

Aliasing, Off-Resonance Saturation, and Residual Signal Analysis for PCASL

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Introduction: Pulsed continuous arterial spin labeling (PCASL) was developed to provide improved label and control efficiencies and reduced RF dose compared to multi-slice CASL with a double adiabatic inversion (DAI) control, thus allowing PCASL to be used at high fields (1, 2). However, PCASL is susceptible to label and control plane aliasing and other artifacts related to the design of its label and control irradiations (1, 3). In this study, the aliasing, off-resonance saturation, and residual signals for PCASL were characterized to identify the optimal operational parameters for PCASL.

Methods: A cylindrical phantom filled with 2% (weight/volume) agar in distilled water ($T_1 = 2.5$ s, $T_2 = 0.2$ s) was placed inside a Siemens 1.5 T Avanto MRI using the body coil (for transmission) and 4-element receive-only phased array head coil. For the off-resonance and aliasing experiments, coronal single-shot echo planar images (EPI) of the phantom were obtained using a PCASL sequence with either the label or control turned on (the equilibrium magnetization M_0 was acquired from the alternating acquisitions). PCASL parameters were: tag duration: 3 s, tag delay: 0 s, tag angle: 23° (i.e., $B_{1max} = 7.4$ μ T), and 10 repetitions. EPI parameters were: TR: 10 s, TE: 24 ms, FOV: 150 mm, Matrix: 64x64, single slice, 1800 Hz/pixel. G_{avg} was fixed at 0.8 mT/m while G_{max} was varied from 1 to 7 mT/m. The normalized signal (M_L/M_0), was calculated. The tag offset was placed -7 cm from the center of the imaging volume.

For the residual signal measurements, G_{max} was varied from 5-7 mT/m and the tag angle was varied from 0 to 56° (i.e., $B_{1max} = 18$ μ T). PCASL parameters were: tag duration: 3 s, tag delay: 0 s, tag offset: -10 cm. EPI parameters were: TR: 10 s, TE: 38 ms, FOV: 125 mm, Matrix: 64x64, single coronal slice, 1800 Hz/pixel, and 50 repetitions. The normalized residual signals were calculated as $(M_c - M_L)/M_c$ from the label (M_L) and control (M_c) images.

Results & Discussion: The results of the off-resonance study show a decrease in signal as the distance (or frequency offset) from the label plane is decreased. Aliased labeling planes were present for $G_{max} < 4$ mT/m (Fig. 1). Aliased control planes were observed for all values of G_{max} (Fig. 2) with the primary peak occurring at 12 mm, dictated by the 2.4 ms period (T_c) of the phase-modulated control and G_{avg} , i.e., $2\pi/(\gamma G_{avg} T_c)$. The aliased planes for both label and control were spaced 24 mm apart as dictated by the 1.2 ms gradient and label period (T_l), i.e., $2\pi/(\gamma G_{avg} T_l)$. In general, the amplitude of aliasing increased with B_1 (not shown) and decreased with G_{max} . The distal aliasing planes decreased as G_{max} was increased.

The phase modulation of the control splits and offsets the primary from the labeling plane, as with DAI. DAI uses a control amplitude $\sqrt{2}$ greater than the label to match off-resonance saturation while they have the same amplitude in PCASL. Fortunately, the low residual signal (control – label) in PCASL suggests that the label and control off-resonance features are well matched within the imaging volume (outside of the labeling region) and contribute only a small error to the resulting perfusion signal especially for high G_{max} (Fig. 3).

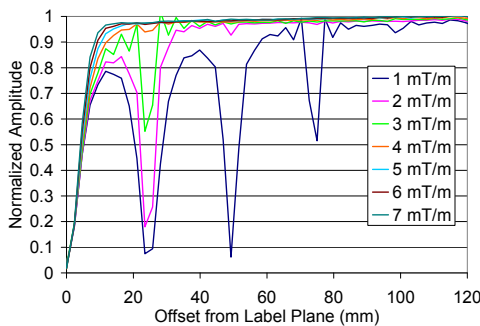


Figure 1: Normalized label signal vs. the offset in mm from the labeling plane for $G_{max} = 1 - 7$ mT/m. Aliasing is significant for $G_{max} < 4$ mT/m.

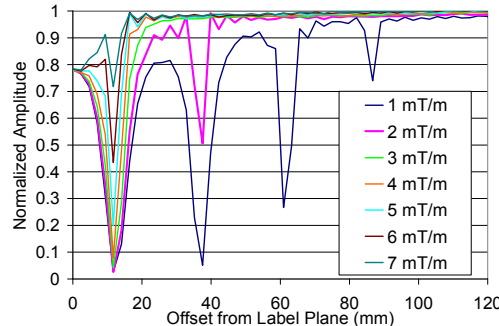


Figure 2: Normalized control signal vs. the offset in mm from the labeling plane for $G_{max} = 1 - 7$ mT/m. Aliasing decreases with increasing G_{max} .

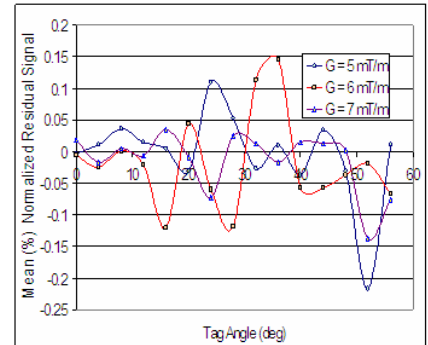


Figure 3: Residual signal averaged over the coronal slice versus tag angle. Note: $B_{1max} = 0.2$ μ T*tag angle (degrees).

References: 1). Dai W et al, MRM, 60:1488-1497 (2008). 2). D.C. Alsop & J.A. Detre. Radiology 208(2):410-416 (1998). 3). W-C Wu et al., MRM 58: 1020-1027 (2007).