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Abbreviations:

CNR = contrast-to-noise ratio
DSA = digital subtraction angiography
SNR = signal-to-noise ratio
3D = three-dimensional

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Peripheral Vasculature: Whole-Body MR Angiography with Midfemoral Venous Compression—Initial Experience¹

Five volunteers and 10 patients suspected of having peripheral vascular disease underwent multistation contrast material-enhanced three-dimensional whole-body magnetic resonance (MR) angiography. The first examination, based on standard protocol, lasted 72 seconds, while the following two examinations, performed with a high-spatial-resolution T1-weighted gradient-recalled-echo sequence for the last two stations (lower extremities) lasted 170 seconds. In the second high-resolution examination, midfemoral venous compression was used. Intraindividual comparison showed the high-resolution protocol with venous compression resulted in the best qualitative and quantitative image quality through higher signal-to-noise and contrast-to-noise ratios in the calf arteries. Despite prolonged acquisition times, there was no venous contamination. The data suggest that midfemoral venous compression should be incorporated in multistation protocols of the lower extremities to improve depiction of calf arteries without disturbing venous overlap.

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Contrast material-enhanced three-dimensional (3D) magnetic resonance (MR) angiography has become well established as a safe, reliable, and accurate means for the evaluation of almost all arterial territories.

While initial MR angiography studies were focused on spatially limited anatomic regions, the introduction of bolus-chase techniques allowed coverage to be extended to encompass successive regions, thereby enabling the display of the peripheral arteries in their entirety (1–5). The intravenously administered paramagnetic bolus of contrast material is followed over several imaging volumes from proximal to distal; successive fields of view match the time course of the contrast material bolus.

Motivated by the systemic nature of atherosclerotic disease, the concept of bolus-chase MR angiography has recently been expanded to whole-body MR angiography, a technique that encompasses the arterial tree from the carotid arteries to the trifurcation vessels. Driven by high-performance gradients and the availability of a rolling table platform for rapid unimpeded total-body coverage, 3D whole-body MR angiography is completed in 72 seconds (6). Like most other bolus-chase techniques, whole-body MR angiography has been shown to be both sensitive and specific in the detection of arterial disease (7). However, evaluation of the lower extremities can be hampered by venous contamination, as the contrast material bolus arrives at least 30 seconds before data collection. In addition, restricted spatial resolution limits the delineation of small collaterals or asserts graft vessel patency in patients with peripheral arterial disease (8,9). A desired increase in spatial resolution requires lengthening the acquisition time, which thereby intensifies venous enhancement. The achievement of high-spatial-resolution MR imaging of the calf arteries as part of a multiregion protocol without

venous enhancement has been as desirable as it has remained elusive.

The purpose of this study was to assess, in an intraindividual comparison, whether the display of the calf arteries at whole-body MR angiography can be improved by combining midfemoral venous compression with high-spatial-resolution T1-weighted 3D gradient-recalled-echo MR angiography.

I Materials and Methods

Subjects

Within an 8-week period, whole-body MR angiography was performed in five volunteers (four men [age range, 25–33 years; mean age, 29.1 years], one woman [26 years of age]) with no history of peripheral vascular disease and in 10 consecutive patients (seven men [age range, 59–75 years; mean age, 68.4 years], three women [age range, 61–68 years; mean age, 64.6 years]) who were referred to undergo whole-body MR angiography for suspected peripheral vascular disease (Fontaine grade IIa, five patients; grade IIb, two patients; grade III, two patients; grade IV, one patient) (10). All patients underwent catheter-based digital subtraction angiography (DSA) of the aortoiliac and lower extremity arteries 2–8 days (mean, 4.6 days) prior to MR angiography. All DSA examinations were performed and evaluated by one author with special training in vascular radiology (M.G., 5 years experience). All study participants were asked about specific symptoms of peripheral venous disease: history of deep vein thrombosis, varicosis, swollen legs, or dermal changes. None of these criteria applied to everyone in the study group. The study protocol was approved by our institutional review board, and informed consent was obtained from all subjects prior to enrollment.

