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Aortic Annulus Diameter Determination by Multidetector Computed Tomography

Reproducibility, Applicability, and Implications for Transcatheter Aortic Valve Implantation

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Objectives This study sought to determine the most reproducible multidetector computed tomography (MDCT) measurements of the aortic annulus and to determine methods to improve the applicability of these measurements for transcatheter aortic valve implantation.

Background The reproducibility and applicability of MDCT annular measurements to guide transcatheter aortic valve implantation remain unclear.

Methods Annular measurements were performed in 50 patients planed for transcatheter aortic valve implantation in multiple planes: basal ring (short- and long-axis, mean diameter, area-derived diameter), coronal, sagittal, and 3-chamber projections. A theoretical model was developed taking into account the differences between the most reproducible MDCT measurements and transesophageal echocardiography to guide valve size choice.

Results The most reproducible measurements were the area-derived diameter and basal ring average diameter (inter-reader intraclass correlation coefficient: 0.87 [95% confidence interval: 0.81 to 0.92] and 0.80 [95% confidence interval: 0.70 to 0.87]; respectively; intrareader $>$0.90 for all readers). These were generally larger than transesophageal echocardiography diameters (mean difference of 1.5 $\pm$ 1.6 mm and 1.1 $\pm$ 1.7 mm, respectively). When a strategy of valve-sizing is undertaken using these CT measurements using an echocardiographic sizing scale, a different THV size would be selected in 44% and 40% of cases, respectively. When adjusting the sizing cutoffs to account for the differences in observed diameters, this was reduced to 10% to 12% ($p < 0.01$ for both, respectively).

Conclusions The most reproducible MDCT measurements of the annulus are the area-derived diameter and basal ring average diameter, with derived values generally larger than those obtained with echocardiography. If MDCT is used for valve sizing, a strategy incorporating these differences may be important. MDCT using these easily derived measurements may be ideally suited to sizing transcatheter aortic valves as they account for the eccentricity of the aortic annulus, are reproducible, and are noninvasive. (J Am Coll Cardiol Intv 2011; 4:1235–45) © 2011 by the American College of Cardiology Foundation

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Transcatheter aortic valve implantation (TAVI) is becoming an accepted procedure for selected patients with severe aortic stenosis (1). Accurate evaluation of the native aortic valve annular dimensions is critical to optimize selection of the correct bioprosthetic valve size. In contrast to surgical aortic valve replacement where surgeons perform valve sizing under direct visualization and with the aid of annular sizing probes, noninvasive imaging methods are generally required in the setting of TAVI. Incorrect valve sizing may lead to paravalvular aortic regurgitation, which is a predictor of worse long-term outcome (2), valve embolization, patient prosthesis mismatch, or catastrophic annular rupture (3,4).

Given the complex shape of the aortic annulus, which includes a generally noncircular profile coupled with a conical form that is bounded at its nadir by the attachment of the 3 aortic leaflets (5), accurate evaluation by 2-dimensional imaging modalities, such as echocardiography, is intrinsically difficult. Recently, 3-dimensional multidetector computed tomography (MDCT), which is not limited by planar imaging, has been shown to provide fine anatomical detail and accurate assessment of the complex anatomical shape of the aortic valve and annulus (6–8). Whereas some have suggested that MDCT-derived measurements may better serve as a gold standard for aortic valve sizing, the reproducibility, reliability, and applicability of these measurements have not been well defined. Furthermore, the clinical utility of MDCT measures remains limited. Previous studies have also suggested that despite propitious clinical outcomes of patients undergoing TAVI with echo-based aortic valve sizing, an MDCT-based valve sizing strategy might result in up to 39% of cases requiring a different valve size or exclusion from candidacy for TAVI using currently available devices (9–11). However, these prior MDCT studies employed aortic annular measurements in limited planes and without systematic adjustment for discordance between MDCT and echocardiographic modalities.

