Intraobserver and interobserver variability of 64-row computed tomography abdominal aortic aneurysm neck measurements

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Background: **Integrity of the abdominal aortic aneurysm (AAA) neck is crucial for the long-term success of endovascular AAA repair (EVAR). However, suitable tools for reliable assessment of changes in small aortic volumes are lacking. The purpose of this study was to assess the intraobserver and interobserver variability of software-enhanced 64-row computed tomographic angiography (CTA) AAA neck volume measurements in patients after EVAR.**

Methods: **A total of 25 consecutive patients successfully treated by EVAR underwent 64-row follow-up CTA in 1.5-mm collimation. Manual CTA measurements were performed twice by three blinded and independent readers in random order with at least a 4-week interval between readings. Maximum and minimum transverse aortic neck diameters were measured twice on two different levels within the proximal neck. Volumetry of the proximal aortic neck was performed by using dedicated software. Variability was calculated as 1.96 SD of the mean arithmetic difference according to Bland and Altman. Two-sided and paired *t* tests were used to compare measurements. *P* values <.05 were considered to indicate statistical significance.**

Results: **Intraobserver agreement was excellent for dedicated aneurysmal neck volumetry, with mean differences of less than 1 mL ($P > .05$), whereas it was poor for transverse aortic neck diameter measurements ($P < .05$). However, interobserver variability was statistically significant for both neck volumetry ($P < .005$) and neck diameter measurements ($P < .015$).**

Conclusions: **The reliability of dedicated AAA neck volumetry by using 64-row CTA is excellent for serial measurements by individual readers, but not between different readers. Therefore, studies should be performed with aortic neck volumetry by a single experienced reader. (J Vasc Surg 2007;45:263-8.)**

Endovascular abdominal aortic aneurysm (AAA) repair (EVAR) is associated with significant advantages over open surgical repair in the perioperative period.[1,2] However, serious concerns regarding the long-term durability of this treatment option have been raised.[3,4] Progressive expansion of proximal attachment sites is a commonly observed situation in mid-term follow-up after open surgical AAA repair as well as after EVAR and probably reflects the natural course of progressive aneurysmal disease.[5,6] Occurring in up to 28% of patients, aortic neck dilatation thereby leads to reintervention rates of up to 20% within the first 2 years after EVAR (Diehm N, Hobo R, Baumgartner I, Do D, Keo H, Dick F, unpublished data).[6-8]

Several experimental and clinical studies have given promising insight into the biological mechanisms associated with the evolution of AAA, thus raising hope for potential therapeutic drug targets to inhibit aneurysmal aortic wall degeneration.[9-15] Evaluation of the clinical efficacy of such drugs will rely on precise baseline and follow-up imaging methods to correctly assess aortic size changes, especially in the infrarenal aortic neck segment. It has been shown that aortic neck diameter measurements can be associated with substantial observer variability[16,17] and, therefore, might be inappropriate for this purpose. Aortoiliac volume measurements, conversely, are an accepted method for analyzing changes in total AAA volumes after EVAR.[18-20] However, the precision of volume measurements has not yet been assessed for dedicated AAA neck volumetry. The purpose of this study was to assess the intraobserver and interobserver differences of sequential 64-row computed tomographic angiography (CTA) aortic neck volume measurements after EVAR.

METHODS

Twenty-five consecutive patients (23 men and 2 women; mean age, 75.5 ± 6.25 years) undergoing 64-row follow-up CTA after EVAR were prospectively studied. The following endografts had been used to treat AAA with a mean maximal diameter of 55.13 ± 11.84 mm (range, 42-79 mm): Vanguard (Boston Scientific, Oakland, NJ), n = 1; Excluder (WL Gore, Flagstaff, Ariz), n = 1; Ancure (Guidant, Indianapolis, Ind), n = 2; Aorfix (Lombard Medical, Oxfordshire, UK), n = 2; Anaconda (Sulzer Vascutek, Hamburg, Germany), n = 3; and Talent (Medtronic, Sunrise, Fla), n = 16. Ethics committee ap-

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Competition of interest: none.

