Correcting for off-resonance induced degradation of inversion efficiency in pseudo-continuous ASL

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Introduction: Pseudo-continuous arterial spin labeling (pCASL) uses a long train of labeling pulses to provide multi-slice cerebral perfusion measurements while compensating for magnetization transfer effects without using additional hardware [1]. The inversion efficiency of pCASL is known to be sensitive to the amount of phase shift (ϕ) experienced during the time between two consecutive RF pulses [1]. Uncontrolled changes in local resonance frequency and field gradients, due to field inhomogeneities, can compromise the tagging efficiency of pCASL, which causes loss in SNR and can lead to quantification error. Here we examine the efficacy of dynamically changing the residual gradient moment (η) to systematically compensate the unwanted changes in ϕ, thus restoring the tagging efficiency of PCASL. The method is demonstrated using numerical simulation and In-vitro data.

Methods: The amount of error introduced to the phase shift (ϕ_{error}) between two RF pulses caused by an arbitrary field inhomogeneity modeled 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 (Fig. 1) can be calculated using Eq. 1. This error can be fixed by updating the amplitude of the gradient refocusing lobe using Eq. 2.

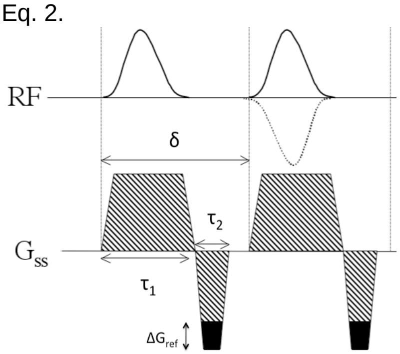

Fig. 1. pCASL pulse sequence.

$$\phi_{error} = \gamma B_{error}\delta + \gamma G_{error}V(\delta\tau_1 - 3\tau_1^2/4 - \tau_2^2/2 - \tau_2\tau_1/2 + \tau_2\delta + \delta^2/2) \quad \text{(Eq. 1)}$$

$$\Delta G_{refocus} = \phi_{error}/(\gamma\tau_2 Z_0\delta + \gamma V(3\tau_1\tau_2/2 + \tau_2^2)) \quad \text{(Eq. 2)}$$

in which Z_0 and V represent the distance of tagging plane from iso-center and the velocity of flowing spin, respectively.

We simulated the behavior of the magnetization vector of an ensemble of moving spins (T1=1660ms, T2=100ms, velocity=30cm/s) in the presence of a pseudo-continuous inversion pulse sequence (η = 0.25, flip angle = 22.5°, Hanning-shaped RF of 500µs duration) using a numerical implementation of the Bloch equations. The effect of field inhomogeneity was simulated by introducing an artifactual gradient (G_{error}) to the pulse sequence. This error was then corrected using the proposed method.

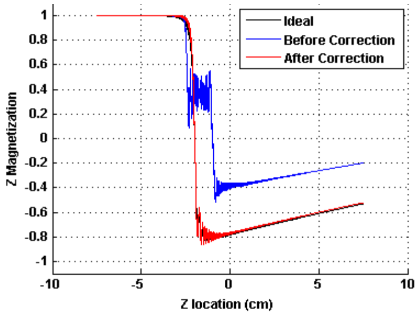

Fig.2. Simulated Mz Profile of a spin passing the pCASL tagging plane located at Z=-2 cm: Black: No field inhomogeneity; Blue: field inhomogeneity (No correction); Red: field inhomogeneity after correction (Note overlap between Red/Black).

The pCASL pulse sequence shown in Fig. 1 was implemented on a 3.0 T Signa Excite scanner (General Electric, Waukesha, WI) using the parameters described in [2]. A flow phantom (flow velocity = 30 cm/s) was scanned using a gradient echo spiral imaging sequence (TR= 3000 ms, TE = 12 ms, 1 sagittal slice, sl. thickness = 10 mm, FOV = 28 cm, tagging duration = 2000 ms, post inversion delay = 2 ms). B0 field map was also acquired separately (Fig. 3). Residual gradient moment first was set to the optimum value obtained from the simulation (η = 0.25 ; results not shown here) and then modified (η=0.07) according to Eq.2 using G_{error} estimated from the B0 field map.

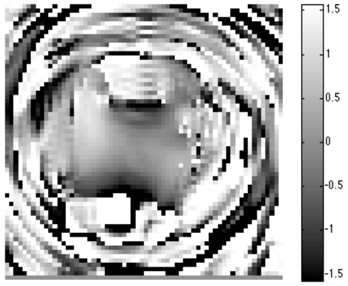

Fig. 3. B0 Field map of scanned flow phantom.

Results: The behavior of moving spin in the absence and presence of G_{error} (0.1 G/cm) (with and without correction) is shown in Fig. 2. The inversion efficiency for different values of error with and without the correction was also calculated (results not shown here) for all errors, the inversion efficiency was recovered perfectly using the proposed method (similar to Fig.2) even at very large phase errors (e.g. 0.2 G/cm). Fig 4. shows the inversion efficiency measured on the flow phantom using different residual gradient moments. The theoretical optimum and the corrected working points are shown by arrows. The proposed modification of η improved the tagging efficiency by ~40%.

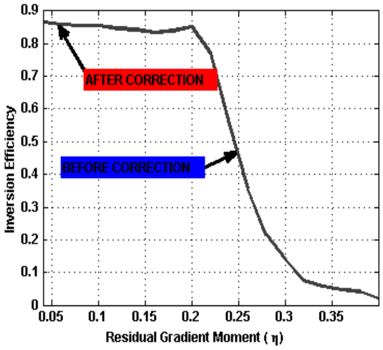

Fig. 4. Measured inversion efficiency on the flow phantom for different residual gradient moment (η) values. The working point before and after correction are shown with arrows.

Conclusion and Discussion: Tagging efficiency of pCASL can be compromised by local shifts in resonance frequency in the tagging plane. In this study we showed that estimating these field inhomogeneities using B0 field map information to update the optimum residual gradient moment of pCASL pulse sequence accordingly (Eq.2), can effectively recover the compromised tagging efficiency.

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References: [1] Wu *et al*, MRM 58:1020–1027 (2007). [2] Garcia *et al*, ISMRM, 2005.