Cardiovasc Intervent Radiol (2011) 34:1182–1189
DOI 10.1007/s00270-010-9992-x

CLINICAL INVESTIGATION

Maximum Diameter Measurements of Aortic Aneurysms on Axial CT Images After Endovascular Aneurysm Repair: Sufficient for Follow-up?

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Received: 11 June 2010 / Accepted: 30 August 2010 / Published online: 14 October 2010

Abstract

Purpose To assess the accuracy of maximum diameter measurements of aortic aneurysms after endovascular aneurysm repair (EVAR) on axial computed tomographic (CT) images in comparison to maximum diameter measurements perpendicular to the intravascular centerline for follow-up by using three-dimensional (3D) volume measurements as the reference standard.

Materials and Methods Forty-nine consecutive patients (73 ± 7.5 years, range 51–88 years), who underwent EVAR of an infrarenal aortic aneurysm were retrospectively included. Two blinded readers twice independently measured the maximum aneurysm diameter on axial CT images performed at discharge, and at 1 and 2 years after intervention. The maximum diameter perpendicular to the centerline was automatically measured. Volumes of the aortic aneurysms were calculated by dedicated semiautomated 3D segmentation software (3surgery, 3mensio, the Netherlands). Changes in diameter of 0.5 cm and in volume of 10% were considered clinically significant. Intra- and interobserver agreements were calculated by intraclass correlations (ICC) in a random effects analysis of variance. The two unidimensional measurement methods were correlated to the reference standard.

Results Intra- and interobserver agreements for maximum aneurysm diameter measurements were excellent (ICC = 0.98 and ICC = 0.96, respectively). There was an excellent correlation between maximum aneurysm diameters measured on axial CT images and 3D volume measurements ($r = 0.93$, $P < 0.001$) as well as between maximum diameter measurements perpendicular to the centerline and 3D volume measurements ($r = 0.93$, $P < 0.001$).

Conclusion Measurements of maximum aneurysm diameters on axial CT images are an accurate, reliable, and robust method for follow-up after EVAR and can be used in daily routine.

Keywords Endovascular aneurysm repair · Computed tomography · Diameter measurements · Follow-up

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Introduction

Abdominal aortic aneurysms are a potentially serious and life-threatening condition. The implementation of endovascular aneurysm repair (EVAR) represents one of the latest advances in the field of minimal invasive vascular interventions and has revolutionized the treatment of vascular aneurysms [1–4]. Nevertheless, it requires accurate preinterventional imaging to correctly evaluate the suitability for EVAR and to enable improved endograft sizing and placement [5, 6] as well as stringent postinterventional follow-up [7, 8] by using a precise and reproducible imaging modality to reliably assess the long-term performance of endoluminal stent graft devices and procedural success [9]. Postinterventional follow-up imaging of the stent graft, the aortic aneurysm, and the adjacent vascular anatomy is of utmost importance to reliably identify existing complications. Therefore, it is crucial to evaluate the integrity and patency of the endoluminal stent graft and its position, as well as the presence of endoleaks and other potentially life-threatening complications [10] that may necessitate further interventional therapy. The most important predictor for the presence of complications is the continuous growth of the excluded aneurysm sac [11]. Therefore, accurate assessment of the size of the excluded aneurysm during postinterventional surveillance is mandatory.

Multidetector computed tomography (MDCT) has become the most accepted and most widely applied diagnostic tool in current clinical practice of postinterventional follow-up imaging to accurately evaluate the chronological sequence of abdominal aortic aneurysm extension after EVAR [12–15]. In daily clinical routine, the measurement of maximum aneurysm diameters on axial MDCT images is still the most commonly used method to assess changes in size because they are easily and quickly acquired. Another method to assess the size of aneurysms is to measure the maximum aneurysm diameters perpendicular to the intravascular centerline, which is supposed to be more accurate [16, 17]. The intravascular centerline can be assigned by performing multiplanar reformations or by means of semiautomated three-dimensional (3D) segmentation software.

