Non-contrast-enhanced Flow-independent Peripheral Angiography with Magnetization-prepared IDEAL Balanced-SSFP

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Introduction: Flow-independent angiography can depict vessel morphology without contrast agents and in cases of slow flow, because it relies on only T1, T2 and chemical shift [1]. 3D balanced (b)SSFP sequences are excellent candidates for producing these angiograms [2-4], but the vessel contrast can be compromised by several factors including field inhomogeneity, partial-volume effects, large volumetric coverage requirements, and insufficient venous suppression. In this work, we propose a new strategy to address these issues and reliably produce high-resolution non-contrast-enhanced bSSFP angiograms of the extremities.

Methods: The proposed strategy generates reliable vessel contrast by combining several effective methods. First, dual-acquisition complex-sum bSSFP reduces the sensitivity to field inhomogeneity [5]. Then, vessel loss due to partial-volume artifacts (when fat and water occupy the same voxel) can be minimized with a robust multi-peak IDEAL fat suppression (investigational version) [6] on a three-echo fly-back bSSFP sequence [7]. The prolonged TR of this sequence yields improved venous suppression [8]. Finally, subsequent inversion recovery (IR) and adiabatic T2-preparation pulses reduce the synovial fluid and muscle signals respectively. To effectively capture the transient contrast (Fig. 1), k-space is segmented into several interleaves with centric phase-encode ordering [3]. Magnetization preparation can be repeated more frequently to improve contrast, when ARC parallel imaging is used [9].

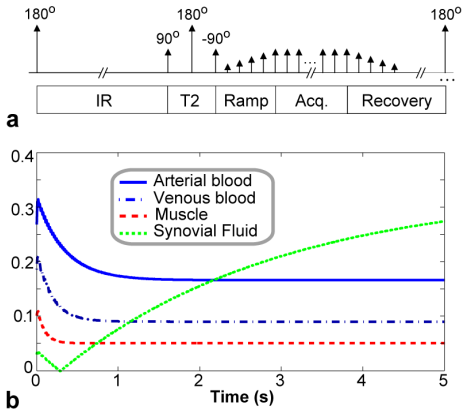

Figure 1. a: Pulse sequence diagram. **b:** The magnetization-prepared transient signal for arterial blood (T1/T2=1000/200 ms), venous blood (1000/100 ms), muscle (870/47 ms) and synovial fluid (4000/2000 ms).

Lower extremity angiograms of 5 subjects were produced on a 1.5 T GE scanner with the following parameters to maximize the blood-background contrast: $\alpha=90^{o}$, TR=10 ms, 2.8 ms echo spacing, 1.8 s IR, 80 ms T2-Prep, 3 s recovery time, and 2.8-fold acceleration with an 8-channel array, 1.4 mm^3 (in the thigh) and 1 mm^3 (in the calf and foot) isotropic resolutions. The FOV, scan time, number of phase-encodes per preparation were: 35 cm, 6:28 s, 600 in the thigh; 31 cm, 8:15 s, 600 in the calf; 27 cm, 8:14 s, 300 in the foot.

Results: The improvements from the individual steps of the technique are demonstrated in Fig. 2. Complex-sum bSSFP removes the banding artifacts. Multi-peak IDEAL achieves superior fat suppression compared to the single-peak modeling. Finally, more frequent magnetization preparation reduces the synovial fluid signal. Fig. 3 shows typical thigh, calf, and foot angiograms. The long-TR sequence improves the venous suppression in addition to reducing SAR at high fields and allowing larger flip angles. The proposed technique produces high-resolution flow-independent peripheral angiograms without contrast agents by reliably reducing the signal from fat, synovial fluid, muscle, and veins.

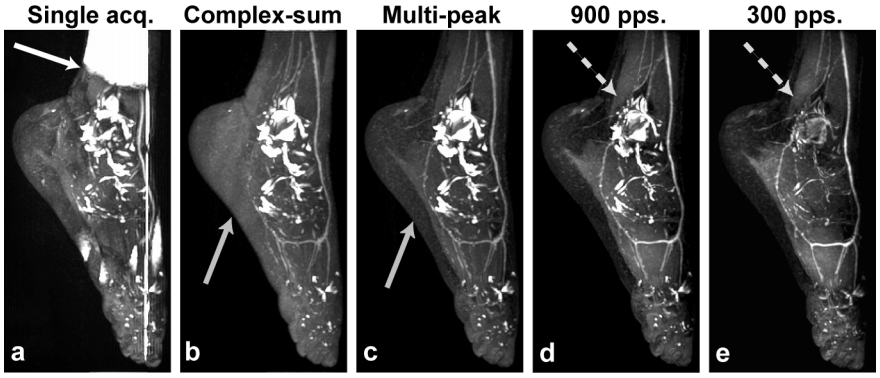

Figure 2. Targeted MIPs of foot angiograms. **a:** Banding artifacts in bSSFP can result in IDEAL failures. **b:** Banding artifacts removed with complex-sum bSSFP. **c:** Improved fat suppression with multi-peak IDEAL recon. **d:** The synovial fluid signal is reduced with magnetization preparation (900 phase-encodes per segment). **e:** More frequent preparation (300 encodes per segment) improves the synovial fluid suppression.

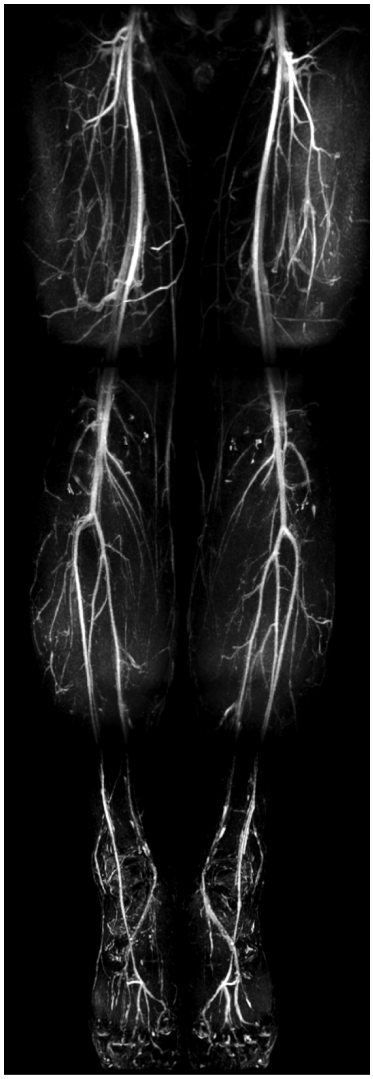

Figure 3. MIPs of the thigh, calf, and foot angiograms.

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