MR Imaging

To determine the quantitative and qualitative effect for the two lower stations of a high-resolution (high-spatial-resolution) protocol with and without venous compression at the midfemoral level, all study participants were examined on three separate occasions: once with standard whole-body MR angiography, the second time with the high-resolution protocol, and the last time with the high-resolution protocol in combination with venous compression. The examinations were separated from one an-

other by at least 24 hours and were carried out in random order.

All imaging examinations were performed with a 1.5-T MR system (Magnetom Sonata; Siemens Medical Systems, Erlangen, Germany) that was equipped with a high-performance gradient system characterized by an amplitude of 40 mT/m and a slew rate of 200 mT/m/msec. All subjects were placed feet first within the bore of the magnet and examined in the supine position on a fully MR-compatible rolling table platform, which had been placed on the existing table top. This rolling table platform (AngioSURF [System for Unlimited Rolling Fields of view]; MR-Innovation, Essen, Germany) fits most standard MR systems. It is 240 cm long and is placed on seven pairs of roller bearings, which are anchored within the existing patient table. As many as six 3D data sets, with a cranio-caudal coverage of 38 cm each, can be collected successively. Markers on the table permit adjustment to the desired fields of view. Signal reception is achieved through posteriorly located spine coils and an anteriorly located torso phased-array coil. While the two utilized elements of the spine coil are integrated in the stationary patient table, the standard torso phased-array coil is anchored in a height-adjustable holder, which remains fixed to the patient table. Thus, data for up to five stations are collected with the same fixed coil set, positioned in the isocenter of the magnet.

Whole-body MR angiography was based on the acquisition of five slightly overlapping (2 cm) 3D data sets acquired in immediate succession, with a cranio-caudal coverage of 174 cm. The first data set included the aortic arch, supraaortic branch arteries, and thoracic aorta, while the second data set included the abdominal aorta with its major branches, including the renal arteries. The pelvic arteries were contained in the third image set, and the fourth and fifth sets contained the thighs and the calves, respectively.

On the basis of a moving-vessel scout sequence and the subsequent acquisition of nonenhanced data sets of the two lowest stations for subsequent subtraction, the travel time of the contrast agent from the antecubital vein to the proximal third of the thoracic aorta was determined with a 2-mL test bolus. Hereafter, five consecutive 3D data sets were collected in the coronal plane with a fast 3D T1-weighted gradient-recalled-echo sequence for the standard whole-body MR angiography protocol (repetition time

msec/echo time msec, 2.2/0.74; flip angle, 20°; slab thickness, 120 mm; field of view, 390 × 390 mm; matrix, 220 × 256; voxel size, 2.8 × 2.2 × 3.0 mm³; one signal acquired; bandwidth, 930 Hz/pixel; acquisition time, 12 seconds) resulting from zero interpolation in a voxel size of 1.8 × 1.4 × 1.9 mm³.

For the high-resolution protocol, the first three stations were collected in a manner identical to that in standard whole-body MR angiography. The last two stations, which covered the lower extremities, were imaged with a sequence characterized by 2.86/1.02, with a 40° flip angle, a bandwidth of 610 Hz/pixel, two signals acquired, and an acquisition time of 61 seconds. Hence the examination time for the high-resolution protocol was increased to 170 seconds. An 80-mm slab divided in 80 × 1-mm partitions and combined with a 400 × 400-mm field of view and a 307 × 512 matrix rendered a spatial resolution of 1.3 × 0.8 × 1.0 mm³. The high-resolution protocol was performed a second time with venous compression. For compression, a 30-cm-wide thigh cuff (Speidel & Keller, Jungingen, Germany) was placed at the midfemoral level. From the start of the contrast material injection to the end of the examination, the cuff was manually adjusted to maintain a permanent pressure of 60 mm Hg.