However, maximum diameter measurements on axial or multiplanar MDCT images are still discussed controversially [11, 16, 18, 19], while 3D volume analysis for the assessment of postinterventional changes in aortic aneurysm dimensions and morphology is propagated as the standard of reference because it is more accurate, more reliable, and even more reproducible [11, 19]. Nevertheless, it has some disadvantages, such as being time-consuming and necessitating the use of often costly postprocessing software. Moreover, accurately performed volumetric segmentation is required.

Therefore, the purpose of our study was to retrospectively assess the accuracy of maximum diameter measurements of aortic aneurysms after EVAR on axial MDCT images in comparison to maximum diameter measurements perpendicular to the intravascular centerline for follow-up with 3D volume measurements as the standard of reference.

Materials and Methods

Patient Population

A total of 49 consecutive patients (46 men, 3 women, mean age 73 ± 7.5 years, range 51–88 years) who underwent clinically indicated MDCT of the abdomen for postinterventional follow-up after EVAR of an infrarenal aortic aneurysm were retrospectively enrolled onto this study. Only patients who underwent elective stent grafting were included. The following two stent types were used: Excluder (W. L. Gore, Flagstaff, AZ) and Zenith (Cook, Bloomington, IN) devices. None of the included patients required repeated postoperative interventions or experienced type I, III, or IV endoleak. The presence of type II endoleaks was not an exclusion criteria. Patients with nephropathy (defined as serum creatinine level of >150 μmol/l) and known hypersensitivity to iodine-containing contrast agents were excluded from the study because they underwent only unenhanced computed tomography (CT). Institutional review board approval was obtained. Written informed consent was waived by the institutional review board because of the retrospective nature of the study and because all CT studies were clinically indicated.

MDCT Protocol

All examinations were performed on a first generation dual-source CT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany).

All patients underwent a triple-phase MDCT protocol consisting of image acquisitions during an unenhanced phase, an arterial phase, and a venous phase of contrast enhancement before hospital discharge after undergoing EVAR, as well as a dual-phase MDCT protocol consisting of image acquisitions during an arterial and a venous phase of contrast enhancement at 1 and 2 years of follow-up. The unenhanced phase serves as a baseline study for future follow-up and helps to identify high-density structures such as calcifications or residual contrast material after EVAR and to distinguish them from endoleaks seen on the arterial phase images. The venous phase was performed to accurately detect the presence of low-flow endoleaks that were not visible during the arterial phase [20]. MDCT scans were performed in the craniocaudal direction during mid-inspiration and ranged from the level of the cardiac apex to the greater trochanter. For the contrast-enhanced CT scans, a bolus of 100 ml of nonionic, iodinated contrast material (iopromidum, Ultravist 300, 300 mg iodine/ml; Bayer Schering Pharma, Berlin, Germany) followed by 40 ml saline flush was injected at a flow rate of 4 ml/s into an antecubital vein for contrast-enhanced abdominal CT angiography. The scan start was defined by the bolus tracking technique (the region of interest in the abdominal aorta at the level of the celiac trunk) with a signal attenuation threshold of 120 HU. After reaching the threshold, data acquisition was initiated after 8 s for the arterial and after 20 s for the venous contrast phase.

All patients were examined using the following scanner-specific settings: detector collimation of 2 × 32 × 0.6 mm, slice acquisition of 2 × 64 × 0.6 mm by means of a z-flying focal spot, gantry rotation time of 330 ms, tube voltage of 120 kV for venous phase and 100 kV for arterial phase, and tube-current–time product of 350 mAs/rotation. For the unenhanced and venous phase, pitch was 1.2; for the arterial phase, it was 1.0.

MDCT Data Reconstruction

All reconstructions of unenhanced arterial and venous CT scans were performed in a monosegment mode using 2-mm-thick nonoverlapping sections and a medium smooth tissue convolution kernel (B30f).

All images were anonymized and transferred to an external workstation (Multi-Modality Workplace; Siemens Healthcare, Forchheim, Germany) for further analysis.

