Published in final edited form as:

J Magn Reson Imaging. 2014 December ; 40(6): 1422–1429. doi:10.1002/jmri.24477.

Detection of infragenual arterial disease using noncontrast-enhanced MR angiography in patients with diabetes

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Abstract

Purpose—To evaluate the diagnostic performance of a newly developed noncontrast-enhanced MR angiography (NCE-MRA) technique using flow-sensitive dephasing (FSD) prepared steady-state free precession (SSFP) for detecting calf arterial disease in patients with diabetes.

Materials and Methods—Forty-five patients with diabetes who underwent routine CE-MRA of lower extremities were recruited for NCE-MRA at the calf on a 1.5T MR system. Image quality evaluated on a four-point scale and diagnostic performance for detecting more than 50% arterial stenosis were statistically analyzed, using CE-MRA as the standard of reference.

Results—A total of 264 calf arterial segments were obtained in the 45 patients with 88 legs. The percentage of diagnostic arterial segments was all 98% for NCE- and CE-MRA. The image quality, SNR, CNR was 3.3, 177, 138 and 3.5, 103, 99 for NCE-MRA and CE-MRA respectively. The average sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of NCE-MRA were 97%, 96%, 90%, 99%, and 96%, respectively on a per-segment basis and 90%, 84%, 82%, 91%, and 87%, respectively on a per-patients basis.

Conclusion—The NCE-MRA technique demonstrates adequate image quality in the delineation of calf arteries and consistent diagnostic performance for detecting significant stenosis with CE-MRA in patients with diabetes.

Keywords

noncontrast-enhanced MR angiography; diabetes; peripheral vascular disease; steady-state free precession; flow-sensitive dephasing

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INTRODUCTION

Contrast-enhanced MR angiography (CE-MRA) has become a non-invasive modality of choice for detecting arterial disease in many vascular areas of the body. However, patients with renal insufficiency who receive gadolinium-based agents are at risk for developing a debilitating and potentially fatal disease known as nephrogenic systemic fibrosis (NSF) (1, 2). As a result, a substantial population will not be able to benefit from this important diagnostic tool as multiple studies have shown the clear link between renal insufficiency and adverse cardiovascular events (3), especially in diabetic patients (4). Therefore, MRA methods that do not require contrast agents will have importance for patients with renal insufficiency. Furthermore, with CE-MRA, the short contrast first-pass window in arteries often limits imaging coverage or spatial resolution and venous contamination may be present at distal run-off vessels, particularly for calf and foot arterial imaging. Noncontrast-enhanced MRA (NCE-MRA) methods have the potential to overcome these limitations.

Conventional NCE-MRA techniques based on time-of-flight and phase-contrast are not widely applied in lower extremities, primarily due to limited time efficiency, slow flow, or potential image artifacts in the presence of complex flow (5). Several new techniques have been developed for peripheral MRA, including fresh blood imaging (FBI) (6), quiescent interval single-shot (QISS) (7), Ghost (8), and phase contrast vastly undersampled isotropic projection reconstruction (PC-VIPR) (9). Of them, FBI and QISS have undergone preliminary clinical validation for peripheral run-off MRA (10–12). FBI is well suited for peripheral MRA due to its large spatial coverage and robustness to B_0 inhomogeneity. Because of the inherent flow-spoiling effects of fast spin-echo, however, FBI MRA could exhibit signal void at fast and/or turbulent flow that is commonly present distal to stenosis, potentially leading to overestimation of stenosis (13). QISS is a user-friendly and time-efficient run-off MRA technique and showed high diagnostic accuracy for detecting significant arterial disease in diabetic patients with symptomatic peripheral arterial disease (14). However, due to its 2D acquisition nature, slice resolution is limited (13). More recently, NCE-MRA using flow-sensitive dephasing (FSD) prepared steady-state free precession (SSFP) has been developed (15). This method shares several features with FBI, including suppression of flow signal based on intravoxel spin-phase dispersion, systolic and diastolic acquisitions, and magnitude image subtraction. Compared to FBI, however, FSD SSFP is more suited for fast flow (16, 17) due to the flow insensitivity nature of SSFP and allows for more flexible suppression of flow signal due to the strength- and direction-tunable FSD preparation.

