Pseudo-continuous Flow Driven Adiabatic Inversion for Arterial Spin Labeling

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Introduction: Flow driven adiabatic inversion (1) has been used to continuously label arterial blood for arterial spin labeling perfusion and angiography studies. Continuous ASL (2) produces the largest ASL signal change, potentially the greatest SNR, and can be advantageous for other reasons as well. Continuous labeling has drawbacks, however. It requires near continuous wave RF transmit capability that is often not available on imagers. Multi-slice implementations of continuous ASL (3-7) suffer from signal attenuation, velocity sensitivity or imperfect static tissue subtraction or require special hardware and labeling geometries. Here we propose and implement a method for flow driven adiabatic inversion that employs repeated RF pulses rather than continuous RF. This method potentially overcomes a number of the limitations of previous implementations of continuous ASL.

Theory: It has previously been shown that repeated application of RF pulses support a steady state in the absence of T1 and T2 decay (8). Magnetization oriented along this steady state direction at the midpoint between two pulses will return to this orientation after the next pulse. The angle of the steady state is determined by the phase shift experienced during the time between pulses, ϕ, and the flip angle of the RF, α. If the phase shift or phase is slowly varied, such that the change in the steady state angle is slow, then the magnetization tends to follow the steady state solution.

$$M_z = \frac{\pm M_0 \sin\alpha \sin\frac{\phi}{2}}{\sqrt{(1-\cos\alpha)^2 + \sin^2\alpha \sin^2\frac{\phi}{2}}}$$

The z magnetization for the steady state solution is given by the equation to the left and its value is plotted for a 22.5° flip angle, figure 1. Magnetization with near zero phase shift will be in the transverse plane while magnetization with 180° phase shift will be nearly along the z axis. Gradually changing the phase shift from –180° to 180° will cause an inversion. Hence the behavior of this pulsed experiment is very similar to the continuous irradiation used for flow driven adiabatic inversion except that the solution is periodic in ϕ, for the pulsed solution. The periodicity can be eliminated, however, if the RF pulse is sufficiently selective such that the RF is negligible at frequencies corresponding to the other inversion planes.

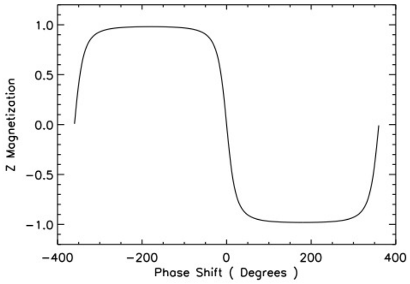

Figure 1: The steady state solution for Mz with repeated pulses as a function of the phase shift between pulses.

Using these concepts one can design a flow driven adiabatic inversion strategy using pulsed RF and gradients. In the pulse sequence of figure 2, selective RF pulses are applied at equal spacing. For the control, we choose to maintain a 180° phase shift for all positions. This is achieved by alternating the sign of the RF from pulse to pulse and assuring there is zero average gradient between each pair of pulses. The control is shown with dashed lines in figure 2 whenever it deviates from the label. For the label, we add some imbalance in the gradients to causes a position dependent phase shift. The average gradient over the time between pulses should be comparable to the value used for continuous flow driven adiabatic inversion and the average B1 over the same time interval should be comparable to the continuous case.

Methods: The sequence of figure 2 was implemented on a GE 3 Tesla scanner. 500μs Hanning window shaped pulses were used for the RF, a gradient amplitude of 0.6 G, an average B1 of 20 mG, and an average gradient of 0.15 G were employed for the labeling. The labeling was performed prior to image acquisition with a gradient echo echoplanar image acquisition. A post-labeling delay of 1.2 s and a labeling duration of 1.5 seconds were selected. Studies were performed in 2 normal volunteers following a protocol approved by our institution's human subject study review board. Imaging was performed with labeling applied below the imaged slab and also with the labeling above the head, in order to assess subtraction errors.

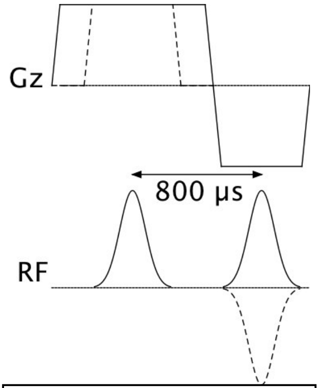

Figure 2: One cycle of the repeated pattern of RF and gradient pulses used for pseudocontinuous ASL. Where the control sequence deviates from the label is shown with a dashed line.

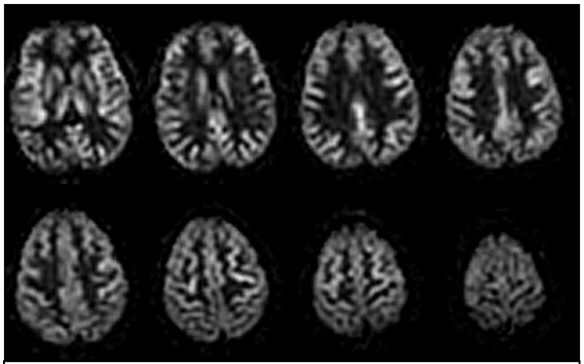

Figure 3: Example perfusion images acquired using the pseudocontinuous inversion labeling strategy.

Results: Difference images showed clear signatures of perfusion, figure 3, with higher perfusion in gray matter than white matter. When labeling was performed above the brain, no measurable signal was observed.

Discussion: Pseudo-continuous flow driven adiabatic inversion was successful at both labeling arterial spins and controlling for off-resonance errors. Further work will assess the relative efficiency of this and other approaches to continuous ASL.

References: 1. Dixon et al. MRM. 3:454-62 (1986) **2.** Williams et. al. Proc. NAS. 89:212-16 (1992) **3.** Alsop et. al. Radiology. 208: 140-16 (1998) **4.** Talagala et. al. ISMRM 1998 #381 **5.** Alsop et. al. ISMRM 2001 #1562 **6.** Silva et. al. MRM. 33(2):209-14 (1995) **7.** Zaharchuck et. al. MRM. 41(6):1093-8 (1999) **8.** Alsop. MRM. 37:176-84 (1997).