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Engellau, Lena; Albrechtsson, Ulf; Dahlström, N.; Norgren, Lars; Persson, A; Larsson, Elna-Marie

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MEASUREMENTS BEFORE ENDOVASCULAR REPAIR OF ABDOMINAL AORTIC ANEURYSMS

MR imaging with MRA vs. angiography and CT

L. ENGELLAU[1], U. ALBRECHTSSON[1], N. DAHLSTRÖM[2], L. NORGREN[3], A. PERSSON[4] and E.-M. LARSSON[1]

[1]Department of Radiology, Lund University Hospital, Lund, [2]Department of Radiology, Hudiksvall Hospital, Hudiksvall, [3]Department of Vascular Diseases, Lund University, Malmö University Hospital, Malmö and [4]Center for Medical Image Science and Visualization (CMIV), Linköping University Hospital, Linköping, Sweden.

Abstract

Purpose: 1) To compare measurements obtained with MR imaging (MRI)/contrast-enhanced MR angiography (CE MRA) with measurements obtained with angiography (DSA) and CT, for stent-graft sizing of abdominal aortic aneurysms (AAA). 2) To compare MRA measurements obtained with the two post processing techniques MIP (maximum intensity projection) and VRT (3D volume rendering technique).

Material and Methods: The prospective study included 20 consecutive patients with AAA identified by DSA and CT as suitable for endovascular repair. For the study, MRI/CE MRA was performed. Five measurement variables for stent-graft sizing were chosen. Comparisons were made between MRI/CE MRA, DSA and CT, and between observers. Comparisons were also made between MIP and VRT.

Results: Significantly shorter lengths were obtained with MRA-MIP than with DSA. Three out of six diameter measurements were significantly smaller on MRI/CE MRA than on DSA and CT. No significant differences were found between the observers. One diameter measurement was significantly smaller on MIP than on VRT, while the other measurements showed no significant differences.

Conclusion: The length measurements obtained with MRA-MIP were probably more correct than those with DSA. For more reliable diameter measurements with CE MRA, improvements of the technique, including VRT reconstructions and a standardized determination of the vessel boundaries, are needed.

Key words: Abdominal aortic aneurysm, endograft sizing; MR angiography, volume rendering technique; angiography; CT.

Correspondence: Lena Engellau, Department of Radiology, Lund University Hospital, SE-221 85 Lund, Sweden.
FAX +46 46 12 18 37.
E-mail: lena.engellau@drad.lu.se

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Endovascular stent-graft planning in patients with infrarenal abdominal aortic aneurysms (AAA) requires more accurate morphologic information and detailed measurements than open repair. The contour, length and diameter of the proximal aortic neck, the presence of thrombus and calcification, the angle between the proximal aortic neck and suprarenal aorta, the anticipated required length of the stent-graft, the quality and dimensions of the iliac arteries and the presence of any accessory renal arteries are relevant (11). The 2D methods, digital subtraction angiography (DSA) and contrast-enhanced (CE) conventional CT, do not provide the required accuracy for sizing of stent-grafts as sole

imaging methods (3, 4, 9, 16). CE spiral CT angiography (CTA), which is a 3D method, provides more accurate information (2, 4) and is now widely used for stent-graft planning. MR imaging (MRI) with CE MR angiography (MRA) also provides 3D information (6, 16). MRI/CE MRA is non-invasive, does not expose the patient to ionizing radiation and uses a non-nephrotoxic paramagnetic contrast agent (10) and would thus be preferable. The most widely used MRA post processing technique is maximum intensity projection (MIP) (13, 14). Volume rendering technique (VRT) is a new promising technique that is similar to MIP, but instead of using the maximum value, which is only about 10% of the available data, in VRT up to 100% of the available data can be used (12).

The purpose of this study was to compare measurements obtained with MRI/CE MRA with measurements obtained with DSA and CT, the methods used at our center in planning for endovascular stent-graft repair of AAA. In addition, MRA measurement comparisons were made between the post processing techniques MIP and VRT.

Material and Methods

Between January 1995 and November 1998, 20 consecutive patients (17 men and 3 women; mean age 69 years, range 52–77 years) with infrarenal AAA, identified by DSA and CT as potential candidates for endovascular repair, were enrolled in this prospective study. For the study, MRI with CE MRA was also performed. (DSA and CT are used as imaging methods for stent-graft planning at our center.)

The Ethics Committee of Lund University approved the study protocol. Informed consent was obtained from each patient.