For all MR angiography examinations, a commercially available paramagnetic contrast agent (gadobutrol, Gadovist; Schering, Berlin, Germany) was administered intravenously at a weight-adjusted dose of 0.15 mmol per kilogram of patient body weight (11). The agent was diluted with normal saline to a total volume of 60 mL. Contrast material was injected automatically (MR Spectris; Medrad, Pittsburgh, Pa) with a biphasic protocol: The first half was administered at a rate of 1.4 mL/sec, while the second half was administered at a rate of 0.7 mL/sec and was followed with a 20-mL saline flush.

Cuff inflations employed for the high-resolution protocol with venous compression were well tolerated by all subjects. All examinations were technically adequate.

Conventional DSA

DSA of the pelvic and lower extremity vessels was performed with a standard angiography unit (Integris; Philips Medical Systems, Best, the Netherlands). All 10 patients underwent conventional angiography, which extended from the dis-

tal aorta (including the renal arteries) to the proximal pedal vessels, with a transfemorally inserted 5-F pigtail catheter. The catheter tip was positioned just above the branching of the renal arteries for DSA of the distal aorta; the tip was then pulled back to a position just proximal to the aortic bifurcation for assessing the pelvic arteries, followed by multiple acquisitions encompassing the thigh and lower limbs. At each station, 20 mL of iodinated contrast material (io-bitridol, Xenetix; Guerbet, Aulnay-sous-Bois, France) was administered. Select catheterization of individual extremities was not deemed necessary in any of the 10 examinations.

Image Analysis

All MR angiography data sets were first assessed in regard to diagnostic quality; this assessment was performed by the MR angiography image readers (S.G.R. and J.F.D., each with more than 10 years experience in MR angiography). For the purpose of this assessment, the depiction of each arterial segment was characterized as either diagnostic or nondiagnostic. Display of an arterial segment was considered diagnostic when image quality allowed reliable detection or exclusion of relevant vascular disease. DSA and MR angiography image sets were analyzed for the presence of arterial disease as follows: normal artery, mild stenosis with luminal narrowing not exceeding 50%, severe stenosis with luminal narrowing exceeding 50%, arterial occlusion, or aneurysmal disease with luminal widening.

Luminal assessment was based on the most severe reduction or increase of the arterial diameter compared with the most normal-appearing segment proximal or distal to the area of arterial disease.

For quantitative and qualitative analyses of the MR angiography data sets, the arterial tree was divided into 30 segments as follows: segments 1 and 2, bilateral internal carotid arteries; segments 3 and 4, bilateral common carotid arteries; segment 5, brachiocephalic trunk and left subclavian artery; segment 6, thoracic aorta; segment 7, suprarenal abdominal aorta; segment 8, infrarenal abdominal aorta; segments 9 and 10, bilateral renal arteries; segments 11 and 12, bilateral common iliac arteries; segments 13 and 14, bilateral external iliac arteries; segments 15 and 16, bilateral common femoral arteries; segments 17 and 18, proximal half of bilateral superficial femoral

arteries; segments 19 and 20, distal half of bilateral superficial femoral arteries; segments 21 and 22, bilateral popliteal arteries; segments 23 and 24, bilateral tibio-peroneal trunk; segments 25 and 26, bilateral anterior tibial arteries; segments 27 and 28, bilateral peroneal arteries; and segments 29 and 30, bilateral posterior tibial arteries.

For an intraindividual quantitative comparison of the three MR examination protocols, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) values were calculated on the basis of signal intensity measurements in regions of interest (minimum size, 4–6 mm³); these were placed by one author (C.U.H., 3 years experience in MR angiography) in the center of all 30 arterial segments in each subject. Absolute signal intensity measurements were related to noise (SD_N), which was defined as the SD of signal intensity measurements collected in a circular region of interest (10 mm³) placed in the air to the right or left outside the body for each station. SNR and CNR values were calculated with the following equations: $SNR = SI_V / SD_N$ and $CNR = (SI_V - SI_{AT}) / SD_N$, where SI_V is the signal intensity of the vessel, and SI_{AT} is the signal intensity of adjacent tissue.

