Abdominal aortic aneurysm diameter: A comparison of ultrasound measurements with those from standard and three-dimensional computed tomography reconstruction

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Objective: **Aortic aneurysm size is a critical determinant of the need for intervention, yet the maximal diameter will often vary depending on the modality and method of measurement. We aimed to define the relationship between commonly used computed tomography (CT) measurement techniques and those based on current reporting standards and to compare the values obtained with diameter measured using ultrasound (US).**

Methods: **CT scans from patients with US-detected aneurysms were analyzed using three-dimensional reconstruction software. Maximal aortic diameter was recorded in the anteroposterior (CT-AP) plane, along the maximal ellipse (CT-ME), perpendicular to the maximal ellipse (CT-PME), or perpendicular to the centerline of flow (CT-PCLF). Diameter measurements were compared with each other and with maximal AP diameter according to US (US-AP). Analysis was performed according to the principles of Bland and Altman. Results are expressed as mean ± standard deviation.**

Results: **CT and US scans from 109 patients (92 men, 17 women), with a mean age of 72 ± 8 years, were included. The mean of each series of readings on CT was significantly larger than the mean US-AP measurement ($P < .001$), and they also differed significantly from each other ($P < .001$). The CT-PCLF diameter was larger than CT-AP and CT-PME by mean values of 3.0 ± 6.6 and 5.9 ± 6.0 mm, respectively. The CT-ME diameter was larger than CT-PCLF by a mean of 2.4 ± 5 mm. The US-AP diameter was smaller than CT-AP diameter by 4.2 ± 4.9 mm, CT-ME by 9.6 ± 8.0 mm, CT-PME by 1.3 ± 5 mm, and smaller than CT-PCLF by 7.3 ± 7.0 mm. Aneurysm size did not significantly affect these differences. Seventy-eight percent of 120 pairs of intraobserver CT measurements and 65% of interobserver CT measurements differed by <2 mm.**

Conclusions: **CT-based measurements of aneurysm size tend to be larger than the US-AP measurement. CT-PCLF diameters are consistently larger than CT-PME as well as CT-AP measurements. These differences should be considered when applying evidence from previous trials to clinical decisions.** (J Vasc Surg 2009;50:263-8.)

Reporting standards for endovascular aneurysm repair from the Society for Vascular Surgery (SVS) recommend that abdominal aortic aneurysm (AAA) size is most accurately measured using three-dimensional (3D) reconstructions of computed tomography (CT) images and by measuring the maximal aortic diameter perpendicular to the line of flow. As a second best, the axial diameter perpendicular to the maximal elliptical diameter is recommended.[1] Unfortunately, these methodologic recommendations vary from those used in the large trials on which many decisions for intervention are based, most often using maximal diameter in any direction and not always accounting for tortuosity.[2,3]

The landmark trials that used ultrasound (US) as the primary measurement tools are no less inconsistent. The United Kingdom Small Aneurysm Trial (UKSAT) used the maximal anteroposterior (AP) diameter on US.[4-6] The Multicentre Aneurysm Screening Study (MASS) trial measurements included both maximal AP and maximal transverse diameter and used which ever was the larger of the two.[7]

Although the use of callipers, marked paper, and a magnifying glass to determine size is still standard practice in some centers, many now use more modern imaging and analytic technology that allows precise computer-based measurement as well as automatic centerline determination. It is likely that significant differences exist between size measurements for the same aneurysm depending on the methodology used.

Because the timing of operative intervention for AAA is a balance between the risk of continued observation and the risk of operation itself, it is critical to determine the level of agreement between values derived from clinical trials and current reporting standards. The clinician should know whether the cutoff points for intervention and the aneurysms for which outcomes are reported in the clinical trials are greater or smaller than would be determined by using the currently recommended methods for size calculation. Furthermore, the correlation between US measurement of screen-detected aneurysm sac size and measurement of the same aneurysm on CT using centerline flow analysis has yet to be defined.

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The purpose of the present study was to compare diameter measured by US with that of CT, with particular attention to the comparison between the currently recommended modality based on centerline of flow computation and the methodology used in previous landmark trials.

METHODS

All patients referred for assessment of newly diagnosed AAA during a 35-month period (n = 196) were eligible for inclusion. According to departmental protocol at the time, US measurement of aortic diameter was performed on all patients after the first CT scan, before intervention. We excluded 27 patients in whom >90 days had elapsed between the time of the CT scan and the US measurement. Another 55 patients were excluded because either they did not have thin-slice CT scans ≤5 mm in thickness, they did not have contrast-enhanced scans, a centerline calculation was not possible due to the presence of orally administered contrast material, or because they had previously undergone aortic intervention. Five patients with saccular or inflammatory aneurysms were also excluded.