MDCT Image Evaluation and Measurement Method

On axial MDCT images acquired during the venous phase of contrast enhancement, two blinded readers (T.F. and S. B., with 8 and 3 years of experience in vascular radiology, respectively) twice independently measured the maximum aneurysm diameter, which was defined as the largest aneurysm diameter in any direction (further referred to as axial diameter) (Fig. 1) performed at discharge and at 1 and 2 years after intervention. The time interval between the two readings was 14 days.

By means of a dedicated 3D vessel analysis software (3surgery, 3mensio, the Netherlands), maximum diameters perpendicular to the centerline (further referred to as centerline diameter) were measured, and segmentation and volumetry of the excluded aneurysm sack were performed by using the MDCT data set acquired during the venous phase of contrast enhancement. The centerline was defined by placing points in the center at the proximal and distal end of the aneurysm, which were then connected automatically (Fig. 2). The centerline could be corrected manually. Volumetry was performed by marking the outer border of the aneurysm sack every 22.5 degrees in the craniocaudal direction starting at the level immediately below the renal artery ostia and ending at the level of the aortic bifurcation (Fig. 3). These measurements were performed by a third reader (T.N., with 2 years of experience in vascular radiology).

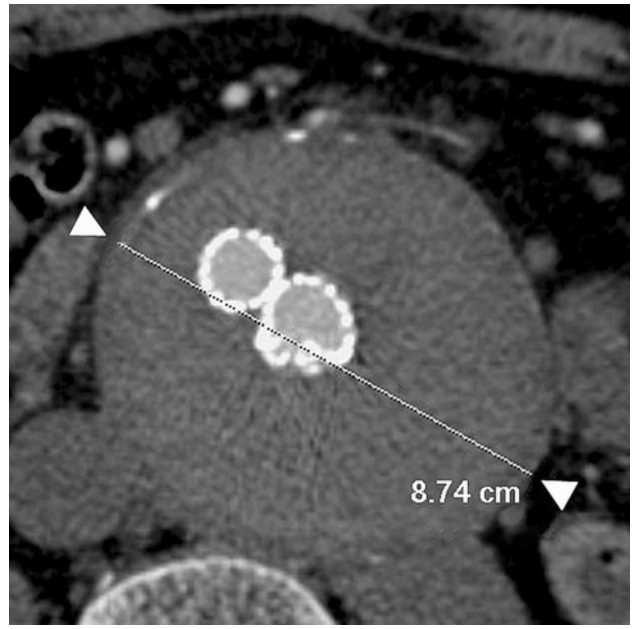

Fig. 1 Illustration of a maximum aneurysm diameter measurement of an abdominal aortic aneurysm after EVAR on an axial MDCT image during the arterial phase of contrast enhancement in an 82-year-old man. The maximum aneurysm diameter was defined as the largest aneurysm diameter in any direction on an axial MDCT image (*arrowheads*) and measured 8.7 cm in this particular case

Statistical Analysis

Statistical analysis was performed by commercially available software (SPSS, release 17.0 for Windows; SPSS, Chicago, IL). Continuous variables were reported as mean ± standard deviation (range). Three-dimensional volume measurements were considered as the standard of reference.

To reflect temporal changes of aortic aneurysm extension between discharge and 1 year after intervention, between discharge and 2 years after intervention, and between 1 and 2 years after intervention, changes in diameter and volume measurements were mathematically generated by subtracting follow-up measurements from preinterventional measurements. Changes in diameter of 0.5 cm and in volume of 10% were considered to be clinically significant, as previously described [9, 18].

Intra- and interobserver agreements were calculated for measurements of maximum aneurysm diameters on axial CT images by using intraclass correlations computed by restricted maximum likelihood estimation in a random effects analysis of variance comprising the factors time, observer, repetition, and patient.