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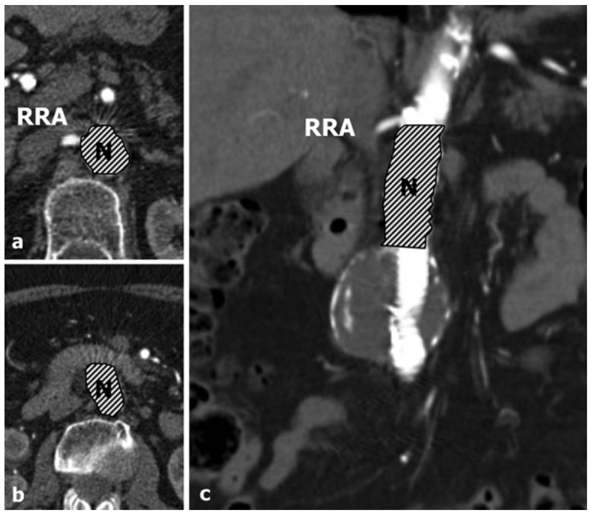

Fig 1. a, Infrarenal aortic aneurysm neck. *RRA,* Right renal artery; *N,* extent of the aortic neck on the first transverse computed tomographic slice distal to the RRA. **b,** Infrarenal aortic aneurysm neck. *N,* Extent of the aortic neck on the last transverse computed tomographic slice of the neck segment defined as the infrarenal neck by consensus agreement of two experienced readers. **c,** Infrarenal aortic aneurysm neck. *N,* Extent of the aortic neck on two-dimensional reconstruction of the infrarenal aorta.

proval was not obtained because CTA scans were performed on a regular clinical basis.

CTA measurements. CTA was performed on a 64-channel multislice computed tomography (CT) scanner (Somatom Sensation Cardiac 64; Siemens, Forchheim, Germany). Data acquisition parameters were 100 kVp, 320 mA quality reference, a 32 × 1.2-mm collimation, a pitch of 1.25, a reconstruction interval of 1.5 mm, and a 0.5-second gantry rotation speed. A total of 100 mL of nonionic iodinated contrast (350 mg/mL; Ioversol; Guerbet SA, Zurich, Switzerland) was injected at a flow rate of 3 mL/s by a power injector by using real-time bolus-triggering software (C.A.R.E.-Bolus; Siemens). Soft tissue window settings with a width of 600 HU and a center of 100 HU were used.

Aortic neck volume was measured from the raw CTA data set by using Syngo CT 2006A UB 20B software (Siemens). The aortic neck was defined as the nondiseased portion of the infrarenal aorta (a nondilated cylinder beginning distally to the most caudal renal artery and extending to the first CTA slice showing a ≥15% larger aortic wall diameter as compared with the diameter measured directly below the lowermost renal artery; Fig 1). To standardize measurements, the exact extent of the infrarenal aneurysm neck was predefined in consensus by two experienced readers (F.D. and N.D.) providing start and stop numbers of CTA slices for all readers assessing aortic morphometry. Aortic neck volumetry then was performed semiautomatically by each reader by manually segregating each single consecutive axial CTA slice strictly between start and stop slices and calculated by the above-mentioned software (Fig 1). Measurement of AAA neck morphology yielded neck volume (given in milliliters) and aortic neck diameter measured from outer adventitia to outer adventitia (given in millimeters) as the smallest ($D2a_{min}$) and the largest diameter ($D2a_{max}$) on axial CTA slices on the first slice distal to the lowermost renal artery and 10 mm below this landmark ($D2b_{min}$, $D2b_{max}$).

Evaluation. CTA volume measurements were performed by three blinded readers with different degrees of experience: reader 1 (H.R.) was a resident in radiology with 5 years of experience, reader 2 (F.D.) was a vascular surgeon with 7 years of experience in vascular imaging, and reader 3 (N.D.) was a resident in clinical and interventional angiology with a special interest in endovascular intervention and imaging and 6 years of experience in CTA imaging. To assess intraobserver variability, CTA data were analyzed twice by each reader in random order with an interval of at least 4 weeks between readings.

Statistical methods. To report AAA neck characteristics, mean values ± SD of pooled data from first measurements by three readers were considered. Intraobserver and interobserver differences were estimated by calculating the mean of the arithmetic differences between repeated measurements on the same subject.

