Is Ultrasound More Accurate than Axial Computed Tomography for Determination of Maximal Abdominal Aortic Aneurysm Diameter?

L. R. Sprouse, II* G. H. Meier, III F. N. Parent, R. J. DeMasi, M. H. Glickman and G. A. Barber

Eastern Virginia Medical School, 250 West Brambleton Avenue, Suite 101, Norfolk, VA 23510, USA

Objective(s). Clinical assessment of maximal abdominal aortic aneurysm (AAA) diameter assumes clinical equivalency between ultrasound (US) and axial computed tomography (CT). Three-dimensional (3D) CT reconstruction allows for the assessment of AAA in the orthogonal plane and avoids oblique cuts due to AAA angulation. This study was undertaken to compare maximal AAA diameter by US, axial CT, and orthogonal CT, and to assess the effect that AAA angulation has on each measurement.

Methods. Maximal AAA diameter by US (US\textsubscript{max}), axial CT (axial\textsubscript{max}), and orthogonal CT (orthogonal\textsubscript{max}) along with aortic angulation and minor axis diameters were measured prospectively. Spiral CT data was processed by Medical Media Systems (West Lebanon, NH) to produce computerized axial CT and reformatted orthogonal CT images. The US technologists were blinded to all CT results and vice versa.

Results. Thirty-eight patients were analyzed. Mean axial\textsubscript{max} (58.0 mm) was significantly larger (P < 0.05) than US\textsubscript{max} (53.9 mm) or orthogonal\textsubscript{max} (54.7 mm). The difference between US\textsubscript{max} and orthogonal\textsubscript{max} (0.8 mm) was insignificant (P > 0.05). When aortic angulation was ≤ 25°, axial\textsubscript{max} (55.3 mm), US\textsubscript{max} (54.3 mm), and orthogonal\textsubscript{max} (54.1 mm) were similar (P > 0.05); however, when aortic angulation was > 25°, axial\textsubscript{max} (60.1 mm) was significantly larger (P < 0.001) than US\textsubscript{max} (53.8 mm) and orthogonal\textsubscript{max} (53.0 mm). The limits of agreement (LOA) between axial\textsubscript{max} and both US\textsubscript{max} and orthogonal\textsubscript{max} was poor and exceeded clinical acceptability (± 5 mm). The variation between US\textsubscript{max} and orthogonal\textsubscript{max} was minimal with an acceptable LOA of 2.7 to 4.5 mm.

Conclusion. Compared to axial CT, US is a better approximation of true perpendicular AAA diameter as determined by orthogonal CT. When aortic angulation is greater than 25° axial CT becomes unreliable. However, US measurements are not affected by angulation and agree strongly with orthogonal CT measurements.

Key Words: Abdominal aortic aneurysm diameter; Axial computed tomography; Duplex ultrasound; Three-dimensional aneurysm reconstruction; Orthogonal aneurysm measurements.

Introduction

Maximal aortic diameter remains the best clinical predictor of abdominal aortic aneurysm (AAA) rupture.1–4 The appropriate selection of patients for aneurysm repair relies primarily on the accurate assessment of AAA size by axial computed tomography (CT) and ultrasound (US) derived measurements.5–7 These values are often assumed to be equivalent; however, several authors, including ourselves,8 have documented a significant discrepancy between the two measurements.1,2,6–13 Although both US and axial CT are commonly accepted as reliable, the current literature suggests that axial CT and US measurements should not be used interchangeably in the clinical setting.

Axial CT is often recognized as the gold standard for an accurate measurement of AAA diameter.9–13 Recently it has been recognized that this benchmark may often represent an oblique slice of the AAA and over-estimate maximal aneurysm diameter in instances of significant vessel angulation.12,14 Lederle12 proposed that US can correct for aortic angulation, because the US probe is adjusted by the technologist to maintain a view of the aorta perpendicular to blood flow. For this reason, US may allow for a true cross-sectional, or orthogonal to flow, measurement that is more accurate than the oblique slice of an axial CT.15 Angle correction by US most likely explains...
why those investigating this topic have consistently reported AAA measurements smaller by US than with axial CT.