The two unidimensional measurement methods (maximum axial and centerline diameter) were correlated all in all to the cube root of 3D volume measurements by Pearson correlation. In addition, corresponding changes of maximum axial diameter, maximum centerline diameter, and

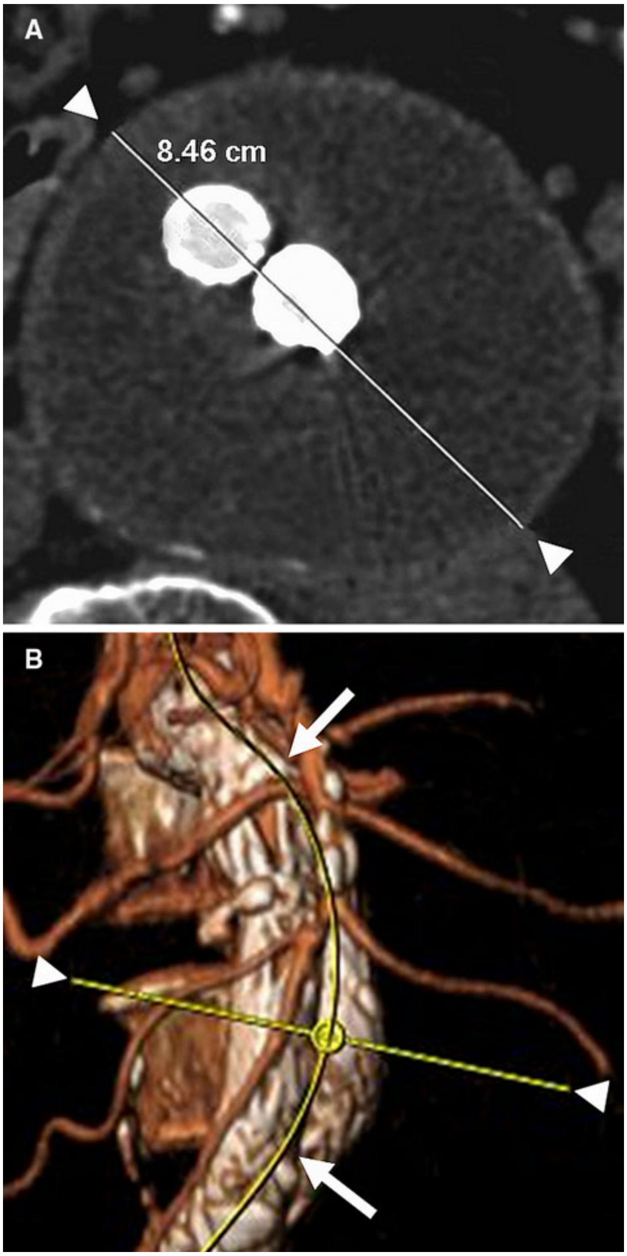

Fig. 2 **A** Multiplanar reformation perpendicular to the centerline illustrating the maximum diameter measurement (*arrowheads*) perpendicular to the centerline of the same abdominal aortic aneurysm as in Fig. 1. The measured diameter was 8.5 cm. **B** The centerline (*arrows*) was defined by placing points in the center at the proximal and distal end of the aortic aneurysm, which were then connected automatically using dedicated 3D vessel analysis software (3surgery, 3mensio, the Netherlands). Note that the multiplanar reformation (*arrowheads*) displayed in (A) is placed perpendicular to the centerline

the cube root of 3D volume measurements were correlated by means of multivariate regression models. All values characterizing multivariate regressions were expressed by adjusted squared correlation coefficients (r^2) to circumstantiate the degree of dependence even more precisely.

Fig. 3 Stretched vessel view demonstrating the 3D volume measurement of the same abdominal aortic aneurysm as in Figs. 1 and 2. By means of dedicated 3D vessel analysis software (3surgery, 3mensio, the Netherlands), volumetry was performed by marking the outer border of the aneurysm starting at the level immediately below the renal artery ostia and ending at the level of the aortic bifurcation. The assessed volume in this particular case was 313 cm^3

Sensitivity, specificity, positive predictive values, negative predictive values, and accuracy of maximum axial diameter measurements for the assessment of significant changes in aneurysm size, with 3D volumetry used as the standard of reference, were analyzed using cross-tabulation in an overall fashion and at all three predefined abovementioned time intervals.

P-values less than 0.05 were considered to be statistically significant.