MRI/CE MRA was performed with a 1.5 T system, Siemens Magnetom Vision using a body coil and a lumbar spine array coil. The MR sequences used are shown in Table 1. A 3D image volume was obtained from the origin of the superior mesenteric artery to the proximal femoral arteries before and after contrast injection. For the MRA, 40 ml Gd-DTPA (Magnevist, Schering) or gadodiamide (Omniscan, Amersham Health) was injected i.v. by hand. The injection time for the non-breath-hold MRA sequence was 70 s. For the breath-hold MRA sequence the scan delay had been determined by a test bolus and the injection time was equal to the scan time. After subtraction, the MRA dataset was reconstructed by one of the authors (L.E.) using the satellite console of the MR scanner, as MIP in coronal and sagittal views (15% increments), and multiplanar reconstruction (MPR) 5-mm slices in the transverse plane.

DSA was performed on a Polydiagnost A (Philips) equipment with digital reconstruction. A 5 F (1.7 mm) pigtail universal measuring catheter (Angiomed) with 6 side holes was used. Iohexol (Omnipaque 300 mg I/ml, Amersham Health), 40 ml/series was injected with a power injector at a rate of 20 ml/s. Posterior-anterior (p.a.) and lateral projections of the abdominal aorta and p.a. projection of the iliac arteries were obtained. Unsubtracted and subtracted images were used for evaluation. Two of the examinations were performed at other centers using the same technique as at our center.

Table 1
MR parameters

No. of examinations	MR sequence	TR, ms	TE, ms	Slice thickness, mm	Matrix	FOV, mm	Scan time, min: s
20	T1 SE tra Abdomen and pelvis	580	14	10	148 × 256	350	5 : 46
8	T1 SE tra + Gd Abdomen and pelvis	580	14	10	148 × 256	350	5 : 46
20	T2 TSE tra (ETL = 11) Abdomen and pelvis	3800	99	10	176 × 256	350	5 : 07
8	3D MRA cor (3D FLASH) + Gd Aorta and iliac arteries	21	6	3D volume 70 Partition thickness 2.5	256 × 256–512	400	2 : 33
14	3D MRA tra (3D FLASH) + Gd Iliac arteries	21	6	3D volume 140 Partition thickness 5	256 × 256	350	2 : 33
12	3D MRA cor breath-hold (3D FLASH) ±Gd Aorta and iliac arteries	4.6–5	1.8–2	3D volume max 108 Partition thickness max 3.38	94–200 × 256–512	360–500	0 : 17–0 : 35

TR, repetition time; TE, echo time; FOV, field-of-view; TSE, turbo spin-echo; sag, sagittal; ETL, echo train length; SE, spin-echo; tra, transversal; Gd, gadolinium-based contrast agent; cor, coronal; FLASH, fast low-angle shot.

Spiral CT was performed on a Toshiba Xpress/SX, starting just above the origin of the celiac artery and covering the iliac bifurcations; 1-s rotations were executed with a table speed of 5 mm/s. Collimation was 5 mm (pitch=1). Iohexol (Omnipaque 300 mg I/ml) 90 ml was given i.v. at a rate of 1.5–2.0 ml/s with a power injector. The scan delay was 60 s. The scans were reconstructed as single 5–10-mm-thick slices with an interval of 5–15 mm. Three of the examinations were performed at other centers. One of these examinations was reconstructed as single 10-mm-thick slices with an interval of 15 mm, the second as single 4-mm-thick slices with an interval of 5 mm and the third examination as single 10-mm slices with an interval of 20 mm. The third examination was performed without contrast enhancement.

