Optimizing the inversion efficiency of pseudo-continuous ASL pulse sequence using B0 field map information

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Introduction: The recent introduction of pseudo-continuous inversion pulses (pCASL) has the potential to greatly facilitate the use of continuous Arterial Spin Labeling (ASL) (1). However, field inhomogeneities, can compromise the inversion efficiency of pCASL, which causes loss in SNR and severe quantification error (2). We propose a method to restore the loss in inversion efficiency by correcting the phase of the RF pulses in combination with a z-shimming scheme. This will provide more robust perfusion measurements than the conventional pseudo-continuous technique. The method is demonstrated using numerical simulation and In-vivo data.

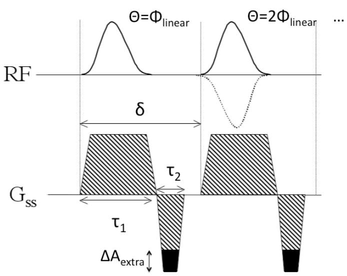

Fig 1. pCASL Pulse Sequence.

Theory: We model the local field inhomogeneities as a constant shift plus a linear Z-gradient in the local magnetc field (B_{error} and G_{error}) at the tagging plane for the pCASL pulse sequence. B_{error} and G_{error} can be estimated by mapping the field inhomogeneities using a first order linear approximation. G_{error} induces an, unwanted, velocity-dependent phase in the magnetization vector during the interval between RF pulses that degrades the adiabatic inversion (2). B_{error} (off-resonance) produces a position-dependent phase error in the magnetization vector that further degrades the inversion. We propose to compensate for G_{error} by updating the refocusing lobe of the G_{ss} (Fig 1) using Eq. 1. Unwanted phase caused by B_{error} will then be compensated by adding a linear phase (ϕ_{linear}) defined by Eq. 2 to the RF pulses.

$$\Delta A_{extra} = -G_{error}\delta \qquad \text{(Eq. 1)}$$

$$\phi_{linear} = -\gamma B_{error}\delta \qquad \text{(Eq. 2)}$$

Methods: We simulated the behavior of the magnetization vector of an ensemble of moving spins (T1=1660ms, T2=250ms, laminar flow with peak velocity=100cm/s) in the presence of the pCASL pulse shown in Fig.1 (Residual fractional moment (η) = 0.12, flip angle = 35°, Hanning-shaped RF of 500µs duration, δ=1.5 ms) using a numerical implementation of the Bloch equations. The effect of field inhomogeneity was simulated by introducing an artifactual gradient and a shift in resonance frequency (G_{error} and B_{error}) to the pulse sequence. This error was then corrected using the proposed method. A pCASL sequence was implemented on a 3.0 T Signa Excite scanner (General Electric, Waukesha, WI) using the same parameters used in the simulation study. Residual fractional moment (η) was first set to the optimum value obtained from a simulation study, assuming no B_0 inhomogeneity (η=0.12 ; results not shown here). B0 field inhemogenities were then mapped from two sets of images at the location of tagging plane, acquired with a TE difference of 1 ms (3). B_{error} and G_{error} were estimated from the obtained field map. Refocusing lobe of slice selective gradients and phase of RF pulses were then modified according to Eqs.1 and 2.

Results: The effects of off-resonance and gradient error on the inversion efficiency of pCASL were investigated using a simulation study. Fig. 2 shows the inversion efficiency achieved by pCASL in the presence of different amounts of off-resonance and gradient error before (Fig. 2.a) and after (Fig. 2.b) applying the proposed correction method. As can be seen, the proposed method successfully restored all the lost inversion efficiencies. Fig 3.a shows the perfusion images acquired from one subject before (using the optimum values derived from simulation study) and after correction. To make sure that the proposed method provides the optimum inversion efficiency, we also measured the inversion efficiency in the carotid arteries at neck for different values of RF phases. The predicted optimum phase by the proposed method is marked with a red arrow. The proposed method improved the inversion efficiency by ~45%.

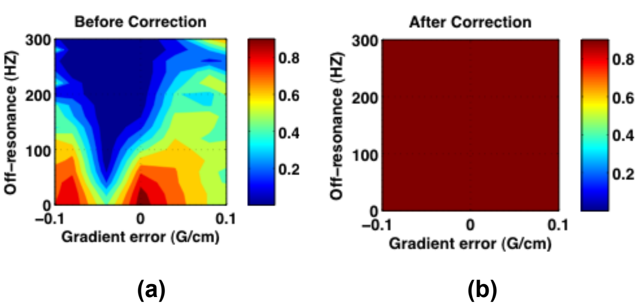

Fig 2. Simulation study results: inversion efficiencies measured for different amounts of off-resonance and gradient error; a) before correction b) after correction using the proposed method.

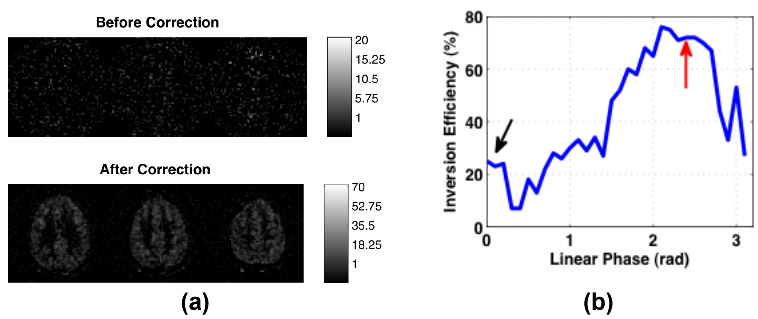

Fig 3. In vivo results: a) Perfusion difference images acquired before and after correction with the proposed method. b) Inversion efficiencies measured at carotid arteries in the same subject for different RF phase values. Black and red arrows show the optimum phases defined by simulation under ideal conditions and the proposed method respectively.

Conclusion and Discussion: Inversion efficiency of pCASL can be compromised by local shifts in resonance frequency and the local gradient of the inhomogeneity at the tagging plane. In this study we showed that estimating these field inhomogeneities using B0 field map information, modeling their effects and compensating for them using the proposed method could effectively recover the compromised inversion efficiency.

Acknowledgements: This work is supported by the NIH grant EB004346.

References: [1] Dai et al, MRM 60(6):1488-97, 2008. [2] Jahanian et al, ISMRM, 2009. [3] Yip et al, MRM 56(5):1050-9, 2006.