The readers (S.G.R. and J.F.D.) of the MR angiography image sets were blinded to the DSA results but not to the clinical history of each patient. The 3D MR angiography data sets were available on a workstation (Virtuoso; Siemens Medical Systems) that allowed for review of the source images, as well as maximum intensity projection and multiplanar reconstructions. Two additional radiologists (C.U.H., M.G.), working in consensus, assessed the image quality of randomized MR angiography data sets with concern to venous contamination, including the intraabdominal veins. This assessment was based on a five-point Likert scale: score of 5, excellent (all arteries of interest fully assessable without any venous contamination); score of 4, good (all arteries of interest still assessable, with some venous contamination); score of 3, equivocal (arteries of interest incompletely assessable, considerable venous contamination); score of 2, suboptimal (arteries of interest hardly assessable, severe venous contamination); and score of 1, poor (arteries of interest unassessable, complete venous contamination).

In the 10 patients with peripheral vascular disease, whole-body MR angiography image sets were further analyzed for the presence of arterial disease. Thus, each vascular segment was assessed for

the presence of stenoses with (a) luminal narrowing exceeding 50% on the basis of the most severe reduction of the arterial diameter compared with the most normal-appearing segment proximal or distal to the area of arterial compromise, (b) vessel occlusion, or (c) aneurysmal disease.

Statistical Analysis

The intraindividual comparison of qualitative and quantitative measurements of image quality was based on a Student *t* test analysis designed to determine the effect of the high-resolution protocol both alone and in conjunction with venous compression. Statistical significance was established at $P < .05$. A Bonferroni correction for multiple comparisons was applied. Furthermore, overall sensitivities and specificities for the detection of severe stenoses (luminal narrowing, >50%) were calculated for each whole-body protocol of all arterial segments in the 10 patients. Results at DSA were used as the standard of reference.

I Results

For the 45 whole-body MR angiography examinations (three examinations each in 15 subjects), high diagnostic image quality was achieved of the entire vascular tree from the carotid to the calf arteries; this was achieved with all three protocols in the five volunteers, as well as in the 10 patients with peripheral vascular disease (Fig 1).

Quantitative analysis (Table) revealed SNR values of the first three stations for the standard protocol, as well as the high-resolution whole-body protocol both with and without venous compression, to range between 69 and 87 (mean, 75). CNR values were similar, with a mean of 71 (range, 61–82). The highest SNR and CNR values were found in the thoracic aorta. Differences between SNR and CNR values between the three protocols for the first three stations were not statistically significant ($P > .10$).

In the lower extremities, the data sets for the high-resolution protocol with venous compression were associated with considerably higher values compared with those of both the standard and the high-resolution protocols. SNR values for the venous compression acquisition ranged between 59 and 77 (mean, 68 ± 7 [SD]), and CNR values ranged between 53 and 72 (mean, 62 ± 7). These were significantly higher compared with mean SNR and CNR values for the standard

protocol (mean SNR, 60 ± 7 ; mean CNR, 54 ± 8) and the high-resolution protocol (mean SNR, 57 ± 7 ; mean CNR, 51 ± 7). Comparative analysis between SNR and CNR values of the standard and high-resolution protocols also proved statistically significant ($P < .01$).

Improved SNR and CNR values associated with the high-resolution protocol with venous compression translated into an improved qualitative assessment. For the last two stations, the consensus reading demonstrated significantly higher mean values for high resolution with venous compression compared with the other evaluated protocols: 4.5 ± 0.4 (with venous compression) versus 4.2 ± 0.3 (standard protocol) and 3.9 ± 0.4 (high-resolution protocol), respectively. The other stations were rated at similar quality without significant differences.