Measurements on MRI/CE MRA, DSA and CT were performed individually by three radiologists (L.E. and E-M.L., who were experienced in MR and CT, and U.A., who was experienced in DSA and CT) (Table 2). Five measurement variables for stent-graft sizing were chosen by the radiologist performing the stent-graft implantations (U.A.) (Fig. 1). Inner diameters (contrast-filled lumen) $D1^{i}$ and $D2^{i}$ were measured on MRA, DSA and CT, while the outer diameters $D1^{\circ}$ and $D2^{\circ}$ (including mural thrombus) were measured on MRI and CT. Missing data for MRA-MIP of L3 measurements in 10 patients were due to positioning of the 3D volume in CE MRA too far anteriorly, and thus not including the whole extent of the iliac arteries. One observer (U.A.) judged an additional 4 MRA-MIP examinations to have too poor image quality for measurement. For 1 DSA examination all three observers found the catheter markers too vague for measurements (Table 2). The measurements on MRI/CE MRA were made on a PACS workstation (picture archiving and communication system) with the software system VRS Report (Cedara Software Corporation, Canada). The optimum window setting was chosen by each observer. The accuracy and precision of the gradients of our MR system were checked and, if necessary, adjusted 4 times every year. The variations have normally been smaller than 1 pixel (in the order of 1–4 mm) for the sequences used in this study. The MRA-MIP corresponding to the p.a. DSA projection was used for measurements, but the other MIP projections were available. The measurements on DSA were made with a soft ruler on film. On CT, the measurements were performed with a ruler on a film viewer with three-fold magnification. To avoid measurement differences caused by different interpretation of the proximal margin of the aneurysm, this margin was marked by U.A. with a line perpendicular to the aorta on the DSA films. The first slice showing the proximal portion of the aneurysm was also

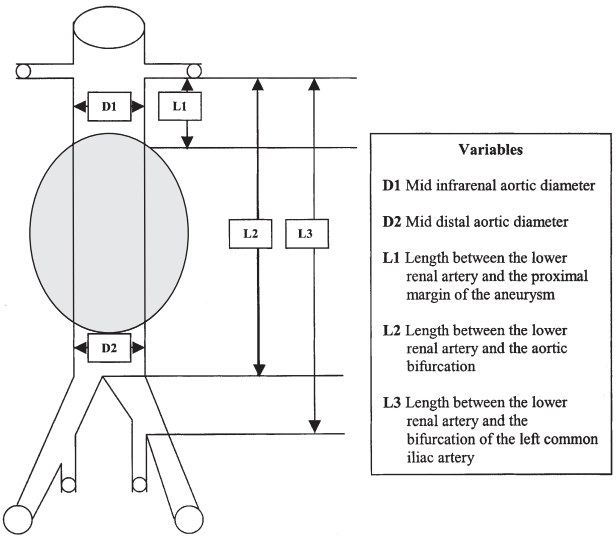

Fig. 1. Measurement variables for stent-graft sizing.

Table 2
Number of measurements

Observers	Methods	Variables						
		$D1^{i}$	$D1^{\circ}$	$D2^{i}$	$D2^{\circ}$	L1	L2	L3
L.E, U.A.,	MRA-MIP	60		60		60	60	26
E-M.L.	DSA	57		57		57	57	57
(Ideally 3 × 20	MRA-MPR	60		60				
measurements)	CT	55		57				
	MR-T1		49		60			
	CT		53		57			
A.P., N.D.	MIP	20		20		20	20	9
(Ideally 1 × 20	VRT	20		20		20	20	10
measurements)								

The variables are explained in Table 1, ^{i} = inner diameter, $^{\circ}$ = outer diameter.

noted by U.A. on transverse MR-T1 and CT images. The diameters on MRA-MIP and DSA were measured perpendicularly to the local length axis of the aorta. If the neck of the distal aorta (D2) had the shape of a cone, the largest diameter was measured. The diameter D1 was measured at the midpoint of the length L1. The lengths were measured in the mid aorta adjusted for tortuosity. The level of the bifurcation of the left common iliac artery was marked by U.A. with a line perpendicular to the common iliac artery. The lengths were not measured on MR-T1, MRA-MPR and CT, since we had no means to perform length measurement adjusted for the tortuosity with these techniques (4) (Table 2).

The comparisons between the post processing techniques MIP and VRT using the same MRA data as above were performed at another center. Two radiologists (A.P. and N.D.) with experience of VRT measured the variables on MIP and VRT in consensus (Table 2). The CE MRA datasets were loaded into a workstation (3D Virtuoso VA31, Siemens) equipped with VolumePro (Mitsubishi Precision Co., Ltd) accelerator graphics card for VRT and MIP post processing. In VRT, a predefined preset ramp describing opacity, brightness and gray scale colors assigned to the voxel histogram for the volume-rendering parameters was selected. The position of the preset ramp due to varying general signal intensities was adjusted in consensus. For the MIP a simpler predefined preset, defining window level, was used. The displayed VRT volume or MIP was then magnified to a predefined zoom level. For the measurements on MIP and VRT the volume was kept in its original position (Fig. 2), which corresponded to the p.a. DSA projection. A measuring tool that allows straight as well as curved measurements was used. The proximal margin of the aneurysm was defined in consensus and marked with a line perpendicular to the local length axis of the aorta at the same level on MIP and VRT. The DSA films on which U.A. had marked the upper margin of the aneurysm were available for comparison to obtain a similar upper margin. The diameters were measured perpendicular to the aorta. If the aorta distal to the aneurysm had the shape of a cone with a proximal base, the largest diameter was measured. The lengths were measured in the mid aorta and iliac vessels adjusted to tortuosity.

