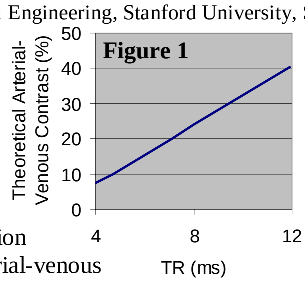
SSFP Non-Contrast-Enhanced MR Angiography at 3.0T: Improved Arterial-Venous Contrast with Increased TR

J. H. Brittain[1], A. Shimakawa[1], J. W. Johnson[1], R. Dharmakumar[2], G. E. Gold[3], B. Hu[4], G. A. Wright[2], B. A. Hargreaves[5]

[1]Applied Science Lab - West, GE Healthcare, Menlo Park, CA, United States, [2]Dept. of Medical Biophysics, Sunnybrook & Women's College HSC, University of Toronto, Toronto, Ontario, Canada, [3]Dept. of Radiology, Stanford University, Stanford, CA, United States, [4]Dept. of Cardiology, Palo Alto Medical Foundation, Palo Alto, CA, United States, [5]Dept. of Electrical Engineering, Stanford University, Stanford, CA, United States

Introduction: In contrast-enhanced angiography below the knee, the short time interval between arterial and venous enhancement limits the duration and spatial resolution of the acquisition. Even with restricted scan duration, arterial conspicuity is often compromised by the superposition of enhancing deep veins [1]. Recent work has explored high-SNR balanced-SSFP methods to acquire non-contrast-enhanced (NCE), flow-independent angiograms with high spatial resolution [2-8]. These methods depend on the generation of sufficient arterial-venous contrast and reliable fat suppression. Prior work has demonstrated improved arterial-venous contrast in NCE angiograms acquired at 3.0T compared to 1.5T [3,4]. Recently, Dharmakumar *et al.* used theoretical models and *in vitro* validation to characterize the increased sensitivity of the SSFP blood signal to oxygen saturation (%O_2) at higher field strength [9]. This work also revealed increased SSFP blood signal sensitivity to %O_2 with increasing TR [9]. Figure 1 plots the predicted arterial-venous contrast (% of arterial signal) at 3.0T as a function of TR assuming venous %O_2 = 70% and arterial %O_2 = 98%.



In this work, we explore the impact of TR on SSFP %O_2 sensitivity in the context of NCE angiography and demonstrate increased arterial-venous contrast with longer TR in NCE angiograms acquired using balanced SSFP with intermittent fat saturation (FS-SSFP) [10]. The increased TR also permits increased spatial resolution and/or reduced bandwidth acquisitions.

Methods: A FS-SSFP sequence was implemented on our 3.0T Signa VH/i system (GE Healthcare, Milwaukee, WI) with maximum gradient performance of 40 mT/m and 150 mT/m/ms. Experiments had IRB approval, and informed consent was obtained prior to scanning.

To experimentally assess arterial-venous NCE angiographic contrast at different TR, six healthy volunteers were imaged with two parameter sets: (a) TE/TR=2.3/4.7ms, scan time=6:13 and (b) TE/TR=4/8 ms, scan time=10:11. For both scans, BW=±100kHz, matrix = 256x204x96 zero-padded to 512x512x96, FOV=24x19x9.6cm^3, resolution=0.9x0.9x1mm^3, and flip=50°. Three signal averages (NSA) were used to increase SNR for signal measurements. A fat-selective inversion was repeated every 24 TRs and was followed by two excitations with ramped flip angle amplitude and discarded acquisitions to reestablish the steady state. A transmit/receive quadrature extremity coil (Medical Advances, Milwaukee, WI) was used. Maximum intensity projections (MIP) and source images were reviewed. Arterial blood, deep venous blood, and muscle signal levels were measured in source images and recorded.

To illustrate the potential for increased spatial resolution with the increased TR, a more aggressive protocol was developed. Three healthy volunteers were imaged using FS-SSFP and the following parameters: TE/TR=3.55/7.1 ms, fat-selective inversion every 14 TRs, BW=±62.5kHz, NSA=1, matrix = 384x230x96 zero-padded to 512x512x96, FOV=25x15x9.6cm^3, resolution=0.7x0.7x1mm^3, flip=50°, and scan time=4:33.

