Non-contrast-enhanced peripheral MRA: Comparison of 3D fast spin-echo based and flow sensitive dephasing prepared steady state free precession techniques at 1.5 T

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Purpose:

Peripheral arterial disease patients may have co-existing severe renal disease, placing them at risk of Nephrogenic Systemic Fibrosis with gadolinium-enhanced MRA[1]. Two 3D flow dependent techniques, fast-spin echo MRA (FSE-MRA)[2] and flow sensitive dephasing-prepared balanced SSFP MRA (FSD-MRA)[3] are potential non-contrast-enhanced alternatives that exploit differences in systolic and diastolic arterial flow. The below-knee arteries can be challenging for flow dependent techniques due to relatively low arterial velocities. With FSE-MRA, flow-related dephasing of the arteries occurs inherently at fast arterial velocities, and size of constant refocusing flip angles[4], or a variable refocusing flip angle approach[5,6] can be used to increase systolic dephasing at slow velocities[7]. For FSD-MRA, an adjustable flow sensitive dephasing (FSD) preparation gradient is applied during systolic acquisition only. No prospective studies compare clinical effectiveness of these techniques. Our purpose was to evaluate infragenual non-contrast enhanced FSE-MRA, using both a variable (VFA-MRA) and constant (CFA-MRA) flip angle approach, and FSD-SSFP-MRA in a clinical population.

Methods:

21 patients (M=13, mean 63y) referred for claudication (n=8), foot ulcer (n=8), rest pain (n=1) and suspected vascular malformation (n=4) were imaged with calf VFA-MRA, CFA-MRA and FSD-SSFP-MRA in random order at 1.5T (Avanto, Siemens Healthcare) with a multi-element peripheral coil array. VFA-MRA parameters: TR 1 R-R interval, TE 22 ms, variable flip angle, FOV 450 mm, echo train length 51 echoes, acquisition window 122 ms, echo spacing 2.4 ms, shots per slice 2. CFA-MRA parameters were identical, apart from TE 20 ms, refocusing FA (120°), acquisition window 143 ms, echo spacing 2.8 ms. FSD-SSFP-MRA parameters: TR 1 R-R interval, TE: 1.4 ms, flip angle 70°, FOV 400 mm, segments 50, echo spacing 3.1 ms, shots per slice 2. The strength of FSD preparation for FSD-SSFP-MRA was based on a 2D m1 scout sequence (TA=20s). Voxel size (1.4 x 1.4 x 1.9 mm^3) and average acquisition time (171s for both systolic and diastolic acquisitions) were matched for all sequences. Finally, Gd-MRA using Time-resolved imaging WIth Stochastic Trajectories (TWIST, Siemens Healthcare) was performed: TR/TE 3.1/1.0 ms, flip angle 25°, voxel size 1.3 x 1.0 x 1.5 mm^3, full/partial matrix TA 17/5s, FOV 450 mm, 10 measures, TWIST % factors A (center)=10%, B (periphery)=25%. An acceleration factor of 3 was used for all sequences. Four radiologists retrospectively reviewed subtraction images, with each non-contrast dataset interpreted by 2 blinded radiologists. Segmental stenosis (0=no stenosis to 4=100% occlusion) was evaluated in 13 segments per leg (popliteal artery; tibioperoneal trunk; proximal/ mid/ distal anterior tibial/ posterior tibial/ peroneal arteries; dorsalis pedis; plantar artery). Image quality (0=unevaluable, 1=poor, 2= satisfactory, 3=good) and artifacts were recorded. The reference standard was Gd-MRA, interpreted in consensus by all radiologists.

Results:

1092 segments (42 legs, 2 readers per segment) were evaluated, with hemodynamically significant (defined as ≥50%) stenosis in 296 segments (27%). Image quality scores were satisfactory to good for all sequences (VFA 2.1±1.0; CFA 2.2±0.9; FSD 2.4±0.7), with CFA-MRA significantly superior to VFA-MRA ($p < 0.001$), and FSD-MRA to CFA-MRA and VFA-MRA ($p<0.001$). However, 104/1092 (9.5%) and 54/1092 (4.9%) segments were unevaluable for CFA-MRA and VFA respectively, due to perceived motion, and less commonly, background noise. No segments were unevaluable for FSD-MRA. Of evaluable segments, overall accuracy of VFA-MRA, CFA-MRA and FSD-MRA was 81%, 83% and 80% respectively, without significant difference between sequences (Fig 1). Sensitivity/ specificity for each sequence for hemodynamically significant stenosis were: VFA, 86%/ 79%; CFA-MRA, 83%/ 83%; FSD-MRA, 81%/ 80%, without significant differences between sequences. Flow sensitivity requirements varied between and within subjects; VFA-MRA was problematic with fast diastolic flow (Fig 2). Most common artifacts were motion and background noise for all sequences (statistically significantly less for FSD-MRA compared with CFA-MRA and VFA-MRA). Mild venous signal on FSD-MRA did not affect assessment.