A total of 224 arterial segments were depicted at DSA in 10 patients. The suprarenal abdominal aorta could not be assessed in six patients because of low catheter tip placement. Vascular abnormalities were identified in 39 segments. In addition to the 224 segments depicted at DSA, whole-body 3D MR angiography depicted an additional 76 arterial segments, so that there were a total of 300 segments depicted in the same 10 patients. Imaging of the entire arterial system with whole-body MR angiography depicted two high-grade stenoses of the internal carotid artery, which were not clinically suspected but were confirmed at subsequent color-coded duplex ultrasonography.

Standard and high-resolution whole-body MR angiography protocols caused 10 segments to be overgraded as severely stenosed ($>50\%$; distal superficial femoral artery, $n = 4$; peroneal artery, $n = 4$; anterior tibial artery, $n = 2$); at DSA, these segments were shown to be merely mildly stenosed ($<50\%$). Four severe stenoses of the tibial artery were falsely interpreted as occluded on standard and high-resolution images. However, these four vessel segments were correctly assessed on images obtained with venous compression (Fig 2). Standard whole-body MR angiography had a sensitivity of 88.6% and a specificity of 94.3% for the detection of severe stenoses and occlusions. Whole-body MR angiography with the high-resolution protocol alone and the high-resolution protocol with venous compression revealed overall sensitivities of 88.1% and 91.2% and specificities of 94.7% and 95.1%, respectively. These differences were not statistically significant ($P > .20$).