The clinical potential of FSD-SSFP has been demonstrated in peripheral arteries (15, 18, 19). However, a large-scale clinical evaluation of the technique has yet to be conducted, particularly in diabetic patients. The detection of infragenual arterial disease may be complicated by alterations in local tissue microstructure and circulation induced by systemic and/or local pathological dynamics of diabetes, potentially making the performance of the flow-based MRA techniques less predictable (20). The aim of this study was to assess the diagnostic performance of FSD-SSFP for detecting calf arterial disease in patients with diabetes, using conventional CE-MRA as the reference standard.

MATERIALS AND METHODS

Patients

This study was approved by the hospital's review board. Informed consent was obtained from all patients. From May 2010 through October 2011, 55 diabetic patients referred for CE-MRA of the lower extremity arteries were consecutively recruited in a single hospital. Ten patients were excluded from the study based on the exclusion criterion for CE-MRA of the hospital (severe renal failure with a glomerular filtration rate [GFR] < 30 ml/min in 4 patients) and general contraindications to MR examination (claustrophobia in 3 patients and pacemaker in 3 patients). Thus, the study population consisted of 45 patients with diabetes diagnosed according to 2006 WHO diabetes criteria (21). Characteristics of the 45 patients were detailed in Table 1. Because calf arteries are more difficult to delineate than pelvic and thigh arteries, NCE-MRA was only performed at calves where significant stenoses are often present in diabetic patients (22). In order to investigate the relationship between image quality and patient characteristic of insufficient renal function, the patients were classified into two subgroups: patients with normal GFR, and patients with insufficient renal function (GFR < 60 ml/min). One patient (a female aged 65 years) underwent X-ray angiography within one week of MR examination to determine if revascularization or bypass surgery would be indicated.

MR Imaging

MRA examinations were performed on a 1.5 T scanner (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany). Two 6-element body matrix coils were positioned anteriorly for bilateral thigh and calf artery imaging, respectively along with a TIM spine coil located posteriorly. Patients were placed feet-first and in the supine position in the scanner. For the calf station, NCE-MRA was performed first and followed by CE-MRA immediately and same coils were used in both scans.

NCE-MRA

NCE-MRA was performed using ECG-triggered 3D segmented SSFP with FSD preparation (15). The 3D imaging volume was prescribed to cover the calves on a scout scan. Cardiac systolic and diastolic phases were determined using a 2D phase-contrast scan and two consecutive measurements of dark-artery and bright-artery were obtained during systole and diastole, respectively. The imaging parameters included: Oblique coronal orientation with bilateral coverage, TE/TR = 1.9/3.8 msec, receiver bandwidth = 965 Hz/pixel, field of view = 400×320×(60–70) mm³, voxel size = 0.9×0.9×0.9 mm³, flip angle = 90°, parallel imaging (GRAPPA) acceleration factor = 2 in the phase-encoding direction, 60 lines per heartbeat, acquisition time = 4–5 min (depending on heart rate). The first-order moments (m1) of the FSD gradient were individually optimized using a scout approach (25–45 mTms²) (23). FSD gradients were applied in the readout direction only, along with the principal flow direction, i.e., in parallel with the anterior/posterior tibial artery. Note that FSD gradients were not applied simultaneously in all three directions as this approach has recently been suggested to be sometimes ineffective for multiple coherent flows (all spins flow along a single direction) in different directions (24).

CE-MRA

Lower extremity CE-MRA was performed with a multi-station technique using a 3D gradient-echo sequence. Based on scout images, three overlapping 3D imaging volumes were prescribed. The coronal image sets were collected before (as a mask) and during intravenous administration of gadopentetate dimeglumine (Gd-DTPA, Magnevist®, Schering AG, Berlin, Germany). Relevant imaging parameters included: TE/TR = 1/3 msec, flip angle = 25°, slab thickness = 1.2 mm, field of view = 320×320 ×96 mm³, matrix size = 256×256, voxel size = 1.2×1.2×1.2 mm³. Parallel imaging (GRAPPA) acceleration factor = 2 in the phase-encoding direction, linear k-space trajectory. The time to collect a single 3D MRA data set was 18–19 sec. After data acquisition of each station, the table was moved by 30 cm to the next table position. The total acquisition time for the three stations was 60 seconds. The contrast transit time from the injection site to the common femoral arteries was determined using a time-resolved axial scan following the administration of a 2-ml test bolus. Gd-DTPA was administered at a dose of 0.2 mmol/kg body weight using an automated injector (Medrad®, Warrendale, PA, USA). The injection rate (2 to 2.5 ml/sec) was adjusted to cover 70% of the total acquisition time, and the tubing was flushed with 30 mL normal saline at the same rate for the remaining time period.