Statistical analyses: Clinically accepted variations of measurement were chosen by U.A.: ± 2 mm for D1, D2 and L1, ± 10 mm for L2 and ± 20 mm for L3.

Comparisons between methods and comparisons between observers were performed. We assessed the agreement between the methods MRA-MIP vs. DSA, MRA-MPR vs. CT, MR-T1 vs. CT, and MIP vs. VRT by comparing paired measurements, matched on patient and observer. Similarly, we assessed the agreement between the observers U.A. and E-M.L. by comparing paired measurements, matched on patient and method. The measurements for the different methods/observers, and of the corresponding pairwise differences, were not normally distributed. Method comparisons were therefore based on non-parametric statistics (1). The location of the data was expressed by the median and the spread of the data by the range or relevant percentiles. Here we report the percentage of clinically unacceptable variations of measurement for each variable. Wilcoxon signed-rank test was used and p-values less than 0.05 were considered significant. However, that a statistically significant systematic difference might be indicated even though the difference was small and not clinically significant (1).

We also examined whether there was an association between patients and observers regarding clinically unacceptable variations of measurement ($> \pm 2$ mm for the variables D1, D2 and L1 and ± 10 mm for L2; L3 was excluded because of many missing measurements) between the methods MRA-MIP vs. DSA and between MIP and VRT. This was done by pairwise comparison between the methods, matched on patient and observer. The results were tested with the Chi-square test against the frequencies of clinically unacceptable variations of measurement (no association being the null hypothesis).

The statistical computations were carried out using SPSS for Windows (release 10.0.05) and StatXact 5 (Cytel Software Corp.).

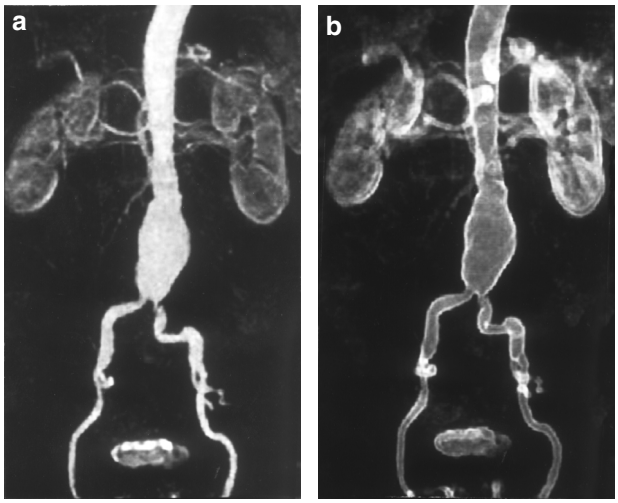

Fig. 2. CE 3D MRA. a) MIP and b) VRT, both in p.a. projection.

Table 3

Measurements in mm: median (range)

Methods	Variables						
	D1^{i}	D1°	D2^{i}	D2°	L1	L2	L3
MRA-MIP	18 (12–25)		20 (11–31)		25 (13–74)	120 (91–158)	177 (102–232)
DSA	19 (12–25)		20 (12–39)		31 (12–68)	126 (95–170)	166 (150–179)
MRA-MPR	19 (13–25)		22 (11–38)				
CT	21 (13–25)		25 (12–52)				
MR-T1		23 (16–31)		30 (15–64)			
CT		24 (15–30)		34 (17–61)			
MIP	18 (13–24)		20 (11–30)		24 (12–64)	121 (91–160)	164 (148–190)
VRT	20 (14–23)		20 (12–29)		23 (12–62)	118 (91–174)	164 (147–185)

The variables are explained in Table 1.

Results

The method comparisons are presented in Tables 3–5.

The length measurements obtained with MRA-MIP were significantly shorter than those with DSA. Three of the diameter measurements were significantly smaller on MRI/CE MRA than on DSA and CT, while 3 showed no significant difference.

No significant differences were found between the observers. The largest interobserver difference was found for the variable D2 and for the method CT.

We found no association of patients and observers regarding the clinically unacceptable variations of measurement between MRA-MIP vs. DSA.

