Clinical advances in cardiovascular magnetic resonace imaging and angiography

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Chapter 6

Peripheral Arterial Occlusive Disease: 3.0-T versus 1.5-T MR Angiography Compared with Digital Subtraction Angiography

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Radiology 2013; 266:337-346

Abstract

Purpose
To prospectively evaluate the diagnostic accuracy of 3-T versus 1.5-T contrast material–enhanced (CE) magnetic resonance (MR) angiography with high spatial resolution in patients who have peripheral arterial occlusive disease, with conventional digital subtraction angiography (DSA) serving as the reference standard.

Materials and Methods
Institutional review board approval and written informed consent were obtained. DSA and standardized single-injection, three-station, moving-table CE MR angiography, with similar acquisition protocols and contrast agent doses at 3 T and 1.5 T, were consecutively performed in 19 patients (13 men and six women; mean age ± standard deviation, 67 years ± 9). Stenosis was scored visually in 500 arterial segments (97.5% of all available) in consensus by two radiologists in a blinded manner (the radiologists were unaware of the field strength and prior DSA and MR angiographic results and used randomized analysis order). Contrast-to-noise ratio was determined in the vascular tree of both legs. Statistical significance in stenosis scoring was evaluated by using generalized estimating equations. Contrast-to-noise differences were evaluated with paired *t* tests. Agreement between MR angiography and DSA was evaluated by using Fleiss-Cohen κ statistics.

Results
Both 3-T and 1.5-T CE MR angiography showed similar excellent agreement with DSA regarding stenosis classification (κ =0.96 and 0.93, respectively). All sensitivity and specificity values exceeded 90%. Mean contrastto-noise ratio was 3.0–4.2 times higher at 3 T than at 1.5 T.

Conclusion
Standardized single-injection, three-station, moving-table 3-T CE MR angiography is reliable for classification of stenosis in patients suspected of having peripheral arterial occlusive disease, and diagnostic performance was similar to that seen with 1.5-T MR angiography. There was a significantly increased contrast-to-noise ratio for identical contrast agent dose at 3-T MR angiography.

Introduction

Contrast material–enhanced (CE) magnetic resonance (MR) angiography has evolved in recent years into a reliable imaging technique in patients with peripheral arterial occlusive disease (PAOD). Previous studies have shown good correlation between CE MR angiography and conventional digital subtraction angiography (DSA) for stenosis detection.[1–4]

In clinical routine, CE MR angiography with 1.0-T and 1.5-T MR imagers is now widely used for diagnosis and treatment planning. In daily practice, a single-injection, three-station, multiposition CE MR angiographic protocol covering the peripheral arterial tree from the aorta to the lower legs is a clinically accepted routine.[5,6] Other examination approaches have also been reported, such as moving-table hybrid CE MR angiography[7–9] and step-bystep CE MR angiography.[10]

In the past few years, high-fieldstrength 3-T whole-body MR imaging units have been introduced in clinical practice. The potential benefit of 3-T MR imaging is an increased signal-tonoise ratio (SNR), which enables acquisition with higher spatial resolution within a similar imaging time and with similar contrast agent dose.[11,12]

Until recently, a drawback of 3-T whole-body MR imaging units was a restricted field of view (FOV) compared with 1.5-T MR imaging due to the limited homogeneity of the magnetic field; this limited FOV hampered imaging of large anatomic regions.[13] Advances in MR imaging technology, such as improved integrated quadrature whole-body coils, have led to the availability of a large homogeneous magnetic field. Thus, the FOV at 3 T is similar to that with 1.5 T, which allows visualization of the complete runoff vascular tree with a single-injection, three-station, moving-table protocol.

Several studies have shown that 3-T CE MR angiography is feasible in large vascular territories, such as the abdominal arteries[14] and other regions.[15,16] Recent reports showed promising results in patients who have PAOD with use of a time-resolved CE MR angiographic approach,[17] high-acceleration parallel imaging,[18,19] and blood pool agents.[20] However, to our knowledge, no previously published study has evaluated the diagnostic accuracy of peripheral CE MR angiography with a single-injection, three-station, moving-table protocol at 3 T versus 1.5 T.

The hypothesis of our study was that because of these recent advances in 3-T MR imaging technology—which offers FOV similar to that available with 1.5-T MR imaging—single-injection, three-station, moving-table 3-T CE MR angiography will offer diagnostic performance at least similar to that of 1.5-T CE MR angiography in patients with PAOD. Therefore, the purposes of our study were to prospectively evaluate the diagnostic accuracy of 3-T CE MR angiography with high spatial resolution in patients with PAOD and to compare it with that of 1.5-T CE MR angiography involving a similar acquisition protocol, with conventional DSA serving as the reference standard.

