

Near-Contiguous Spin Echo Imaging Using Matched-Phase RF and its Application in Velocity-Selective Arterial Spin Labeling

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INTRODUCTION

Potential crosstalk between slices limits the minimal feasible slice spacing in spin-echo imaging, and this limits the number of slices that can be acquired for each scan. Here we show that a matched-phase 90°-180° pulse pair [1] can be used to achieve slice profiles that enable smaller slice spacing without disturbing adjacent slices. We demonstrate more compact slice acquisition for cerebral blood flow (CBF) imaging using velocity-selective arterial spin labeling (VSASL) [2] based on this improved slice profile.

METHODS

Pulse design: Unlike conventional RF pulses, 90° and 180° matched-phase RF pulses can have nonlinear phases. These phases are matched to each other such that a linear phase is obtained at the end of the pulse pair. This creates more flexibility to RF design, which can be utilized to sharpen slice profile, reduce the echo time (TE), or lower peak B1 for a given RF pulse duration. We designed matched-phase RF pulses using Shinnar-Le Roux algorithm with $\beta_{90}(z) = \beta_{180}^2(z)$ [3]. Beginning with a minimum-phase β_{180} and repeating the design for all root-flipped combinations of passband roots, we found a pulse pair with close-to minimum peak-B1. Furthermore, we truncated the 90° pulse by 25% in time without much signal loss, to avoid increasing TE. **Signal measurement:** Six axial slices with linear ordering were imaged in a brain without ASL preparation to measure intrinsic signal intensity in each slice (total imaging time = 50 ms x 6 = 300 ms). Except for the first slice, all slices are prone to signal reduction since the initial Mz is perturbed by previous slice excitation. We measured this signal reduction rate in 3 volunteers, using reference signal intensity measured with 30 s of recovery time between slices. **VSASL signal stability:** VSASL with 30 pairs of tagged/control images was performed and CBF was measured in 5 volunteers. To estimate ASL signal stability, we calculated temporal standard deviation (SD) of CBF time series. **Experimental setup:** VSASL is comprised of velocity-selective tagging ($V_c = 2$ cm/s) and 2D single-shot spiral spin-echo imaging with TR = 5 s, TE = 16 ms, TI = 1630 ms, 64 x 64 matrix size, FOV = 220 cm, and 6 mm slice thickness. All imaging was performed on a GE MR750 3.0 T scanner.

RESULTS AND DISCUSSION

Pulse design: Figure 1 shows the designed matched-phase RF pulses and slice profiles measured in a phantom using matched-phase RF as well as conventional RF. While Mxy profiles are similar, Mz profiles clearly indicate that the conventional pulse pair disturbs the spins beyond excited Mxy region. This is because the inversion slab is twice as large as the imaging slice to refocus all spins excited by 90° pulse. **Signal measurement:** When slice spacing was reduced from 6 mm to 2 mm, the mean reduction rate in slices (except the first slice) increased from 4±0.2% to 23±0.9% using conventional pulses, but only increased from 3±0.5% to 5±0.5% using the matched-phase RF (see Figure 2 top). **VSASL signal stability:** When slice spacing was reduced from 6 mm to 2 mm, the temporal SD doubled from 27±2 ml/100g/min to 51±7 ml/100g/min using conventional RF pulses, but was maintained at 27±3 ml/100g/min using matched-phase RF (see Figure 2 bottom). While signal reduction with Mz perturbation is logically straightforward, how it increases the temporal noise is uncertain. Because the temporal SD of CBF was much higher in periphery of the brain with conventional RF, we presume that the Mz perturbation is sensitive to head motion or off-resonance due to time-varying susceptibility. This will be investigated in future work. Figure 3 contains CBF maps and temporal SD maps acquired using conventional RF and matched-phase RF from the same slice in a healthy volunteer.

CONCLUSION

Minimum-peak-RF matched-phase pulses were successfully used in VSASL to reduce the slice spacing to one third of the slice thickness without compromising SNR or ASL signal stability.

REFERENCES [1] Balchandani *et al*, MRM 62:183, 2009. [2] Wong *et al*, MRM 55: 1334, 2006. [3] Pauly *et al*, IEEE TMI 10: 53, 1991.

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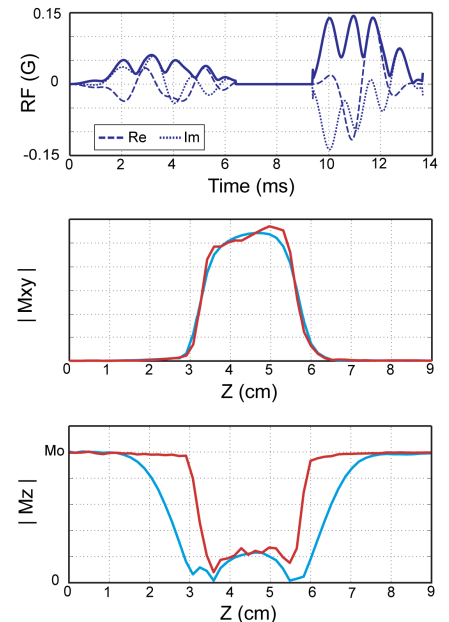


Figure 1. Top: Matched-phase RF pulse pair with minimum peak B1, obtained by root-flipping the $B(z)$ polynomial from a minimum-phase design and truncating the 90° pulse. **Middle & Bottom:** Mxy and Mz profiles measured in a phantom using conventional RF (blue) and matched-phase RF (red) with a nominal slice thickness 2.4 cm.

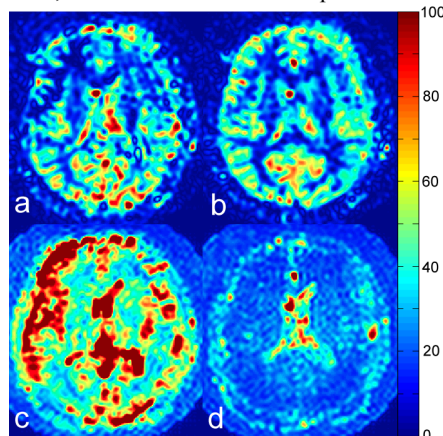


Figure 3. a: CBF with conventional RF. **b:** CBF with matched-phase RF. **c:** Temporal SD with conventional RF. **d:** Temporal SD with matched-phase RF. All are from the same slice selected from multislice images with 6 skip 2 (units of ml/100g/min).

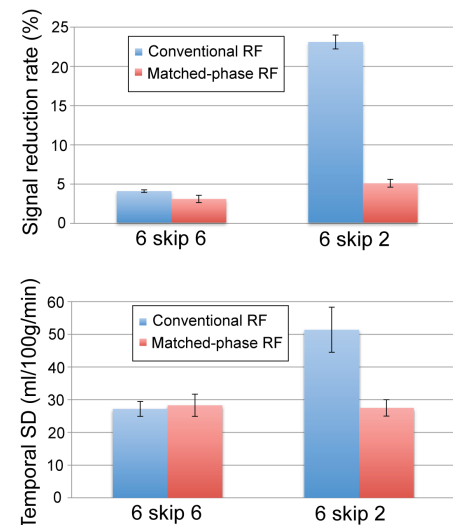


Figure 2. Comparison of conventional RF and matched-phase RF in 6 skip 6 and 6 skip 2. Top: Signal reduction due to disturbance from previous slice excitation measured in 3 volunteers. **Bottom:** Temporal SD of CBF time series measured in 5 volunteers.