Comparison of Phase-Sensitive and Alternating Repetition Time SSFP for Flow-Independent Peripheral Angiography

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Introduction: Magnetic resonance angiography of the extremities can help in the diagnosis of conditions such as peripheral arterial disease and peripheral vascular occlusion. In recent work, non-contrast-enhanced high-resolution flow-independent angiograms of the hand have been acquired with SNR-efficient balanced steady-state free precession (SSFP) imaging [1]. The simple and efficient phase-sensitive (PS) SSFP method [2] was used to remove fat; however, the method suffers from partial volume effects. In the case of small vessels in the vicinity of bone marrow and subcutaneous fat tissue, partial volume averaging leads to a loss of blood signal.

Instead, alternating repetition time (ATR) SSFP can be used to suppress fat signal [3]. Partial volume effects are significantly reduced, enhancing the visualization of vascular structure. When B_0 inhomogeneity or susceptibility variations are significant, fat suppression will be imperfect in certain regions due to the wedge-shaped stop-band of fat-suppressing ATR. Another ATR image with a shift in the echo-time can be used for fat-water separation through post-processing.

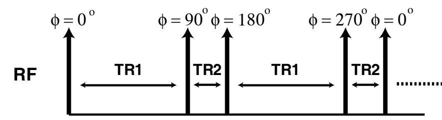

Figure 1. Sequence diagram for ATR-SSFP with (0-90-180-270)° phase cycling.

Methods: The ATR-SSFP sequence begins with a segmented BIR-4 pulse for T2-weighted preparation [4] and a linear ramp catalyzation that reduces transient oscillations [5]. The generated blood-muscle contrast can be captured with centric square-spiral [6] phase-encode ordering. Phase encodes are interleaved to restore the desired contrast during the course of acquisition by repeating the magnetization preparation [7].

The ATR sequence displayed in Fig. 1 was implemented on a 1.5 T GE Signa Excite scanner. A linear extremity coil was utilized to acquire 3D isotropic 1 mm resolution images with the following parameters: 26x13x13 cm^3 FOV, $\alpha = 60^o$, $TR_1/TR_2/TE = 3.45/1.15/1.7$ ms, ±125 kHz BW, a 10-excitation catalyzation, 80 ms T2-prep time, 4 interleaves and a 10 sec recovery time. The acquisition time for the ATR sequence, 1:48, was the same as the PS-SSFP acquisition with TR = 4.6 ms.

When the fat-suppression is not sufficient to view the volume as an MIP, a second ATR image with a TE = 1.1 ms is acquired. The difference of the phase profiles of the two acquisitions is a linear phase across the spectrum, placing fat and water approximately 60^o out-of-phase. The phase-difference image can be thresholded to filter-out fat tissue. Finally, the two fat-removed images are magnitude-summed.

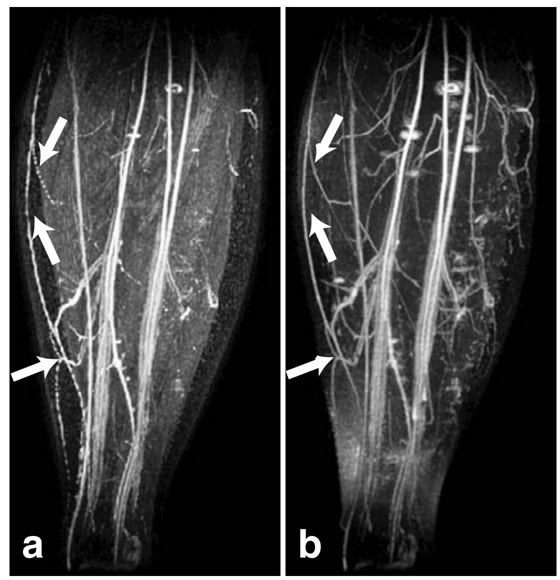

*Figure 2. MIPs of the calf for **a:** balanced SSFP images followed by phase-sensitive reconstruction **b:** ATR-SSFP. The fat suppression is better with ATR-SSFP. The bands in the vessels are not as pronounced in **b** (arrows).*

Results: Calf images acquired with PS-SSFP and with ATR-SSFP are displayed in Fig. 2. The stripes seen in PS-SSFP images on some of the vessels in vicinity of fat tissue are the result of partial-volume cancellation. These stripes are not observed in the ATR images. Moreover, the small-vessel depiction is dramatically improved. Figure 3 demonstrates the reduced partial volume effect in the foot by utilizing the ATR sequence compared to using PS-SSFP reconstruction. The range of off-resonance variation observed in the foot leads to imperfect fat suppression. A shifted-echo data set is used to enhance vessel depiction in regions with imperfect fat suppression.

Conclusion: High-resolution flow-independent angiograms of the extremities have been acquired using a 3D ATR-SSFP sequence. We have shown that fat suppression during acquisition improves small-vessel visibility and reduces artifacts seen in vessels in proximity to fat tissue, as compared with PS-SSFP. Finally, enhanced fat-removal comprising a shifted-echo ATR acquisition has been demonstrated.

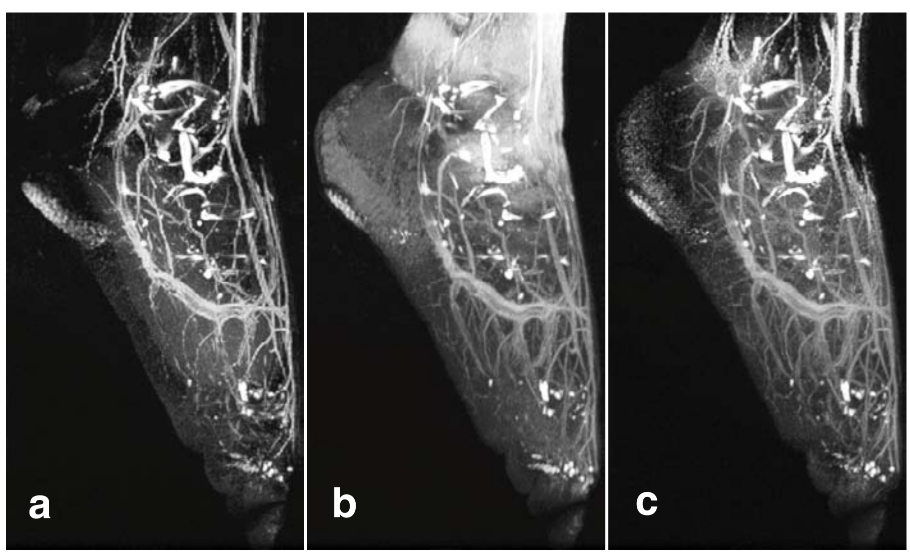

*Figure 3. MIPs of the foot for **a:** balanced SSFP images followed by phase-sensitive reconstruction **b:** fat-suppressing ATR. The imperfect fat suppression with ATR decreases the visibility of vessels in **b.** A shifted-echo data set can be used to enhance the fat suppression **(c)**.*

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