US technique. All measurements were performed on patients in the supine position by one of two experienced technicians. Maximal AP diameter was registered with echo-tracking US equipment (Diamove, Teltec AB, Lund, Sweden) using a 3.5-MHz B-mode real-time linear array transducer. The technique has been previously described in detail.[8,9] Briefly, the aorta is visualized in the longitudinal axis, and the point of maximal AP diameter is identified (US-AP). Electronic markers are automatically aligned with and locked to the luminal interface of the B-mode echo image of the anterior and posterior wall, and the diameter is registered from intimal layer to intimal layer throughout the cardiac cycle. We have shown that the echo-tracking feature allows us to obtain more accurate and reproducible readings than would otherwise be possible, and we have previously reported intraobserver variability and interobserver variability as 0.78 mm and 0.93 mm (standard deviations), respectively.[10]

CT analysis. Data sets acquired by a multidetector row spiral CT scanner (Siemens, Erlanger, Germany) were analyzed using 3D software tools at a postprocessing workstation (Aquarius, Terarecon Inc. San Mateo, CA). Measurements taken from axial cuts included the AP maximal aortic diameter (CT-AP), the diameter of the maximal ellipse in any direction (CT-ME), and the diameter perpendicular to the maximal ellipse at the widest point (CT-PME). The semiautomated centerline calculation was then performed on the 3D aortic reconstruction, and its accuracy was confirmed by examining the images perpendicular to the projected centerline. Maximal diameter in any direction was measured from the 2D image representing the plane orthogonal to the centerline of flow (CT-PCLF) (Fig 1). All measurements were taken from outer wall to outer wall, and images were stored electronically.

Interobserver and intraobserver variability. Two of the authors, blinded to patients' details and to previous measurements, separately analyzed 30 randomly selected scans. For intraobserver variability assessment, the same aneurysm measurements (CT-AP, CT-ME, CT-PME, and CT-PCLF) were taken on two separate occasions for the same patients in a similarly blinded fashion.

Statistical analysis. For interobserver and intraobserver analysis and for comparison of the measurements obtained from US and CT, we used the methods described by Bland and Altman.[11] Linear regression analysis was performed to assess correlation, and the paired-sample Wilcoxon signed-rank test was used to compare diameters. The difference between aneurysm measurements based on the various methods was recorded for each patient, and a mean difference in diameter, positive or negative, was recorded for each pair of tests. Results are expressed as mean ± standard deviation. SigmaPlot 11 software (Systat Software Inc, San Jose, Calif) was used for these calculations.

RESULTS

Patients. The study included 109 patients (male/female ratio: 5.4:1) with a mean age of 72 ± 8 years. Mean time from the initial CT scan to the US test was 30 ± 33 days. The US scan took place subsequent to the CT scan in 88% of cases. Fig 2 illustrates the good correlation that exists between the US-AP measurement and CT-AP (correlation coefficient, 0.91). Similar correlation was observed when US measurements were compared with other CT-based readings and when CT readings were compared with each other. In the clinical setting, however, agreement between measurement techniques is more important than correlation, and to express this, we have used the Bland-Altman method (Fig 3), plotting the difference between the measurement methods against their mean (the mean value of the two measurements). If both measurement techniques were in very good agreement, in each case we would see a cluster of dots around the mean, equally above and below, and the mean difference would be approximately zero. We observe that this is not the case. There is persistent bias toward larger readings on all CT measurements compared with US, but particularly with CT-ME and CT-PCLF measurements. Similarly, CT-ME and CT-PCLF measurements are consistently greater than CT-AP and CT-PME readings, although to a lesser extent.

Mean maximal aortic diameters as calculated by the different methods are summarized in the Table, where the mean difference between the US-AP diameter and the various CT readings are also presented. The US-AP diameter was significantly smaller than the diameter measured by any means on CT scan. Although the diameter measured on CT-PME most closely approximated US-AP readings, with a mean difference of 1 mm (greater), the mean difference between US-AP readings and CT-ME diameter was 9.6 mm, with CT-PCLF and CT-AP readings greater than US diameter by a mean of 7 and 4 mm, respectively. The ME diameter on CT was greater than CT-AP readings by a mean of 5 mm, although the CT-PCLF diameter was greater than the CT-AP and CT-PME measurements by a mean of 3 and 6 mm, respectively.

