Optimizing Perfusion Imaging of pTILT in the Presence of Magnetic Field Inhomogeneity

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Introduction

Pseudo-continuous transfer insensitive labeling technique (pTILT) is a novel pseudo-continuous arterial spin labeling method, which employs non-adiabatic saturation RF pulses for tagging [1]. However, magnetic field inhomogeneities, can compromise the labeling efficacy of pTILT, which induces loss in SNR and perfusion quantification errors. We propose a method to restore the signal loss by correcting the field inhomogeneity effects. This will provide more robust perfusion measures than the conventional pTILT technique.

Method: In pTILT, concatenated RF pulses were employed to control magnetization transfer effects (Figure 1). Due to the time spacing between the centers of the RF pulse pair, τ, sensitivity to off-resonance artifacts causes phase offset between two RF pulses and variability in the effective flip angle for tag and control pulse pairs.

<u>*Simulation:*</u> Numerical Bloch simulations were used to explore the labeling response of (45°, ±45°) RF pulse pairs as a function of the off-resonance frequency Δf. The simulation parameters were: windowed-sinc 45° RF pulse with duration of 2560 µs, RF spacing τ 2960 µs with ramp up time of 200 µs, off-resonance frequencies range from -300 Hz to 300 Hz in step of 10 Hz.

<u>*In vivo*</u>: In order to compensate for the off-resonance effects in human brain studies, a phase increment, ΔΦ, was inserted between two consecutive RF pulses. ΔΦ was evenly distributed from –π to π in step of π/15, resulting in 30 pairs of control and tag images in total. The acquired data was used to fit the predefined labeling response function obtained from our simulation study. In vivo acquisition parameters were: 3 T Siemens Trio scanner, FOV 22 cm, in-plane matrix size 64×64, TR/TE 5000/44 ms, SE-EPI readout, imaging slice thickness 6 mm, slice gap 1.2 mm, 30 averages. Labeling slice thickness 10 mm, RF pair spacing 30 ms, RF pair repetitions 100, total labeling duration 3 s, post-labeling delay 1 s, spoiler duration and amplitude 4000 ms/[±10, ±12, ±14, ±16 G/cm]. In order to demonstrate the effectiveness of the proposed method, mis-shimming by shifting the center frequency by ~60 Hz was performed prior to data acquisition.

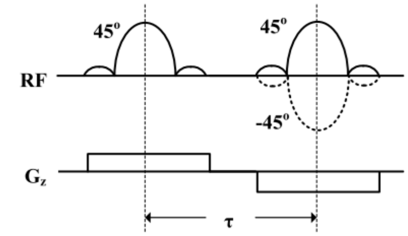

Figure 1: Concatenated RF pulse pairs in pTILT. (45°, 45°) is used for tag and (45°, -45°) for control. τ denotes RF spacing.

Results: The labeling response function versus off-resonance frequency Δf is shown in Figure 2. The tag (45°, 45°) response function (black) follows Equation (1) and the control (45°, -45°) response function (red) follows Equation (2), where $S_{\text{tag/control}}$ indicates the normalized signal. The simulation results were in good agreement with the signal profile by (1, ±1) binomial pulses in literature [2].

$$S_{\text{tag}}(\Delta f) = \sin^2(\pi\tau\Delta f) \quad (1) \qquad S_{\text{control}}(\Delta f) = \cos^2(\pi\tau\Delta f) \quad (2)$$

$$S_{\text{flow}}(\Delta f, \Delta\Phi) = A\cos^2(\pi\tau\Delta f + \frac{\Delta\Phi}{2}) - A\sin^2(\pi\tau\Delta f + \frac{\Delta\Phi}{2}) \quad (3)$$

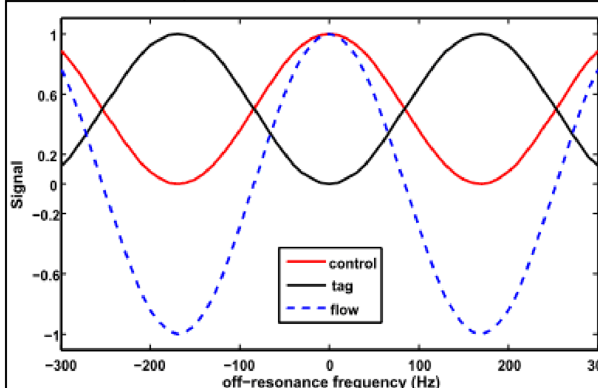

Figure 2: simulated labeling response function to the off-resonance frequency.

By inserting phase offset ΔΦ between the RF pulse pair, the signal model of pTILT follows Equation (3), where S_{flow} is the measured data and A is the recovered flow signal without off-resonance errors.

As shown in Figure 3, the CBF maps acquired with the proposed method (b) provides improved CBF estimates than the conventional pTILT (a), as the tagging efficiency of the latter is reduced by off-resonance errors. In addition to the recovered ASL signal, the fitting algorithm provides estimates of the magnetic field inhomogeneity at the tagging plane. The estimated off-resonance frequencies from Equation (3) (shown in Figure 3c) matched the magnetic field map values measured at the labeling arteries.

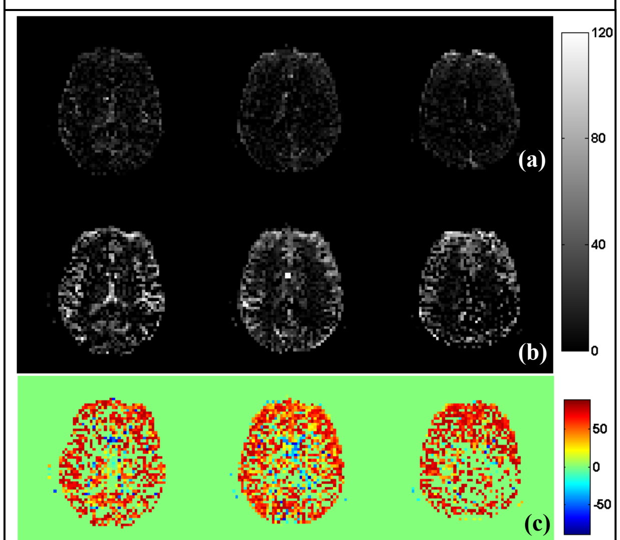

Figure 3: CBF maps (mL/100 g/min) measured using conventional (a) and proposed (b) pTILT. (c) The estimated off-resonance frequency in Hz.

Discussions: Compared to multi-phase pCASL [3], which was proposed previously to correct the off-resonance errors for pseudo-continuous ASL acquisitions, pTILT has a analytical expression of the labeling response function, while pCASL has no theoretical equation describing the labeling response as a function of off-resonance frequency. Sampling a range of off-resonant phases allows for excellent recovery of the flow-weighted signal in pTILT free from field inhomogeneity induced flow signal losses.

Acknowledgements: This work was supported by NIH grant 1R21EB010095-01A1 and Award Number 1RC1 AG035927 Z-ARRA from the National Institute on Aging.

References:

1. Ouyang et al. ISMRM 2010, p1740. 2. Hore et al. J Magn Reson. 1983; (54) 539-542. 3. Jung et al. ISMRM 2009, p622.