Image Analysis

MRA images were transferred to a workstation (Leonardo, Siemens Healthcare, Erlangen, Germany) for post-processing. Maximum intensity projection (MIP) images of the entire volume and targeted thin slab of the calf arteries were created by an experienced radiologist (L.X.) with standardized post-processing procedures for both CE-MRA and NCE-MRA.

Image quality and severity of arterial stenosis were assessed on MIPs. CE-MRA was evaluated in consensus by two radiologists (P. L. and Q.Y.) with five years of experience in cardiovascular imaging. NCE-MRA was evaluated separately by the same two radiologists using the same criteria as the analysis of CE-MRA. To reduce potential bias, the paired NCE-MRA and CE-MRA images were assessed in random order, with an interval of four weeks in between. The reviewers were allowed to create additional MIP images or check source images if an arterial stenosis was suspected. The two reviewers were not involved in performing the examinations and were unaware of other clinical test information.

Image quality was evaluated on 3 calf arterial segments including anterior tibial artery, posterior tibial artery, and peroneal artery. Each arterial segment was rated on a four-point scale (14, 15): 1, poor delineation due to severe contamination of soft tissue or deep veins accompanying the arteries; 2, fair delineation of arteries with medium contamination of soft tissue or deep veins; 3, good delineation of arteries with minor contamination of soft tissue or deep veins; 4, excellent delineation of major arteries without contamination soft tissue or deep veins. A fractional point of 0.5 was allowed. An image quality score of 2 to 4 was defined as diagnostic image quality and the reasons for nondiagnostic image quality were assessed.

As a quantitative evaluation, arterial blood signal-to-noise ratio (SNR) and artery-tissue contrast-to-noise ratio (CNR) were calculated from the subtracted image sets for both NCE-

MRA and CE-MRA. Signal intensity measurements of arterial blood were performed by one author (Z.N.) using circular regions of interest (ROIs) with an area of 0.02~0.07 cm² for NCE-MRA and 0.08~0.11 cm² for CE-MRA placed within the center at the normal portion of the arterial segments, defined as a region with the highest but also homogeneous signal intensity. Tissue signal intensity was measured from the muscle tissue immediately adjacent to the arteries (ROI area was 1.0 cm²). Because of the inhomogeneous noise distribution with parallel imaging, the mean of standard deviations of background signal intensities in four large ROIs (area was 0.51~1.28 cm²) in the air space without discernible image artifacts were calculated as noise (25). SNR was defined as the measured arterial signal intensity divided by the calculated noise. CNR was defined as the difference in the measured signal intensity between the individual arterial segment and the surrounding muscle tissue divided by the calculated noise.

To investigate the effect of patient characteristics on the image quality of NCE-MRA, a subgroup analysis was performed as described above in patients with and without renal insufficiency.

The severity of arterial stenosis was evaluated visually as normal vessel, vessel irregularities or less than 50% luminal narrowing, 50% or more than 50% luminal narrowing, and occlusion based on segmental evaluation. Stenoses of 50% luminal narrowing or occlusion were considered hemodynamically significant. When two or more stenoses were present in one segment, the most severe lesion was used for severity grading.

Statistical Analysis

The analysis was adjusted for clustering of segments statistically. Among the 45 patients, the image quality score, SNR and CNR of each arterial segment from the two calves were averaged except for two patients who had one leg amputated. To compare NCE-MRA to CE-MRA, a Wilcoxon signed rank test was performed for determining the difference in image quality and a McNemar test for evaluating the difference in the number of diagnostic arterial segments (percentage). For the comparison of quantitative measurements, independent and paired t-test was used to assess the difference of SNR and CNR between the two subgroups of patients and MRA techniques, respectively. A two-tailed p value of 0.05 or less was considered to indicate a significant difference.