Fig 1. Differing diameter measurements according to axis. Clockwise from left: maximum anteroposterior, maximum ellipse and perpendicular to maximum ellipse, perpendicular to the centerline of flow, and three-dimensional reconstruction along the axis of the centerline of flow.

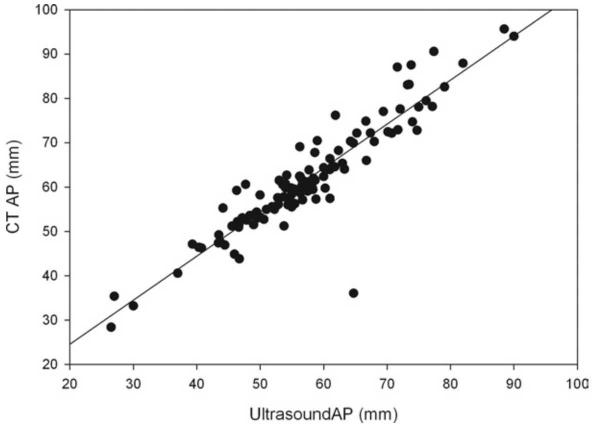

Fig 2. Correlation between computed tomography (*CT*) anteroposterior (*AP*) measurement and ultrasound AP measurement. Correlation coefficient was 0.91.

Variation between intraobserver measurement pairs was <2 mm in 78% and >5 mm in 2.5% of pairs. Interobserver variation was <2 mm in 65% and >5 mm in 9.5% of pairs.

DISCUSSION

In perhaps no other surgical condition is size such a critical determinant of the need for intervention as it is with AAAs. This importance is reflected by the large multicenter trials that have been conducted to elicit the appropriate cutoff point beyond which the risk of aneurysm rupture is likely to outweigh the risks associated with treatment. The advent of endovascular aneurysm repair (EVAR), thin-slice CT, digital imaging and measurement capability as well as readily available software to analyze and reconstruct aneurysms in 3D has rendered previously described measuring methods for aneurysm diameter out-of-date. However, evidence-based on studies using less sophisticated techniques are still the gold standard that guide clinicians. The findings of the present study should be interpreted in the context of the