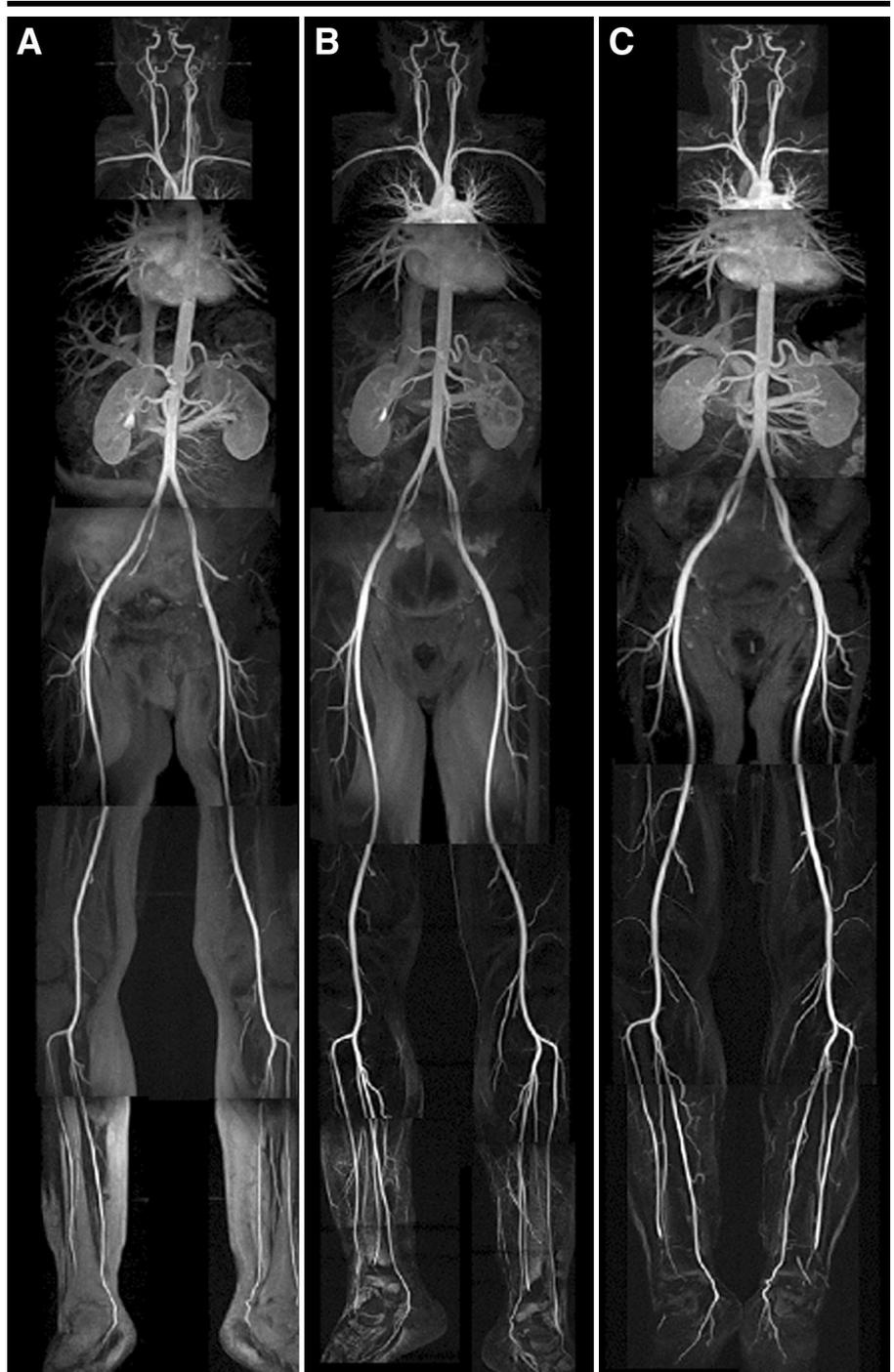


Figure 1. Coronal 3D T1-weighted gradient-recalled-echo fast low-angle shot whole-body MR angiograms obtained with a rolling table platform and five contiguous stations in a 31-year-old volunteer. *A*, Images obtained with standard protocol. *B*, Images obtained with high-resolution protocol for the lower extremities. *C*, Images obtained with high-resolution protocol with mid-femoral venous compression. All three protocols provide high diagnostic quality, but the arterial signal is improved with venous compression.

Venous contamination in the calf was most severe in the high-resolution images collected without compression. There was virtually no venous overlap in data sets collected with standard and venous compression protocols.

Discussion

The outlined whole-body MR angiography examination with midfemoral venous compression in conjunction with high spatial resolution for the lower ex-

Quantitative Analysis of Three MR Angiography Protocols in 15 Study Participants

Vessel Segment	No. of Segments	Standard		High Resolution		High Resolution/ Venous Compression	
		SNR	CNR	SNR	CNR	SNR	CNR
Internal carotid artery	2	72	65	73	67	74	69
Common carotid artery	2	73	67	75	67	74	74
Brachiocephalic trunk and left subclavian artery	1	78	71	84	77	78	74
Thoracic aorta	1	87	79	86	82	83	78
Suprarenal abdominal aorta	1	79	71	77	71	81	75
Infrarenal abdominal aorta	1	79	73	75	71	69	65
Renal artery	2	72	67	74	69	77	72
Common iliac artery	2	76	71	79	73	73	68
External iliac artery	2	73	66	71	65	73	68
Common femoral artery	2	75	61	74	67	75	70
Superficial femoral artery proximal	2	73	66	70	61	77	72
Superficial femoral artery distal	2	66	62	62	57	75*	70*
Popliteal artery	2	63	58	60	53	73*	66*
Tibioperoneal trunk	2	57	52	56	50	66*	61*
Anterior tibial artery	2	54	48	52	47	64*	59*
Peroneal artery	2	55	48	53	45	62*	57*
Posterior tibial artery	2	51	45	49	43	59*	53*

Note.—For each protocol, data are mean SNRs and CNRs.

* Significantly higher values compared with those obtained with the other two protocols ($P < .01$).



