Highly accelerated non contrast enhanced MRA of the lower extremity arteries at 3 Tesla using an ECG-triggered variable flip angle 3D fast spin echo (SPACE) sequence

R. P. Lim[1], P. Storey[1], I. P. Atanasova[1], D. C. Kim[1], E. M. Hecht[1], D. R. Stoffel[1], J. Xu[2], Q. Chen[1], H. Rusinek[1], and V. S. Lee[1]

[1]Radiology, NYU Langone Medical Center, New York, New York, United States, [2]Siemens Medical Solutions, New York, New York, United States

Purpose:
ECG-gated fast spin echo SPACE (Sampling Perfection with Application optimized Contrasts using different flip angle Evolutions) MRA, using a variable refocusing flip angle approach[1] is a potential non contrast alternative based on a half Fourier fast spin echo technique (SSFSE-MRA)[2,3]. Variable flip angle MRA (VFA-MRA) enables shorter interecho spacing and a shorter readout duration than is possible with SSFSE-MRA at 3 Tesla due to SAR limitations, decreasing vessel blur, and potentially, susceptibility to tachyarrhythmias[4,5]. As VFA-MRA is a subtraction technique, shortening acquisition time is desirable to minimize patient motion. With the increase in SNR afforded by imaging at 3T, higher acceleration factors become feasible. Applying parallel imaging in the phase encode direction shortens the readout duration for decreased vessel blur, and in the slice select direction shortens acquisition time by decreasing the number of partitions collected. Reference lines for coil sensitivity information are acquired once with a gradient echo sequence at the commencement of scanning, and shared for systolic and diastolic acquisitions, further minimizing scan time. We hypothesize VFA-MRA with parallel imaging in the slice select and phase encode directions will have comparable image quality compared with VFA-MRA with parallel imaging in the phase encode direction alone.

Methods:
Calf MRA examinations were performed on 7 volunteers (M=3, mean age 37y, range 27-62y) and 1 patient (F, 65y) with a history of diabetes and intermittent claudication. All examinations were performed at 3 Tesla (Trio, Siemens) with a multichannel peripheral phased array coil. Average heart rate was 65bpm, range 49-96 bpm. Imaging parameters were: TR/TE = 2 R-R intervals/18 ms, variable flip angle[1], voxel size 1.7 x 1.4 x 1.7-2.0 mm, FOV 440mm, 1 echo train per slice, interecho spacing 2.54ms, 75 echoes per train (echo train duration 193ms). Acquisition time was approximately 5 minutes with GRAPPA[6] acceleration factor of 3 (P3) and 2.5 minutes with an acceleration factor of 3x2=6 (P6), varying with subject heart rate. With this sequence, systolic arterial flow voids are subtracted from bright slow-flowing diastolic blood, generating an arteriogram. No flow spoiling was required, as phantom experiments were performed that demonstrated increased flow sensitivity of VFA-MRA compared with SSFSE-MRA sufficient to depict calf systolic arterial velocities. Systolic trigger delays were based on a 2D phase contrast "scout" to determine peak arterial velocity, and diastolic images were acquired with 0ms trigger delay. Time-resolved contrast enhanced MRA (TR-MRA) using time-resolved imaging with stochastic trajectories (TWIST, Siemens) was performed in the clinical patient following administration of 7.5cc Gd-DTPA at 2ml/s: TR/TE 2.8/1.3ms, FA 20°, voxel size 1.3 x 1.6 x 1.3mm, FOV 500mm, acquisition time 13.6s (full matrix) and 5.97s (partial matrix), 14 measures. Two radiologists in consensus reviewed images for image quality (0=non-diagnostic, 1=poor, 2=fair, 3=good, 4=excellent) on a per leg basis. Segmental vessel conspicuity was evaluated (popliteal, tibioperoneal, proximal and distal anterior tibial, posterior tibial and peroneal, dorsalis pedis and plantar arteries): 0=non-diagnostic; 1=poor, impairing diagnosis; 2=suboptimal without diagnostic impairment; 3=good arterial signal. Factors limiting assessment were recorded, particularly motion (0=absent, 1=present, not limiting image interpretation; 2=present, limiting interpretation; 3=severe). Presence and location of stenoses were recorded.