The diagnostic sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of NCE-MRA (only on arterial segments that were considered diagnostic on CE-MRA) for detecting significant stenosis were calculated on segmental and patient's basis using CE-MRA as the reference standard. An intention-to-diagnose approach was used for calculating diagnostic accuracy and non-diagnostic segments on NCE-MRA were considered as false (26). Cohen's kappa statistic was used to evaluate interobserver agreement for assessing significant arterial stenosis on NCE-MRA.

CE-MRA was used as the reference standard based on its high diagnostic accuracy for detecting significant arterial stenosis (> 50%) in the leg and has been widely accepted as a routine alternative to invasive digital subtraction angiography for assessing peripheral arterial disease (27, 28).

A statistical software package (SPSS 17.0, Chicago, IL, USA) was used for statistical analyses.

RESULTS

All patients successfully underwent both CE-MRA and NCE-MRA scans. A total of 264 calf arterial segments were obtained in the 45 patients with 88 legs (two patients who had one leg amputated).

NCE-MRA and CE-MRA showed equivalent performance in delineating calf arteries. There was no significant difference in the number of diagnostic arterial segments between the two techniques (258 segments [98%] vs. 260 segments [98%] for NCE-MRA and CE-MRA, respectively, $p = 0.75$). Among the 6 nondiagnostic arterial segments on NCE-MRA, 4 were due to severe soft tissue signal contamination and 2 were due to poor arterial blood SNR. Among the 4 nondiagnostic segments on CE-MRA, all were due to severe venous contamination. Two examples of diagnostic and nondiagnostic images with CE- and NCE-MRA were shown in Figure 1.

Image quality of CE-MRA was slightly higher than that of NCE-MRA (3.5 ± 0.7 vs. 3.3 ± 0.6 , $p < 0.01$). Soft tissue and venous contaminations were the main reasons for the lower image quality with NCE-MRA. There were noticeable residual signals from superficial veins (66 of 88, 76%), soft tissue (60 of 88, 68%), deep veins (62 of 88, 70%), and motion (30 of 88, 34%). With the high isotropic spatial resolution and high artery-tissue CNR, NCE-MRA demonstrated excellent performance for the delineation of luminal narrowing and small collateral arteries that were consistent with CE-MRA, as showed in Figure 2. Figure 3 further demonstrates excellent correlation with X-ray angiography in the patient who underwent conventional angiography. Quantitative analysis shows that SNR and CNR of NCE-MRA are significantly higher than those of CE-MRA for each arterial segment and all segments combined (177 ± 65 vs. 103 ± 36 , $p < 0.01$ and 138 ± 45 vs. 99 ± 35 , $p < 0.01$ for SNR and CNR, respectively). Comparison of image quality and SNR and CNR of arterial segments between CE-MRA and NCE-MRA is provided in Table 2.

Subgroup analysis shows that the image quality of NCE-MRA in patients without kidney damage is significantly higher than that in patients with kidney damage (3.4 ± 0.5 vs. 3.0 ± 0.6 , $p < 0.01$). There are no differences in SNR and CNR between the two patient groups (174 ± 55 vs. 180 ± 73 , $p = 0.67$ and 137 ± 40 vs. 139 ± 49 , $p = 0.86$ for SNR and CNR, respectively) (Table 3).

Of the 260 diagnostic segments on CE-MRA images, 61 segments were identified to have significant stenosis by both two readers on consensus. Among these 61 segments, both readers 1 and 2 identified 59 (Sensitivity 97%) on NCE-MRA images. Of the remaining 199 arterial segments that are either normal or have insignificant stenosis on CE-MRA, 5 segments (anterior tibial artery in 2, posterior tibial artery in 2, and peroneal artery in one) were rated as nondiagnostic on NCE-MRA images and were considered to have a significant stenosis according to the intention-to-diagnose analysis. Thus, 192 (specificity 96%) and 193 (specificity 97%) segments were correctly identified by Reader 1 and Reader 2

respectively based on NCE-MRA images. The average sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of NCE-MRA were 97%, 96%, 90%, 99%, and 96%, respectively on a per-segment basis and 90%, 84%, 82%, 91%, and 87%, respectively on a per-patients basis. The kappa value for interobserver agreement between the two readers was 0.95.