Abbreviations and Acronym

CI = confidence interval

ICC = intraclass correlation coefficient

IQR = interquartile range

MDCT = multidetector computed tomography

TAVI = transcatheter aortic valve implantation

TEE = transesophageal echocardiography

TTE = transthoracic echocardiography

In the present study, we thus aimed to: 1) evaluate the aortic annular dimensions in patients undergoing TAVI using MDCT in multiple planes; 2) assess which measurements have the greatest interobserver and intraobserver reproducibility; and 3) determine the difference in valve sizing recommendations if MDCT measurements are used according to current (transesophageal echocardiography [TEE]–based) sizing cutoffs (“unadjusted criteria”) versus a strategy of incorporating the observed differences between MDCT and echocardiography into the sizing criteria (“adjusted criteria”).

Methods

Patient population. Fifty patients with severe symptomatic aortic stenosis being considered for TAVI underwent preprocedural evaluation using MDCT imaging. Forty-one of these patients underwent TAVI, and all these patients had matched transthoracic echocardiography (TTE) and TEE images. Patients with bicuspid aortic stenosis were excluded. MDCT was clinically indicated for evaluation before the procedure to assess the peripheral vasculature and determine the optimal angiographic projection angles for valve implantation (12,13). Following implantation, implantation height was angiographically defined as optimal or suboptimal, with optimal position defined as occurring when the native leaflet insertion point was within the middle third of the stent frame. All other valve positions were defined as suboptimal.

Patients were evaluated by a team of senior cardiologists and cardiothoracic surgeons to determine if they posed a prohibitively high surgical risk before being accepted for TAVI. Patients underwent transfemoral or transapical implants of Edward Sapien/Sapien XT balloon expandable bioprostheses (Edwards Lifesciences, Irvine, California) of 23-mm, 26-mm, or 29-mm diameter with valve size chosen based on annulus diameters as derived by TEE as previously described (14–18).

CT images acquisition. MDCT examinations were performed on a 64-slice Discovery HD 750 High Definition scanner (GE Healthcare, Milwaukee, Wisconsin), and 80 to 120 ml of iodixanol 320 (GE Healthcare, Princeton, New Jersey) were injected at 5 ml/s followed by 30 ml of normal saline. The timing delay of the scan was determined using a smart prep of the ascending aorta with a preset threshold of 150 Hounsfield units. The MDCT examinations were performed in the craniocaudal direction with retrospective gating from the aortic arch through to the diaphragm. Heart rate reduction with beta-blockade was avoided as interpretation of the coronary arteries was not required and because of clinical concern regarding severe aortic stenosis. MDCT scanner detector collimation width was 0.625 mm, detector coverage was 40 mm, reconstructed slice thickness was 1.25 mm, and the slice interval was 1.25 mm. Gantry rotation time was 0.35 s, and the scan pitch ranged between 0.16 and 0.20 (adjusted per heart rate). Depending on the patient size, the maximum tube current ranged between 450 and 700 mA with a fixed tube voltage of 100 kVp for patients with a body mass index <30 kg/m^2 and 120 kVp used in larger patients. Electrocardiography-gated dose modulation was used with tube current reduced to 60% of maximum tube current in systole. This provided adequate image

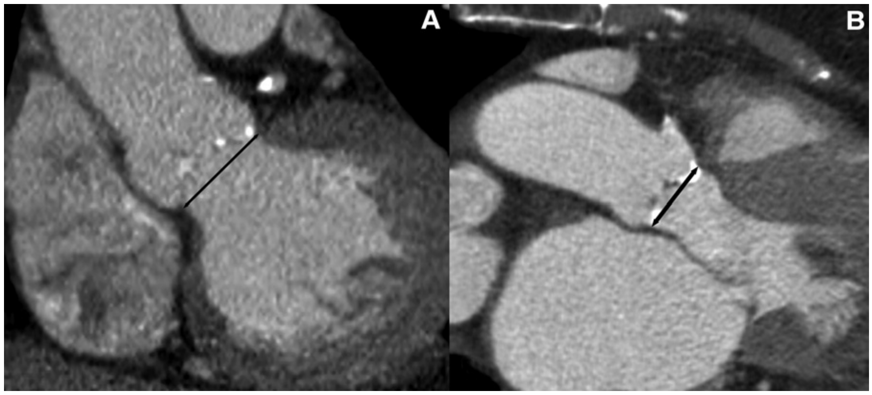

Figure 1. Aortic Root Reconstructions

Coronal **(A)** and sagittal oblique **(B)** views. The arterioventricular plane is elliptical in shape, measuring 25.4 mm in the coronal plane and 21.1 mm in the sagittal plane.

quality for annular assessment in the systolic phases while reducing the estimated effective radiation dose.