Angle correction can now be investigated through post-processing of spiral CT data. Commercially available computerized programs produce reformatted CT images that are oriented perpendicular (orthogonal) to aortic blood flow. This advance in vascular imaging provides a unique opportunity to evaluate the discrepancy of AAA diameter measurements by US and axial CT as influenced by vessel angulation. The current study compares the measurements of AAA diameter obtained by US, axial CT, and orthogonal CT and evaluates the effect that aortic angulation has on each of these measurements.

**Methods**

Thirty-eight patients presenting with AAA during an 8-month period were prospectively analyzed. Only patients evaluated with asymptomatic aneurysms larger than 4.0 cm in the outpatient setting were included. Patients with suprarenal AAAs, aortic dissection, and those with previous aortic surgery were excluded. Eight additional patients were excluded because they failed to undergo either US \( (n = 6) \) or CT \( (n = 2) \).

Duplex US and spiral CT were performed to evaluate the AAA in each case. The interval between the US and CT was less than 60 (mean 6.4, range 0–56) days in all cases. In 35 (92%) patients the interval was less than 15 days.

**Ultrasound**

Standard aortoiliac duplex US was performed by four registered vascular technologists in an ICAVL accredited lab. The scans were performed with a 3.5 MHz probe and either an ATL/Phillips 3000 or 5000 system. With the US probe positioned transversely on the abdomen, the AAA from the lowest renal artery to the aortic bifurcation was assessed for maximal diameter. The probe is routinely maintained perpendicular to aortic blood flow by color Doppler to yield orthogonal diameters. Multiple measurements were performed to arrive at the maximal US diameter \( (US^{\text{max}}) \) along the major axis. The \( US^{\text{max}} \) was defined as the largest external diameter (adventitia to adventitia) of the AAA measured in any direction from the representative images. On screen calipers were used for all measurements. The diameter of the AAA within the same plane and perpendicular to \( US^{\text{max}} \) defined the minor axis diameter and was recorded as \( US^{\min} \).

Diameter measurements were entered into a computer spreadsheet and both video tapes and hard copies of the US images were archived for future reference. In conjunction with institution standards and ICAVL accreditation, an attending vascular surgeon reviewed all studies; however, no data were deleted based on this review. The technologists performing the studies were blinded to the results from the CT scans and vice versa.

**Computed tomography**

Abdominal and pelvic CT was performed with 100–150 cm\(^3\) of non-ionic contrast. All scans were performed with a multi-detector spiral CT (General Electric, Light Speed Plus) with four detectors. The detector width was 1.25 mm with a collimation of 5.0 mm. The image thickness ranged from 2 to 5 mm in each case. The spiral CT data were processed by Medical Media Systems (West Lebanon NH, USA) to produce a reconstructed 3D model of the AAA. The post-processed data were transferred to a computer disk for each patient. The MMS images were viewed on a Dell Desktop XPS-B800 computer with Pentium IV processor at 2.0 GHz. The monitor used was a Dell Trinitron Ultrascan P991.

Specifics of the MMS Preview software and details of use have been described elsewhere.\(^\text{15}\) Briefly, the MMS Preview software creates a computerized interactive environment that allows on-screen measurements to be made from the CT images in both the axial and orthogonal (perpendicular to blood flow) planes (Fig. 1). In addition, calculation of vessel angulation along the path of blood flow can be performed.

The 3D model was scanned from the lowest renal artery to the aortic bifurcation by two observers to locate the site of maximal diameter. Using a combination of the model and the CT slices measurement of maximal AAA diameter was performed in both the axial \( (axial^{\text{max}}) \) and orthogonal \( (orthogonal^{\text{max}}) \) planes. Multiple measurements were performed by each observer. The final recorded maximal diameter represented an average of the maximal diameter (adventitia to adventitia) measured by each observer. Minor axis CT diameters were also performed in the axial and orthogonal planes as described for US. The mean difference of aortic diameter measurements between the two observers was 0.7 mm (SD 1.1). The inter-observer variability was not directly assessed.

