Improved Multislice Cerebral Blood Flow Imaging Using Velocity-Selective Arterial Spin Labeling

Zungho Zun[1], Brian A. Hargreaves[1], and Greg Zaharchuk[1]
[1]*Radiology, Stanford University, Stanford, CA, United States*

INTRODUCTION Velocity-selective arterial spin labeling (VSASL) is a promising method for measuring tissue blood flow in presence of slow or delayed flow, and has been nicely compared with pulsed ASL [1]. In this study, we demonstrate improvement in VSASL particularly for multislice cerebral blood flow (CBF) imaging. We improved ASL signal stability using stimulated echo (STE) removal and timing optimization, and reduced the slice spacing to achieve near-contiguous multislice using improved slice profile. We also used off-resonance correction to minimize blurring from the spiral trajectory. These changes dramatically improve the robustness of multislice VSASL CBF imaging, which is critical for clinical imaging.

METHODS STE removal: STE can be generated by consecutive RF excitations, each followed by a gradient spoiler with consistent area. In Look-Locker ASL imaging, STE's are formed by multiple image acquisition performed on the same slice, and can be removed using a suitable set of spoilers [2]. Here we claim that STE can also arise from RF excitations of different slices because each slice profile is imperfect. To remove this STE, we used a similar variable spoiler scheme where the axis and the area of the gradients are varied for each slice.

Slice profile improvement: Spin-echo imaging using conventional RF pulses requires minimum slice spacing to avoid disturbing spins in the adjacent slices. This limits the number of slices that can be acquired for each scan. We used Shinnar-Le Roux (SLR) algorithm [3] to design a matched-phase RF pulse pair [4] by root-flipping the B(z) polynomial from a minimum-phase design and truncating the 90° pulse.

Timing optimization: Unlike other ASL techniques, pre-saturation in VSASL is required to be nonselective to avoid confounding the absolute quantification [1]. Longer time between pre-saturation and tagging increases ASL signal but reduces time efficiency [5]. Based on this tradeoff, the optimal TR can be found using simulation (see Figure 1). The calculated SNR efficiency gain from initial TR (3 s) to optimal TR was 20% for single slice imaging, and increased up to 53% for 10 slices (imaging time per slice = 50 ms). For SNR efficiency comparison, VSASL was performed with 3 ms TR/50 tag-control pairs and 5 ms TR/30 tag-control pairs in vivo, maintaining overall imaging time at approximately 5 min.

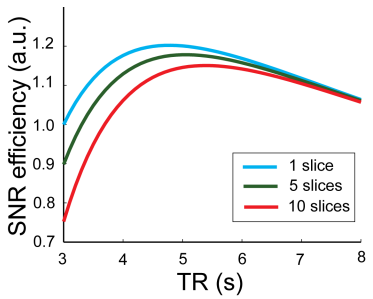

Figure 1. *Calculated SNR efficiency as a function of TR for different number of slices.*

Off-resonance correction: Off-resonance maps were acquired using two different TE's in the first two repetitions (ΔTE = 2 ms), and were used to compensate for off-resonance during spiral readout.

Experimental setup: VSASL sequence was composed of twice-refocused spin echo for tagging (V_c = 2 cm/s) and single-shot 2D spin echo spiral imaging as an image acquisition with 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 ASL signal stability is characterized by temporal standard deviation (SD) of CBF time series [1]. Using TR optimization alone, temporal SD was reduced by 34% with 5 slices in 3 volunteers. Off-resonance correction led to no significant change in temporal SD in 10 subjects (p = 0.202), but reduced blurring significantly in individual images (not shown). Because STE removal and slice profile improvement can have interaction effect, we performed 8 combinations of VSASL in 5 volunteers as shown in Figure 2. For 6 mm slice thickness and 6 mm spacing, the variable spoiler reduced temporal SD by 27% while matched-phase RF slightly increased temporal SD (7%). For 6 mm slice thickness and 2 mm spacing, only the combination of matched-phase RF and variable spoiler achieved temporal SD comparable to that using variable spoiler in 6 skip 6. Figure 3 compares CBF maps acquired with and without all aforementioned improvements in one representative volunteer.

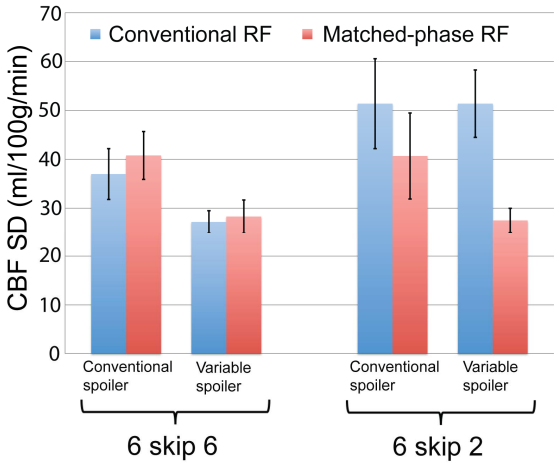

Figure 2. *Comparison of temporal SD of CBF using conventional/variable spoilers and conventional/matched-phase RF.pulses using slice/skip configurations of 6 skip 6 and 6 skip 2. The combination of matched-phase RF and variable spoiler achieves the lowest temporal SD in 6 skip 2.*

DISCUSSION The multiple improvements we describe increase the ASL signal stability and reduce slice spacing in VSASL, which is expected to enable more reliable diagnosis. Although demonstrated in VSASL, STE removal and matched-phase RF can be applied to any multislice ASL imaging.

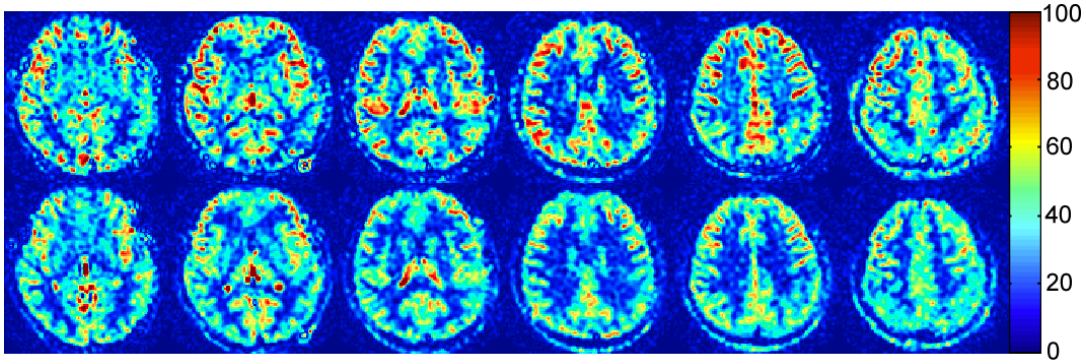

Figure 3. *CBF maps (ml/100 g/min) acquired without (top) and with (bottom) stimulated echo removal, slice profile improvement, timing optimization, and off-resonance correction in a healthy volunteer.*

REFERENCES [1] Wong *et al,* MRM 55: 1334, 2006. [2] Gunther *et al*, MRM 46: 974, 2001. [3] Pauly *et al,* IEEE TMI 10: 53, 1991. [4] Balchandani *et al,* MRM 62:183, 2009. [5] Guo *et al,* ISMRM p296, 2011.

ACKNOWLEDGEMENT: NIH (2RO1NS047607, 1R01NS066506, 5P41RR09784), Lucas Foundation, Oak Foundation, and Eric C. Wong for providing the initial version of VSASL sequence.