Achieving the different imaging planes and measuring the aortic annulus. Following MDCT image acquisition, reformats were performed to allow evaluation of the aortic annulus in multiple planes. A number of reported and proposed methods for measuring the aortic annulus with MDCT have been suggested (11,13). We evaluated 6 methods: coronal and sagittal oblique (Fig. 1); 3-chamber; double oblique transverse short axis of the basal ring (6,9);

Figure 2. Reconstructing a Double Oblique Transverse Image of the Basal Ring

From the coronal projection **(A),** a vertically oriented oblique tool **(dashed line)** is placed to produce a sagittal oblique reconstruction of the ascending aorta. A transverse or axial cutplane is then placed on the sagittal reconstruction **(B)** at the level of the commisures. This transverse cutplane yields a double oblique transverse image of the aortic root **(C).** The dataset is then scrolled up or down until the most caudal attachments of the aortic valve are identified **(D).** The nadirs of all 3 cusps must be identified on the 1 transverse image, ensuring the appropriate plane for assessment of the aortic annulus.

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long axis of the basal ring; and an area measurement of the basal ring of the aorta. In addition, we calculated the area-derived diameter, as well as the basal ring average diameter (see the next paragraph). For all these measurements, the reader would determine the optimal projection for measurement. Importantly, all 3 readers had agreed on the defined principles behind each measurement and had read 25 previous cases in collaboration to ensure a standardized approach.

As all MDCT studies were performed with retrospective gating, reading physicians first selected the appropriate phase of the cardiac cycle. By convention, the annulus was measured in systole during maximum valve opening. Following this, physicians performed post-processing and analysis beginning in the coronal projection with an axial-cut plane rotated in a counterclockwise direction such that the annular plane ran from right-caudal to left-cranial position. After ensuring that the various imaging planes are locked, attention is turned to the sagittal projection, which is vertically oriented to be orthogonal to the long axis of the aortic annulus (Fig. 2). At this point, the horizontal line representing the axial cutplane is moved up or down on either the sagittal or coronal projection to create a double oblique transverse or axial image of the aortic root. This horizontal line is then pulled down through the root of the aorta until the most caudal attachments of the 3 aortic cusps are identified. Importantly, to accurately define the basal ring, the plane must be balanced so that all 3 leaflets come into view when scrolling cephalad at the same time (Fig. 2). At this point, the short- and long-axis dimensions of the basal ring are measured (Fig. 3A), and the area is traced out accurately (Fig. 3B). From the former, a basal ring average diameter is determined by (basal ring short axis + basal ring long axis)/2, and from the latter, the area-derived diameter is calculated using:

$$diameter = 2\sqrt{\frac{area}{\pi}}$$

To generate a 3-chamber projection of the aortic annulus, a standardized approach is also used. A transverse image of the mitral valve with maximal visualization of the left ventricular cavity that allows for identification of the ventricular apex is bisected with an oblique plane creating a long-axis reconstruction. The left ventricle is then cut in a plane from the left atrium through the center of the mitral valve through the left ventricular apex resulting in a 4-chamber projection. An oblique plane is then used to rotate the left ventricle in a perpendicular fashion to the interventricular septum to create a short-axis projection. Finally, a cutplane is placed in an oblique fashion at the base of the short-axis projection out of the left ventricular outflow tract and aorta to create a 3-chamber projection (Fig. 4).

All measurements were conducted in blinded fashion by the 3 independent readers. Each reader evaluated the annulus in all planes. Following this, to assess intraobserver reliability, readers reread 20 randomly selected cases at least 1 month following the original assessment, with the readers blinded to the original results.