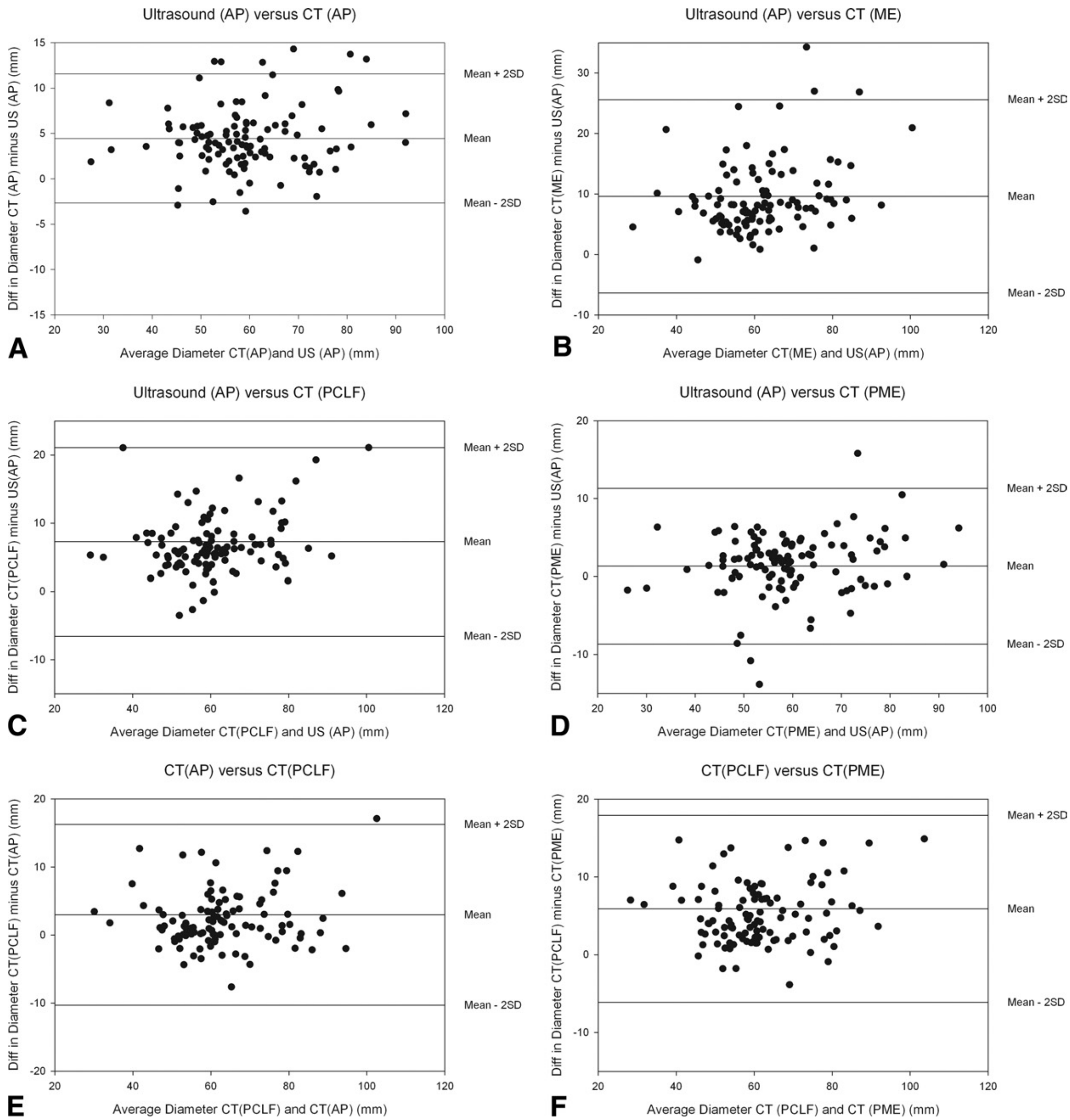

Fig 3. Bland-Altman plots illustrate the bias towards smaller mean diameter measurements for AP ultrasound (*US*) when compared with computed tomography (*CT*) in different planes (**A**) anteroposterior (*AP*) (**B**) maximum ellipse (*ME*), (**C**) perpendicular to the centerline of flow (*PCLF*), (**D**) perpendicular to the maximum ellipse (*PME*). Differences between CT measurements are also shown in **(E)** CT-AP vs CT-PCLF and **(F)** CT PCLF vs CT PME. Note that the x-axis range varies between plots.

current guidelines from the SVS on the optimal technique for measuring aortic diameter,[1] as well as the findings of these large trials.

The UKSAT trial recommended surgical repair for aneurysms >5.5 cm, maximal AP diameter, measured by US.[5] We have found that CT-PCLF, the currently recommended CT measurement technique, shows consistent bias toward a larger diameter value than AP diameter on US, with a mean difference of 7 mm. Therefore, what would be a 5.6-cm aneurysm by current standards is actually a 4.9-cm aneurysm using UKSAT methods and would not warrant intervention. The Aneurysm Detection and Management (ADAM) trial, which produced similar recommendations to those of the UKSAT, used CT measurements of diameter to determine eligibility, without the benefit of digitally based measurements or 3D reconstruction.

Table. Comparison of mean aortic diameter for each method of measurement

Method of measurement	*Median diameter (IQR, mm)*	*Difference from US-AP, mm*[a]	P[b]	*Difference from CT-PCLF, mm*[a]	P[b]
US-AP	56.5 (49.6-63.5)	. . .	. . .	−7.3 ± 7.0	<.001
CT-AP	59.9 (53.7-69.3)	+4.2 ± 4.9	<.001	−3.0 ± 6.6	<.001
CT-ME	65.5 (58.1-75.3)	+9.6 ± 8.0	<.001	+2.4 ± 5.0	<.001
CT-PME	57.2 (51.3-64.5)	+1.3 ± 5.0	<.001	−5.9 ± 6.0	<.001
CT-PCLF	62.4 (54.9-71.6)	+7.3 ± 7.0	<.001	. . .	. . .

AP, Anteroposterior; *CT,* computed tomography; *ME,* maximum ellipses; *IQR,* interquartile range; *PCLF,* perpendicular to the centerline of flow; *PME,* perpendicular to the maximum ellipse; *US,* ultrasound.
[a]Values are mean ± standard deviation.
[b]*P* values relate to comparison of means with CT-PCLF or US-AP.

Although maximal diameter in any dimension was described in the methodology, in tortuous sections of aorta, diameter perpendicular to the line of flow was used.[3] We found that when maximal diameter in any direction on axial CT slices was used, diameter was overestimated by a mean of 9.6 mm compared with US-AP measurement, whereas when the diameter perpendicular to the maximal ellipse on axial sections was used, the overestimation was only 1 mm. Therefore, of all CT measurement techniques, diameter perpendicular to the maximal ellipse on axial sections most closely approximates the findings of US and so would be the most appropriate measurement to use when applying UKSAT results to the decision whether to offer intervention.