Materials and Methods

Patients

In our study, 20 consecutive patients clinically suspected of having PAOD were included from July 2008 to February 2009. Patients were referred to our department for further work-up. This sample size potentially results in 540 evaluable arterial segments, a number similar to or higher than that reported in previously published studies that compared CE MR angiography with DSA.[3,6,9,10,19,20]

Seventeen patients (85%) presented with intermittent claudication (Fontaine classification, 2): 10 patients (50%) with pain-free claudication while walking more than 200 m and seven patients (35%) with pain-free claudication while walking less than 200 m. One patient (5%) presented with pain at rest (Fontaine classification, 3) and two patients (10%) had necrosis (Fontaine classification, 4).

The institutional review board approved the study, and written informed consent was obtained from all patients. One patient (Fontaine classification, 2) was excluded because of claustrophobia. Therefore, 19 patients (13 men and six women; mean age ± standard deviation [SD], 67 years ± 9; range, 53–82 years) underwent peripheral CE MR angiography at both 3-T and 1.5-T MR imaging (order was defined per available examination time slot). Both CE MR angiographic examinations were performed within a 1-week period in which no intervention occurred. DSA was performed within a mean of 23 days (range, 6–33 days) after the latest CE MR angiographic examination (with no vascular intervention taking place between CE MR angiography and DSA). DSA was used as the reference standard.

CE MR angiography was performed with 3-T MR imaging (Achieva X-series, release 2.1; Philips Healthcare, Best, the Netherlands) and 1.5-T MR imaging (Achieva, release 2.5; Philips Healthcare). In all patients, the glomerular filtration rate was greater than 60 mL/min per 1.73 m^2. No adverse reactions or complications occurred during or after MR angiography or DSA.

MR Angiographic Protocols

A three-station, single-injection protocol was used for both 3-T and 1.5-T CE MR angiography. A biphasic contrast agent protocol was used. Gadoterate meglumine (Guerbet, Paris, France), 0.2 mmol per kilogram of body weight, was injected by using an MR imaging–compatible injector (Spectris MR injector; Medrad, Indianola, Pa).The first half of the contrast agent bolus was administered at 1.2 mL/sec and the remaining half at 0.6 mL/sec. Contrast agent injection was followed by 15-mL saline flush at 0.6 mL/sec. To determine timing of arrival of contrast agent, a 2-mL test bolus was administered at 1.2 mL/sec, followed by 15-mL saline flush at 1.2 mL/sec.

For 1.5-T CE MR angiography, a quadrature body coil was used for signal transmission

and reception in the pelvic and thigh stations and a four-element phased-array coil was used for the calf station. For 3-T CE MR angiography, a quadrature body coil was used in all three stations. In this study, imaging parameters at 3-T CE MR angiography were intentionally kept similar to those used for 1.5-T CE MR angiography. Imaging parameters of the three-dimensional fast gradient-echo sequences at 3-T and 1.5-T CE MR angiography are presented in Table 6.1. At 1.5-T CE MR angiography, the first station was acquired with linear k-space filling; at 3-T CE MR angiography, reversed linear k-space filling was used. At both MR angiographic protocols, the second and third stations were acquired with centric k-space filling. Table speed was set at 180 mm/sec between all imaged stations.

Table 6.1 Acquisition parameters for 1.5T and 3T contrast-enhanced MRA.

	1.5T CE-MRA				
station	**TR/TE**	**flip angle (°)**	**FOV (mm)**	**acquisition resolution (mm^3)**	**acquisition time (s)**
Pelvic	2.5/1.00	25	430	1.28×1.68×3.00	13.3
Thigh	2.5/1.00	25	430	1.28×1.68×3.00	13.3
Calf	4.7/1.45	25	430	0.96×1.07×1.40	43.2
	3T CE-MRA				
Pelvic	3.6/1.25	20	410	1.25×1.84×3.70	14.6
Thigh	3.6/1.26	20	410	1.30×1.75×3.00	14.6
Calf	5.5/1.80	30	410	0.80×0.90×1.40	74.7

CE: contrast-enhanced; TR: repetition time msec; TE: echo time msec; FOV: Field-of-View.

DSA Imaging

DSA was performed with a dedicated angiographic system (Multistar T.O.P.; Siemens Medical Engineering, Forchheim, Germany) by using nonionic contrast agent (iomeprol, Iomeron 350; Bracco s.p.a., Milan, Italy). The tip of a 4-F pigtail or straight catheter was positioned in the infrarenal abdominal aorta after retrograde puncturing of the common femoral artery and insertion of a 5- or 6-F introducer sheath (Cordis, Rhoden, the Netherlands). DSA images of the infrarenal aorta and iliac arteries were obtained in anteroposterior, leftoblique, and right-oblique projections. For each series, a 15-mL contrast bolus was administered with a power injector (Medrad, Warrendale, Pa) at a flow rate of 18 mL/sec. Typically, 117–124 mL of contrast agent was administrated. A 5-F celiac catheter (Cordis) was used for selective catheterization of the contralateral extremity, and, unless there was an iliac occlusion, the catheter tip was placed in the external iliac artery. The imaging protocol for the contralateral extremity included acquisition of overlapping images from the common femoral artery down to the dorsal pedal artery by repeated 7-mL manual injections of contrast agent. Magnification views of suspected stenoses were obtained in two orthogonal projections. When image quality in the calf station was not adequate, an intraarterial vasodilator was administered (slow manual injection of 25 mg papaverine [Pharma Chemie, Haarlem, the Netherlands]) to optimize delivery of contrast agent.