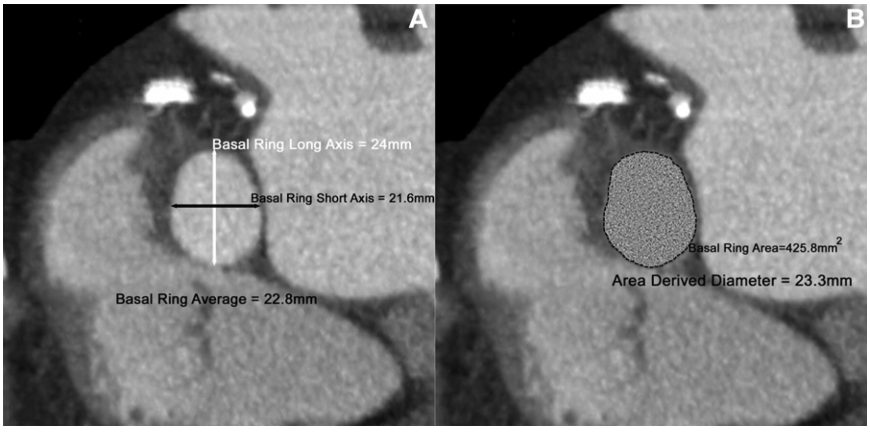

Figure 3. Double Oblique Transverse Reconstruction Just Below the Commissural Insertions of the Aortic Leaflets Demonstrating Various Basal Ring Measurements

(A) The long- and short-axis dimensions measure 24 mm and 21.6 mm, respectively, with an average diameter of 22.8 mm. **(B)** The circumference is carefully traced, generating a direct measurement of the basal ring area **(shaded):** 425.8 mm^2. From this, the area-derived diameter is calculated using:

$$diameter = 2\sqrt{\frac{area}{\pi}}$$

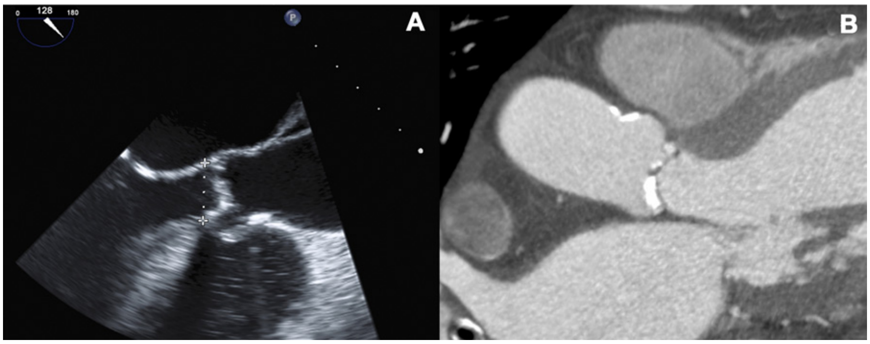

Figure 4. The 3-Chamber View

(A) Three-chamber transesophageal view in a zoomed-up image at approximately 120° is used to measure the aortic annulus diameter. The multidetector computed tomography reconstructed 3-chamber projection **(B)** is created to measure a similar plane.

Echocardiography. Scans were performed either before or during the TAVI procedure and interpreted by an echocardiographer experienced in TAVI and pre-procedural evaluation. All patients undergoing TAVI had both TTE and TEE imaging, with all scans clinically indicated as part of the routine clinical evaluation of patients undergoing TAVI. Phillips iE33 or Sonos 5500 ultrasound systems (Philips HealthCare, Minneapolis, Minnesota) were used for image evaluation. The aortic annulus was measured at the base of the leaflet insertion point in a zoomed-up 3-chamber view at approximately 120° (TEE), corresponding to the nadirs of the noncoronary and right coronary leaflets, or in a parasternal long-axis view in a zoomed-up view (TTE). All measurements were performed in early systole as recommended by the American Society of Echocardiography for quantification of stroke volume and aortic stenosis severity (19). All images were stored on disk for offline analysis. All patients undergoing TAVI had pre-hospital discharge TTE evaluation of valvular function and hemodynamics. The degree and origin of post-procedural aortic regurgitation was assessed using pre-hospital discharge TTE.

Impact of using MDCT images on valve size selection. To evaluate the clinical applicability of MDCT images on valve size selection, a sizing model was created based on annular diameters and current implantation guideline cutoffs. Given that we found MDCT images to be generally larger than TEE measurements, the mean difference between the particular MDCT measurements and TEE measurements were incorporated into an "adjusted" sizing model. A comparison was then made between a strategy in which MDCT measurements were used with existing TEE-based sizing guidelines for the Sapien valve (23-mm valve for annular diameters of 18 to 21 mm, a 26-mm valve for 22 to 25 mm, and a 29-mm valve for 26 to 28 mm) and another strategy in which these sizing cutoffs were adjusted to incorporate the observed mean difference between the specific MDCT views tested and TEE.