We also studied the vessel morphology of the 5 patients with the best agreement of measurements as well as the 5 patients with the largest differences of L1 (MRA-MIP vs. DSA) and D2 (MRA-MPR vs. CT) as these differences were clearly significant (Table 4). No differences in vessel tortuosity, angulation or aneurysm size were found between the patients with the best and the least agreement of measurements.

The comparisons between the MRA post processing techniques MIP and VRT showed significantly smaller diameter measurements for D1 on MIP, but no significant differences with regard to the D2 or measurements of length (Table 3).

We found no association between patients and observers regarding the clinically unacceptable variations of measurement between MIP vs. VRT.

Discussion

A correct length and diameter of the stent-graft minimizes the most common complications of endovascular repair of AAA: persistent endoleak, stent-graft migration and secondary interventions. Over-sizing of stent-graft diameters may cause folding at the level of the attachment sites, which can result in misalignment of the stent-graft and the arterial wall. Overinflation of the balloon can stretch and weaken the aorta or iliac arteries. Diameters

Table 4

Pairwise differences in mm: median (5th and 95th percentile) and p-*values*

Methods	Variables						
	D1^{i}	D1°	D2^{i}	D2°	L1	L2	L3
MRA-MIP vs. DSA	−1 (−6, 3)		0 (−9, 4)		−4 (−25, 9)	−4 (−17, 5)	−6 (−24, 11)
p-value	0.02		0.09		< 0.001	< 0.001	0.03
MRA-MPR vs. CT	0 (−5, 4)		−2 (−20, 4)				
p-value	0.10		0.004				
MR-T1 vs. CT		0 (−5, 5)		−2 (−25, 8)			
p-value		0.5		0.008			
MIP vs. VRT	−1 (−3, 0)		−1 (−2, 1)		2 (−7, 8)	1 (−3, 9)	3 (−5, 6)*
p-value	< 0.001		0.05		0.4	0.16	0.3

The variables are explained in Table 1. Wilcoxon signed-rank test: *p*-value < 0.05 means that there was a significant systematic difference. *Corresponds to the range of pairwise differences, due to the small number of measurements (8).

Table 5
Pairwise differences with clinically unacceptable variations of measurement, %

Methods	Variables						
	D1[i]	D1°	D2[i]	D2°	L1	L2	L3
MRA-MIP vs. DSA	25		23		77	16	12
MRA-MPR vs. CT	38		56				
MR-T1 vs. CT		30		61			
MIP vs. VRT	15		10		45	5*	0

The variables are explained in Table 1. Clinically unacceptable variations of measurement: $> \pm 2$ mm for D1, D2 and L1, ± 10 mm for L2 and ± 20 mm for L3. *One pairwise difference $= -52$ mm.

chosen too small may cause false channels into the aneurysm sac. Too long a stent-graft with an unsupported body may kink or fold. If the proximal or distal end of a stent-graft is cut too short, it is at risk of being deployed in the aneurysm sac (4). In their study, STANLEY et al. found that proximal aortic neck contour, length and diameter, in that order, are the most important criteria of risk for endoleak development (15).

Length measurements with MRA-MIP vs. DSA: The results of this study showed that significantly shorter lengths were measured on MRA-MIP than on DSA (Table 4). Measurements may be overestimated on DSA by errors due to the imaging method as well as by the calibration method used. Foreshortening in the image of the measuring catheter (i.e., when the catheter is not oriented parallel with the imaging plane) will lead to an overestimation of the calibration factor. Also, out-of-plane magnification occurs if the distance between the measuring catheter and the image intensifier is not equal to the distance between the vessel of interest and the image intensifier. The segment of the catheter with the measuring markers is usually positioned in the aorta proximal to the aortic bifurcation. Measurements on the iliac arteries are therefore not necessarily carried out in the same plane as the calibration (17). In the study by THURNHER et al. (16), shorter lengths were obtained with CE MRA than with CTA. They believed that this could have been due to uncertainty of the observers as to where the aneurysm began. The length of the proximal aortic neck (L1) is the most crucial for secure anchoring of a stent-graft (8, 16). Our results showed a high percentage (77%) of pairwise differences with clinically unacceptable variations of measurement for L1 ($> \pm 2$ mm) for MRA-MIP vs. DSA (Table 5). One explanation for these differences could be the mural thrombus in the proximal portion of the aneurysm. DSA only delineates the vessel lumen and therefore tends to overestimate the length of the proximal aortic neck (L1) (2). Thus, the L1 measurements obtained by CE MRA are probably more correct due to the simultaneous access to transverse images showing the vessel lumen as well as the mural thrombus. Differences in our study do not depend on interobserver variations as to where the aneurysm began on DSA since the proximal margin of the aneurysm was marked.