Accordingly, we would expect the ADAM trial to overestimate aneurysm sac size compared with the UKSAT, and this has implications for comparing the outcomes of these trials. Acknowledging the reproducibility differences between US and CT, the authors of the EVAR trials recommended CT scans for all aneurysms with a diameter >5 cm and measured diameter in any direction on CT.[2] Taking this to mean the diameter of the maximal ellipse, then aneurysm size according to standards of the EVAR trial would be a mean of 9.6 mm greater than what we measured on US-AP (or what served as the basis for the UKSAT). However, although not specifically stated, it is of course possible that clinicians measuring size on CT would intuitively take account of tortuosity on axial sections and not always measure the maximal elliptical diameter where the aorta is angulated, even though this may represent the largest point of the aneurysm.

What are the implications of these findings? Is it acceptable to "correct" a reading from CT, which is likely to be more accurate than US? Although the current SVS recommendations require 3D reconstruction to produce a view of the aorta perpendicular to the line of blood flow, diameters measured in this way have not previously been used in the relevant trials and are therefore not correlated with indications and outcomes. That is not to say that the current recommendations will not give more reproducible measurements, which in accounting for tortuosity in the aorta, may in fact be more representative of the in vivo size of the aneurysm.

It follows that correction of CT results is necessary when evidence from trials such as the UKSAT is applied to allow for the bias toward undersizing, which we have demonstrated. It is important to emphasize that this negative bias occurs despite very good correlation, resulting in poor agreement between US and CT. According to the principles of Bland and Altman, it is always appropriate to correct for consistent bias with one technique by subtracting the mean difference between the techniques from the other. Adjusting the CT-based reading downwards, or adjusting the threshold for intervention based on CT results upwards from for example, 5.5 cm, should ideally be done on an institution to institution basis, owing to the variability in US measurement techniques and differing scan protocols from center to center. Intraobserver variability for AP diameter measured by US has been varyingly reported from 2.3 mm to 5 to 8 mm.[12,13]

In this and most other series,[14-17] US diameter measurements have been consistently smaller than measurements of the same aneurysm made on CT. Although CT measurements are only sometimes specified as being taken from outer wall to outer wall (adventitia to adventitia), reports on US-based measurements for the most part have not specified this. It is perhaps inadvisable to assume the outermost echogenic focus in an aneurysm wall is the adventitia when atherosclerotic plaque tends to be concentrated in the intimal layer and medial degeneration is often characteristic of aortic aneurysms. At least as relevant in explaining the difference between CT-AP and US-AP measurements is the angulation of the US transducer, which most ultrasonographers will hold parallel to the long axis of the aorta when taking measurements. Because CT-AP measurements on transverse slices do not correct for this, they are likely to be oblique to the long axis of the aorta to varying degrees, overestimating what the AP diameter perpendicular to the line of the aorta will be.

CT results are likely to be more reproducible,[15,18] although even with a standardized measurement protocol interobserver variation has been previously shown to vary by a mean of 2.8 ± 4.4 (SD) mm.[19] Our interobserver and intraobserver variability rates for CT measurements are consistent with previous reports.[15] It is noteworthy that we found the diameter PCLF to be consistently greater compared with diameter PME, with a mean difference of 6 mm and less of a difference compared with maximal AP diameter measured by CT, with a mean difference of 3 mm. Diameter PME is currently recommended by the SVS as an alternative to diameter PCLF when 3D reconstruction and CLF calculation is not possible.

We also investigated whether aneurysm size had a bearing on the bias toward larger CT measurements on CT, comparing patients with diameter of ≤55 mm (on US-AP) with those who had larger aneurysms, but we found no significant change in the mean differences between the two groups for the different measurements taken.

CONCLUSIONS

This study reaffirms the important difference that exists between CT- and US-based measurements of aortic aneurysm diameter. Importantly, we demonstrate that the two currently recommended methods for measurement of aortic diameter will result in consistently different readings for most patients, with the diameter perpendicular to the centerline of flow being a mean of 6 mm greater than the diameter perpendicular to the maximal ellipse on CT, and also larger than the AP measurement whether on CT or US. These differences should be taken into account when recommending intervention for smaller aneurysms.

AUTHOR CONTRIBUTIONS

Conception and design: BM, BS, TR
Analysis and interpretation: BM, BS, TR
Data collection: BM, TK, TR
Writing the article: BM
Critical revision of the article: BS, TR
Final approval of the article: BS, TR, TK
Statistical analysis: BM
Obtained funding: Not applicable
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