Velocity-selective magnetization-prepared non-contrast-enhanced peripheral MR angiography at 3T

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Target Audience: MR engineers and clinicians interested in non-contrast-enhanced peripheral angiography.

Purpose: Velocity-selective magnetization-prepared non-contrast-enhanced (NCE) MR angiography (VS-MRA) has an advantage that large-FOV 3D angiograms can be obtained directly from single acquisition [1]. While promising initial results have been shown at 1.5 T, VS-MRA has been deemed challenging at 3 T due to the sensitivity of VS preparation pulse to B_0 and B_1 inhomogeneities. This study aims to upgrade VS-MRA pulse sequences for improved performance at 3 T in the lower extremities.

Theory and Methods: VS preparation pulse design: A refocused VS excitation pulse can be generated by adding a composite 180° pulse between the halves of each bipolar gradient in the k-space-based design [1]. A more robust refocusing strategy was recently introduced for VS arterial spin labeling, which pairs two 180° pulses interleaved with four unipolar gradients [2]. In both designs, a composite pulse train of 90°-360°-90° was used [3], and was weighted by MLEV phase cycling [4]. Bloch simulations show that the passband remains nearly invariant to the B_1 offset due to the improved refocusing, and the excitation flip angle in the stopband varies in proportion to the B_1 ratio (Fig. 1d).

Suppression of stripe artifact: Imperfect 180° rotation of the refocusing pulse can create stripe artifact in static tissues, which is approximately sinusoidal with a period of λ proportional to the inverse of the area of the unipolar gradient. The period λ is smaller than typical spatial resolution (~1mm) in the single refocusing case, making the artifact invisible, but is large enough to make the stripe visible in the paired refocusing case due to the smaller unipolar area. A simple solution is to apply another VS excitation pulse with a shifted excitation profile along the spatial dimension by 0.5 λ by applying an RF phase: $\theta(t) = \gamma\int_t^T (t-s)(0.5\lambda)G(s)ds$ where γ = gyromagnetic ratio, T = pulse duration

In-vivo experiments: NCE MRA was performed in the calf of a healthy subject using the following parameters: 3 T MR scanner (Tim-Trio; Siemens Medical Solutions), 2nd-order shimming with "standard" shim mode, coronal orientation, spatial resolution = 1.0×1.0×1.3 mm^3, TR=3.1 ms (minimized by ramp-sampling), 2-fold parallel imaging, 2R-R repetition time, scan time = 320 heart beats. Single or double VS preparation pulses were applied each of which used either single refocusing or paired refocusing, yielding 4 cases in total. A field map and a B_1 map (5) were measured with the same 3D FOV.

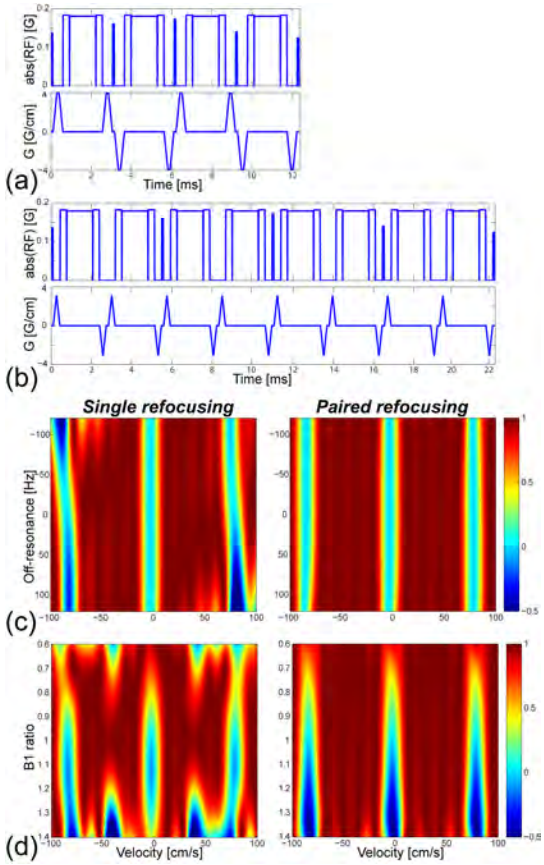

Figure 1. *VS excitation pulse sequences with single refocusing (a) and paired refocusing (b). Simulated longitudinal magnetization with B_0 (c) and B_1 (d) offsets.*