Statistical methods. Continuous variables are described as mean ± SD when normally distributed or as medians with interquartile ranges (IQR) when not. Normality was tested using the Shapiro-Wilks goodness-of-fit test. Categorical variables are described by frequencies and percentages. Comparison of categorical variables was performed using a chi-square analysis or the Fisher exact test as appropriate. A mixed-effect model was used to estimate the between-subject variance and within-subject variance. Intraclass correlation coefficient (ICC) was defined as the ratio of between-subject variance to the total variance. The 95% confidence interval (CI) was calculated using the delta method (20). The Spearman correlation coefficient was used to assess the relationship between echocardiographic and MDCT measurements. All analyses were performed using SAS (version 9.1.3, SAS Institute, Cary, North Carolina).

Results

Baseline characteristics. A total of 50 patients underwent evaluation with MDCT (Table 1). The mean age was 81 ± 8 years, 48% were women, and the median Society of Thoracic Surgeons risk score for mortality was 7.5% (IQR: 5.4% to 9.4%). Mean aortic valve area was 0.67 ± 0.21 cm^2

Table 1. Baseline Patient Characteristics (N = 50)

Age, yrs	81 ± 8
Female, %	48
STS risk score	7.5 (5.4–9.4)
Mean AVA, cm^2	0.67 ± 0.21
Mean transaortic gradient, mm Hg	41.2 ± 15.1
Baseline atrial fibrillation	7 (17)

Values are mean ± SD, n, median (interquartile range), or n (%).
AVA = aortic valve area; IQR = interquartile range; STS = Society of Thoracic Surgeons.

Table 2. Procedural Characteristics (N = 41)

Transfemoral procedure	30 (73)
Transapical procedure	11 (27)
Procedural success	41 (100)
Procedural mortality	0 (0)
Valve embolization	0 (0)
23-mm valve	15 (37)
26-mm valve	23 (56)
29-mm valve	3 (7)
Post-procedural paravalvular aortic regurgitation*	
None	4 (10)
Trivial/mild	34 (83)
Moderate	3 (7)
Moderate/severe	0 (0)
Severe	0 (0)

Values are n (%) or n. *No patients had more than trivial valvular regurgitation.

and the mean transaortic baseline gradient was 41.2 ± 15.1 mm Hg. Atrial fibrillation was present in 17% of patients at baseline. The mean heart rate at the time of CT acquisition was 74 ± 8.5 beats/min.

Procedural outcomes. Forty-one patients underwent TAVI (Table 2). All procedures were successful with no procedural mortality, annular rupture, valve embolization, or coronary occlusion. All implants were at optimal height but 1 (too high), with the latter patient having mild paravalvular regurgitation and no other complications. Thirty patients had transfemoral procedures, and 11 had access via a transapical route. A 23-mm valve was used in 15 cases, 26-mm valve in 23 cases, and 29-mm valve in 3 cases. After the procedure, no paravalvular regurgitation was observed in 4 patients, trivial/mild paravalvular regurgitation in 34 patients, and 3 patients had moderate paravalvular regurgitation. No patients had more than trivial transvalvular regurgitation.

Interobserver reliability. The interobserver reliability assessed by ICC was only acceptable by statistical standards (≥0.80) for the area-derived diameter [ICC: 0.87, 95% CI: 0.81 to 0.91) and the basal ring average diameter (ICC: 0.80, 95% CI: 0.70 to 87) (Table 3). The 3-chamber view had lower reliability (ICC: 0.70, 95% CI: 0.58 to 0.80), and the sagittal oblique measurement showed the lowest interobserver reliability (ICC: 0.54, 95% CI: 0.39 to 0.69).

Intraobserver reliability. The greatest reliability and the only 2 measurement points that consistently showed ICC >0.90 for each reader, were the area-derived diameter and the basal ring average diameter (Table 4). The 3-chamber values were not as reliable (ICC: 0.75 to 0.98).

