

Functional perfusion imaging using pseudo-continuous ASL with low-flip-angle segmented 3D spiral readouts

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Introduction

Arterial Spin Labeling (ASL) provides quantitative and reproducible measurements of cerebral blood flow, and is an attractive method for functional MRI. Most existing ASL fMRI protocols are based on 2D multislice or 3D spin-echo, and suffer from low image signal-to-noise ratio (SNR) or through-plane blurring. 3D ASL with multi-shot (segmented) readouts can improve the SNR efficiency relative to 2D multislice, and does not suffer from T2-blurring. However, it is not yet clear how to optimize this sequence with regard to flip angle schedule and RF phase cycling scheme (gradient or RF-spoiled), and the SNR advantage over 2D multislice has not been firmly established. We characterize the temporal SNR of a segmented 3D spiral ASL sequence, and investigate the effects of RF phase-cycling scheme and flip angle schedule on the ASL time-course signal. We conclude that RF-spoiled segmented 3D spiral ASL with a cubic flip angle schedule starting at 15° can produce high-quality functional activation maps with only modest through-plane blurring.

Methods

Pulse sequence: After spin labeling and a post-inversion delay, a “snapshot” image of the magnetization is acquired with a center-out stack-of-spirals readout consisting of a train of low-flip-angle excitations, with one z phase-encode being acquired after each excitation (Fig. 1). For each kz plane, a 2D spiral covering the full kx-ky space is sampled after every RF excitation, and a total of 24 kz-encodes were acquired.

Simulations of kz-blurring filter: During the multishot 3D acquisition, the signal level can change from shot-to-shot due to both (1) incomplete T1 recovery and (2) the

kinetics of the labeled spins in the tissue. This results in a weighting kernel of the data along the kz dimension. We performed numerical Bloch calculations of the kz-blurring kernels resulting from either relaxation or inflow effects. A flat weighting due to T1 recovery alone can be achieved with the Ernst-based flip angle schedule in [1], but requires low flip angles which lowers the SNR. We allowed the flip angle to vary from shot-to-shot according to several different schedules (constant, linear, quadratic, cubic), in order to identify a better tradeoff between z-blur and SNR. Polynomial flip angle schedules have the additional advantage that they are simple to calculate and implement on the scanner.

Volunteer Studies I – Baseline ASL measurements: In the first set of volunteer studies, we (i) compared the performance of 2D multislice and 3D ASL, and (ii) investigated the effect of different RF phase-cycling schemes on the temporal SNR of the baseline ASL signal (constant, random, and RF-spoiled). All human volunteer experiments were performed on a GE Signa 3T scanner using a quadrature birdcage transmit-receive headcoil.

Volunteer Studies II – Visual fMRI experiments: In the second set of volunteer studies, three subjects were scanned using the proposed 3D spiral pCASL acquisition scheme while undergoing a visual stimulation paradigm. The acquisition used RF spoiling with linear phase increment of 117° per degree, and a cubic flip angle schedule with starting angle 15° . The inversion tagging duration was 1800 ms and the post inversion delay was 1500 ms, leaving 700 ms for acquisition of the k-space data (30 ms per plane). The subjects were stimulated visually with a circular checkerboard pattern flashing at 8 Hz for 30 seconds followed by 30 seconds of no stimulation, which was repeated 5 times.

Results: Our simulations (not shown) indicate that a starting flip angle of 15° and a cubic flip-angle schedule produces a relatively flat weighting across most of kz-space, and was therefore used in our experiments. kz-filtering due to blood inflow is relatively modest. Figure 2 shows that segmented 3D ASL with 15° starting flip angle and cubic schedule produces a

roughly 2-fold tSNR increase relative to 2D multislice, with no noticeable blurring along z. Figure 3 shows that RF-spoiling achieves the same ASL signal as constant/random RF phase cycling, but reduces the temporal variance significantly. Figure 4 demonstrates good visual activation in a volunteer using the proposed optimal scheme.

Discussion and Conclusions: Segmented 3D spiral ASL can improve temporal SNR two-fold relative to 2D multislice when using a simple polynomial (cubic) flip angle schedule, and RF-spoiling. Functional MRI results using the proposed segmented 3D ASL protocol show excellent activation in the visual cortex.

References: [1] Gai et al. JMIR 2011

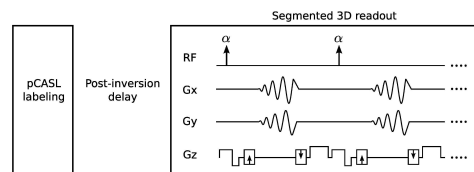


Figure 1. 3D ASL pulse sequence diagram.

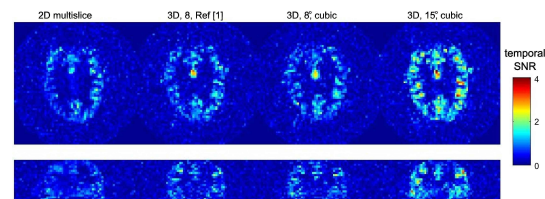


Figure 2. Temporal SNR of 2D and 3D ASL.

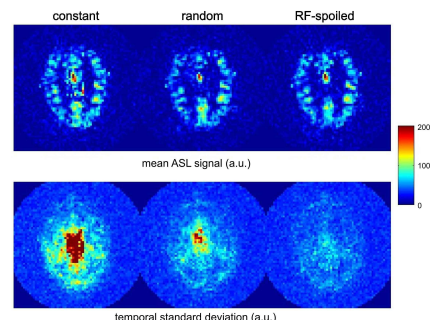


Figure 3. Effect of different RF phase-cycling schemes on temporal SNR of the ASL signal.

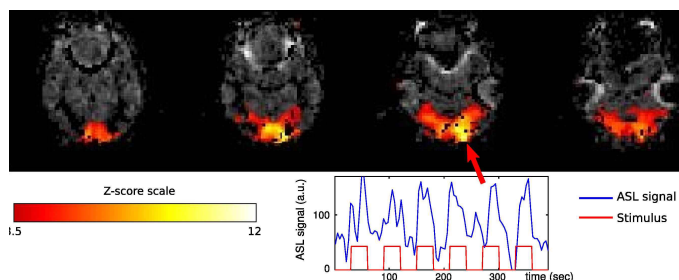


Figure 4. Functional MRI results obtained with the proposed optimized 3D pCASL sequence.