DISCUSSION

We evaluated the diagnostic performance of the newly developed FSD-prepared SSFP NCE-MRA technique for the detection of infragenual arterial disease in patients with diabetes, using CE-MRA as the reference standard. Without the need for gadolinium-based contrast media, the technique demonstrated a high success rate and reliable image quality with high SNR and CNR for the delineation of calf arteries, and consistent diagnostic accuracy for the evaluation of significant stenosis with CE-MRA. The preliminary experience, while limited to diabetic patient population, shows the potential of NCE-MRA as a clinical tool for the evaluation of lower extremity arterial disease in patients with renal insufficiency.

The high image quality of the NCE-MRA technique is primarily attributed to the use of SSFP for data acquisition along with a separate FSD-based dark/bright artery magnetization preparation module. SSFP is ideally suited to MR angiography as it is fast, SNR efficient, and less sensitive to fast flow and complex flow patterns (29, 30). Fast imaging speed permits data acquisition with highly isotropic spatial resolution, improving the diagnostic accuracy for luminal narrowing and visualization of collateral arteries. Inherently high SNR enables excellent differentiation of arterial vasculature from background tissues and deep veins. Insensitivity to fast flow and complex flow patterns relative to other sequences, such as fast spin-echo, allows excellent delineation of severe and diffuse arterial lesions as shown in Figs. 2 and 3. Arterial signal preparation is achieved through the FSD module, separate from the readout sequence, which allows flexibility in flow sensitivity for patients with variable arterial hemodynamics. These features gave rise to high diagnostic performance of FSD-SSFP. In this study, except for the 5 nondiagnostic segments on NCE-MRA images, readers 1 and 2 had only two and one false-positive findings due to overestimation, respectively, and both had two false-negative findings due to underestimation.

The slightly lower image quality of NCE-MRA than CE-MRA was mainly caused by signal contamination from deep veins and soft tissues. FSD-SSFP exploits the different blood flow velocities in arteries and veins to maintain high arterial blood signal while suppressing venous blood signal. As blood flow velocity difference between arteries and veins diminishes in patients (either slow arterial flow or fast venous flow (31)), venous contamination may occur. On the other hand, residual soft tissue signal arises primarily from the signal difference between bright-artery and dark-artery measurements. The diffusion effect induced by the FSD gradients during the dark-artery measurement can result in discernible signal attenuation in soft tissues such as nonvascular fluids. Weighted subtraction may address this issue. Nevertheless, signal contamination from deep veins and soft tissues may not have significant impact on the evaluation of arterial lesions because of the high arterial contrast as well as isotropic spatial resolution of the images.

Because of its ability to adjust flow sensitivity individually by changing FSD gradients, FSD SSFP is well suited for the depiction of arterial flow with various velocities such as in healthy legs (fast flow) or diseased hands (slow flow) (15, 18). In addition, without the restriction of contrast bolus window, the spatial resolution could be increased to submillimeter level, which is highly desired for imaging the tiny pedal arterial segment.

Our study shows that image quality of NCE-MRA is lower in patients with renal insufficiency, resulting from increased deep venous contamination potentially caused by faster deep venous flow. However, kidney insufficiency had no significant effect on arterial SNR and CNR because the bright blood signal with SSFP does not depend on flow velocity. In this study, NCE-MRA had higher SNR and CNR than CE-MRA. However, the overall visibility of the targeted arteries is also dependent on signal contamination from the local soft tissue and veins. Therefore, increased SNR and CNR do not necessarily translate to higher image quality, especially when assessed visually.

With high image quality, NCE-MRA using FSD and SSFP demonstrated higher diagnostic accuracy for significant stenosis compared to previous study (10). The interobserver agreement was also high in this study ($\kappa = 0.95$). Two possible reasons may contribute to the excellent agreement. First, most patients in this study population have noticeable stenosis of the arteries. Second, the diagnosis of significant stenosis is a binary decision. As such, there were not many cases where the decisions would be ambiguous and affect diagnostic accuracy.