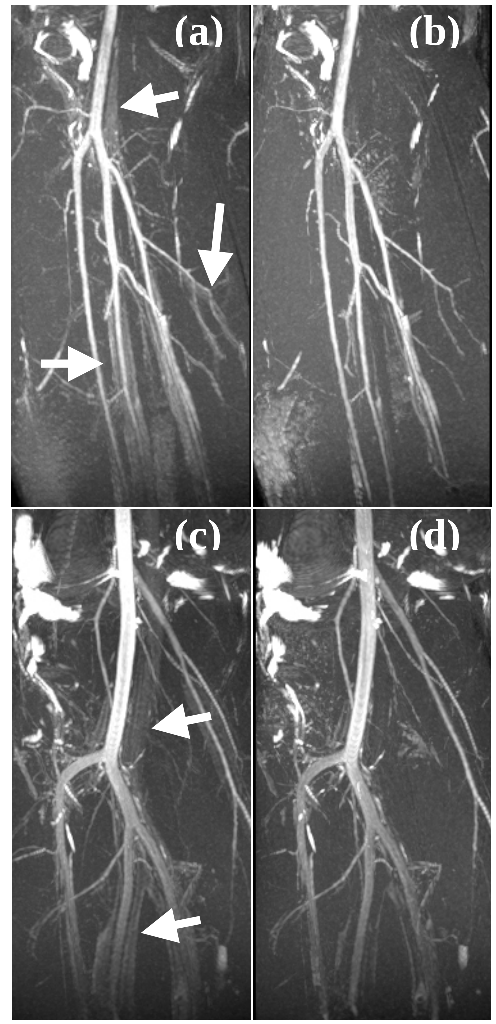


Figure 2: MIPs of FS-SSFP 3D NCE angiograms of two healthy volunteers comparing (a) & (c) TR=4.7 ms to (b) & (d) TR = 8 ms. Note appearance of deep veins (arrows) that are suppressed at the longer TR.

Results: Fig. 2 shows targeted MIPs of non-contrast-enhanced angiograms of the popliteal trifurcation of two healthy volunteers acquired with FS-SSFP using TR=4.7ms (a & c) and TR=8 ms (b & d). As predicted by theory, contrast between arteries and deep veins improved with increased TR (arrows). Measurement of deep venous signal was difficult because of venous suppression (low vein conspicuity) in source images acquired with 8-ms TR. This prevented comparison of measured contrast to theory. Figure 3 shows a MIP of a healthy volunteer acquired using the higher-resolution protocol. Despite the reduction in SNR resulting from the more aggressive protocol, the popliteal, anterior tibial, peroneal, and posterior tibial arteries are clearly depicted. No deep veins are visible. In all studies, despite long TRs few SSFP banding artifacts were seen and none impacted vessel visualization.

Figure 3: MIP of FS-SSFP 3D NCE angiograms of healthy volunteer. Longer TR is exploited to acquire higher spatial resolution with reduced bandwidth.

Discussion: Arterial-venous contrast improves with increased TR in balanced SSFP non-contrast-enhanced angiograms. The increased TR allows increased spatial resolution and/or reduced bandwidth acquisitions but increases scan time as well as the likelihood of SSFP off-resonance banding artifacts. Scan time could be reduced using time-varying acquisitions such as EPI or spiral that efficiently utilize the longer TR. In addition, partial *k*-space methods and/or parallel imaging techniques with appropriate coils could reduce scan time. Phase-cycled SSFP methods could be used to eliminate potential banding artifacts.

Conclusions: NCE angiography with increased TR provides improved arterial-venous contrast and is a promising method to achieve high resolution, high contrast images of the small arteries below the knee.

References: (1) Bilecen *et al.*, Acta Radiol 2004 Aug;45:510-5. (2) Hargreaves *et al.*, Magn Reson Med 2003 Jul;50:210-3. (3) Brittain *et al.*, 11th ISMRM, 1710 (2003). (4) Brittain et al., *J Card Mag Res* 6(1), 503, 2004. (5) A. Lu *et al.*, JMRI 19:117-123, 2004 (6) Bangerter *et al.*, 12th ISMRM, 11 (2004). (7) Brittain *et al.*, 12th ISMRM, 12 (2004). (8) A. Lu *et al.*, Magn Reson Med, in press. (9) Dharmakumar *et al.*, Magn Reson Med, in press. (10) Scheffler, *et al.*, Magn Reson Med 2001 45:1075, 2001.