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Proximal thoracic aortic diameters: Transesophageal Echocardiography versus Computed Tomography derived measurements

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Abstract

Purpose—To compare proximal aortic measurements from ECG-gated CT to transesophageal echocardiography (TEE) and to evaluate differences in cusp-cusp and cusp-commissure CT measurements of sinus of Valsalva (SOV).

Methods—This retrospective study (n=25) compared aortic diameters from CT using manual double-oblique multiplanar reformats (MPR) and semiautomatic centerline method to TEE.

Results—CT MPR and centerline measurements were higher than TEE for sinotubular junction and ascending aorta. At SOV, cusp-cusp diameters (MPR and centerline methods) and cusp-commissure measurement (centerline method) were larger than TEE.

Conclusions—Aortic measurements were larger on CT than TEE. Precise difference depended on location and measurement technique.

Keywords

Aorta; thoracic; Computed tomography; Transesophageal echocardiography; diameter

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The University of Michigan IRB approved this retrospective study

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1. Introduction

Accurate determination of aortic size and growth rate is of critical importance in clinical decision making and management. While several imaging modalities are available for aortic assessment, the two most commonly utilized techniques include echocardiography (transthoracic and transesophageal) and Computed Tomography (CT). Magnetic Resonance Imaging (MRI) is now increasingly used in follow-up of young individuals, though is not as widely available, and requires longer examination time. Among noninvasive imaging modalities, CT has become the mainstay of aortic imaging due to its 3D capability, high spatial resolution and short examination time. The 3D CT dataset can be manipulated in various ways to obtain aortic dimensions. Though diameter measurements made on standard axial images are easy to perform, this method is prone to errors particularly with tortuous aortas. Manual double oblique measurements on multi-planar reformatted (MPR) images and semiautomatic centerline analysis methods are now commonly used for precise aortic diameter measurement, with the latter requiring shorter post processing time (1). Several recent publications have focused on variability and reproducibility of the two CT measurement techniques (1–4) and most have shown lower variability for centerline method. Moreover, study interpretation time for radiologists may be reduced when experienced 3D technologists perform the centerline analysis. Therefore, the semiautomatic centerline method is gaining popularity over the more established manual MPR method.

Though direct comparison of the two CT measurement techniques has been performed in several studies, it is not clear how these two compare to other imaging modalities, particularly echocardiography. This is an important gap in our current knowledge as patients may have echocardiography followed by CT or vice versa. Transthoracic echocardiography (TTE) is typically a first line imaging modality, however can be limited in some patients. In such cases transesophageal echocardiography (TEE) may provide superior image quality. In this paper, we aim to compare measurements of the proximal aorta including sinuses of Valsalva (SOV), sinotubular junction (STJ) and ascending aorta (AA) obtained from ECG gated CT using manual double oblique MPR measurements and semiautomatic centerline measurements to those obtained from TEE.

Another practical issue in obtaining and reporting aortic measurements is the lack of standardization about the precise technique of aortic measurement (5). This is even more challenging in the region of the SOV because of its clover leaf shape, rather than a round or elliptical appearance. Different measurements techniques are variably used among radiologists and various institutions, which can lead to erroneous assumptions about interval change in caliber. Hence, in this study we also aim to evaluate how two commonly used methods of SOV measurement on CT i.e. maximum cusp-opposing commissure measurement and maximum cusp-cusp diameter compare to each other and to TEE measurements.

2. Materials and Methods

This HIPAA compliant retrospective study was approved by the Institutional review board with waiver of informed consent.

2.1 Study population

The study population consisted of the same subjects selected for a prior study aimed at determining variability in CT measurements of proximal thoracic aortic diameters using double oblique short axis and semiautomatic centerline techniques (4). To summarize, 37 consecutive patients without previous surgery who had ECG gated chest CT and TEE within 3 months (range 0–84 days) were identified by a search of hospital records for the period April 1, 2010 to September 30, 2010. Of these, 12 were excluded due to motion artifact on the CT scan. The remaining 25 patients (19/25 males, 76%) with a mean age of 64.1 ± 13.4 yrs (range 22–80 years) formed the study population. None of these patients had acute proximal aortic abnormality, prior proximal thoracic aortic surgery or significant motion artifact. Of the 25 patients, 24 had imaging performed for assessment of aortic aneurysm (known aneurysm in 14 and aortic evaluation in the setting of aortic valve disease in 10). The remaining one patient had imaging for assessment of aortic dissection, but was found to have no acute aortic abnormality.