Variability was calculated as ±1.96 SD of the mean arithmetic difference according to Bland and Altman.[21] Assuming a normal distribution, 95% of the differences lie within a range of ±1.96 SD of the mean difference. This range will be referred to as the limits of agreement. Paired two-sided *t* tests were used for comparisons among measurements. *P* values <.05 were considered to indicate statistical significance. All analyses were performed with SPSS for Windows version 12.0.1 (SPSS Inc, Chicago, Ill).

RESULTS

Detailed information on AAA neck dimensions is given in Table I.

Intraobserver variability of CTA volume and diameter measurements. Intraobserver agreement was high for dedicated neck volumetry by all readers, with individual mean differences of less than 1 mL ($P > .05$ by *t* test; Tables II-IV; Fig 2). However, intraobserver variability for neck diameter measurement was significant for $D2a_{min}$, $D2b_{min}$, and $D2b_{max}$ in reader 2 as well as for $D2a_{min}$ in reader 3 ($P < .05$ by *t* test; Tables II-IV). Intraobserver variability did not differ among different endografts ($P > .05$ by *t* test).

Interobserver variability of CTA volume and diameter measurements. The distribution of absolute volumes measured by all readers is shown in Fig 3. Neck volumetry was associated with significant interobserver variability in both readings ($P < .005$ by *t* test; Tables V and VI) except for measurements comparing reader 1 with reader 2. In almost the same manner, aortic neck diameter measurement was associated with statistically relevant interobserver variability ($P < .015$ by *t* test; Tables V and VI) except for single measurements comparing results from readers 1

Table I. Morphologic characteristics of proximal aortic necks in this series (n = 25)

Neck dimension	*Data*
Neck length (mm)	31.9 ± 20.4 (range, 18.3-75)
$D2a_{min}$ (mm)	24.6 ± 3.7 (range, 18.6-33.4)
$D2a_{max}$ (mm)	28.2 ± 5.0 (range, 19.8-39.7)
$D2b_{min}$ (mm)	25.1 ± 3.5 (range, 17.8-34.2)
$D2b_{max}$ (mm)	28.6 ± 4.3 (range, 21.3-38.4)
$Neck_{Vol}$ (mL)	23.4 ± 9.9 (range, 10.9-50.7)
Neck angulation 0°-15°	n = 19 (76%)
Neck angulation 16°-30°	n = 5 (20%)
Neck angulation 31°-45°	n = 1 (4%)
Circumferential thrombus 0%-25%	n = 3 (12%)
Circumferential thrombus 26%-50%	n = 1 (4%)
Circumferential thrombus >50%	n = 0 (0%)
Tapered neck	n = 3 (12%)
Reverse tapered neck	n = 1 (4%)

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2a_{max}$*, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2b_{min}$*, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$D2b_{max}$*, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$Neck_{Vol}$*, neck volume.

Table II. Intraobserver differences for repeated CTA measurements in 25 patients for reader 1

Variable	*Difference*	*SD*	*Limits of agreement*	P *values**
$Neck_{Vol}$	−0.58	1.48	−1.19 to 0.03	.062
$D2a_{min}$	−0.06	0.22	−0.15 to 0.04	.225
$D2a_{max}$	−0.06	0.26	−0.17 to 0.04	.230
$D2b_{min}$	−0.008	0.24	−0.11 to 0.09	.863
$D2b_{max}$	0.006	0.28	−0.11 to 0.12	.917

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2a_{max}$*, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2b_{min}$*, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$D2b_{max}$*, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$Neck_{Vol}$*, neck volume.
*Paired two-sided *t* test.

and 3. Interobserver variability did not differ among different endografts ($P > .05$ by *t* test).

DISCUSSION

The introduction of multidetector row CTA technology has greatly advanced its role in diagnostic imaging in patients with vascular diseases. Thus, CTA has become a key imaging modality in patients with AAA, and 64-row CT technology promises to further improve image quality, because high precision and reliability of volumetric measurements are important prerequisites for the detection of AAA neck growth after EVAR.