Figure 2. Images obtained in a 68-year-old woman with peripheral arterial occlusive disease and multiple stenoses (arrows). *A*, Coronal DSA image. *B–D*, Coronal 3D T1-weighted gradient-recalled-echo fast low-angle shot MR angiograms obtained with a rolling table platform at the two distal stations with the standard (*B*), high-resolution (*C*), and high-resolution with venous compression (*D*) protocols. The posterior tibial artery (arrowheads) was judged to be occluded on both the standard and high-resolution MR angiograms, whereas multiple eccentric stenoses can be assessed on the venous compression MR angiogram, which is in good correlation with the DSA image. Note the considerable venous contamination in *C* and the high vessel signal intensity in *D*.

tremity permitted substantial improvements regarding both the qualitative and quantitative assessment of the arterial display in the calf. Although not statistically significant, the high-resolution protocol with venous compression was asso-

ciated with the highest sensitivity and specificity compared with those of DSA. The presented data suggest that mid-femoral venous compression should be incorporated into multistation protocols of the lower extremities for improved de-

lineation of calf arteries without disturbing venous overlap.

The increasing prevalence of peripheral arterial occlusive disease in an aging population combined with the known limitations inherent to a duplex-based

assessment, as well as the costs and risks associated with catheter-based DSA, have motivated the rapid development and clinical integration of MR angiography as a noninvasive and accurate alternative in the assessment of peripheral arteries. Albeit two-dimensional time-of-flight methods initially provided high diagnostic accuracy (12), lengthy examination times and artifactual signal voids from saturation effects led to replacement of these methods with contrast-enhanced 3D MR angiography.

Contrast material dose limitations and overlying parenchymal enhancement initially allowed the display of only a single vascular territory contained within a field of view. The implementation of bolus-chase techniques with integrated table motion algorithms now permits the contiguous acquisition of images of the pelvic and runoff arteries in a single examination (2,5,13). Sensitivities and specificities of these techniques for depicting severe stenoses (>50%) and occlusions have been reported to range from 77% to 98%. In some studies, results obtained in the calves were limited by venous overlap, which was reported to be present in 30% of examinations (14–16).

Whole-body MR angiography has been shown to have similar accuracy for depicting disease affecting the peripheral arteries, with the added merit of displaying additional vascular territories (6). The systemic nature of atherosclerotic disease is reflected in the fact that whole-body MR angiography depicts additional unsuspected arterial disease in 23% of patients with peripheral vascular disease (7). The clinical effect of this protocol is underscored by the limited number of patients assessed as part of our study: Whole-body MR angiography enabled identification of two patients with a clinically unsuspected high-grade carotid lesion.

Despite the encouraging results of initial evaluations, whole-body MR angiography faces some relevant limitations regarding spatial resolution for the depiction of tight stenoses and small vessels in the lower legs. This has resulted in some over- and undergrading of disease, as also evidenced in this study. Potential advantages associated with the acquisition of higher resolution data sets are offset by the development of venous overlap. Hence, delineation of small arteries, particularly those potentially needed for surgical grafting, remains challenging with whole-body MR an-

giography (6), as well as with most other bolus-chase techniques (17).

Various strategies have been employed to achieve high-resolution peripheral MR angiography images without venous overlap. The mere increase in spatial resolution is not sufficient, as is illustrated in the analysis of the presented data. The quality of the high-resolution images of the calf arteries was both quantitatively and qualitatively inferior in comparison with that of the standard protocol with an interpolated matrix. In addition, the longer acquisition times translated into considerable venous contamination of the high-resolution image set in comparison with the standard whole-body MR angiography protocol, thereby further reducing diagnostic confidence. The need for imaging at the two distal stations with high resolution is reflected by the localization of the infrapopliteal trifurcation in whole-body MR angiography; this important vascular region is acquired either at the penultimate or the last station, depending on the size of the patient. High resolution with submillimeter isotropic voxel size for the last station in multistation MR angiography has been described with parallel imaging techniques (eg, sensitivity encoding) (18) and thus might be extended to the last two stations in whole-body MR angiography.

