Specialty area: Ultra-High Magnetic Field Diffusion, Perfusion & Functional MRI

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Highlights:

- Pseudo-continuous arterial spin labeling can provide the best SNR efficiency at ultra-high fields but is very sensitive to off-resonance fields at tagging location.
- Labeling RF phase and gradients parameters can be estimated robustly with a 'Prescan' procedure of 1-2 minutes to compensate for off-resonance effects.

TITLE: NIH Experience

TARGET AUDIENCE: MRI Scientists and Clinicians interested in applying arterial spin labeling (ASL) techniques at ultra-high magnetic fields

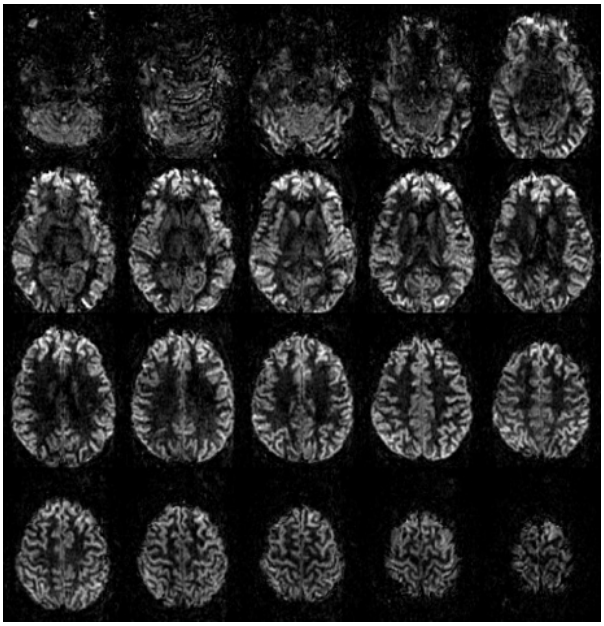
OUTCOME/OBJECTIVES: To provide a detailed account of the major efforts in applying ASL at 7T in the NIH over the past few years. This talk will address the issues and challenges in applying ASL at 7T.

PURPOSE: It is advantageous to apply ASL at high magnetic field since the signal-to-noise ratio (SNR) of ASL techniques increases with the magnetic field due to the increase in intrinsic sensitivity and longer T1 of blood. The longer T1 at higher field also allows for better compensation of long blood transit times often found in pathological cases since the lifetime of tagged blood signal is increased. In addition, the tagging duration needed to achieve the best SNR per unit time also increases with the magnetic field strength (1). However, it is challenging to realize the increased SNR with conventional ASL techniques such as pulsed and continuous ASL techniques for whole brain coverage. Since pulsed ASL relies on the physical space below the imaging area to create a sufficient tag duration, it is difficult to create a tag duration longer than 1 s with a head-size RF excitation coil at 7T in order to obtain whole brain coverage. Even at 3T with commercial body-size RF excitation, whole brain coverage with tag durations longer than 1 s is challenging due to fast flowing spins in the neck area (2). On the other hand, CASL is limited at 7T due to higher specific absorption rate unless a dedicated local neck coil (3) is used for tagging. This approach however requires additional hardware and extra setup time. Pseudo-continuous arterial spin labeling (PCASL) can provide the best SNR efficiency with a sufficiently long tag at high fields such as 7T, but it is very sensitive to off-resonance fields at the tagging location. Here a robust Prescan procedure is demonstrated to estimate the PCASL RF phase and gradients parameters required to compensate the off-resonance effects at each vessel location. The Prescan is completed in 1-2 minutes and is based on acquisition of label/control pair-wise ASL data as a function of the RF phase increment applied to the PCASL RF pulse train (4).