The celiac catheter was then removed and DSA of the ipsilateral extremity was performed by manual injection of contrast agent through the femoral sheath. Imaging parameters included a matrix of 1024 x 1024 and FOV of 14–40 cm. All procedures were performed by two interventional radiologists (L.D. and A.T., with >15 and 20 years of experience with DSA, respectively).

Quantitative Data Analysis

MR angiographic images were presented in random order, and observers were blinded to the MR field strength and patient information. The 1.5-T and 3-T images were reviewed intermixed at random and in consensus by two MR radiologists (H.v.d.B. and R.C., with 14 and 5 years of experience with CE MR angiography, respectively); the reviewers were unaware of the results of prior CE MR angiographic or DSA examinations but did know the total number of examinations per patient. DSA images were reviewed in consensus by the same two interventional radiologists (L.D. and A.T.), who were unaware of CE MR angiographic findings.

The arterial tree in each patient was divided into the following 27 segments: the infrarenal aorta, common iliac arteries, external iliac arteries, common femoral arteries, superficial femoral arteries, popliteal arteries in the thigh station, popliteal arteries in the calf station, tibiofibular trunk, and the proximal and distal halves of the anterior and posterior tibial arteries and peroneal arteries. The dorsalis pedis and plantar arteries were not completely included in the FOV. The most severe stenosis in each segment was presented in the classification. Stenosis severity was visually graded according to the following equation: percentage stenosis = [1 - (*D/N)]* x 100%, where *D* is the minimal diameter in the stenosis and *N* is the normal diameter, visually estimated from a reference diameter proximal and distal to the lesion. Categories of percentage stenosis were as follows: 1 (0%), normal vessel; 2 (1%–50%), wall irregularities or mild stenosis; 3 (51%–75%), moderate stenosis; 4 (76%–99%), severe stenosis; and 5 (100%), occlusion. Stenoses were graded on maximum-intensity-projection images and on source images. Both CE MR angiographic and DSA images were analyzed on a remote workstation.

Quantitative analysis of SNR and contrast-to-noise ratio (CNR) for the external iliac artery, superficial femoral artery, and popliteal artery in the right and the left leg of each patient were calculated by one radiologist (H.v.d.B.). Regions of interests to determine signal intensity were manually defined and equivalent in size and location for 3 T and 1.5 T (calculation of signal intensity was not blinded). An additional region of interest (approximately 10 cm^2) was placed in the FOV but was outside the patient's body to determine the SD of noise. SNR was calculated by dividing signal intensity measured in the artery by SD of noise. CNR was defined by signal intensity measured in the artery compared with signal intensity in the surrounding tissue, divided by SD of noise.

Statistical Analysis

Only segments that were evaluated with both 3-T and 1.5-T CE MR angiography and DSA were considered. Sensitivity, specificity, and positive and negative predictive values, with DSA as the reference standard, were calculated for the following categories of stenosis scoring in each segment: stenosis >0% (1%–100%), stenosis >50% (51%–100%), stenosis >75% (76%–100%), and occlusion (100% stenosis). Regression modeling of proportions was performed by using generalized estimating equations with the use of a robust estimator for the covariance matrix and an autoregressive correlation matrix to take data clustering within the same patient into account.[21] In addition, 95% confidence intervals (CIs) were determined for sensitivity, specificity, and positive and negative predictive values; 95% CIs and *p* values were obtained for differences in these proportions in case of no complete agreement. A *p* value of less than .05 was considered to represent a statistically significant difference. Continuous variables are expressed as the mean ± SD (range) when appropriate. CNR values are also presented by median and quartiles in box-plot presentation. Statistical significance of the differences in CNR at 3 T and 1.5 T was evaluated with a paired *t* test. Agreement between both 1.5-T and 3-T CE MR angiography and DSA regarding stenosis classification was evaluated by using the Fleiss-Cohen quadratic weighted κ statistics, and κ was interpreted as follows: κ value of 0 indicates poor agreement; κ value of 0.01–0.20, minor agreement; κ value of 0.21–0.40, fair agreement; κ value of 0.41–0.60, moderate agreement; κ value of 0.61–0.80, good agreement; and κ value of 0.81–1; excellent agreement.[22] Statistical analysis was performed with SPSS software, version 17 (IBM, Somers, NY).