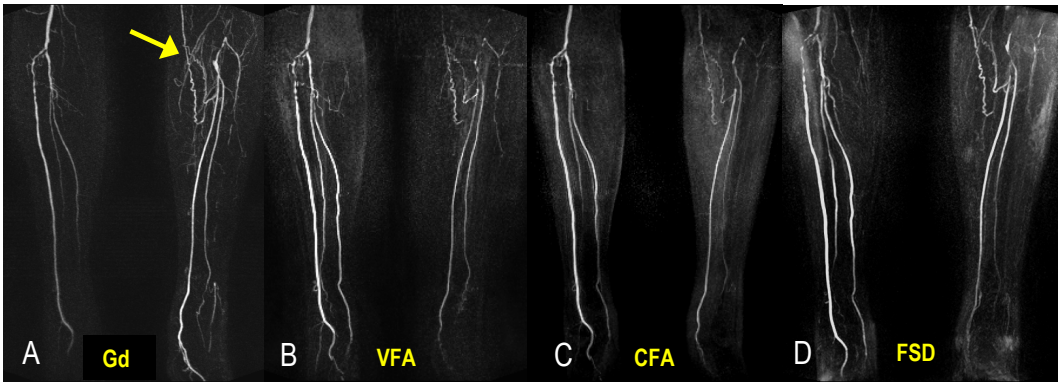
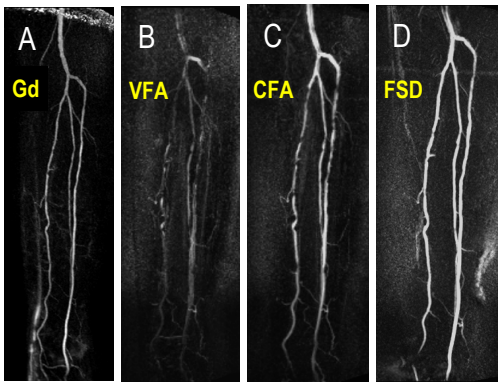


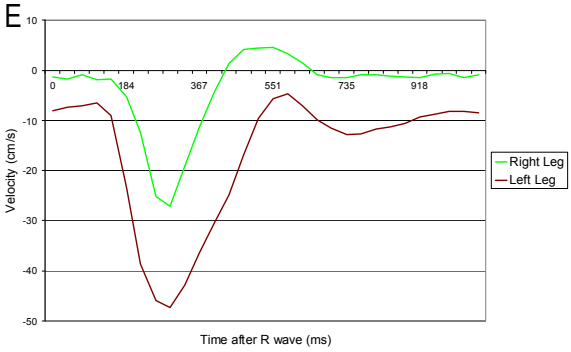
Fig 1 (left). 80yo male with claudication. A) Gd-MRA, B) VFA-MRA, C) CFA-MRA, D) FSD-MRA depicting an occluded left popliteal artery with collateral vessel (arrow) supplying left calf arteries.

Fig 2 (below). 73yo diabetic with left foot ulcer. Left leg only: A) Gd-MRA, B) VFA-MRA C) CFA-MRA, D) FSD-MRA. Arteries poorly visualized with VFA-MRA, due to signal dephasing from high diastolic flow as depicted in E) phase contrast velocity-time graph of posterior tibial arteries at mid calf level.

Conclusion:

Clinical results for ECG-gated non-contrast enhanced VFA-MRA, CFA-MRA and FSD-MRA are encouraging for assessing the below knee arteries in peripheral arterial disease. Image quality was highest for FSD-MRA, and perceived motion/noise were responsible for unevaluable segments for CFA-MRA and particularly for VFA-MRA. There was no significant difference in accuracy of the 3 sequences for evaluable segments. Further work on image acceleration, tailoring flow sensitivity within and across patients, and higher spatial resolution may improve performance of these techniques.





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