Aortic angulation was calculated as described previously\(^\text{15}\) and shown in Fig. 2. In brief, three
marks were in the center of the aortic lumen at three locations: in the aortic neck (within 10 mm of the lowest renal artery), at the point identified as the breakpoint of the AAA from the 3D model, and at the aortic bifurcation. The angle between these three points was performed by the Preview software. By this method, both lateral and anterior–posterior angulation were accounted for and the final angulation represented the most acute centerline angulation along the path of blood flow.

Statistical analysis

The paired Student’s t-test was used to assess the differences between US, axial CT, and orthogonal CT measurements. The limits of agreement (LOA) between each method were calculated according to the method described by Bland. The mean difference between the three methods was calculated and related to aortic angulation by linear regression analysis. A difference of more than 5 mm was considered clinically significant. Limits of agreement relative to aortic angulation were performed by comparing the difference in measurements using Student’s t-test. Minor axis diameters were analyzed in a similar fashion.

Results

Axial CT versus orthogonal CT

Axial\textsuperscript{max} (mean = 58.0 mm) was significantly larger ($P < 0.05$) than orthogonal\textsuperscript{max} (mean = 54.7 mm). Axial\textsuperscript{max} was greater than orthogonal\textsuperscript{max} in 95% ($n = 36$) of the cases and the LOA (95% CI) between the two measurements was poor: $-3.6$ to $10.4$ mm (Fig. 3).

The difference between axial\textsuperscript{max} and orthogonal\textsuperscript{max} in relation to aortic angulation was analyzed by linear regression. There was a direct relationship (slope = 0.015) between aortic angulation and the difference between axial\textsuperscript{max} and orthogonal\textsuperscript{max}. When angulation was <25° ($n = 17$) the axial\textsuperscript{max} (mean = 55.3 mm) and orthogonal\textsuperscript{max} (mean = 54.1 mm) were similar ($P > 0.05$) with a mean difference of 1.2 mm (SD = 1.2). However, in cases where the aortic angulation was greater than 25°, axial\textsuperscript{max} (mean = 60.0 mm) was significantly greater ($P < 0.001$) than orthogonal\textsuperscript{max} (mean = 55.1 mm) with a mean difference of 5.0 mm. The LOA was $-1.2$ to 3.6 mm when angulation was <25° compared to a LOA of $-2.4$ to $12.4$ mm above an angulation of 25° (Table 1).

Axial CT versus ultrasound

Axial\textsuperscript{max} (mean = 58.0) was significantly larger than US\textsuperscript{max} (mean = 53.9 mm) with a mean difference of 4.1 mm. As found with orthogonal CT, the LOA
between axial\textsuperscript{max} and US\textsuperscript{max} was poor (−2.6 to 11.0 mm (Fig. 4)). Also, linear regression analysis confirmed that the difference between axial\textsuperscript{max} and US\textsuperscript{max} increased with increasing degrees of aortic angulation (slope = 0.013). The LOA between axial CT and US below an angle of 25° was −2.4 to 6.4 mm, compared to a LOA of −0.4 to 12.4 above 25°. Likewise, axial\textsuperscript{max} and US\textsuperscript{max} were similar below 25° (mean difference = 2.0 mm), but were significantly different (P < 0.001) above 25° (mean difference = 6.0 mm (Table 1)).

**Ultrasound versus orthogonal CT**

There was no significant difference between US\textsuperscript{max} (mean = 53.9 mm) and orthogonal\textsuperscript{max} (mean = 54.7 mm). The mean difference was only 0.8 mm (SD = 1.8 mm). The variation between the two measurements was minimal with a LOA of −2.7 to 4.5 mm (Fig. 5).