Correlations between MDCT and echocardiography. The overall correlation between MDCT and echocardiography was higher for TEE than for TTE (Table 5). When compared to the TEE-derived annular diameter, the highest correlation with MDCT was for the 3-chamber view (r = 0.80, 95% CI: 0.64 to 0.89, $p < 0.001$), followed by the area-derived diameter (r = 0.79, 95% CI: 0.63 to 0.88, $p < 0.001$) and the basal ring average diameter (r = 0.79, 95% CI: 0.62 to 0.89, $p < 0.0001$) (Fig. 5). The correlation between TEE and TTE was r = 0.73, 95% CI: 0.54 to 0.85.

Overall annular dimensions and Bland-Altman plots. Annular dimensions tended to be larger when assessed by TEE than by TTE. The mean diameter by TEE was 23.0 mm versus 22.1 mm by TTE (p = 0.27).

The difference between the TEE measurements and area-derived diameter, basal ring average diameter, and 3-chamber dimensions were assessed using Bland-Altman methods. The mean difference was greatest for the area-derived diameter (1.5 ±1.6 mm), followed by the basal ring average diameter (1.1 ± 1.7 mm) and the 3-chamber dimension (0.2 ± 1.2 mm). This is demonstrated by the scatters shown in the Bland-Altman plots (Fig. 6).

Applicability of MDCT measurements. To evaluate the potential clinical applicability of MDCT measurements, we studied the theoretical choice of valve size to be implanted if the annulus diameter was determined by MDCT. The analysis was performed using the area-derived diameter, basal ring average diameter, and 3-chamber view. Given that we have shown these measurements to be larger than TEE diameters, a comparison was made between using these diameters with current TEE-based sizing guidelines versus a strategy where these observed differences were incorporated into new "adjusted" sizing criteria.

To adjust the sizing criteria, the observed mean difference between each of these 3 imaging planes and TEE were incorporated to current sizing guidelines. For example, the area-derived diameter is larger than TEE by a mean of 1.5 mm. This resulted in the following theoretical "adjusted" sizing criteria if using the MDCT area-derived diameter: 23-mm valve for annulus ≥19.5 to ≤22.5 mm, 26-mm valve for >22.5 to ≤26.5 mm, and 29-mm valve for >26.5 to ≤29.5 mm (Table 6).

When MDCT measurements were used with current sizing criteria, the valve size indicated was frequently dif-

Table 3. Inter-Reader Reliability as Measured by ICC, Estimates and 95% CI for 3 Readers (N = 50)

Coronal	Sagittal Oblique	Short-Axis Basal Ring	Long-Axis Basal Ring	3-Chamber	Basal Ring Average Diameter	Area-Derived Diameter
0.78 (0.67–0.85)	0.54 (0.39–0.69)	0.71 (0.59–0.81)	0.72 (0.61–0.82)	0.70 (0.58–0.81)	0.80 (0.70–0.87)	0.87 (0.81–0.92)

CI = confidence interval(s); ICC = intraclass correlation coefficient.

Table 4. Intra-Reader Reliability as Measured by ICC,* Estimates and 95% CI (n = 20)

Reader	Coronal	Sagittal Oblique	Short-Axis Basal Ring	Long-Axis Basal Ring	3-Chamber	Basal Ring Average Diameter	Area-Derived Diameter
1	0.93 (0.84–0.97)	0.70 (0.45–0.87)	0.72 (0.47–0.89)	0.87 (0.74–0.95)	0.75 (0.61–0.85)	0.94 (0.87–0.97)	0.93 (0.84–0.97)
2	0.89 (0.75–0.95)	0.84 (0.67–0.93)	0.94 (0.8579–0.9736)	0.87 (0.72–0.94)	0.89 (0.78–0.96)	0.94 (0.86–0.98)	0.93 (0.83–0.97)
3	0.88 (0.75–0.95)	0.84 (0.71–0.94)	0.97 (0.95–0.99)	0.97 (0.93–0.98)	0.98 (0.96–0.99)	0.99 (0.97–0.99)	0.98 (0.94–0.98)

*See Webb and Cribier (1).
Abbreviations as in Table 3.

ferent (area-derived diameter: 44%, basal ring average diameter: 42%, and 3-chamber: 10%). When MDCT measurements were used with the individually adjusted criteria, the strategy was different in significantly lower numbers (area-derived diameter: 10% [$p < 0.01$], basal ring average diameter: 12% [$p < 0.01$], and 3-chamber: 5% [$p = 0.24$]) (Fig. 7).