METHODS: In conventional PCASL, a train of short RF pulses is applied at the labeling location. In tag conditions, a phase increment, equal to the phase accumulated between two consecutive RF pulses under the non-zero mean gradient, is added to each RF pulse if the labeling plane is not at system iso-center. In control conditions, the RF and gradient waveforms are identical as in tag conditions except that an additional π phase shift is added to every other RF pulse. For 7T whole brain studies, however, the phase increment is often not adequate due to B_0 inhomogeneity, especially for tagging locations below the brain. In the proposed scheme, a short 'Prescan' is performed to determine the actual phase increment required. During the Prescan, paired tag-control data are acquired with an extra phase, equal to a fraction of 2π, added to the phase increment. The extra phase is advanced for successive tag-control pairs in 8 or 16 equal steps to cover a 2π phase cycle. If a total of 8 phases over 2π is sampled, a minimum of 16 TRs plus time for dummy scans will be required for Prescan data acquisition. The acquisition of tag-control pairs allows pair-wise subtraction to minimize slow baseline drift due to respiratory chest movement as often observed at 7T. Moreover, pair-wise subtracted Prescan signal follows a sinusoidal function with zero symmetry in signal amplitude as a function of the added phase, and thus allows robust

estimation of the actual phase increment required to compensate for field inhomogeneity effects. Additionally, low-resolution images with a short post-labeling delay (PLD) are used to maximize the SNR of the Prescan so that off-resonance effects can be estimated accurately with the shortest possible scan time. Since the purpose is to estimate the amount of tagged spins in different perfusion territories, a short PLD, therefore short inversion time, provides high SNR as long as most tagged spins arrive at the imaging voxels even though they may mostly remain intravascular.

RESULTS: The Figure at right shows 7T PCASL perfusion images with a voxel size of 1.5×1.5×3 mm^3 acquired in about 7 minutes after applying the estimated phase and gradient offsets. Images shown were pair-wise subtracted and averaged after rigid body alignment without further masking or post-processing. These data show that high quality and high SNR perfusion images can be readily obtained at 7T by using phase and gradient offsets determined through a PCASL Prescan.



DISCUSSION: The Prescan procedure is based on acquisition of a series of low-resolution PCASL tag/control images with short PLD and different phase offsets applied to the tagging RF train. These images are processed to determine the correct combination of RF phase and gradient offsets required to simultaneously compensate for off-resonance effects at all vessel tagging locations. This approach takes advantage of the periodic and symmetrical properties of tagging efficiency modulation to easily estimate the phase offsets that maximize the signal in each perfusion territory. Acquisition of Prescan data with a large voxel size and utilization of the intravascular signal by using a short PLD provide sufficient SNR for quick and accurate determination of phase offsets within 1 to 2 minutes. It should be straightforward to automate and streamline this procedure. In the current method, the off-resonance effects at all tagged vessels were compensated simultaneously by applying a phase shift to the RF pulse train and by adding in-plane gradients. The off-resonance field was not explicitly compensated for but was made similar at all tagging vessels by the added gradients so that maximum possible signal can be obtained with a single phase offset to the tagging RF pulses.

CONCLUSION: Magnetic field inhomogeneity at the tagging vessels is detrimental to PCASL tagging efficiency at 7T. Using the PCASL Prescan method to sample the phase offsets in a pair-wise fashion by observing the ASL signal of different perfusion territories with large voxels and short PLD, the proper phase offsets can be determined robustly in 1-2 minutes. This Prescan approach can be used robustly to routinely acquire high quality PCASL perfusion data of the human brain at 7T.

REFERENCES: 1. Luh WM, Wong EC, Bandettini PA. How Long to Tag? Optimal Tag Duration for Arterial Spin Labeling at 1.5T, 3T, and 7T. ISMRM 2008. p. 186. **2.** Luh WM, Bodurka J, Bandettini PA. Cardiac Phase Related Limitation on Lower Brain Perfusion Measurements Using Quantitative Pulsed Arterial Spin Labeling. HBM 2006. p. 262 TH-PM. **3.** Talagala SL, Li TQ, Merkle H, Wang S, Bodurka J, Van Gelderen P, Duyn J. Comparison of Continuous Arterial Spin Labeling Perfusion MRI at 7T and 3T. ISMRM 2008. p. 1916. **4.** Luh WM, Talagala SL, Bandettini PA. Pseudo-continuous Arterial Spin Labeling at 7T for Human Brain: Estimation and Correction for Off-resonance Effects Using a Prescan. MRM 69:402-410, 2013.