Improvements to Control Scan of ASL-perfusion MRI by Improving Null Pulse for Use with the Repeated Shallow Flip Angle Excitations

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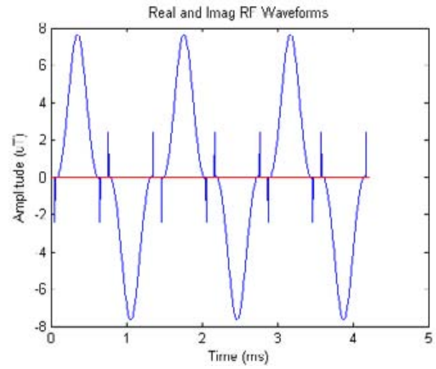
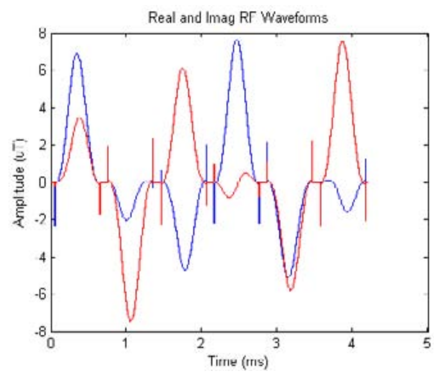
Introduction: Arterial spin labeling (ASL) MRI generates perfusion images by subtracting a labeled image from a unlabeled (control) image. Recently, pseudo-continuous flow driven spin inversion based on repeated shallow flip angle radiofrequency (RF) pulses was proposed for ASL perfusion MRI [1]. For the labeling scan, the series of shallow flip angle RF pulses was applied at constant phase in presence of alternating bipolar slice-selective gradients, yielding effectively spin inversion. For the control scan, the same series of shallow flip angle RF pulses together with bipolar gradients was repeated, but with every other pulse inverted to act as a null pulse retaining longitudinal magnetization (Mz) of the spins [2]. Although the null pulse design worked well for static spins, simulations with MATPULSE [3] showed that the performance quickly degraded for flowing spins, thus reducing the sensitivity of the method to detect perfusion. Previous shallow flip angle flow excitation studies showed that undesirable Mz may occur with increasing flow velocity of spins, prolonging pulse duration, increasing offset frequency, or increasing RF magnitude [4]. Therefore, the overall goal of this study was to develop a pulse scheme for the control scans which completely avoid excitation of inflowing blood during the control scan. Specially the aims were 1) to improve the immunity of the null pulse to flow velocity and off-resonance conditions and 2) to investigate the use of this new null pulse for ASL across a variety of conditions of blood velocity, resonance offset, and RF strength.

Fig. 1. Proposed null pulse for control scan of ASL based on repeated shallow flip angle.
A. Segment of the original null RF pulse (real=blue and imaginary=red).



B. Segment of the proposed and rotated null RF pulse.

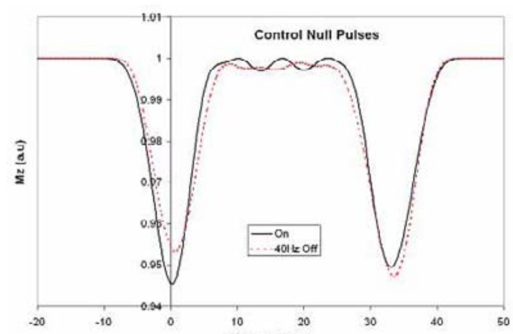


Methods: *Proposed phase-modulated null pulse for control scan*: Fig. 1 shows a segment of the original (Fig. 1A) and proposed (Fig. 1B) null RF pulses in real (blue) and imaginary (red) components with the repeated shallow flip angle excitation. In addition to a frequency sweep across the entire pulse duration, every other pulse is phase shifted by 180 degree. A flip angle for each RF pulse of 30 degrees and a total duration of 85 ms were used for the simulations shown here. Furthermore, bipolar slice-selective gradients with equal gradient amplitudes (10 mT/m) and durations (0.6ms) were used. The 30-degree pulse was based on a Shinnar-LeRoux (SLR) pulse generated with MATPULSE.
Flow velocity and off-resonance effects: The spin labeling version of the pulse as originally proposed by the Garcia [1] was also based on a series of 30-degree flip angle SLR pulse. The area of the positive slice-selective gradient was 15% larger than that of the negative slice-selective gradient. The control pulse was used with the proposed method in here. Simulations for both labeling and control were performed with MATPULSE with flow velocity varying from 20cm/sec to 60 cm/sec, and with off-resonance varying from 0 Hz to 40 Hz. Inversion and null profiles were evaluated for labeling and control pulses, respectively.

Results: Fig 2 shows the simulation result of spins flowing at 40cm/sec to application of the new null pulse under on-resonance (Black) and 40Hz off-resonance (Red) conditions. As shown in the figure, residual Mz of the proposed null pulse is minor (about 6% of Mz). The proposed method worked well for off-resonance conditions up to +/- 40 Hz. The method also worked across 20 to 60 cm/sec flow velocities, which is the typical range for blood velocity in the vertebrae and carotid arteries.

The labeling pulse had good inversion profiles over this same range of parameters although the inversion profile was slightly degraded with off-resonance. In addition, both pulses worked well over an RF amplitude range approaching a factor of 2.

Fig. 2. Simulation of longitudinal magnetization (Mz) of spins flowing at a velocity of 40 cm/sec after applying the proposed null pulses, Both on- (black) and 40 Hz off-resonance (red) conditions are shown. Note that residual Mz is less than 6%.



Discussion: and Conclusion: The simulations show that a refinement of RF phase improved stability of the null pulse for the control scan of ASL with respect to flow velocity and off-resonance effects. In principle, the new null pulse design also works for other pulses such as Hanning-filtered Sinc pulses, hyperbolic secant (HS) pulses, and Gaussian shaped pulses. Hanning-filtered Sinc pulse yielded similar results than SLR pulse. However, the performance degraded when HS and Gaussian pulses were used.

In conclusion, the new null pulse, when used in the control scan of ASL, should improve pseudo-CASL based on repeated small flip angle excitations by eliminating excitation of inflowing blood during the control scan. This improvement should increase the sensitivity of ASL perfusion MRI

References: 1. Garcia et. al, 13th ISMRM 13, p37, 2005; 2. Matson GB and Schleich T, 9th ISMRM, p687, 2001; 3. Matson GB, MRI 1994 12(8), 1205-1225; 4. Lewis, D.P., et. al. MRI 1998. 16(8): p. 907-16.