2.2 CT imaging

All scans were performed using retrospective ECG gating on 64 detector CT (Discovery CT750HD, GE Healthcare, Milwaukee, WI) covering thoracoabdominal aorta and pelvic arteries. Image acquisition parameters and contrast injection technique have been described in detail in the prior publication (4).

All CT aortic measurements were performed in diastole (reconstructions at 75% of the R-R cycle) including the aortic wall in the measurement and were obtained using two techniques:

2.2.1 Manual double oblique measurements using MPR—These measurements were performed by two radiologists with 25 and 5 years of experience and specialization in cross sectional vascular imaging. The radiologists were blinded to clinical data. MPRs perpendicular to axis of aortic flow were generated to obtain the maximum diameters at predetermined levels i.e. sinuses of Valsalva (SOV) (Fig 1a,b), sinotubular junction (STJ) (Fig 1d,e) and ascending aorta (AA) (Fig 1f,g). For the SOV, apart from the maximum diameter (cusp-cusp), three cusp commissure measurements (Fig 1c) were generated by both radiologists for each case.

2.2.2 Semiautomated centerline measurements—In our institution, aortic measurements are routinely performed using this method. To simulate clinical practice, the measurements were done by a 3D technologist with 9 years of experience in 3D measurements. Necessary adjustments were made and were also checked by a radiologist. The maximum diameters at the SOV (cusp-cusp), STJ and AA diameters were recorded (Fig 1h). In addition, the 3D technologist also performed three cusp-commissure measurements at the level of SOV.

The CT readers and 3D technologist recorded measurements at various aortic levels twice with an interval of at least two weeks; the results of these intraobserver and interobserver differences have been previously published (4).

2.3 Transesophageal echocardiography (TEE)

TEE was performed by an experienced echocardiographer using standard echocardiography equipment (Sequoia 256 or 752, Siemens Medical, Mountain View, CA; or Philips 5500, Bothell, WA) with a multiplane phased array 2–7MHz operating range TEE transducer. All studies were performed for clinical indications and were retrospectively reviewed by two cardiologists with 5 and 14 years of experience. The measurements were made in diastole from inner edge to inner edge. The SOV, STJ and AA measurements were made in the long axis plane (120° mid esophageal view) (Fig 2a–b).

The readers recorded measurements at various aortic levels twice with an interval of at least two weeks for estimation of intraobserver and interobserver differences.

2.4 Statistical analysis

The data was summarized and expressed as mean $\pm$ SD with range of maximum and minimum values. For intra-observer TEE differences, the first and second measurements were compared for each observer. For inter-observer differences, the mean measurements of one TEE observer were compared with the mean measurements of second TEE observer. The overall average of the measurements from both TEE observers was calculated for comparison with the overall average of the CT measurements using MPR and centerline techniques at different proximal aortic levels (STJ and AA). For the SOV, the maximum cusp-cusp diameter at the level of the sinuses as well as the largest of the three cusp-commissure CT measurements were compared to the long axis measurements on TEE. We chose to use the maximum cusp-commissure rather than average of the three corresponding measurements, since it is the former that is needed for decision making and for assessing the need for possible intervention. The maximum cusp-cusp and cusp-commissure CT measurements were also compared to each other.

The Wilcoxon signed rank test was used and the direction of the differences was noted. Bland-Altman plots were also created to visually compare CT MPR and centerline measurement techniques with TEE. For each plot, the average of the measurements from CT (MPR or centerline) and TEE were calculated and then plotted against the difference of the two measurements. Horizontal lines were drawn at the mean difference and at the limits of agreement (defined as the mean difference $\pm$ 1.96 times the standard deviation of the differences) (6).

A p value of <0.05 was used to indicate statistically significant differences. All analysis was performed using SAS software version 9.4 (SAS Institute, Cary, North Carolina).

3. Results

For all imaging studies and methods, the readers made respective aortic measurements unless the image quality was considered inadequate for a specific aortic location by the reader. All CT image data sets were of good diagnostic quality and both CT readers and CT technologist completed measurements for all levels for 25 patients. For TEE, one reader did not record a measurement of ascending aorta in one patient due to suboptimal image quality, while the second reader completed all measurements.

The intra and interobserver variability for the two CT techniques (manual versus centerline) have been previously published. The mean intra-observer and interobserver differences for the two TEE readers were not statistically significant (Table 1).

The overall mean diameters at various aortic levels using CT (MPR and centerline methods) as well as TEE are provided in Table 2.