Results: The angiogram obtained from single refocusing has lower signal intensity in the left popliteal arteries due to passband distortion caused by large B_1 ratio (~1.2) (white arrowheads). The background signal is higher in the regions of low B_1 ratios due to lower VS flip angles (open arrow). Using two VS preparations, the popliteal signal loss becomes worse (yellow arrowheads) while the background suppression becomes more uniform. The VS preparation with paired refocusing significantly mitigates the popliteal signal loss but contains strip artifact (arrows, Fig. 2b). Application of two VS preparations removed the stripes and also improves the uniformity of background suppression (Fig. 2d). Off-resonance and B_1 ratio are measured as 1.1±24.3 Hz and 0.90±0.16, respectively.

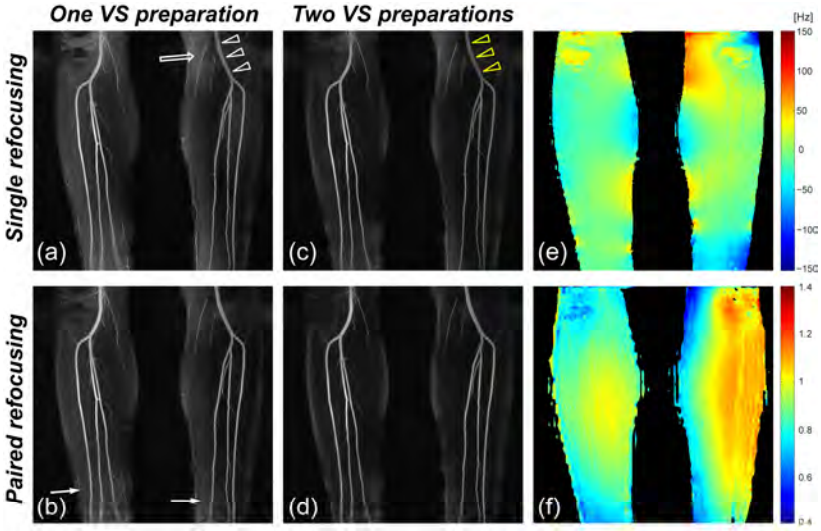

Figure 2. *Calf angiograms obtained from one VS preparation with single (a) and paired (b) refocusing, and two VS preparations with single (c) and paired (d) refocusing, along with B_0 map (e) and B_1 map (f).*

Discussion and Conclusion: In VS excitation pulse sequences, the RF refocusing component is corrupted by both B_0 and B_1 offsets and can cause arterial signal loss due to velocity pass-band distortion, and create stripe artifact when the unipolar gradient is small. Whereas, the excitation component is affected by B_1 only and leads to non-uniform background suppression. We have shown that paired refocusing can significantly improve the immunity to B_0 and B_1 offsets, preventing arterial signal loss. Also, application of two VS preparations with spatially shifted excitation profiles can suppress the strip artifact while improving the spatial uniformity of background suppression. The proposed technique will be tested in the thigh and pelvis which may exhibit different B_0 and B_1 distributions.

References: [1] Shin, *et al.*, MRM 70: 1229-1240, 2013. [2] Qin Q. *et al.*, ISMRM2014: 420. [3] Levitt MH, *et al.*, Progr NMR Specgtrosc 18: 61-122, 1986. [4] Shaka AJ, *et al.*, JMR 77:606-612, 1988. [5] Sacolick LI, *et al.*, MRM 63: 1315-1322, 2010 .