Results

In 19 of 20 patients, 3-T and 1.5-T CE MR angiography and DSA of the peripheral arteries were successfully performed (see an example in Figure 6.1). Mean total contrast agent dose for DSA was 119 mL ± 10. For CE MR angiography, 13 of 513 segments (2.5%) could not be evaluated because of venous enhancement or patient movement. In four patients, venous enhancement occurred in the calf station at 3-T or 1.5-T CE MR angiography. Two of these patients presented with claudication, one patient with rest pain, and one patient with necrosis. In these four patients, venous enhancement occurred in only one of either MR angiographic examination. In these patients, eight segments (1.5%) showed impaired image quality, resulting in nonevaluable images. Because of movement artifacts in two patients, five segments (1%) were also excluded. Maximal number of evaluable segments per patient was 27, and the minimal number of segments was 24 (mean, 26.2). From the remaining total of 500 segments, 105 segments (21%) were appointed with a relevant stenosis (class 2 or higher) at DSA. The 395 segments classified as class 1 (no stenosis) at DSA were also

classified as class 1 at both 1.5-T and 3-T CE MR angiography. Stenosis classification in the remaining 105 segments was compared for 3-T and 1.5-T CE MR angiography, with DSA serving as the reference standard.

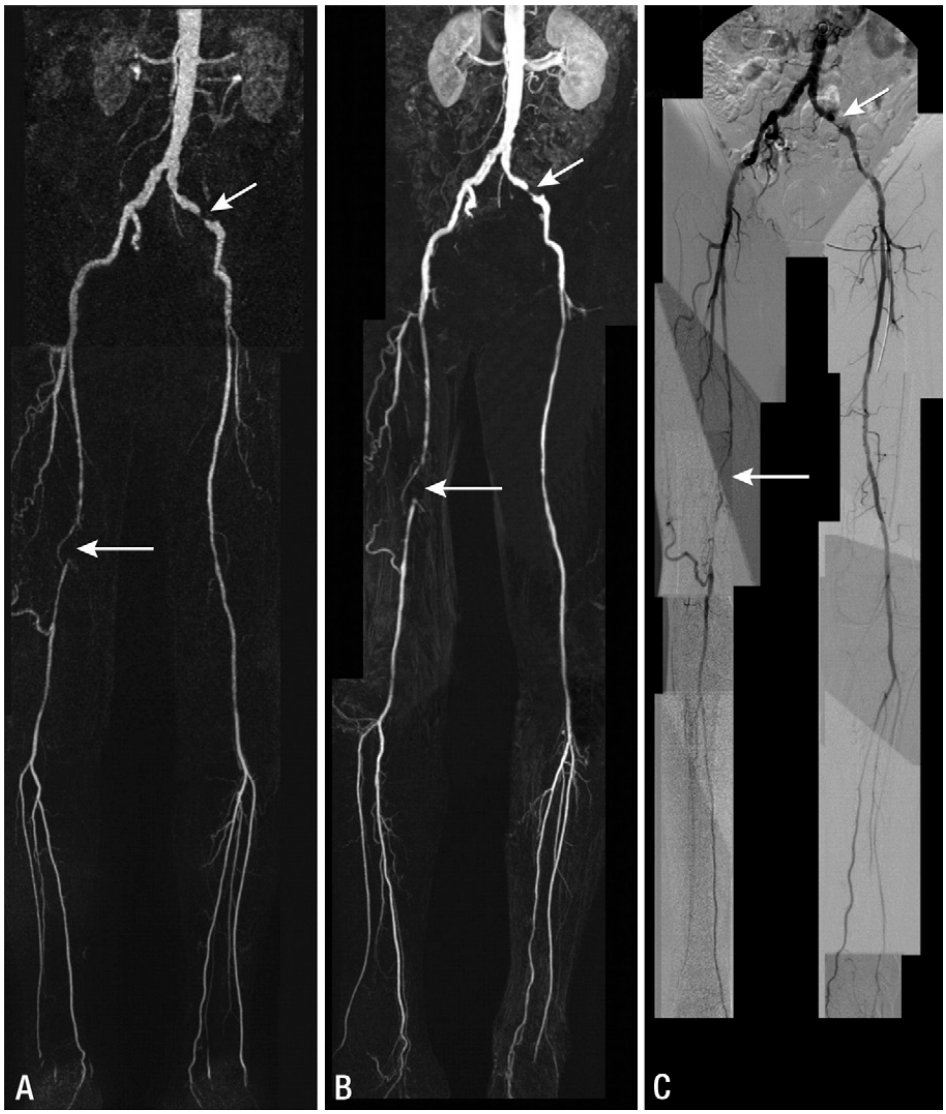

Figure 6.1 Coronal CE MR angiographic maximum-intensity-projection images in 67-year-old man presenting with bilateral claudication. **(A**) 1.5-T and, **(B)** 3-T CE MR angiographic images show a significant stenosis of 80% in the left external iliac artery (short arrow) and an occlusion in the right superficial femoral artery (long arrow). **(C**) There is excellent correlation between MR angiography and DSA, with selective catheterization of both extremities.