The degree of aortic angulation did not affect the difference between US\textsuperscript{max} and orthogonal\textsuperscript{max} (slope = 0.0 (Fig. 6)). The mean difference was 0.9 mm below 25° and 0.7 mm above 25° (P > 0.05). Also, the LOA was similar below and above 25°: −2.6 to 4.4 mm and −2.7 to 4.5 mm, respectively.

**Axial CT—minor axis**

Minor axis diameter measurements by axial CT (axial\textsuperscript{min}) were compared to US\textsuperscript{max} and orthogonal\textsuperscript{max}. The mean axial\textsuperscript{min} was 52.1 mm. The difference of axial\textsuperscript{min} to US\textsuperscript{max} and orthogonal\textsuperscript{max} and the LOA between the measurements in relation to aortic angulation is found in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Mean Difference (mm)</th>
<th>Limits of Agreement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>&lt;25°</td>
</tr>
<tr>
<td>Axial\textsuperscript{max} vs. Orthogonal\textsuperscript{max}</td>
<td>3.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Axial\textsuperscript{max} vs. Orthogonal\textsuperscript{max}</td>
<td>2.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Axial\textsuperscript{min} vs. US\textsuperscript{max}</td>
<td>4.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Axial\textsuperscript{min} vs. US\textsuperscript{max}</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Orthogonal\textsuperscript{max} vs US\textsuperscript{max}</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Measurements of maximal AAA diameter by axial CT and US are not equal. Although axial CT is regarded as more accurate, previous studies suggest that it frequently over-estimates diameter. Over-estimation occurs because axial CT lacks the ability to correct for aortic angulation; however, our report is the...
first to directly address the impact of angulation on axial CT measurements of maximal AAA diameter.

In addition, US appears to have the ability to correct for angulation and is more representative of actual AAA diameter, but this fact has not been proven. The current study investigates the difference of axial CT and US measurement of maximal diameter in relation to aortic angulation based on a 3D AAA reconstruction that allows for measurements of orthogonal CT diameters and aortic angulation.

Similar to previous reports, we found that axial CT measurements were consistently larger than US measurements. The difference between axial CT and US increased with increasing aortic angulation. Although axial CT and US measurements were similar at minimal degrees of aortic angulation (<25°), a significant discrepancy and variation of the measurements occurred above 25°.

As described by others, we believe that US corrects for angulation by the technologist tilting the probe to keep it perpendicular to blood flow, and that above a 25° aortic angulation, it may be more representative of true perpendicular diameter than axial CT. That is, at minimal degrees of angulation (<25°), axial CT and US can be used interchangeably, but above 25° a significant discrepancy is seen between the measurements with a clinically unacceptable LOA.

Recent advancements in CT technology allowed us to compare axial CT and US to orthogonal CT measurements of maximal AAA diameter at different degrees of aortic angulation. Orthogonal CT measurements represent the diameter of the AAA perpendicular to blood flow regardless of angulation. We found that US closely approximates orthogonal CT measurements at all degrees of angulation.

Therefore, the clinical equivalence of US and orthogonal CT measurements supports the idea that US has the ability to correct for angulation and is a better representation of the true AAA diameter in all cases. Ultrasound and orthogonal CT measurements of maximal AAA diameter can be used interchangeably because the variation between the two modalities is minimal. However, at greater degrees of angulation, axial CT over-estimates maximal diameter compared to orthogonal CT measurements with a significant difference occurring above a 25° angle.

In order for two methods to be used interchangeably, most would agree that a difference of less than 5 mm is considered acceptable when measuring maximal AAA diameter. Evaluation of the LOA demonstrates that orthogonal CT and US fall within this range of clinical acceptability at all degrees of angulation. However, the LOA between axial CT and both US and orthogonal CT significantly exceeds the clinically acceptable LOA. As stated by Bland, for two methods of measurement to be considered equal, the upper and lower values of the LOA must fall
within the range of the clinically acceptable difference (± 5.0 mm).