Results

The overall intra- and interobserver agreements for maximum aneurysm diameter measurements on axial CT images were excellent ($r = 0.98$ and $r = 0.96$, respectively).

Mean maximum axial diameters, mean maximum centerline diameters, and the results of mean 3D volume measurements of the aortic aneurysms at discharge and after 1 and 2 years after intervention are displayed in Table 1.

Table 1 Assessed values of maximum aneurysm diameters measured on axial CT images, maximum diameters measured perpendicular to centerline, and 3D volume measurements of aortic aneurysms

Characteristic	Mean ± SD (range)
D_{max} axial T_0 (cm)	6.1 ± 1.6 (2.5–9.3)
D_{max} axial T_1 (cm)	5.7 ± 1.4 (3.2–9.0)
D_{max} axial T_2 (cm)	5.5 ± 1.5 (3.2–9.6)
D_{max} centerline T_0 (cm)	6.1 ± 1.7 (2.5–9.8)
D_{max} centerline T_1 (cm)	5.7 ± 1.4 (2.7–8.7)
D_{max} centerline T_2 (cm)	5.5 ± 1.6 (2.5–9.2)
3D volume T_0 (cm^3)	193.6 ± 121.2 (57.2–474.6)
3D volume T_1 (cm^3)	169.2 ± 95.2 (55.2–463.1)
3D volume T_2 (cm^3)	164.2 ± 102.1 (54.7–436.0)

D_{max}, maximum diameter; T_0, point in time at discharge; T_1, point in time 1 year after intervention; T_2, point in time 2 years after intervention; 3D, three-dimensional

By defining significant growth of the aortic aneurysm as changes of 0.5 cm in diameter and of 10% in volume, four aneurysms were found to be significantly growing. With regard to the standard of reference, all of them were correctly identified by the two measurement methods. Four patients experienced a small type II endoleak. The presence of endoleak did not correlate to changes of maximum aneurysm diameter or maximum centerline diameter. Because of the small number of endoleaks, and because only type II endoleaks were included in this study, we decided not to build a separate group.

There was an excellent and highly significant overall correlation between maximum axial diameters and 3D volume measurements ($r = 0.93$, $P < 0.001$), as well as between maximum centerline diameter and 3D volume measurements ($r = 0.93$, $P < 0.001$).

Correlations among correspondingly generated mathematical differences of maximum axial diameter, maximum centerline diameter, and 3D volume measurements reflecting temporal changes of aortic aneurysm extension between discharge and 1 year after intervention, between discharge and 2 years after intervention, and between 1 and 2 years after intervention are summarized in Table 2. We found substantial and highly significant correlations among changes in diameter between discharge and 1 year and between discharge and 2 years after intervention for maximum axial diameters and 3D volume measurements ($r^2 = 0.75$, $P < 0.001$, and $r^2 = 0.77$, $P < 0.001$, respectively), as well as for maximum centerline diameters and 3D volume measurements ($r^2 = 0.73$, $P < 0.001$, and $r^2 = 0.79$, $P < 0.001$, respectively). However, there were only moderate correlations, but with a high level of significance, among changes in diameter between 1 and 2 years after intervention for maximum axial diameters and 3D volume measurements ($r^2 = 0.46$, $P < 0.001$), as well as for maximum centerline diameters and 3D volume measurements ($r^2 = 0.55$, $P < 0.001$).

Excellent and substantial correlations with a high level of significance were detected among differences of the three predefined time intervals for maximum axial diameters and maximum centerline diameters ($r^2 = 0.83$, $P < 0.001$, $r^2 = 0.88$, $P < 0.001$, and $r^2 = 0.61$, $P < 0.001$, respectively) (Table 3).