Quantitative Analysis of Stenosis Classification

Sensitivity, specificity, and positive and negative predictive values were determined for detection of stenosis greater than 0%, greater than 50%, greater than 75%, and 100% stenosis in each segment with 3-T and 1.5-T CE MR angiography. The results are presented in Table 6.2. For stenosis classification >50%, sensitivity of 3-T CE MR angiography was 99% and sensitivity of 1.5-T CE MR angiography was 92%, with a mean difference of 7 percentage points in favor of 3-T CE MR angiography (p=.052). The lower limit of the CI showed that in 2.5% of the cases, sensitivity of 3-T CE MR angiography still can be 1 percentage point inferior to 1.5-T CE MR angiography. Specificity of 3-T CE MR angiography was 0.1 percentage point inferior to 1.5-T CE MR angiography (p=.30). For stenosis classification >75%, sensitivity of 3-T CE MR angiography was 95% and sensitivity of 1.5-T CE MR angiography was 92%, with a mean difference of 3 percentage points in favor of 3-T CE MR angiography (p=.30). The lower limit of the CI showed that for 2.5% of the cases, sensitivity of 3-T CE MR angiography still can be 3 percentage points inferior to that of 1.5-T CE MR angiography. A maximal value of a 3–percentage point difference in sensitivity may be considered as clinically irrelevant; therefore, the diagnostic performance of 3-T CE MR angiography is considered similar to that of 1.5-T CE MR angiography with use of similar acquisition protocols and contrast agent dose. Specificity was identical for both 3-T and 1.5-T CE MR angiography for stenosis classification >75%. For detection of stenosis >0% and for occlusion detection, sensitivity and specificity of both 3-T and 1.5-T CE MR angiography were identical.

For stenosis classification in each segment, both 3-T and 1.5-T CE MR angiography showed excellent concordance with DSA (κ = 0.96 and 0.93, respectively; cross-tables are presented in Tables 6.3 and 6.4). Agreement between 3-T and 1.5-T CE MR angiography was also very high (κ =0.98; Table 6.5).

Quantitative SNR and CNR Analysis

Mean values ± SDs for SNR and CNR at 1.5-T and 3-T CE MR angiography, measured in the external iliac artery, superficial femoral artery, and popliteal artery, are presented in Table 6.6 for both the left and the right leg. Mean values were for all anatomic regions that were higher at 3-T than at 1.5-T CE MR angiography (all p<.001). Table 6.7 presents the ratios between 1.5-T and 3-T CE MR angiographic SNR and CNR for all anatomic regions. The SNR was on average 2.8–3.9 times higher at 3-T than at 1.5-T CE MR angiography, and the CNR was on average 3.0–4.2 times higher (see an example for the superficial femoral artery in Figure 6.2). Results for CNR for both MR angiographic protocols are also presented in a box plot (Figure 6.3).

Table 6.2 Diagnostic performance for stenosis detection at 3T versus 1.5T contrast-enhanced MRA.

	Stenosis >0%		**Stenosis >50%**		**Stenosis >75%**		**Occlusion**	
	3T	**1.5T**	**3T**	**1.5T**	**3T**	**1.5T**	**3T**	**1.5T**
sensitivity	100% (105/105)	100%	98%	92%	93%	90%	97%	97%
	96%–100%	(105/105)	(63/64)	(59/64)	(56/60)	(54/60)	(35/36)	(35/36)
95%-CI		96%–100%	92%–100%	83%–97%	84%–97%	80%–95%	86%–100%	86%–100%
Difference	not applicable		6%		3%		not applicable	
95%-CI	(complete agreement)		-1%–15%		-3%–11%		(complete agreement)	
p-value McNemar	not applicable		0.13		0.48		not applicable	
	(complete agreement)						(complete agreement)	
specificity	100%	100%	99.5%	99.5%	100%	100%	100%	100%
	(395/395)	(395/395)	(434/436)	(434/436)	(440/440)	(440/440)	(464/464)	(464/464)
95%-CI	99%–100%	99%–100%	98%–100%	98%–100%	99%–100%	99%–100%	99%–100%	99%–100%
p-value McNemar	not applicable		not applicable		not applicable		not applicable	
	(complete agreement)		(complete agreement)		(complete agreement)		(complete agreement)	
positive predictive	100%	100%	97%	97%	100%	100%	100%	100%
value	(105/105)	(105/105)	(63/65)	(59/61)	(56/56)	(54/54)	(35/35)	(35/35)
		96%–100%	89%–99%	89%–99%	94%–100%	93%–100%	90%–100%	90%–100%
95%-CI	96%–100%							
p-value McNemar	not applicable		0.68		0.48		not applicable	
	(complete agreement)						(complete agreement)	
negative predictive	100%	100%	99.8%	99%	99%	99%	99.8%	99.8%
value	(395/395)	(395/395)	(434/435)	(434/439)	(440/444)	(440/446)	(464/465)	(464/465)
95%-CI	96%–100%	99%–100%	99%–100%	97%–100%	98%–100%	97%–100%	99%–100%	99%–100%
p-value McNemar	not applicable		0.37		0.68		not applicable	
	(complete agreement)						(complete agreement)	

