], here in our approach, the signal is modeled as a more general polynomial rather than a Fermi function.

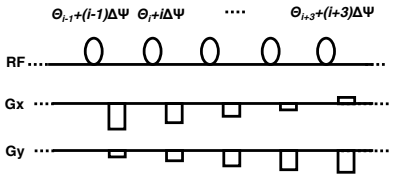

Fig. 1: The sequence scheme of vessel-selective pCASL with off-resonance correction. Θ is the phase related to the original and the basic vessel-selective pCASL sequence, while $\Delta\Psi$ is the extra phase offset added to the sequence for off-resonance considerations.

The parameters used in the simulation and in vivo experiments were: hamming-shaped RF pulses with 600-μs duration, 1.8 mm tagging slice thickness, gradient fraction 0.1, RF spacing 1500 μs, in-plane vessel-selective gradient amplitude 0.7 mT/m, gradient rotation rate of 11°, blood velocity 30 cm/s, tag duration 1.5 s, post-labeling delay 1 s with background suppression. A T_2 of 275 ms and a T_1 of 1680 ms was used in the simulation. One healthy subject was scanned in 3T magnet (Toshiba Vantage Titan™ 3T, Otawara, Japan), FFE2D readout (FA/TR/TE: 20°/9/3.4 ms, matrix size 64^2, imaging slice thickness 10 mm, total TR 6 s, single slice). Three averages at each phase offset and eight offsets (n=1:8, -120°, -90°, -30°, 0°, 30°, 60°, 90°, 120°) were obtained, resulting in an acquisition time of around 4.5 mins. The data acquired at the phase offset of -60° was discarded due to extensive motion artifact.

Results: Fig. 2 shows the simulated inversion responses (blue circles) in the function of phase offset added to pCASL tagging RF pulses. The solid line shows the 12th order polynomial fitted to the inversion response. Fig. 3a is the overlay image acquired at the labeling slice. Fig. 3b is the vessel-selective pattern at the labeling location with phase offset of 0°. The red dashed circles in Figs. 3a and 3b delineate the location of the right ICA and the labeling disk around the right ICA, respectively. The labeling disk is expected to be a smooth circle under ideal conditions. The irregular edge of the labeling disk in Fig. 3b can be caused by B_o inhomogeneities and other off-resonance effects.

The measured perfusion-weighed data at different phase offsets ($m_{i,n}$) is shown in Fig. 3c. Figs 3d and 3e are the estimated CBF-weighted and phase error maps, separately. The mean absolute signal levels at each phase offset of the right ICA (Fig. 3c) are 0.79, 0.59, 0.28, 0.68, 0.65, 0.73, 0.61, and 0.41 in the order as in Fig. 3c, by setting the estimated CBF signal level (Fig. 3d) by Eq. [1] to 1.0. The pattern of signal changes with different phase offsets, which is consistent with the simulation results. An overall signal enhancement (Fig. 3d) was observed after off-resonance correction compared to images obtained with different off-set phases (Fig.3c).The SNR was improved by 47% by the proposed correction method compared to the signal obtained at 0° phase offset.

Discussions and Conclusions: Both simulated and human results demonstrated that the efficiency of vessel-selective pCASL labeling can be degraded in the presence of off-resonance effects. Our results show that the proposed multiple-phase correction method can effectively restore the signal loss due to off-resonance effects and provides higher SNR in vessel-selective pCASL. Another benefit to apply the multiple phase correction method in single-artery pCASL is that, unlike the non-vessel-selective pCASL sequence, for the single-artery labeling, the signal model shown in Fig. 2 or in Eq. [1] is still correct under the scenario of blood mixing, and the off-resonance correction does not compromise accuracy of perfusion signal level. For future work, in order to improve the temporal resolution and SNR efficiency, enhancement of the incorporation of off-resonance correction into vessel-selective pCASL will be investigated.

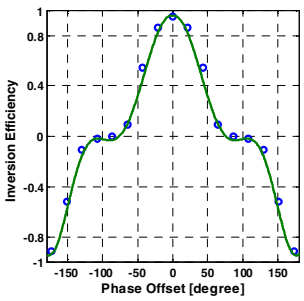

Fig. 2: The simulated inversion efficiency (velocity 30 cm/s) of vessel-selective pCASL at different phase offsets (blue circles). The green solid line is the 12th polynomial fitted to the simulations.

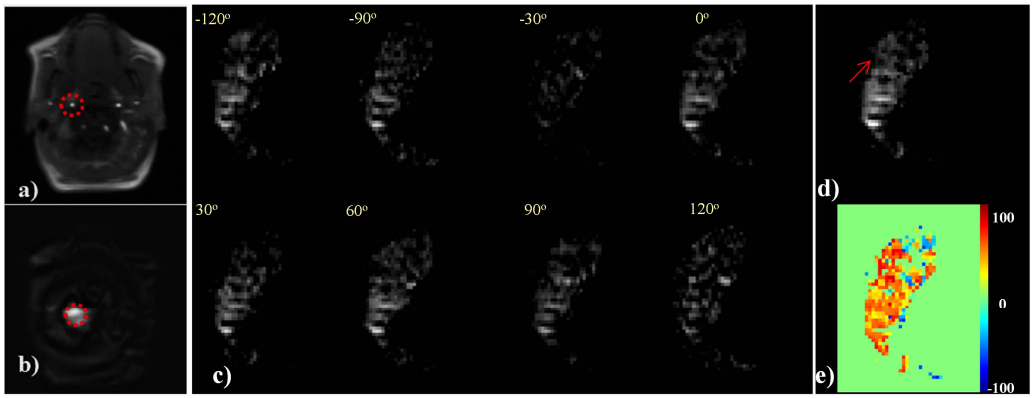

Fig.3: a) the overlay magnitude image of the labeling slice. The red dashed circle stands for the target artery of the right ICA. b) The labeling pattern obtained in vivo at the labeling slice shown in a). The red dashed circle delineates the size and position of the single-artery labeling disk. c) The measured regional control-tag data with different phase offsets. d) The estimated regional CBF-weighted map by Eq. [1]. e) The estimated phase error (unit in degree) map by Eq. [1]. The red arrow in d) indicates a significant signal improvement with correction.

References:
1. Dai et al., MRM 2010; 64:975-982;
2. Jung et al., MRM 2010; 64:799-810;