For the area-derived diameter and basal ring average diameter, a different valve would have been recommended according to the adjusted sizing criteria in 4 and 5 cases, respectively. For both of these, in 3 of the cases (2 × 23-mm valves implanted, 1 × 26-mm valve implanted), greater-than-or-equal-to moderate paravalvular regurgitation was noted following implantation. Importantly, these 3 cases were the only 3 cases of greater-than-or-equal-to moderate paravalvular regurgitation that we observed following the procedure.

Discussion

Overall findings. This study examined patients undergoing multimodality imaging to assess annular dimensions before TAVI. We found that even though MDCT can provide large amounts of anatomical information regarding the complex structure of the aortic annulus in various planes, the most reproducible measurements are those of the area-derived diameter and basal ring average diameter. We found these measurements to be consistently larger than TEE-derived diameters, by a mean of 1.5 mm and 1.1 mm, respectively. If MDCT-obtained dimensions are used for

Table 5. Spearman Correlation Statistics

MDCT Variables	Echo Variable	Correlation	95% Confidence Interval	p Value
Coronal	TTE	0.43	0.12–0.66	<0.01
Sagittal oblique	TTE	0.46	0.15–0.68	<0.01
Short-axis basal ring	TTE	0.54	0.26–0.73	<0.01
Long-axis basal ring	TTE	0.39	0.07–0.63	0.01
Average axis basal ring	TTE	0.59	0.32–0.76	<0.01
Basal ring dimension	TTE	0.51	0.21–0.71	<0.01
3-chamber	TTE	0.57	0.29–0.75	<0.01
Coronal	TEE	0.70	0.49–0.83	<0.01
Sagittal oblique	TEE	0.56	0.29–0.75	<0.01
Short-axis basal ring	TEE	0.74	0.54–0.86	<0.01
Long-axis basal ring	TEE	0.54	0.25–0.73	<0.01
Average axis basal ring	TEE	**0.79**	0.62–0.89	<0.01
Basal ring dimension	TEE	**0.79**	0.63–0.90	<0.01
3-chamber	TEE	**0.80**	0.64–0.89	<0.01
TTE	TEE	0.74	0.54–0.85	<0.01

Bold values are statistically significant.
MDCT = multidetector computed tomography; TEE = transesophageal echocardiography; TTE= transthoracic echocardiography.