It is agreed upon that volumetry has a higher predictive accuracy than maximum diameter measurement in assessment of total AAA size changes after stent-graft insertion.[18-20] However, dedicated aortic neck volumetry involves substantially smaller values than total AAA volumetry, which is usually measured from the renal arteries to the orifice of the hypogastric artery. Therefore, it might bear higher susceptibility to observer variability. However, it has recently been shown that small lung nodules with volumes as low as 7.3 mm^3 can be measured with high precision by using 4-row CT technology.[22]

To our knowledge, observer variability of aortic neck measurements with 64-row CTA has not been assessed. Our hypothesis was that aortic neck volumes can be reliably measured in vivo by using state-of-the-art three-dimensional CTA imaging allowing for maximum spatial resolution. Indeed, we have shown that, even though comparatively small volumes were measured, intraobserver agreement was excellent for all readers, thus indicating that relative volume changes could be reliably reproduced when assessed by a single reader under study conditions. This observation suggests that serial AAA neck measurements as performed on 64-row CTA could be implemented as a valid surrogate end point for assessment of the effect of differentiated medical treatment strategies in the prevention of aortic neck enlargement after EVAR.

Table III. Intraobserver differences for repeated CTA measurements in 25 patients for reader 2

Variable	*Difference*	*SD*	*Limits of agreement*	P *value**
$Neck_{Vol}$	0.25	2.67	−0.86 to 1.35	.645
$D2a_{min}$	0.58	1.36	0.02 to 1.15	.043
$D2a_{max}$	−0.87	7.32	−3.89 to 2.16	.559
$D2b_{min}$	0.77	1.84	0.01 to 1.53	.047
$D2b_{max}$	0.82	1.21	0.32 to 1.32	.002

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2a_{max}$*, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2b_{min}$*, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$D2b_{max}$*, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$Neck_{Vol}$*, neck volume.
*Paired two-sided *t* test.

Table IV. Intraobserver differences for repeated CTA measurements in 25 patients for reader 3

Variable	*Difference*	*SD*	*Limits of agreement*	P *value**
$Neck_{Vol}$	−0.19	0.58	−0.44 to 0.05	.110
$D2a_{min}$	−1.24	1.90	−2.03 to −0.45	.003
$D2a_{max}$	0.32	2.50	−0.71 to 1.36	.524
$D2b_{min}$	−0.51	1.46	1.12 to 0.09	.093
$D2b_{max}$	−0.24	1.00	−0.65 to 0.17	.242

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2a_{max}$*, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; *$D2b_{min}$*, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$D2b_{max}$*, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; *$Neck_{Vol}$*, neck volume.
*Paired two-sided *t* test.

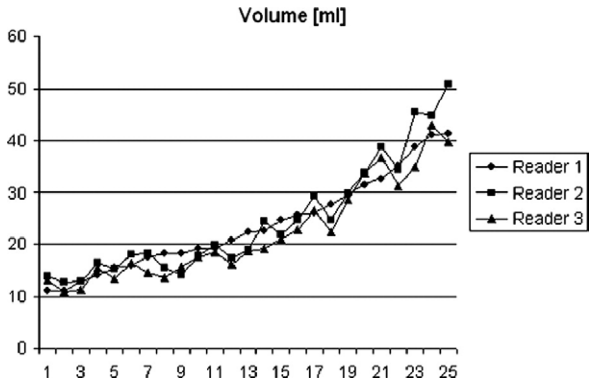

Fig 2. a, Plot of intraobserver differences against the average volume of the aortic neck for reader 1 according to Bland and Altman.[22] **b,** Plot of intraobserver differences against the average volume of the aortic neck for reader 2. **c,** Plot of intraobserver differences against the average volume of the aortic neck for reader 3.

