Flow-Independent Angiography of the Hand with 3D Balanced SSFP Imaging

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Introduction: MR hand angiography is clinically useful in the diagnosis of conditions such as Raynaud's disease and peripheral vascular occlusion. Balanced steady-state free-precession (SSFP) imaging is SNR-efficient and adequate for high-resolution flow-independent angiography (FIA) without the need for injected contrast agent [1]. However, fat gives bright signal obscuring vascular structure. Air-tissue interfaces create SSFP signal nulls/voids. In recent work, flow-independent angiograms of the foot have been acquired with 3D Balanced SSFP imaging [1], where fat has been suppressed using phase-sensitive SSFP reconstruction [2] with complex-sum SSFP [3]. Bands created by air-tissue interfaces result in failure of phase-sensitive SSFP reconstruction. Moreover, complex-sum SSFP degrades contrast-to-noise ratio while doubling the scan time and increasing vulnerability to patient movement.

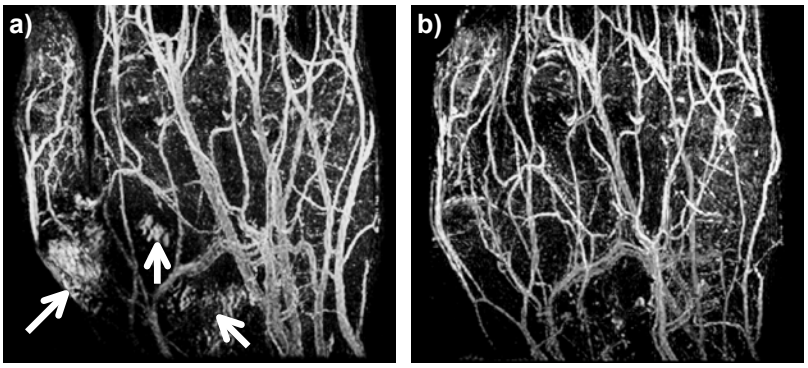

Figure 1. *Maximum-intensity projections of 0.7 mm isotropic resolution hand angiograms* ***a)*** *without and* ***b)*** *with susceptibility-matching material. The locations where the fat-water separation fails are shown with the arrows.*

In this work, a single SSFP acquisition is exploited along with a phase-sensitive SSFP reconstruction for high-resolution hand angiography. The hand is packed in susceptibility-matching material (Kaopectate) to distance the air-tissue interface. This method significantly reduces banding artifacts within the imaging region and improves the robustness of fat-water separation.

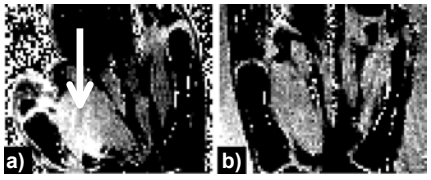

Figure 2. *Field maps* ***a)*** *without and* ***b)*** *with susceptibility-matching material. The region of high off-resonance, corresponding to the problematic locations in Figure 1.a, is shown with the arrow. The images have been masked to remove fat pixels.*

Methods: The sequence uses a spoiled inversion-recovery to null signal from long-T1 fluids, followed by T2-preparation ($90°_x$, $180°_y$, $180°_y$, -90_x) [4] to generate blood/muscle contrast [1]. A linear ramp catalyzation follows to prevent transient oscillations in the balanced SSFP acquisition [5]. The ordering of phase encodes is a centric square-spiral allowing the low-spatial frequencies to have the desired contrast [6]. However, during the acquisition the initial magnetization-prepared contrast is gradually replaced by the steady-state contrast, especially for high-spatial frequencies. Square-spiral phase encodes are interleaved to reduce this problem with the above module repeated for each interleaf with a recovery time between each.

The 3D Balanced SSFP FIA sequence was implemented on a 1.5 T GE Signa Excite scanner with CV/i gradients. Two different protocols were used. For 0.7 mm isotropic resolution with an 8-channel knee coil, subjects were scanned with the following parameters: $\alpha = 75^o$, TR/TE = 4.6/2.3 ms, 16 cm FOV, 125 kHz BW, inversion time = 2 s, T2-Prep time = 80 ms, a 10-excitation catalyzation, 6 interleaves and a 10 sec recovery time. The total scan time was 2:12. The following scan parameters were changed for 0.5 mm isotropic resolution: TR/TE = 4.8/2.3 ms, 10 interleaves and no fluid-suppression inversion-recovery (to compensate for reduced SNR at higher resolution). The total scan time was 3:40. Phase-sensitive SSFP fat-water separation was carried out for each of the 8 channels. A sum-of-squares combination of the multi-channel data was followed by a maximum-intensity projection to visualize the vessels.

Results: The 0.7 mm isotropic-resolution images are shown in Figure 1, without and with the susceptibility-matching material used to keep the air-tissue boundary away from the skin. There are certain locations where the phase-sensitive SSFP reconstruction fails to correctly detect fat (arrows). When the susceptibility matching is carried out, fat suppression works better and removes fat at the problematic locations. Field maps without and with the susceptibility-matching material are displayed in Figure 2. The peak-to-peak variation of off-resonance frequencies is reduced from ±94.6 Hz to ±54.5 Hz with the susceptibility matching. Figure 3 shows the 0.5 mm isotropic-resolution angiograms with some synovial fluid around the joints because long-T1 fluid-suppression has been omitted to achieve higher SNR. High resolution images have less partial volume effect and hence give better depiction of small vessels.

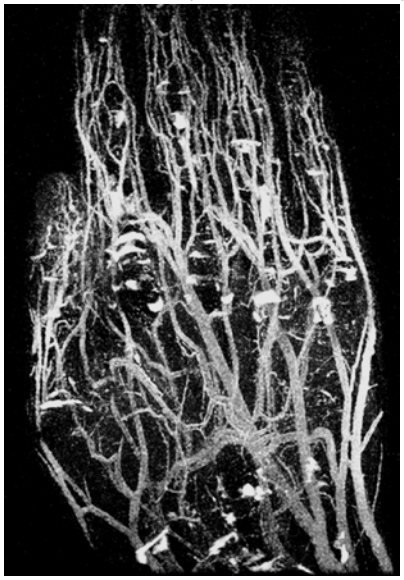

Figure 3. *Maximum-intensity projection of 0.5 mm isotropic resolution angiogram.*

Conclusion: We have demonstrated high-resolution flow-independent angiograms of the hand using magnetization-prepared 3D Balanced SSFP combined with phase-sensitive fat-water separation. We have shown that susceptibility-matching material prevents the formation of SSFP bands within the imaging region, enhancing fat-separation robustness. Finally, we have shown that increasing resolution to 0.5 mm helps mitigate partial volume effects. Hand angiograms can be acquired in less than 4 minutes, without the need for intravenous contrast agent.

References:

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