There were several limitations to this study. Firstly, due to lack of the invasive x-ray angiography, CE-MRA was used as the reference standard, which may lead to bias in the assessment of diagnostic accuracy. This reflects the fact that invasive X-ray angiography is performed only in patients who need to undergo revascularization or bypass surgery and that CE-MRA has been widely accepted as a method of choice for diagnosing peripheral arterial disease. Secondly, applying FSD gradients in two or three directions could improve the image quality in the segments with the flow perpendicular to the superior-inferior direction (24). Thirdly, thigh arteries were not included in this comparative study. This was due to the fact that peripheral arterial disease mainly occurs in the calf in diabetic patients and it is easier for NCE-MRA to image thigh arteries than thinner calf arteries. Fourthly, NCE-MRA was always performed before CE-MRA, which could be favorable to NCE-MRA image quality. Fifthly, the scan time of NCE-MRA is 4–5 minutes, which is much longer than CE-MRA. In addition, the background tissue may not be fully suppressed in NCE-MRA, and may prevent the display of some small arteries branching from main calf arteries in the MIP images. This loss of signal may be misconstrued as insufficient flow or stenosis. Sixthly, image assessment in this study was mainly focused on the calf arteries. Performance of the technique in other arteries of the lower limbs may need to be evaluated in the future. It is also a limitation that the evaluations of image quality and stenosis severity were based on consensus reads. Comparison of the intra-reader variability associated with each of the two techniques is warranted in the future work. Lastly, only the effect of renal insufficiency on image quality of NCE-MRA was analyzed. Further studies should be performed to investigate the relationship between image quality and other patient characteristics such as age, blood glucose level, hypertension, and heart attack.

In conclusion, NCE-MRA using FSD SSFP demonstrated adequate image quality in the delineation of calf arteries and consistent diagnostic performance for detecting significant stenosis with CE-MRA in patients with diabetes. The technique can obtain isotropic, high spatial resolution images of the small arteries at the lower extremities without the use of contrast agent. It provides a good alternative to CE-MRA for the evaluation of calf arterial disease in diabetic patients with renal insufficiency or those who can not receive contrast agent.

Acknowledgments

Grant Support:

National Natural Science Foundation of China (Grant Number 81071147 and 81120108012), National Basic Research Program 973 (Grant No. 2011CB707903), Key Project of Shenzhen Basic Research Program [Grant Number JC201005270317A], National Institutes of Health of USA (Grant Number 1R01HL096119), and American Heart Associate (Grant Number AHA11POST7650043)

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Figure 1.

Contrast-enhanced MR angiography (CE-MRA) (a) and noncontrast-enhanced MRA (NCE-MRA) (b) maximum intensity projections (MIP) images of bilateral calf in a 56-year-old man with diabetes. On NCE-MRA images, right calf arteries are nondiagnostic due to the poor arterial blood SNR and noticeable artifacts of soft tissue. The distal segments of left calf arteries are also nondiagnostic due to noticeable artifacts of soft tissue. CE-MRA (c) and NCE-MRA MIP images (d) of bilateral calf arteries in a 63-year-old man with diabetes. On CE-MRA images, left calf arterial segments are nondiagnostic due to severe venous contamination. On NCE-MRA images, multiple significant stenoses (arrow) were depicted in the right anterior tibia artery, which are consistent with the findings on CE-MRA images.

Figure 2.

Contrast-enhanced magnetic resonance angiography (CE-MRA) (a) and noncontrast-enhanced MRA (NCE-MRA) (b) MIP images demonstrate diffused severe lesions in the calf arteries in a 57-year-old man with diabetes. NCE-MRA allows good delineation of the complex arterial lesions with better resolution and less venous contamination compared to CE-MRA. All images demonstrate occlusions in the right anterior tibia artery (ATA) and posterior tibia artery (PTA) and extensive collaterals in the right arteries (arrowheads).

a

C

Figure 3.

Contrast-enhanced magnetic resonance angiography (CE-MRA) (a) and noncontrast-enhanced MRA (NCE-MRA) (b) MIP images and x-ray angiography image (c) of right upper calf in a 65-year-old woman with diabetes. NCE-MRA clearly depicts luminal narrowing at the proximal anterior tibial artery and peroneal artery consistent with x-ray angiography (arrows). Also, NCE-MRA clearly depicts collaterals (arrowheads) with less

venous contamination compared to CE-MRA in the location of a complete occlusion of proximal posterior tibia artery (PTA).