We agree with Bland\(^\text{16}\) that reporting the correlation between two methods of measurement in a study such as ours can be misleading. We chose not to include correlations in the current study because it is expected that there will be a good correlation because the two methods are measuring the same variable. Importantly, the correlation does not describe the difference or how much the two methods agree. Although there was likely a good correlation, the actual difference between axial\(^\text{max}\) and both US\(^\text{max}\) and orthogonal\(^\text{max}\) was significant. Clearly, the LOA between axial CT and US and axial CT and orthogonal CT does not fall within the clinically acceptable range.

Subgroup analysis demonstrates that above a 25° angle, the unacceptable LOA between axial CT and the other two methods is magnified. In the current study, the LOA for axial CT is clinically acceptable only when the aortic angulation is less than 25°. In the clinical setting, aortic angulation can be suspected from an axial CT, but it is impossible to accurately calculate the exact degree of angulation. Therefore, the ability to determine whether axial CT is accurate in any given patient is limited, and we believe most decisions regarding the management of AAAs should be based on carefully performed US measurements. If questions remain, orthogonal CT measurements should be performed and we believe this represents the current gold standard.

Although minor axis CT diameters can be used when angulation is suspected on axial CT, the relationship between axial\(^\text{min}\) and orthogonal CT diameters is inconsistent. Although axial\(^\text{min}\) was a better approximation of US\(^\text{max}\) and orthogonal\(^\text{max}\) than axial\(^\text{max}\), the LOA exceeded the clinically accepted difference. This difference was consistent at all degrees of angulation. Unlike axial\(^\text{max}\), the relationship of axial\(^\text{min}\) to both US\(^\text{max}\) and orthogonal\(^\text{max}\) was the same below and above a 25 aortic angle; however, the LOA was unacceptable in both subgroups. In summary, axial\(^\text{min}\) diameter is a poor representation of true perpendicular AAA diameter as defined by orthogonal CT and US and the measurements should not be used interchangeably.

The clinical implications of our study are significant. We do not use US and axial CT measurements interchangeably and preferentially use US to screen and follow patients with AAA(s). It appears that the natural history data of AAA based on US measurements (United Kingdom Small Aneurysm Trial) of maximal diameter may be more accurate than studies based on AAA diameter by axial CT (Aneurysm Detection and Management Trial) because US can correct for angulation and is a better representation of true AAA diameter. Furthermore, the expansion rate of AAAs based on axial CT may also be over-estimated and represent, to some extent, an increase in angulation rather than an actual increase in diameter. This concept is supported by the fact that the expansion rate based on US is historically less than that based on axial CT.\(^\text{7}\)

There are several limitations of the current study. First, the number observers for US and CT measurements were not the same. Also, it is possible that the US and CT measurements were not performed at the same location within the AAA sac. In addition, the number of measurements to determine the maximal diameter was not the same for each observer. We believe that these limitations are relatively minor, and that our results are an accurate reflection of what can be expected in the clinical setting.

Future investigations should avoid the practice of accepting axial CT and US measurements of maximal AAA diameter as equal. This is especially true in studies that attempt to define an optimal threshold at which to surgical intervention is appropriate in patients with AAA. Short of orthogonal CT measurements by 3D reconstruction, ultrasound measurements performed in an accredited lab should be regarded as the gold standard rather than axial CT and prospective studies should be based on maximal AAA diameter by US. Our results also suggest that the natural history data of AAA warrants reassessment and previous reports based on axial CT should be viewed with caution.

**Conclusion**

Ultrasound is more accurate than axial CT for determination of true maximal AAA diameter as defined by orthogonal CT measurements. Axial CT significantly over-estimates AAA diameter when aortic angulation exceeds 25°; however, there is minimal variation between US and orthogonal CT, and US measurements are not affected by angulation. Neither major nor minor axial CT diameters should be used interchangeably with US or orthogonal CT measurements. Ultrasound should be regarded as the most practical, non-invasive method for the assessment of maximal AAA diameter in the clinical setting.

**References**


Accepted 30 March 2004
Available online 7 May 2004