Robust Prescan for Pseudo-continuous Arterial Spin Labeling at 7T: Estimation and Correction for Off-resonance Effects

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Introduction

Pseudo-continuous arterial spin labeling (PCASL) technique provides the capability for long tagging duration in order to achieve optimal SNR efficiency at high field strength such as 7T (1). However, PCASL is very sensitive to off-resonance fields at tagging location as often observed at 7T (2). Multi-phase PCASL (3) can be applied to estimate the frequency offset at each vessel tagging location but it requires fitting to an ideal signal model and may suffer from baseline drift. Here we demonstrate a pair-wise approach with high SNR images from large voxels and short post labeling delay (PLD) to derive a robust 'prescan' procedure for estimating and correcting off-resonance effects in 1 minute.

Methods

In the proposed scheme, the incremental phase is added to each RF pulse in the labeling pulse train for both 'tag' and 'control' in a pair-wise fashion similar to traditional PCASL. This allows the pair-wise subtracted signal to follow a periodic oscillation function with zero symmetry in signal amplitude to allow for robust estimation of frequency offsets. In addition, two thick 10mm axial slices across lateral ventricles are acquired with gradient-echo EPI of 48x48 matrix, 24cm FOV and 400ms PLD to optimize SNR efficiency since intravascular tagged blood is actually beneficial to SNR. With 400ms PLD, a labeling duration of 2500ms is optimized at 7T as calculated with the General Kinetic Model (1, 4). A total of 8 or 16 phases after 4 dummy volumes were acquired with 3sec TR for a scan time of 1 min and 1min 48sec, respectively. Three ROIs composed of perfusion territory for left/right carotids and vertebral arteries were selected based on pair-wise subtracted signal among sampled phases. The average signal in each ROIs was fitted to a cosine function to determine the phase offset at each tagging vessel. To compensate for off-resonance fields at the tagging location, the measured offsets were applied in the subsequent PCASL scan with additional x/y gradients and fixed phase offset (5, 6). PCASL labeling pulse train consists of repetitive Hanning-shaped RF pulses of 800 µs long and 0.05 G amplitude with intervals of 1708 ms during a maximum/mean gradient strength of 0.8/0.06 G/cm. Imaging were performed on a whole-body 7T GE MRI scanner with a birdcage transmit coil and a multi-channel receiver coil on 6 healthy subjects under approved protocols.

Results

Fig. 1 shows the acquired low resolution images after pair-wise subtraction using 8 phases at each phase offset before (left top row) and after (left bottom row) applying only x/y gradient corrections. The raw EPI image (right top) and ROI masks (right bottom) are shown on the right. The vertebral artery territory has a different phase offset than the carotid territories without compensation. The average signal (blue line) from each ROI of three perfusion territories and the fitted curves (red line) are showed in Fig. 2. After correction, all three territories have the same frequency offset. Two 5min scans with 8 and 16 phases were also acquired to measure the fluctuation of the measurement by fitting every consecutive 8 and 16 data points, respectively. The SD over 5min scan for 8 and 16 phases is 8.0Hz(0.028π) and 3.3Hz(0.011π) for carotid territories, and 9.6Hz and 6.5Hz for vertebral territory, respectively. The CBF maps of 20 slices with 2.5x2.5x3mm^3 voxels obtained in 4min after compensation are shown in Fig. 4.

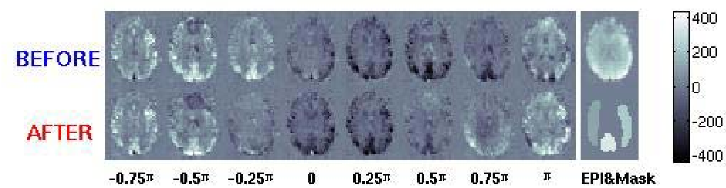

Fig. 1. Pair-wise subtracted images of 8 phases before (left top row) and after (left bottom row) compensation. One the right, EPI raw image (top) and ROI masks (bottom).

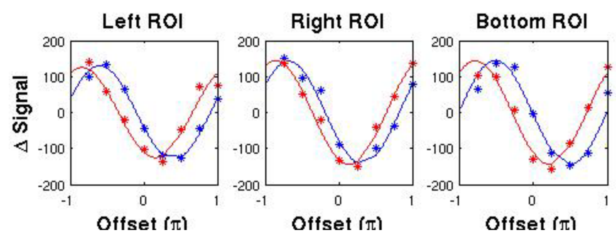

Fig. 2. Measured and fitted curves for each perfusion territory using 8 phase offsets before (blue) and after (red) applying x/y gradient compensation.

Discussion and Conclusion

Contrary to our experience at 3T where a typical high-order shimming over the whole brain is sufficient, at 7T significant off-resonance effects at tagging location are often observed. The quick prescan procedure demonstrated here is a robust and necessary step to obtain quality CBF maps at high fields. Given the fact that the tagging slab is approximately 2cm thick and the vessels are not always perpendicular throughout the tagging slab, the proposed method takes advantage of the symmetry in amplitude and phase to derive robust estimation as shown in the SD over time. With short PLD and large voxels, sufficient SNR can be obtained in less than 1min for the purpose of determining phase offsets. The intravascular signal actually provides SNR benefits here. With the proposed robust estimation and correction of frequency offsets at the tagging vessels, optimal PCASL images can be successfully obtained at 7T.

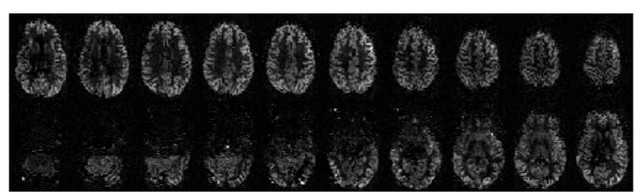

Fig. 3. PCASL images obtained in 4min at 7T with 2.5x2.5x3mm^3 resolution after compensation for off-resonance effects with x/y gradient and tagging phase offset.

References

1. Luh et al., *ISMRM*: 186 (2008). 2. Luh et al., *ISMRM*: 3339 (2008). 3. Jung et al., *ISMRM*: 622 (2009). 4. Buxton et al., *MRM* 40: 383 (1988). 5. Wong, *MRM 58*: 1086 (2007). 6. Jung et al., *ISMRM*: 1578 (2009).