Wedge-shaped slice-selective adiabatic inversion pulse for bolus temporal width control in pulsed arterial spin labeling

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Target Audience: Researchers who are interested in adiabatic pulse design and its application, such as arterial spin labeling.

Purpose: In Turbo-QUASAR [1], Petersen and colleagues proposed a strategy to improve the temporal signal-to-noise (tSNR) of arterial spin labeling (ASL) experiments by repeatedly applying pulsed labeling pulses in between Look-Locker readouts. This strategy works optimally when the temporal width of the tagged boluses matches the inter-pulse spacing. However, because the feeding arteries will generally have different velocities and geometries, this cannot be accomplished using a conventional labeling slab. In order to remedy this, we propose a novel labeling strategy by creating a wedge-shaped (WS) inversion slab, with the thickness at different arteries matching their velocities, aiming for an equal temporal bolus width that matches the inter-pulse spacing in different feeding arteries, therefore optimized tSNR.

Methods: The WS inversion pulse uses a combination of conventional slice-selective adiabatic fast passage (SS-AFP) and additional in-plane gradient pulses. In conventional SS-AFP, a constant gradient pulse accompanies the AFP radiofrequency (RF) pulse for slice-selection, resulting in an excitation/inversion slab with a constant thickness. In the frequency-modulated frame [2], the frequency of the AFP RF pulse moves from one side to the other within its frequency sweeping range. In the presence of a gradient, the "on-resonance" frequency determines a moving plane in space where spins are rapidly perturbed. With in-plane gradient pulses, the movement of the "on-resonance" plane can be modulated differently in space, resulting in a modified shape of the excitation/inversion slab. Various gradient waveforms can be utilized, however, given a predesigned SS-AFP pulse, it is important to minimize the reduction in adiabaticity due to the addition of in-plane gradient pulses. A simple solution is to use the frequency sweeping waveform of the AFP pulse. This way, the frequency-sweeping pattern and the inversion profile at any in-plane location is a linearly scaled version of that without the in-plane gradient. Given that the adiabatic condition is satisfied at the location with the largest designated thickness, all other locations with smaller thickness have higher adiabaticity.

Fig. 1 shows an example of WS inversion using an SS hyperbolic secant (HS) pulse with sech/tanh modulation in amplitude and frequency accordingly [2]. The in-plane gradient takes the frequency modulation in HS pulse: $G_x(t) = G_{x,max} \cdot \tanh(\beta t)$, where β is the truncation factor. Bloch simulation was done to examine the performance of WS inversion using an HS pulse, shown in **Fig. 1**, where the G_x was offset to maintain a horizontal upper boundary, which is preferred in pulsed ASL (PASL) labeling. The WS inversion pulse was implemented on a GE MR750 3T scanner, and compared with a conventional SS HS inversion pulse on a gel phantom. Images were collected immediately after application of the inversion pulses. Reference images without inversion were also collected.

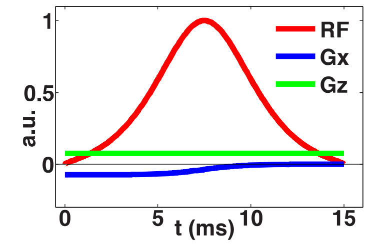

Fig. 1. Diagram of the wedge-shaped SS-AFP pulse.

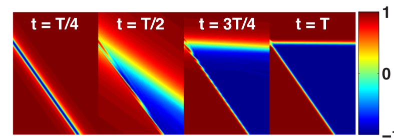

Fig. 2. Longitudinal magnetization (M_z) evolution during the WS inversion.

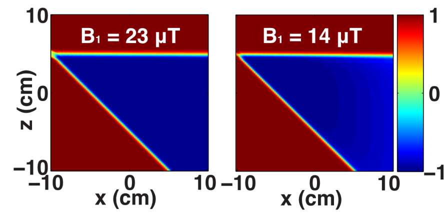

Fig. 3. M_z after the WS inversion at two B_1 levels.

Results: The evolution of the longitudinal magnetization (M_z) and the movement of the "on-resonance" plane during the WS inversion pulse are shown in **Fig. 2**, where T is the duration of the pulse. The final longitudinal M_z after application of WS inversion at two B_1 levels is shown in **Fig. 3**. A smooth inversion profile along the z direction was achieved at all positions along the x direction when the adiabatic condition was well met. When B_1 decreased the overall adiabaticity was reduced. However, at locations where the designated inversion thickness is smaller, the adiabaticity was better preserved and sufficiently high as expected. The M_z measured after application of the conventional and WS inversion pulses was normalized to that measured without inversion, and shown in **Fig. 4**, with the M_z profile along depicted paths shown at the bottom.

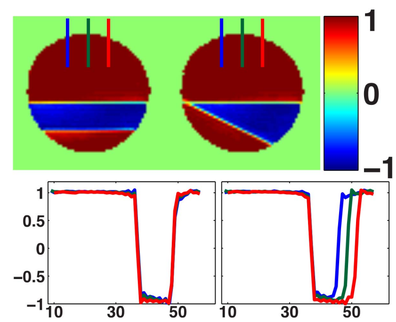

Fig. 4. Normalized M_z measured after a conventional and a WS inversion, signal profiles shown below.

Discussion: The combined gradient at the beginning and the end of the AFP determines the two boundaries of the selected slab. Adding an offset to the in-plane gradient pulse can tilt both boundaries. In **Fig. 4**, slightly rounded corners were observed on the profiles measured using WS inversion, especially on the tilted side. This may be due to reduced adiabaticity at the beginning of the pulse, where the amplitude of G_x was high. In controlling the bolus temporal width in PASL, the tilted edge of the inversion band can be rotated to fit up to three different inversion thicknesses at different locations, sufficient for perfusion measurement in brain, where left and right internal carotid and the vertebrobasilar arteries are the main feeding arteries. The modification demonstrated in the inversion example is also applicable to SS adiabatic excitation.

Conclusions: A novel method to generate a wedge-shaped inversion slab using a combination of conventional SS AFP and in-plane gradient pulses is introduced. It can potentially be used in PASL experiments to maximize its tSNR.

References: 1. Petersen. ISMRM, 2013, p2146; 2. Garwood. JMR 153(2001), p155. **Acknowledgements:** NIH-NS036722.