Phase Modeling in Arterial Spin Labeling FMRI

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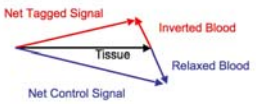
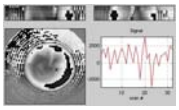
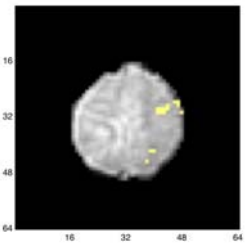
Introduction: Complex-valued image analysis boosts the sensitivity and specificity of BOLD contrast [2,4] and ASL [3] FMRI time series. We explore the physical basis for the ASL signal phase changes.
Figure 1 illustrates a simple vector model for the ASL signal. Perfusion is calculated from the change in the net magnetization vector due to the tagged inflowing spins.
Phase accrual is determined by the motion of the spins, applied gradients, and off-resonance effects while in the transverse plane. The state of the inflowing arterial spins alters the net magnetization vector's magnitude and phase. If the imaging portion of the pulse sequence is T2*-weighted, BOLD induced phase changes [2] also modulate the time course.



Methods: Simulation: The magnetization vector of a grey matter voxel in a continuous ASL experiment was simulated. The voxel consisted of two compartments: capillary and tissue. Capillary spins acquired phase relative to tissue spins during imaging. A first order dynamic model [1] was used to predict the concentration of tagged spins in the capillaries and the tissue. The net magnetization was calculated.
Phantom: A simple flow phantom was constructed to mimic the behavior of fast and slow flowing spins. The phantom was imaged using a pCASL [5,6] sequence followed by a spiral acquisition sequence fitted with flow crushing gradients of varying amplitude. The average magnitude and phase of the signal across the phantom were measured at different flow velocities (6, 12, 18 cm/s) and flow crusher gradient strengths (0–4 G/cm).
Human: Two human subjects were scanned using a pCASL sequence while performing three cycles of a finger opposition task (50 s rest–50 s active). Activation maps were calculated by estimating magnitude only, phase only and complex models [2] of the unsubtracted signal using a generalized least squares approach [7].

Results: Simulation: The simulations showed increasing phase difference between net tagged and control images as a function of phase accrual by the moving spins and capillary fraction.
Phantom: Approximately PI radians phase fluctuation was observed in the "artery" between control and tagged images (Figure 2). This difference decreased monotonically with increasing gradients as the fast flowing spins signal was crushed.
The net phase change over the entire slice ("tissue") was much more subtle (0–0.22 rad). The phase changes increased with the applied gradient during the imaging sequence.
Human: Activation in motor and visual cortices was observed using all three models. Significant changes in phase were observed in activated regions (Figure 3) implying that as perfusion increased, so did the phase difference between tagged and control images.





Conclusions: Our data indicate phase difference between tagged and control ASL images. This could arise from the opposing phase contributions of the perfusing water during the inverted and control cases. Phase information into account increases specificity of the ASL model.

References: [1] Buxton, 1998. MRM 40, 383-396. [2] Rowe, 2005. NIMG 25, 1310-1324. [3] Rowe, Proc ISMRM, 15:1422. [4] Rowe, 2004. NIMG 23, 1078-1092. [5] Wu, 2007. MRM 58, 1020-1027. [6] Garcia, 2005. Proc ISMRM, 37. [7] Mumford, 2006. NIMG 33, 103-114.

Category: *Modeling and Analysis*
Sub-Category: *Univariate modeling, linear & nonlinear*