Overall sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for the detection of significant changes by maximum axial diameter measurements using 3D volumetry as the standard of reference

Table 2 Overview of correlation values (r^2) among correspondingly generated mathematical differences of maximum aneurysm diameter on axial CT images, maximum aneurysm diameter perpendicular to intravascular centerline, and cube root of 3D volume measurements

Characteristic	$\Delta\sqrt[3]{}$(3D volume $T_0 - T_1$) (cm)	$\Delta\sqrt[3]{}$(3D volume $T_0 - T_2$) (cm)	$\Delta\sqrt[3]{}$(3D volume $T_1 - T_2$) (cm)	*P*
ΔD_{max} axial $T_0 - T_1$ (cm)	0.75		–	<0.001
ΔD_{max} axial $T_0 - T_2$ (cm)	–	0.77	–	<0.001
ΔD_{max} axial $T_1 - T_2$ (cm)	–	–	0.46	<0.001
ΔD_{max} centerline $T_0 - T_1$ (cm)	0.73	–	–	<0.001
ΔD_{max} centerline $T_0 - T_2$ (cm)	–	0.79	–	<0.001
ΔD_{max} centerline $T_1 - T_2$ (cm)	–	–	0.55	<0.001

Δ, mathematically generated difference; $\sqrt[3]{}$, cube root; D_{max}, maximum diameter; T_0, point in time at discharge; T_1, point in time 1 year after intervention; T_2, point in time 2 years after intervention; 3D, three-dimensional; *P*-values were generated performing an analysis of variance (ANOVA) with the patient as a random factor

Table 3 Overview of correlation values (r^2) among correspondingly generated mathematical differences of maximum aneurysm diameter on axial CT images and of maximum aneurysm diameter perpendicular to the intravascular centerline

Characteristic	ΔD_{max} centerline $T_0 - T_1$ (cm)	ΔD_{max} centerline $T_0 - T_2$ (cm)	ΔD_{max} centerline $T_1 - T_2$ (cm)	*P*
ΔD_{max} axial $T_0 - T_1$ (cm)	0.83	–	–	<0.001
ΔD_{max} axial $T_0 - T_2$ (cm)	–	0.88	–	<0.001
ΔD_{max} axial $T_1 - T_2$ (cm)	–		0.61	<0.001

Δ, mathematically generated difference; D_{max}, maximum diameter; T_0, point in time at discharge; T_1, point in time 1 year after intervention; T_2, point in time 2 years after intervention; *P*-values were generated performing an analysis of variance (ANOVA) with the patient as a random factor

Table 4 Diagnostic performance of maximum aneurysm diameter measurements on axial CT images for the assessment of aneurysm extension in comparison with three-dimensional volume measurements

Characteristic	ΔD_{max} axial $T_0 - T_1$ (cm)	ΔD_{max} axial $T_0 - T_2$ (cm)	ΔD_{max} axial $T_1 - T_2$ (cm)
Sensitivity	84% (0.64–0.95)	84% (0.66–0.95)	46% (0.24–0.68)
Specificity	96% (0.79–0.99)	78% (0.52–0.94)	96% (0.81–0.99)
PPV	96% (0.77–0.99)	87% (0.69–0.96)	91% (0.59–0.99)
NPV	85% (0.66–0.96)	74% (0.49–0.91)	68% (0.51–0.83)
Accuracy	90% (0.77–0.97)	82% (0.68–0.91)	74% (0.59–0.85)

Δ, mathematically generated difference; D_{max}, maximum diameter; T_0, point in time at discharge; T_1, point in time 1 year after intervention; T_2, point in time 2 years after intervention; PPV, positive predictive value; NPV, negative predictive value. Data are presented as % (95% confidence interval)

were 73, 91, 91, 75, and 82%, respectively. The parameters of diagnostic performance of maximum axial diameter measurements for the assessment of changes in aneurysm extension at all three above-mentioned time intervals (between discharge and 1 year after intervention, between discharge and 2 years after intervention, and between 1 and 2 years after intervention) are listed in Table 4. Whereas the diagnostic accuracy of maximum axial diameter measurements was high for the time interval between discharge and 1 year after intervention (90%) and between discharge and 2 year after intervention (82%), it seemed to be moderate for the time interval between 1 and 2 years after intervention (74%).

Discussion

Our study demonstrates that measurements of maximum aneurysm diameters on axial CT images are an accurate and robust method for follow-up after EVAR and can be used in daily routine.