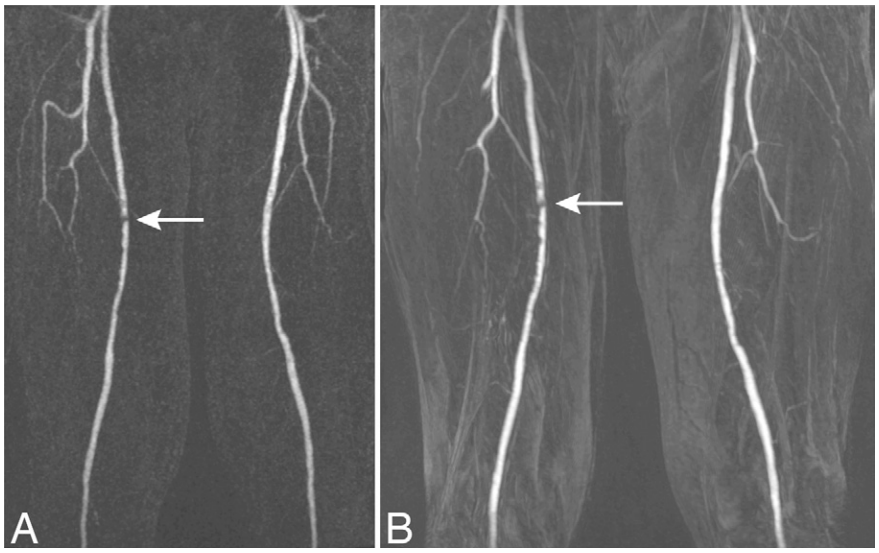

Figure 6.2 Coronal CE MR angiographic maximum-intensity-projection images of the thigh station in a 66-year-old man who presented with right-sided claudication. **(A)** 1.5-T and, **(B)** 3-T CE MR angiographic images show significant stenosis (.75%) in the right superficial femoral artery (arrow). The 3-T CE MR angiographic image presents a 2.0 times higher SNR and 1.9 times higher CNR in the superficial femoral artery with the same contrast dose, as compared with the 1.5-T CE MR angiographic image.

Table 6.3 Agreement between 3T contrast-enhanced MRA and DSA**.**

			DSA		
Stenosis Class per 3-T CE MR Angiography	**1**	**2**	**3**	**4**	**5**
1	395	0	0	0	0
2	0	39	0	0	1
3	0	2	4	3	0
4	0	0	0	21	0
5	0	0	0	0	35

Values are numbers of segments. Class 1, 0% stenosis; class 2, 1%–50%; class 3, 51%–75%; class 4, 76%-99%; class 5: 100%. κ = 0.96.

Table 6.4 Agreement between 1.5T contrast-enhanced MRA and DSA**.**

			DSA		
Stenosis Class per 1.5-T CE MR Angiography	**1**	**2**	**3**	**4**	**5**
1	395	0	0	0	0
2	0	39	2	2	1
3	0	2	2	3	0
4	0	0	0	19	0
5	0	0	0	0	35

Values are numbers of segments. Class 1, 0% stenosis; class 2, 1%–50%; class 3, 51%–75%; class 4, 76%-99%; class 5, 100%. κ = 0.93.

Table 6.5 Agreement between 3T and 1.5T contrast-enhanced MRA.

	DSA				
Stenosis Class per 3-T MR Angiography	**1**	**2**	**3**	**4**	**5**
1	395	0	0	0	0
2	0	41	0	0	0
3	0	2	6	0	0
4	0	1	1	19	0
5	0	0	0	0	35

Values are numbers of segments. Class 1, 0% stenosis; class 2, 1%–50%; class 3, 51%–75%; class 4, 76%–99%; class 5, 100%. κ = 0.98.

Table 6.6 SNR and CNR on 1.5T and 3T CE-MRA

	1.5T CE-MRA				3T CE-MRA			
	SNR	***p***	**CNR**	***p***	**SNR**	***p***	**CNR**	***p***
left external iliac artery	23±5	0.91	21±5	0.88	61±18	0.95	58±17	0.71
right external iliac artery	23±6		21±6		61±20		57±19	
left superficial femoral artery	34±10	0.60	30±10	0.81	108±34	0.22	96±31	0.39
right superficial femoral artery	32±11		29±10		100±47		92±42	
left popliteal artery	26±8	0.48	23±8	0.15	92±46	0.84	84±43	0.86
right popliteal artery	25±9		22±9		92±44		84±39	

SNR: signal-to-noise ratio; CNR: contrast-to-noise ratio.