Results:
156 segments were assessed in total. Mean image quality was judged good for P3 (3.0±1.0) and fair to good for P6 (2.5±1.3) VFA-MRA. There was good vessel conspicuity for P3 (2.6±0.6), slightly lower for P6 (2.3±0.9) (Fig 1). Motion artifact not limiting evaluation was noted for P3 (n=3 legs) and P6 (n=2) VFA-MRA. Central luminal signal loss in popliteal segments related to flow sensitivity of the sequence (4 subjects) was noted for both P3 and P6 VFA-MRA. Signal loss due to B1 heterogeneity that limited evaluation of the right popliteal artery was present for both P3 and P6 VFA-MRA, but more pronounced for P6 VFA-MRA, with images judged non-diagnostic for 5 segments. Evaluation of pedal segments was impaired for P6 VFA-MRA, with a higher level of perceived noise (5 non-diagnostic segments, none for P3). For the clinical patient, bilateral focal stenoses and occlusions identified at TR-MRA were clearly depicted with P6 VFA-MRA (Fig 2), with excellent arterial signal equal to TR-MRA in 18/20 segments.
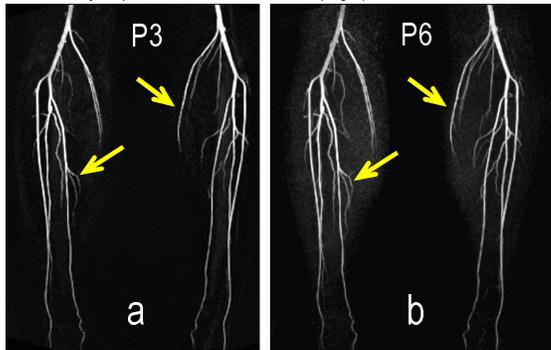

Figure 1. MIP subtraction VFA-MRA with acceleration factors of a) 3 (TA 6 min 10s) and b) 6 (TA 2min 56s) on a female volunteer, heart rate 49 bpm. There is excellent vessel conspicuity, with visualization of muscular branches (arrows).
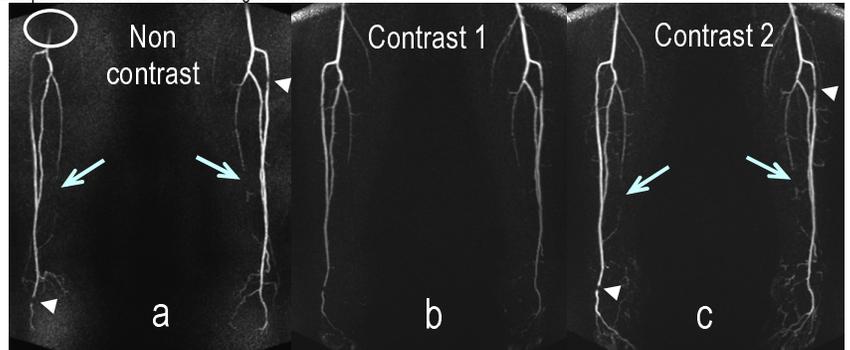
Figure 2. a) P6 VFA-MRA (TA 1min 37 s), b) & c) consecutive time resolved contrast enhanced MIP subtraction images of a diabetic female with intermittent claudication, heart rate 65 bpm. Bilateral posterior tibial artery occlusions (arrows) and focal right dorsalis pedis and left anterior tibial artery stenoses are present (arrowheads), well depicted on non contrast MRA images. Note right popliteal artery signal loss (circle) from B1 inhomogeneity.

Conclusion:
Non-gadolinium enhanced MRA of the lower extremities using an ECG-gated fast spin echo technique with variable flip angle can be performed with parallel imaging in 2 directions at 3 Tesla, maintaining satisfactory image quality and vessel conspicuity with substantially decreased imaging time. B1 inhomogeneity and increased background noise limit visualization of popliteal and pedal segments respectively with the more accelerated technique. Further optimization includes tailoring the flip angle profile of VFA-MRA to maximize blood signal intensity.

References
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