Most recently, time-resolved imaging of contrast kinetics, or TRICKS, 3D MR angiography has been employed for peripheral vessels in patients with peripheral arterial occlusive disease (19). This technique relies on repeated sampling of the central k space, which results in high temporal resolution and thereby prevents venous contamination (20). Spatial resolution is maximized by sharing peripheral k-space data from temporally adjacent acquisitions. Initial clinical evaluations proved satisfactory, with high sensitivity and specificity regarding the reliable depiction of arterial disease in the lower extremities. Complex and voluminous reconstructions have limited the technique to only a few centers. Furthermore, only a single station can be imaged with this technique, thereby necessitating multiple contrast material injections for coverage of the entire runoff system.

In contrast to TRICKS 3D MR angiography, the high-resolution protocol with venous compression does not require voluminous data reconstructions and can be implemented into a multistation protocol. Its effect on image quality was similar: High resolution that permits better delineation of small calf arteries is

achieved without venous contamination. The superiority of the high-resolution protocol with venous compression was evidenced by significantly higher SNR and CNR values of the arteries of the lower leg in comparison with those of both the standard and the high-resolution whole-body examinations. In addition, the visualization of small arteries was apparently improved at least in part because of the increased blood volume in the arterial bed. This finding was underlined by the improved differentiation between patent and occluded vessels when analysis was based on the high-resolution images with venous compression compared with the standard protocol. Furthermore, venous compression caused prolonged arterial and delayed venous filling and thus allowed for better arterial visualization.

Venous compression has so far been applied for MR angiography of the venous vessels (21) to prevent rapid wash-out following contrast material administration into a peripheral vein, which is similar to conventional fluoroscopic x-ray phlebography. Venous compression for arterial imaging has, to date, been employed for imaging of arteriovenous fistulas and has been described before for imaging of peripheral vascular disease (U.S. patent 5,924,987). However, this method has not been evaluated in a larger trial for the peripheral arteries. The technique is simple and appears to be highly effective. Venous compression was well tolerated by all subjects, who were without complaints about pain or other discomfort. Since the venous compression time exceeds 3 minutes, peripheral venous disease should be excluded, as a precautionary measure.

For maximal arterial enhancement, an extracellular neutral gadolinium chelate (gadobutrol) with high intravascular relaxivity was employed. Although it has not been approved for use with MR angiography, this contrast agent has been found to be superior to gadopentetate dimeglumine even when employed at a lower dose (11). In our study, the agent was applied by using a biphasic injection protocol, in which we collected the first two 3D data sets (thoracic and abdominal aorta) with a relatively high flow rate (1.4 mL/sec) and the remaining three data sets with a lower flow rate (0.7 mL/sec) to minimize venous contamination in the distal stations (11).

Our study has recognized limitations. First, we did not evaluate how much venous compression slows down blood flow and thus how much acquisition

times can be lengthened for the lower stations. Furthermore, simple subtraction of a nonenhanced mask from the contrast-enhanced imaging study probably would have improved the standard protocol. However, subtraction techniques often produce motion artifacts and thus may impair visualization of small crural arteries, especially in a patient population with peripheral arterial occlusive disease. And finally, the sequential assessment of vascular segments in each patient might cause a dependency effect on the reader to be more alert to look for atherosclerotic lesions in adjacent segments, particularly in such a small study group.

We conclude that multistation whole-body MR angiography with high spatial resolution of the femoral and trifurcation arteries in conjunction with venous compression at the midfemoral level leads to a vastly improved display of the arterial vasculature of the lower extremities. The high resolution is achieved without any venous contamination. Venous compression whole-body MR angiography is simple to implement and is likely to enhance the performance of all other multistation MR angiography strategies for assessment of the peripheral arterial tree.

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