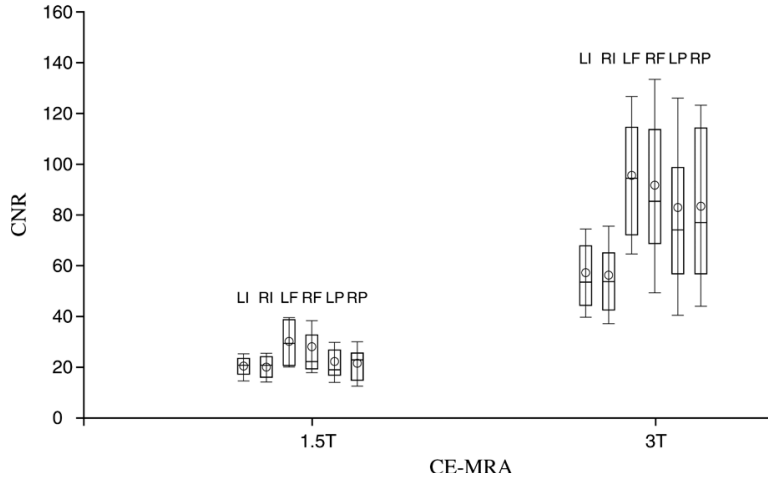

Figure 6.3 Box plot of CNR determined in external iliac artery, superficial femoral artery, and popliteal artery in both left and right leg, imaged with 3-T and 1.5-T CE MR angiography, respectively. Circle in each box represents mean; error bar, standard deviation; box, first and third tertile; and horizonal lines, medians. LF= left femoral; LI = left iliac; LP = left popliteal; RF = right femoral; RI = right iliac; RP = right popliteal.

Table 6.7 Ratios for SNR and CNR between 3T versus 1.5T CE-MRA, measured in the external iliac artery, superficial femoral artery and popliteal artery, in both the left and right leg.

	SNR 3T vs. 1.5T	CNR 3T vs. 1.5T
left external iliac artery	2.8±1.2 (1.5-5.8)	3.0±1.4 (1.6-6.8)
right external iliac artery	2.8±1.2 (1.7-6.2)	3.0±1.4 (1.7-7.0)
left superficial femoral artery	3.4±1.3 (1.4-6.1)	3.4±1.4 (1.4-6.2)
right superficial femoral artery	3.3±1.7 (0.8-7.4)	3.4±1.7 (0.9-7.5)
left popliteal artery	3.8±1.9 (1.2-8.5)	3.9±1.9 (1.3-8.2)
right popliteal artery	3.9±2.3 (1.2-11.1)	4.2±2.4 (1.3-11.5)

SNR: signal-to-noise ratio; CNR: contrast-to-noise ratio

Discussion

In our study, the diagnostic accuracy of single-injection, three-station, moving- table 3-T CE MR angiography was prospectively evaluated in patients with PAOD and compared with that of 1.5-T CE MR angiography, with conventional DSA serving as the reference standard. The main findings of our study are as follows: *(a)* 3-T CE MR angiography showed similar excellent agreement with DSA when compared with 1.5-T CE MR angiography regarding agreement, sensitivity, and specificity for classification of stenosis severity; *(b)* 3-T CE MR angiography achieved, on average, 3.0–4.2 times higher (p<.001) CNR in the external iliac artery, superficial femoral artery, and popliteal artery in both the left and the right leg when compared with 1.5-T CE MR angiography and with use of the same contrast agent dose.

In the imaging work-up of patients with PAOD, noninvasive techniques, such as duplex ultrasonography, computed tomographic (CT) angiography, and CE MR angiography, have become increasingly important. Although DSA is the generally accepted reference standard, noninvasive techniques have proved to be accurate for stenosis assessment.[1,3,5,6,23,24] Moreover, CT angiography and CE MR angiography can provide a detailed roadmap for treatment planning. CE MR angiography has two main advantages over CT angiography: MR angiography provides radiation-free imaging and does not disturb the overlay of calcified plaques (which would hamper stenosis assessment).

To our knowledge, this is the first study to prospectively compare the diagnostic value of 3-T versus 1.5-T CE MR angiography by using a moving-table technique in patients with PAOD, with DSA serving as the reference standard. Since the introduction of 3-T MR imaging in clinical practice, the limited FOV at 3 T hampered the imaging of large anatomic regions.[12,13] Recently, advances in MR imaging technology, such as an improved integrated quadrature body coil, have made possible a large homogeneous magnetic field and, therefore, an FOV at 3-T that is similar to that seen with 1.5-T MR imaging. Our study was performed with 3-T MR imaging with an FOV of 45 cm, as compared with a 48-cm FOV with 1.5-T MR imaging. These large FOVs enable

visualization of the peripheral arterial tree from the aorta to the lower legs with a single-injection, three-station, moving-table technique. We used three overlapping FOVs for both methods: 430 mm each at 1.5-T and 410 mm each at 3-T CE MR angiography. For both 1.5-T and 3-T CE MR angiography, overlap was 30 mm, resulting in total coverages of 1200 mm and 1140 mm for 1.5-T and 3-T CE MR angiography, respectively.