When CT measurements were compared to TEE (Table 3), the average of the respective readers was used for each individual case and aortic level. CT measurements (MPR and centerline analysis) were significantly higher than TEE for the STJ and AA, with centerline measurements being higher than the respective MPR measurements. The largest mean difference between CT and TEE measurements was at the level of STJ for centerline method (mean difference of 6.1mm), though in a specific individual case, the inter-modality difference (STJ centerline CT versus TEE) was found to be as high as 11.8 mm.

For the SOV level, the maximum diameter for MPR and centerline CT methods were larger by 4.0 mm and 4.9 mm respectively when compared to TEE long axis measurement. In contrast, the largest cusp-commissure measurements on CT closely mirrored the TEE long axis measurements. No significant differences for largest cusp-commissure SOV measurements versus TEE were noted using MPR method, though the centerline technique yielded slightly larger values by 2.2 mm ($p = 0.0006$).

The Bland-Altman plots depicting the mean bias and the 95% limits of agreement for CT measurements (MPR and centerline analysis) and TEE are shown in Figure 3. These plots demonstrate no pattern to indicate larger intermodality differences with increasing aortic size.

Additionally, the maximum CT measurements of the SOV were larger than the largest cusp-commissure CT measurements by 3.6 mm ($p < 0.0001$) and 2.7 mm ($p < 0.0001$) for MPR and centerline methods respectively (Table 4).

4. Discussion

Our study quantifies and establishes the systematic differences in aortic measurements between CT (using two different methods: MPR and centerline) and TEE. In patients with aortic dilatation, it is crucial to understand these differences in imaging modalities which may be used interchangeably by clinicians. Guidelines for operative intervention are based on size thresholds as well as rate of change of aortic diameters. The absolute size thresholds vary based on the clinical setting, particularly the presence of genetic syndromes (e.g. Marfan syndrome), in which case a smaller aortic size than general population would be eligible for operative intervention.

Since echocardiography has been in use for much longer than CT or MRI, the reference aortic values were historically established using M mode technique from the Framingham heart study (7). With the advent of TTE, the same measurement technique was applied (leading edge) and formed the basis of studies evaluating outcomes. This led to the American Society of Echocardiography guidelines in 2005 (8) advocating a leading edge

technique in diastole for echocardiographic measurement and this was reaffirmed in recent guidelines (9). Because of the multi-planar, volumetric capabilities of modern CT, it is now increasingly used as a primary aortic imaging technique from which management decisions are made. Therefore, how it compares to echocardiography is an important question.

There is a paucity of studies in literature directly comparing echocardiography and various CT measurement methods. Apart from scant studies in literature on this topic, the problem is also compounded by marked heterogeneity in the measurement methods due to lack of clear guidelines about technique of measurement. For instance, studies on CT have reported internal (10) (11) or external diameters (12), systolic (13) or diastolic phases (14) and have variably used long axis or cross sectional views. Similarly for echocardiography, while the American Society of Echocardiography advocated a leading edge technique in diastole for measurement, the recent independently developed pediatric guidelines suggest using inner to inner edge in peak expansion (systole) (15). Since several aortic diseases have a genetic basis and patient care often transitions from pediatric to adult cardiologists, such differences in aortic measurement technique can become relevant (16). The guidelines for diagnosis and management of patients with thoracic aortic disease recommends using external diameters on CT and internal diameters on echocardiography (17). Hence for this study, in compliance with these recent guidelines we have chosen to use external CT diameters and internal echocardiography diameters for comparison. The higher aortic diameters on CT compared to TEE in our study, are at least partly due to these differences in measurement technique and inclusion of wall thickness on CT. We found mean differences between CT and TEE to be as high as 6mm and differences in individual cases of up to 12mm. The maximum inter modality differences were noted at the level of STJ, likely due to the fact that the junction may not be well defined and can be effaced in some patients leading to slight differences in the precise site of measurement. Also, we compared two commonly used CT techniques (MPRs and centerline) with TEE, since the choice of CT measurement technique often depends on institutional preference. In this regard we found that there are systematic differences between the two CT measurement methods, with larger intermodality differences (CT versus TEE) for centerline method.