Table 1

Characteristics of the patients with and without renal insufficiency

Characteristics	Patients with renal insufficiency (n=21)	Patients with normal renal function (n=24)	p value
Age (mean/range)	61 ± 10/41 to 77 yrs	55 ± 11/34 to 76 yrs	0.135
Sex (male/female)	13/10	14/8	0.837
Fasting plasma glucose level (mean/range)	9.2 ± 3.0/5.3 to 14.9 mmol/L	6.9 ± 3.0/3.3 to 13.2 mmol/L	0.416
Two hours after meal glucose level (mean/range)	16.1 ± 5.9/8.3 to 28.2 mmol/L	14.7 ± 5.5/8.5 to 25.5 mmol/L	0.667
Systolic blood pressure (mean/range)	139 ± 20/90 to 180 mmHg	128 ± 14/100 to 150 mmHg	0.059
Diastolic blood pressure (mean/range)	81 ± 12/66 to 98 mmHg	78 ± 11/65 to 98 mmHg	0.134
Type 1 diabetes mellitus	0	1 (4%)	0.350
Type 2 diabetes mellitus	21 (100%)	23 (96%)	0.350
Intermittent claudication	5 (24%)	4 (17%)	0.555
Rest pain	8 (38%)	5 (21%)	0.208
Diabetic foot	8 (38%)	6 (25%)	0.349
Diabetic retinopathy	14 (67%)	11 (46%)	0.165
Neuropathy	16 (76%)	12 (50%)	0.074
Heart attack	5 (24%)	5 (21%)	0.813
Hypertension	13 (62%)	10 (42%)	0.180
Amputation (unilateral leg)	2 (9%)	0	0.126
BMI (Body Mass Index)	15.72 ± 12.44	12.53 ± 12.42	0.405

Table 2

Comparison of image quality and signal noise ratio (SNR) and contrast noise ratio (CNR) of arterial segments between contrast-enhanced magnetic resonance angiography (CE-MRA) and noncontrast-enhanced MRA (NCE-MRA) in 45 patients with diabetes

Arterial segments	Image quality			SNR			CNR		
	CE-MRA	NCE-MRA	P value	CE-MRA	NCE-MRA	P value	CE-MRA	NCE-MRA	P value
Anterior tibial artery (n=45)	3.5±0.7	3.3±0.6	0.113	105 ± 43	178 ± 71	<0.001	102 ± 43	142 ± 51	0.001
Peroneal artery (n=45)	3.4±0.7	3.2±0.6	0.228	94 ± 29	166 ± 62	<0.001	90 ± 27	125 ± 37	<0.001
Posterior tibial artery (n=45)	3.5±0.6	3.3±0.6	0.016	110± 34	189 ± 64	<0.001	107 ± 34	150 ± 44	<0.001
All segments of calf (n=135)	3.5±0.7	3.3 ± 0.6	0.003	103 ± 36	177 ± 65	<0.001	99 ± 35	138 ± 45	<0.001

Note: The analysis is adjusted for clustering of segments statistically by averaging the values of each arterial segment from the two legs and thus a total of 45 arterial segments were available for assessing the image quality score, SNR and CNR. Data of NCE-MRA are averaged values by readers 1 and 2. P values were derived using Wilcoxon signed rank test for image quality and paired t-test for assessing the difference of SNR and CNR.

Table 3

Comparison of image quality, signal noise ratio (SNR) and contrast noise ratio (CNR) of noncontrast-enhanced magnetic resonance angiography (NCE-MRA) in patients with (n=21) and without (n=24) kidney damage

Arterial segments	Image quality			SNR			CNR		
	Patients ¹	Patients ²	P value	Patients ¹	Patients ²	P value	Patients ¹	Patients ²	P value
Anterior tibial artery	3.5 ± 0.5	3.2 ± 0.6	0.080	172 ± 54	184 ± 87	0.667	142 ± 40	141 ± 62	0.979
Peroneal artery	3.4 ± 0.6	3.0 ± 0.7	0.057	156 ± 52	175 ± 69	0.391	118 ± 37	130 ± 38	0.412
Posterior tibial artery	3.5 ± 0.5	3.0 ± 0.7	0.003	198 ± 54	183 ± 72	0.555	153 ± 37	147 ± 49	0.713
All segments of calf	3.4 ± 0.5	3.0 ± 0.6	<0.001	174 ± 55	180 ± 74	0.667	137 ± 40	139 ± 48	0.859

Notes: patients¹ represent patients without kidney damage; patients² represent patients with kidney damage.