MDCT has become the most accepted and most widely used diagnostic tool in current clinical practice of postinterventional follow-up imaging to accurately evaluate the chronological sequence of abdominal aortic aneurysm extension after EVAR [13–15].

Duplex ultrasound is increasingly being used as an alternative imaging modality for follow-up after EVAR. Whereas older publications favor MDCT for follow-up after EVAR [21, 22], newer studies propagate duplex or contrast-enhanced ultrasound [23, 24]. Nevertheless, a new meta-analysis by Mirza et al. [25] concluded that further studies are necessary before contrast-enhanced ultrasound can be utilized as the primary imaging tool for postinterventional follow-up. A possible follow-up strategy for the future might be the use of duplex or contrast-enhanced ultrasound after a primary MDCT follow-up excluding other types of endoleaks than type II, because an increase in diameter of the aneurysm sac is the first sign for an adverse outcome [26]. But until then, we prefer to use MDCT for follow-up after EVAR; the protocol can be optimized for a newer scanner [27].

Nevertheless, in daily clinical routine, MDCT-based measurements of maximum axial diameters are still the most commonly used method to assess changes in aneurysm size because they are easily and quickly acquired. In addition, previous studies demonstrated positive correlations between the extent of the maximum axial diameter and the level of the intraluminal aneurysm sac pulse pressure [28–32]. This means that the shrinkage of aortic aneurysms is associated with a decrease in intraluminal sac pulse pressures, while enlarging aortic aneurysms are associated with elevated sac pulse pressures, a finding that emphasizes the importance of the assessment of maximum diameter on axial MDCT images.

Another method to assess the size of aneurysms is to measure the maximum aneurysm diameters perpendicular to the intravascular centerline, which are supposed to be more accurate [16, 17]. The intravascular centerline can be assigned by performing multiplanar reformations or by using semiautomated 3D segmentation software.

Although previous studies discuss maximum diameter measurements on axial MDCT images controversially [11, 16, 18, 19], our results show an excellent and highly significant overall correlation between maximum axial diameters and 3D volume measurements. Furthermore, our study shows good diagnostic accuracy as well as substantial and highly significant correlations among differences between discharge and 1 year and between discharge and 2 years after intervention for maximum axial diameters and 3D volume measurements. This reflects the fact that measurements of maximum aneurysm diameters on axial CT images are a reliable and robust method for follow-up after EVAR when compared to the first postinterventional baseline examination at discharge. The major reduction in aneurysm size that takes place within the first year after intervention [33, 34] can therefore easily be detected by maximum aneurysm diameter measurements.

On the other hand, when comparing the results of the follow-up examination 1 and 2 years after intervention and thereby ignoring the results of the baseline examination at discharge, our results show only moderate diagnostic accuracy and correlations among differences between maximum axial diameters and 3D volume measurements. This is not surprising given that the size of the aortic aneurysm does only change marginally after the first postinterventional year [33] if no endoleak is present, and thus the assessed maximum aneurysm diameters mainly range by the majority within the accepted margin of error in measurement of 0.5 cm [18, 35, 36].

Changes within the margin of error in diameter measurements cannot be used for follow-up. By contrast, the 3D volumetry allows a more precise assessment of changes in volume even for minor changes.

Thus, we recommend comparison of the results of maximum axial diameters assessed at postinterventional follow-up examinations to the first postinterventional baseline examination at discharge. If the baseline study is not available, the performance of a 3D volume assessment of the size of the aortic aneurysm should be considered to reliably detect any changes in size.

We acknowledge some study limitations. First is the retrospective design of this study. Second, we included two different types of bifurcated endoluminal stent grafts, resulting in a heterogeneous collective. This could be of concern because it has been suggested that particular endograft types are strongly associated with the likelihood of aortic aneurysm sac shrinkage [37–40]. Because the primary goal was the comparison of different measurements methods and not the outcome itself, we decided to include all types of stents so that we would have a larger population.

In conclusion, measurements of maximum aneurysm diameters on axial CT images are an accurate, reliable, and robust method for follow-up after EVAR and can be used in daily routine.

Conflict of interest The authors declare that they have no conflict of interest.

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