The differences in SOV diameters using different measurement techniques have not been evaluated to date in the CT literature. Burman et al compared cusp-cusp and cusp-commissure measurements and advocated the use of diastolic cusp-commissure measurements on steady state free precession MRI as these yield favorable R^2 values with age and body surface area and correspond closely to reference echocardiographic root measurements from the Framingham cohort (18). In our study, we found that maximum root measurements from MPR and centerline CT methods are on average 4.0 and 4.9 mm higher than TEE measurements respectively from a long axis view. Also, the cusp-commissure method of estimating SOV diameters (particularly MPR technique) yields values similar to those obtained from TEE. This may be because the measurement plane on echocardiography in the parasternal view typically passes from the anterior wall of right coronary cusp to the posterior aortic wall close to the commissure (18), similar to the cusp-commissure measurement plane on cross-sectional imaging. Apart from cusp-cusp and cusp-commissure measurements, it is also important to consider systematic differences in MPR versus centerline CT measurements, since the latter tend to be slightly higher.

There are a few studies in the literature comparing aortic SOV diameters between CT and echocardiography. Ocak et al compared CT measurements with TTE in diastole (14) using cusp-commissure technique on manual MPR. The authors found that the CT measurement was on an average higher by 3.9 mm. We found that apart from intermodality (CT versus TEE) differences, there are important differences based on the technique of measurement (cusp-commissure versus cusp-cusp). In our study, the cusp-cusp measurements on MPR and centerline CT techniques were higher than corresponding cusp-commissure CT measurements by 3.6 mm and 2.7 mm respectively. Hence, it is important that the technique of measurement be clearly stated in the report for unambiguous communication with clinical colleagues.

With the increasing use of percutaneous aortic valves in the management of severe aortic stenosis, a few other studies have also compared CT and TEE. However, most of these studies focused on annulus diameters which are crucial for prosthesis sizing. Apart from annulus measurements, Mizia-Stecet al also reported LVOT, SOV, STJ and ascending aortic diameters on CT, TTE and TEE (13). They performed measurements in systole and found no significant differences between the modalities for SOV, STJ and ascending aorta. It can, however, be difficult to extrapolate these results to clinical practice, because most institutions measure CT diameters in diastole when motion related artifact is minimized, particularly at the SOV level. Also, the exact method (cusp-cusp or cusp-commissure) was not specified in the paper.

Our study has a few limitations. First, though our focus was primarily establishing the differences between CT and TEE measurements, we do not know which measurement (CT MPR, CT semiautomatic or TEE) is more accurate in the absence of surgical proof. Also, all our CT studies had excellent image quality, which may not always be the case in routine clinical practice. Additionally, the retrospective nature of the study may have some effect, particularly on TEE measurements. In conclusion, we found that proximal aortic measurements were significantly larger on CT compared to TEE. The exact differences between CT and TEE measurements depended on the anatomic location and the measurement technique (MPR versus centerline and cusp-cusp versus cusp-commissure for SOV). While measurements of the SOV using the cusp-commissure CT MPR technique were not significantly different from TEE measurements, mean differences (CT versus TEE) were as large as 6.1 mm (at the STJ level using centerline technique). In CT reports, it is important to clearly specify the type of measurement technique that was used. It would be best to use the same measurement technique on follow-up scans for assessing interval change.

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a

b

c

d

e

f

50

h

Figure 1.

Depiction of the technique of manual double oblique measurements on multiplanar reformatted (MPR) images at the level of sinus of Valsalva (1a,b, c), sinotubular junction (1d, e) and ascending aorta (1f, g). The crosshairs (1a, d, f) were adjusted to ensure measurement perpendicular to the flow. The measurements were made on the obtained short axis images (1b, c, e, g) in diastole including the aortic wall. For the sinus of Valsalva, the maximum cusp to cusp (1b) and the largest of the three cusp-commissure measurements (1c) were recorded.

The semiautomatic centerline method (1h) was similarly used for aortic measurements by a 3D technologist to obtain short axis views at the predetermined levels (shown by green lines, 1h).

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a

b

Figure 2.

Depiction of the technique of transesophageal echocardiography measurements.

Measurements at the level of sinus of Valsalva (SOV) and sinotubular junction (STJ) are shown in figure 2a and at ascending aorta in figure 2b. These measurements were made in the long axis plane in diastole from inner edge to inner edge.

Max cusp—commissure CT Double Oblique vs. Long Axis View TEE

a

Max cusp—cusp CT Double Oblique vs. Long Axis View TEE

b

Sinotubular Junction: CT Double Oblique vs. TEE

c

Ascending Aorta: CT Double Oblique vs. TEE

d

Max cusp—commissure CT Semiautomatic Centerline vs. Long Axis View TEE

e

Max cusp—cusp CT Semiautomatic Centerline vs. Long Axis View TEE

f

Sinotubular Junction: CT Semiautomatic Centerline vs. TEE

50

Ascending Aorta: CT Semiautomatic Centerline vs. TEE

h

Figure 3.