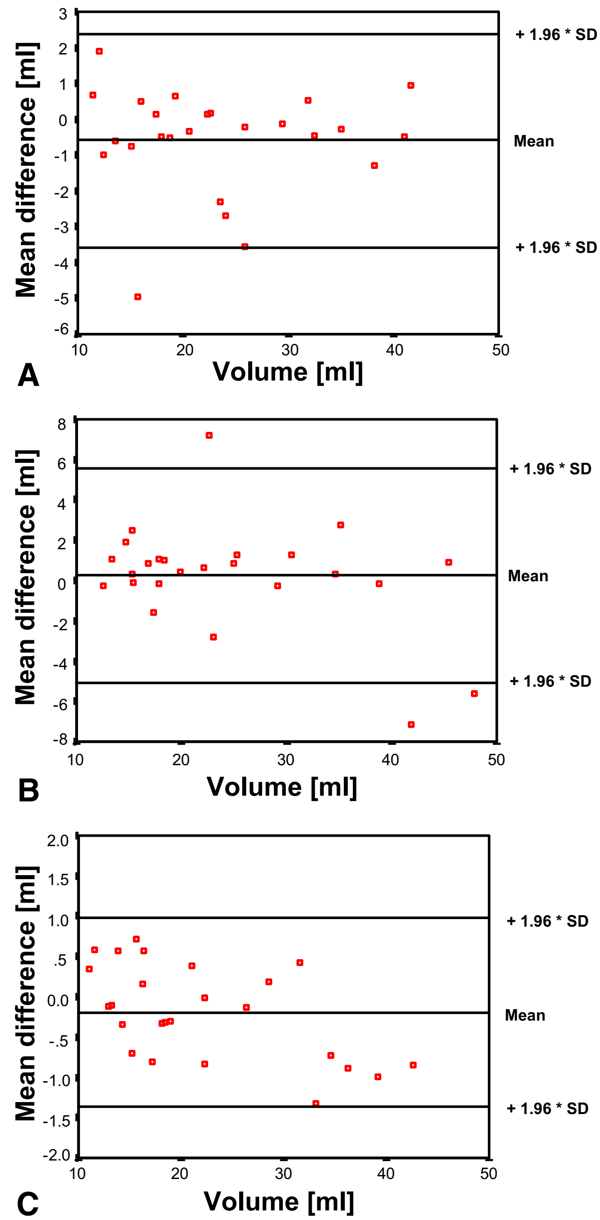

Fig 3. Distribution of aortic neck volume measurement results as measured by three blinded and independent readers.

Measurement methods were optimized by clear predefinition of aortic neck dimensions before individual analysis, thereby limiting potential observer variability. Despite this effort, interobserver variability was considerable in our series. This finding might be explained by the fact that varying interpretation of vascular morphology in the axial section and surrounding structures by each individual observer may lead to relevant measurement differences. Therefore, we recommend that serial volume measurements for assessment of aortic neck size changes should be performed by a single reader.

According to what has been shown for AAA diameter measurements in other studies applying less elaborate imaging methods,[16,23-25] neck diameter measurement on axial CTA slices resulted in statistically significant intraobserver variability. The use of 64-row CTA plus dedicated software did not improve the precision of axial AAA diameter measurements.

Using a two-dimensional tool such as diameter measurement to evaluate a three-dimensional object such as an aortic neck is a potential source for observer variation, especially if slices are not analyzed perpendicular to the aortic centerline. Furthermore, in contrast to volumetry, in which vascular structures are marked by the reader and semiautomatically calculated by the CT software, diameter measurement offers various possibilities for measurement variation around the vessel circumference. In the presence of more sophisticated three-dimensional imaging options, we therefore regard axial diameter measurements as not a first-line method to assess for changes in neck morphology after EVAR, especially in studies aiming at the prevention of aortic neck enlargement.

Two shortcomings of this study have to be addressed. The first limitation is the fact that the true volume of aortic necks measured in this study is not known. However, the study was focused on in vivo assessment of precision because this is most important in assessing the reproducibility of this imaging method before it can be recommended as a tool within prospective trials. Therefore, in vitro evaluation of the accuracy of 64-row CTA AAA neck measurements using calibrated phantoms is warranted to confirm its ability to validly quantify volumes of varying anatomy.

Second, because shortcomings of the software interfered with our standardized measurement protocol, we did not perform diameter measurements perpendicular to the centerline of the infrarenal aortic segment. It has been shown by others that the interobserver variability of diameter measurements can be lessened when measurements are performed perpendicular to the aortic centerline.[23] However, even with standardized measurements, variability was still considerable, thus indicating that the precision required to reliably assess changes in neck dimensions over

Table V. Interobserver differences for CTA measurements in 25 patients: first reading

