Non-Contrast-Enhanced, Flow-Independent, 3D Peripheral Angiography using Steady-State Free Precession at 3T

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Synopsis
A new method of 3D, non-contrast-enhanced, flow-independent angiography (FIA) using refocused steady-state free precession at 3 T is described. Relaxation time constants are measured at 1.5 T and 3 T and imaging parameters are optimized to maximize contrast between arterial blood and surrounding tissues. Changes in blood T2 with field strength and oxygenation result in improvements in predicted arterial-venous contrast at 3 T compared to 1.5 T. High-resolution, high contrast 3D angiograms of the lower leg are presented.

Introduction
Angiography below the knee requires high spatial resolution due to the small diameter of the arteries. The short time window between arterial and venous enhancement limits the spatial resolution of contrast-enhanced angiograms in this region. Non-contrast-enhanced, flow-independent angiography (FIA) approaches for imaging the peripheral vasculature have been explored at 1.5 T [1-3]. FIA methods exploit T1, T2, and chemical shift differences to separate arterial blood from surrounding tissues. The acquired spatial resolution is limited only by available SNR. Clinical acceptance of FIA methods at 1.5 T has been limited by two factors. First, the T2 of venous blood in the periphery is increased in patients with peripheral vascular disease compared to healthy volunteers [3]. This leads to a decreased T2 difference between arterial and venous blood and makes arterial-venous separation more difficult using FIA methods [2]. Second, scan times to acquire high-resolution 3D volumes using previous FIA techniques have been prohibitively long [2].

The T2 of blood varies with oxygenation state and field strength [4-6]. The Luz-Meiboom model predicts that the difference in R2 relaxation rate (1/T2) between arterial and venous blood (R2venous - R2arterial) varies with the square of field strength [7]. Hence, imaging at higher field strengths should improve FIA arterial-venous separation. Here, we propose a new FIA method using refocused steady-state free precession (SSFP) at 3 T. Relaxation time constants are measured at 1.5 T and 3 T to validate expected behavior and to facilitate parameter optimizations. The optimized SSFP acquisition produces high SNR angiograms in short scan times and alleviates the scan time concerns of previous FIA methods. The high SNR also enables increased spatial resolution.

Methods
To generate flow-independent angiographic contrast, signal from arterial blood must be differentiated from muscle and venous blood. Contrast optimization was facilitated by measuring the T1 and T2 relaxation times of arterial, venous blood, and muscle on a 1.5 T Signa TwinSpeed system and a 3 T Signa VH/i system (GE Medical Systems, Milwaukee, WI). T2s were measured using a quantitative T2-preparation method [8,9]. Signal was sampled at TE = 20, 24, 48, 72, 96, and 144 ms utilizing a refocusing interval of 6 ms. T1s were measured using a Look-Locker sequence [9,10]. Signal was measured every 100-150 ms following an inversion pulse. A spiral imaging sequence with the following parameters was used in both experiments: TR = 2 s, 1.1 mm in-plane resolution, FOV = 20 cm, and NEX = 2. The measured signal values were fit to a monoexponential decay curve using a least-squares approach [11].

To select the imaging flip angle that maximizes arterial-blood-to-muscle contrast, SSFP signal was simulated utilizing the measured T1s and T2s. Simulations were also used to calculate expected improvement in the artery-to-vein contrast at 3 T compared to 1.5 T. A 3D, refocused SSFP pulse sequence (True-FISP, Balanced-FFE, FIESTA) with periodic fat-suppression [12] was implemented on a 3.0 T Signa VH/i scanner (GE Medical Systems, Milwaukee, WI). After informed consent, volunteer images were acquired utilizing the following parameters: TE/TR = 2.2/4.8, BW=100 kHz, Matrix = 256 x 176 x 128 zero padded to 512 x 512 x 256, FOV = 24 x 16.8 x 12.8 cm, flip = 50, spectrally-selective inversion every 64 TR. A prototype transmit-receive 3-T extremity coil was utilized.

Results
Measured T2s are listed in Table 1. Measured T1s increased approximately 5% from 1.5 T to 3 T. The measured change in (R2venous - R2arterial) at 1.5 T to 3 T was approximately 3.45, slightly less than the predicted factor of 4 but certainly significant as a mechanism for increased image contrast between arterial and venous blood.

Based on SSFP simulations, a flip angle of 50 degrees was selected to maximize arterial-blood-to-muscle contrast. Simulations comparing 1.5 T and 3 T signal predict up to a 3-fold increase in the artery-to-vein contrast at 3 T compared to 1.5 T.

Figure 1 illustrates a maximum intensity projection (MIP) of a flow-independent angiogram of the popliteal trifurcation of a healthy volunteer acquired at 3 T. Secondary and even tertiary intramuscular arterial branches are visible due to the high blood-to-muscle contrast-to-noise ratio (CNR~20), high arterial blood SNR (SNR~55), and high resolution of 0.9 mm3.

Conclusions
We have demonstrated a new method of flow-independent angiography at 3 T. Our method generates high-resolution, high-contrast angiograms without extrinsic contrast agents and addresses the limitations of previous FIA methods.

Table 1

<table>
<thead>
<tr>
<th>Tissue</th>
<th>1.5 T</th>
<th>3 T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial Blood</td>
<td>280</td>
<td>164</td>
</tr>
<tr>
<td>Venous Blood</td>
<td>190</td>
<td>100</td>
</tr>
<tr>
<td>Muscle</td>
<td>35</td>
<td>32</td>
</tr>
</tbody>
</table>

References

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