Bland Altman plots depicting the bias and limits of agreement for CT and TEE measurements at different aortic levels i.e. aortic root, sinotubular junction and ascending aorta (d, h). The manual double oblique measurements on multiplanar reformats (MPR) compared to TEE are shown in Fig 3a–d and semiautomatic centerline method measurements compared to TEE are shown in Fig 3e–h. The mean bias is shown as a solid horizontal line and limits of agreement are shown as two dashed lines. The plots demonstrate no pattern to indicate larger intermodality differences with increasing aortic size

Table 1

Intraobserver and interobserver differences in TEE diameter measurements (N= 25 patients) ^a

Aortic location	Reader#1 Mean in mm ± SD (min, max)	Reader#2 Mean in mm ± SD (min, max)	Reader#1 Mean intraobserver difference in mm ± SD (min, max)	Reader#2 Mean intraobserver difference in mm ± SD (min, max)	Reader#1 vs. Reader#2 Mean interobserver difference in mm ± SD (min, max)
SOV	38.6±7.8 (29.0, 59.5)	38.3±6.5 (30.5, 56.5)	-0.04±0.7 (-1.0, 1.0)	-0.5±1.3 (-3.0, 2.0)	0.3±2.9 (-3.5, 12.0)
Sinotubular junction	33.9±8.2 (23.0, 63.5)	33.6±6.5 (26.0, 52.5)	0±1.1 (-2.0, 3.0)	-0.5±2.0 (-8.0, 3.0)	0.3±2.8 (-3.5, 11.0)
Ascending Aorta	39.1±6.2 * (26.0, 49.0)	40.0±8.0 (27.0, 66.0)	-0.3±1.4 * (-5.0, 2.0)	0.04±0.9 (-2.0, 2.0)	0.2±1.4 * (-1.5, 4.0)

* N = 24 patients

Table 2

Aortic diameters measurements using CT double oblique MPR, CT semiautomatic centerline, and TEE measurements (N= 25 patients) ^a

Aortic location	CT Double-oblique MPR	CT Semiautomatic Centerline Analysis	Transesophageal Echocardiography
<u>Sinus Of Valsalva</u>			-
Max cusp-commissure	38.9±5.7 (30.3, 52.8)	40.6±5.6 (33.0, 56.0)	-
Max cusp to cusp	42.5±6.2 (32.5, 57.5)	43.3±6.4 (34.0, 59.5)	-
Max SOV on long axis plane (TEE)	-	-	38.5±7.0 (29.8, 56.5)
<u>Sinotubular junction</u>	37.9±7.9 (28.8, 65.5)	39.8±8.0 (30.0, 65.0)	33.7±7.3 (24.8, 58.0)
<u>Ascending aorta</u>	42.4±7.5 (26.5, 64.6)	42.9±7.3 (25.0, 61.0)	40.1±8.1 (26.5, 66.0)

^a Mean measurements in mm ± SD (min, max)

Table 3

Comparison of CT double oblique, and CT semiautomatic centerline with TEE measurements (N= 25 patients)

^a

Aortic location	Double Oblique Views vs. Transesophageal Echocardiography	Semiautomatic Centerline Analysis vs. Transesophageal Echocardiography
<u>Sinus Of Valsalva</u>		
Max cusp-commissure CT versus SOV on long axis view TEE	0.4±2.7 (-6.0, 6.3) (p = 0.2492)	2.2±2.7 (-5.0, 5.5) (p = 0.0006)
Max cusp to cusp (CT)/ long axis plane on TEE	4.0±2.4 (-1.3, 9.0) (p < 0.0001)	4.9±2.2 (-1.3, 8.3) (p < 0.0001)
<u>Sinotubular junction</u>	4.2±1.9 (0.3, 8.3) (p < 0.0001)	6.1±2.4 (1.3, 11.8) (p < 0.0001)
<u>Ascending Aorta</u>	2.3±1.4 (-1.3, 4.3) (p < 0.0001)	2.8±2.5 (-5.0, 8.0) (p < 0.0001)

^aMean measurements in mm ± SD (min, max)

Table 4

Sinus of Valsalva CT measurements.

	Mean difference +/- SD (range)	P value
CT Double Oblique (cusp- cusp versus cusp- commissure)	3.6±1.3 (1.5, 6.5)	< 0.0001
CT centerline (cusp-cusp versus cusp-commissure)	2.7±1.6 (0.5, 7.0)	< 0.0001