A well-shimmed 3-T MR imaging system may provide B_0 homogeneity similar to that of 1.5-T imaging; however, it is well known that susceptibility effects are larger at 3 T.[15] This may result in undesirable image distortions and signal loss. It has been reported that improved local shimming minimizes these negative effects. Increased B_1 heterogeneity at 3 T can cause locally dependent radiofrequency excitation and consequently may introduce spatial variation of signal across the image. This may result in an obscured visualization across the FOV. However, CNR measurements in various segments showed no significant differences when compared in both legs for 1.5-T and 3-T CE MR angiography. Venous enhancement occurred in the calf station at 3-T and/or 1.5-T CE MR angiography in four patients, resulting in impaired image quality in only eight segments (1.5%). Centric k-space filling was used for the calf station at both 3-T and 1.5-T CE MR angiography to minimize venous contamination.

In our study, both 3-T and 1.5-T CE MR angiography showed excellent agreement with DSA for stenosis detection, with k values of 0.96 and 0.93, respectively; between 3-T and 1.5-T CE MR angiography the k value was 0.98. Furthermore, the sensitivity, specificity, and positive and negative predictive values of 1.5-T CE MR angiography presented in our study are in line with those reported in previous published results.[1,25] Sensitivity and specificity for 3-T CE MR angiography in our study are consistent with recently published results obtained by using a four-station hybrid technique[13] and using a blood pool agent.[19]

SNR and CNR were evaluated at the same anatomic level at 3-T and 1.5-T CE MR angiography in the external iliac artery, superficial femoral artery, and popliteal artery in both legs. In our study, these locations were usually free from overprojection and may be interpreted as representative for peripheral CE MR angiography. The three-fold higher CNR at 3-T CE MR angiography can potentially be traded for higher spatial resolution, which may be beneficial for quantitative stenosis classification, or for more cost-effective lower contrast agent dose.[26] In our study, contrast agent dose and spatial resolution were kept similar for both 3-T and 1.5-T CE MR angiographic protocols to enable interimage comparison. The contrast agent dose for both 3 T and 1.5 T was 0.2 mmol/kg body weight. A recent publication showed the clinical feasibility of low-dose CE MR angiography in combination with continued table movement and time-resolved imaging in patients with PAOD.[17] Another study showed that contrast agent dose for 3-T CE MR angiography can be reduced without compromising image quality by use of multiarray surface coils and a hybrid, dual-phase injection protocol.[27] Further evaluation must be performed to determine the

diagnostic accuracy for these low-dose CE MR angiographic protocols with a single-injection, three-station, moving-table imaging strategy. In the literature, several approaches for contrast agent dose in peripheral CE MR angiography have been reported: 30–40 mL gadolinium fixed dose,[1,3,6] double dose (0.2 mmol/kg body weight),[2] or, more recently, single dose.[28,29] In our hospital, the use of double-dose contrast agent is common. Especially in patients with impaired renal function, the amount of administered contrast agent is of clinical importance.[30] In all patients included in this study, the glomerular filtration rate was determined before MR imaging; for all patients, it was greater than 60 mL/min per 1.73 m^2, indicating no evidence for impaired renal function.

We acknowledge certain limitations of our study. For 3-T CE MR angiography, the build-in quadrature body coil was used for signal transmission and reception. However, for 1.5-T CE MR angiography, a phased-array surface coil was used for imaging the calf station because this is routinely performed in a state-of the-art imaging protocol in daily clinical practice at our institution. The use of a surface coil can potentially benefit SNR in this anatomic region. To date, phased-array surface coils for peripheral CE MR angiography are not offered for 3 T by all MR imaging vendors. However, when dedicated surface coils become commercially available for peripheral 3-T CE MR angiography, this technique may benefit from higher SNR. Additionally, recent developments in coil design, such as built-in analog-to-digital converters, may help improve image quality. In addition, parallel imaging techniques, such as sensitivity encoding, can be implemented to allow reduction in acquisition times.[31] Furthermore, stenosis was not classified quantitatively by diameter and length measurements but rather was assessed visually in consensus. Finally, our sample size was relatively small. From 19 patients, 500 angiographic images were included.

In conclusion, CE MR angiography with a 3-T whole-body imaging system in combination with a standardized single-injection, three-station, moving-table protocol is a reliable tool for stenosis detection and classification in patients suspected of having PAOD. It showed similar excellent agreement with DSA for diagnostic performance when compared with 1.5-T CE MR angiography.

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