Variable	*Difference*	*SD*	*Limits of agreement*	P *value**
Reader 1 vs reader 2				
$Neck_{Vol}$	0.84	3.39	−0.55 to 2.24	.225
$D2a_{min}$	1.42	2.62	0.34 to 2.50	.012
$D2a_{max}$	2.09	3.21	0.77 to 3.42	.003
$D2b_{min}$	1.57	3.19	0.25 to 2.89	.022
$D2b_{max}$	2.50	2.33	1.53 to 3.50	.000
Reader 1 vs reader 3				
$Neck_{Vol}$	−1.53	2.49	−2.56 to −0.50	.005
$D2a_{min}$	0.34	2.93	−0.87 to 1.55	.567
$D2a_{max}$	−0.17	2.48	−1.19 to 0.86	.738
$D2b_{min}$	0.020	2.52	−1.02 to 1.06	.969
$D2b_{max}$	1.22	2.32	0.26 to 2.18	.015
Reader 2 vs reader 3				
$Neck_{Vol}$	−2.38	2.83	−3.55 to −1.21	.000
$D2a_{min}$	−1.08	1.98	−1.90 to −0.26	.012
$D2a_{max}$	−2.26	2.76	−3.40 to −1.12	.000
$D2b_{min}$	−1.55	1.75	−2.27 to −0.82	.000
$D2b_{max}$	−1.28	1.51	−1.90 to −0.65	.000

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; $D2a_{max}$, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; $D2b_{min}$, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; $D2b_{max}$, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; $Neck_{Vol}$, neck volume.
*Paired two-sided *t* test.

Table VI. Interobserver differences for CTA measurements in 25 patients: second reading

Variable	*Difference*	*SD*	*Limits of agreement*	P *value**
Reader 1 vs reader 2				
$Neck_{Vol}$	1.67	2.20	0.76 to 2.58	.001
$D2a_{min}$	2.56	2.74	1.43 to 3.69	<.001
$D2a_{max}$	3.31	3.89	1.70 to 4.91	<.001
$D2b_{min}$	2.42	2.55	1.37 to 3.47	<.001
$D2b_{max}$	3.26	2.88	2.07 to 4.45	<.001
Reader 1 vs reader 3				
$Neck_{Vol}$	−1.15	2.10	−1.99 to −0.30	.010
$D2a_{min}$	−0.35	2.74	−1.48 to 0.78	.531
$D2a_{max}$	0.80	3.91	−0.81 to 2.41	.317
$D2b_{min}$	−0.41	2.61	−1.48 to 0.67	.441
$D2b_{max}$	0.92	2.81	−0.24 to 2.08	.115
Reader 2 vs reader 3				
$Neck_{Vol}$	−2.82	1.60	−3.48 to −2.16	<.001
$D2a_{min}$	−2.90	1.79	−3.65 to −2.16	<.001
$D2a_{max}$	−2.51	1.68	−3.20 to −1.81	<.001
$D2b_{min}$	−2.83	2.00	−3.65 to −2.00	<.001
$D2b_{max}$	−2.34	1.31	−2.88 to −1.80	<.001

$D2a_{min}$, Smallest diameter on the axial slice on the first slice distal to the lowermost renal artery; $D2a_{max}$, largest diameter on the axial slice on the first slice distal to the lowermost renal artery; $D2b_{min}$, smallest diameter on the axial slice 10 mm distal to the lowermost renal artery; $D2b_{max}$, largest diameter on the axial slice 10 mm distal to the lowermost renal artery; $Neck_{Vol}$, neck volume.
*Paired two-sided *t* test.

time would not be granted by using this measurement approach. Because our series mainly contained patients with favorable aortic neck morphology, we assume that diameter measurements perpendicular to the centerline would not have added substantial improvements.

In conclusion, our prospective study revealed that AAA neck volumetry can be performed with good intraobserver agreement by using software-enhanced 64-row CTA. Studies assessing differentiated therapies aiming at the prevention of aortic neck degeneration should adopt CTA volumetric measurements performed by a single experienced reader and refrain from serial AAA neck diameter measurements.

AUTHOR CONTRIBUTIONS

Conception and design: ND, RK, BG, IB, FD
Analysis and interpretation: ND, RK, BG, HR, IB, FD
Data collection: ND, RK, D-DD, HR, IB, FD
Writing the article: ND, RK, D-DD, IB, FD
Critical revision of the article: ND, RK, BD, D-DD, JS, HR, IB, FD
Final approval of the article: ND, RK, JS, IB, FD
Statistical analysis: ND, BG, FD
Overall responsibility: ND

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