Significant differences for L2 and L3 were also found between MRA-MIP and DSA (Table 4). The percentages of pairwise differences with clinically unacceptable variations of measurements were smaller than for L1 (Table 5), which could be explained by the fact that we accepted larger variations for L2 and L3 than for L1. The lengths L2 and L3 could be interpreted as longer on DSA due to difficulties in determining the exact position of the bifurcations on a 2D method. The 3D method CE MRA can better visualize the bifurcations by rotation of the MIP volume and by correlation with reconstructed transverse images (MPR). In our study, the differences may also be due to different experience of the observers with MR and DSA examinations, respectively. THURNHER et al. (16) found that even if measurements were performed carefully with a defined protocol, variability in measurements of AAA lengths at CE MRA and CTA is common.

Diameter measurements MRI/CE MRA vs. DSA/CT: In our study, 3 out of the 6 diameter measurements were significantly smaller on MRI/CE MRA than on DSA and CT, while 3 showed no significant difference (Table 4). The variations in diameter measurements on MRA-MIP with significant underestimation of D1 could be due to the observer-dependent determination of the vessel boundaries (individual observer selection of window settings). It has been shown that vessel diameters have the tendency to be underestimated on MIP (17). The pairwise differences with clinically unacceptable variations of measurement were larger for D2 than for D1 (Table 5). In our study, 95% of the aneurysms

did not have a clearly delineated non-aneurysmal distal aorta and therefore D2 was open to individual interpretation. The method with the highest percentage of pairwise differences with clinically unacceptable variations of measurement was CT (Table 5), which can be explained by the thick transverse CT slices used in our study (3).

Observers: No significant differences were found between the observers. The method with the largest interobserver difference was CT, which is in agreement with the study by Jaakkola et al., where conventional CT measurements were subject to significant interobserver variability and where this variability was greater in transverse planes (7).

MIP vs. VRT: We found that the diameter measurement D1 was significantly smaller on MIP than on VRT, but D2 and the length measurements showed no significant differences. The VRT measurement of D1 is probably more accurate since vessel diameters often are underestimated on MIP (17). In our study, we have chosen to compare the MIP with a corresponding 2D image of VRT, and thus have not used the full 3D capacity of VRT. Measurements on 3D VRT should be more accurate than MIP, since the measurements can be obtained in 3D and by using VRT in combination with surface enhancement, the boundaries between the contrast-enhanced blood and the vessel walls may be visualized and the diameters will thereby be more accurately defined (Fig. 2).

MRI/CE MRA reveals complex, tortuous arterial anatomy; accurately delineates aneurysm size, including proximal and distal extent, mural thrombus, relationship to major vessels and number and location of renal arteries (5, 16). MRI/CE MRA reveals iliac thrombi and aneurysms (5, 16) but is less sensitive for the detection of calcification. Stanley et al. found that improvements of the delivery systems enabled safe passage through tortuous and calcified iliac vessels (15). The detection of calcification should therefore become less important.

A disadvantage of MRI is that it is contraindicated in patients with non-MR-compatible metallic implants and pacemakers. Additionally, a few patients are unable to undergo an MR examination because of claustrophobia. The resolution of MRA in our study is not sufficient for accurate measurements of small structures, but with the improvement of the CE MRA technique, better results will be obtained.

This study has some limitations. The patient material is rather small and we have no true reference measurement. Comparisons are made between analog (DSA and CT) and digital measurements (MRI/CE MRA). Due to the development and improvement of the MR technique, the protocols were gradually updated, and therefore all examinations were not performed with the same protocol. The MR measurements would most likely be more accurate if all studies had been obtained using today's (2003) MR technique. The positioning of the 3D volume in CE MRA too far anteriorly, not including the whole extent of the iliac arteries, decreased the number of possible L3 measurements. Three CT examinations were performed at other centers with different protocols. CTA was not available at our center during this study and comparison with this method could not be performed.

We conclude that the length measurements obtained with MRA-MIP were significantly shorter, but probably more correct, than those obtained with DSA. The diameter measurements obtained with MRI/CE MRA were more variable. Improvements of the CE MRA technique including VRT reconstructions and a standardized determination of the vessel boundaries, are needed for more reliable diameter measurements.

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