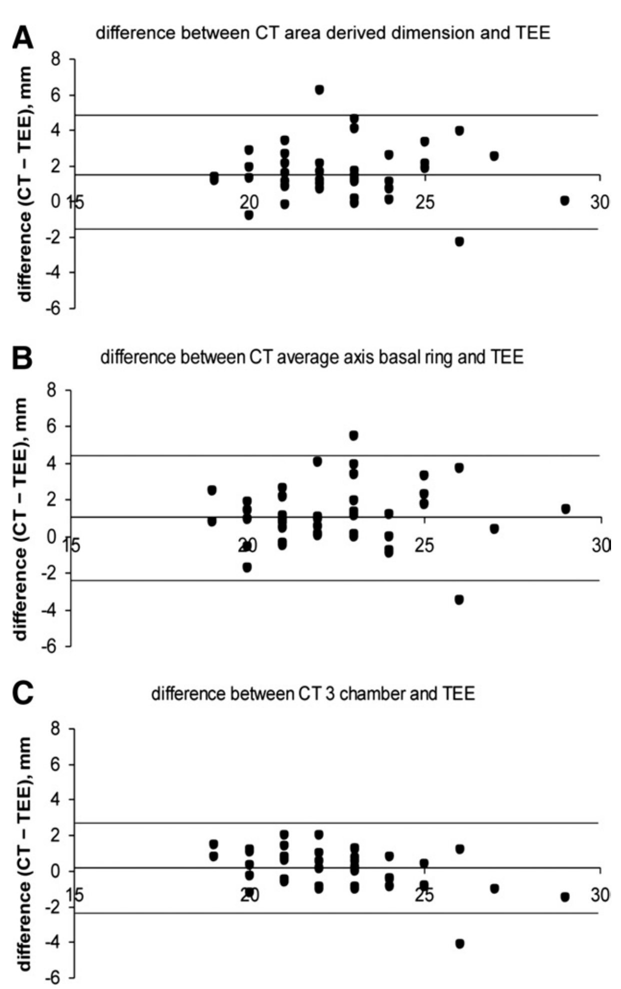

Figure 5. Bland-Altman Plots

(A) Difference between the area-derived dimension and transesophageal echocardiography (TEE). **(B)** Difference between basal ring average diameter and TEE. **(C)** Difference between the multidetector computed tomography (MDCT) derived 3-chamber and TEE.

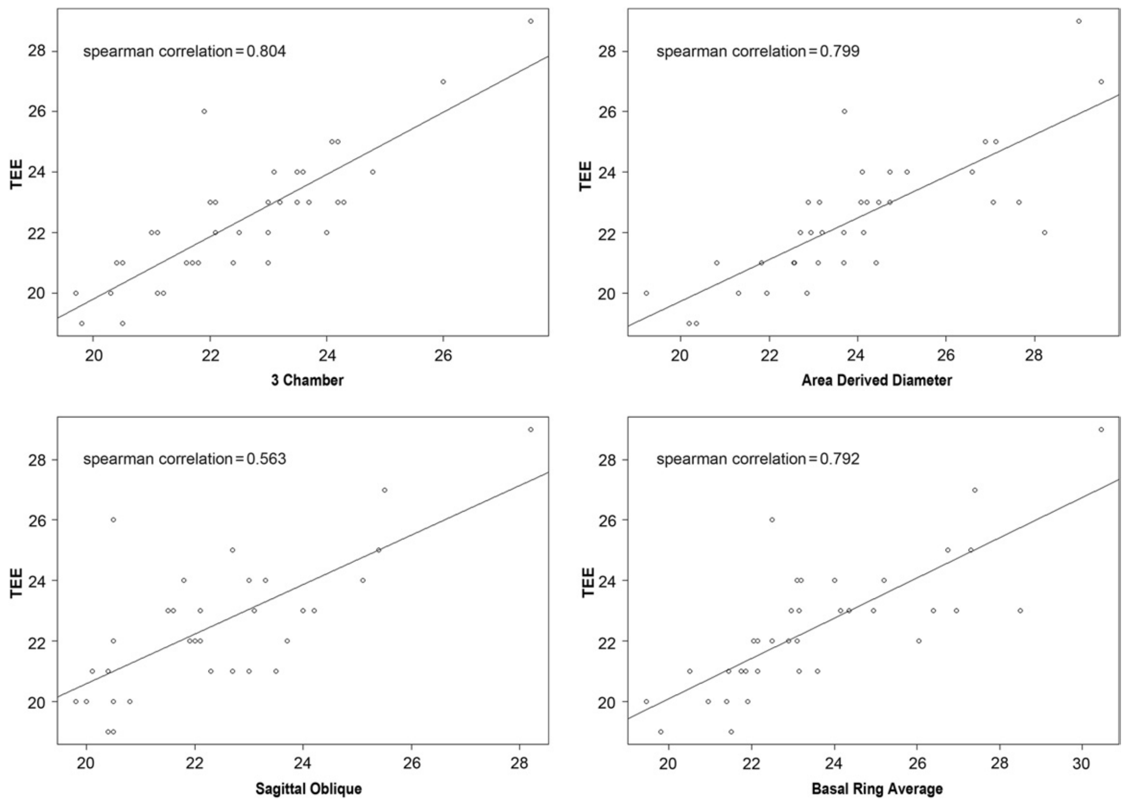

Figure 6. Spearman Correlation Between Various MDCT Dimensions and TEE

The 3-chamber dimensions have the highest correlation (r = 0.8), whereas the sagittal oblique has the lowest (r = 0.56). Abbreviations as in Figure 5.

valve sizing, incorporating these observed differences results in less, but persistent and potentially important discrepancies when compared with TEE-based cutoffs.

Importance of accurate assessment of annular dimensions. The evolution of TAVI has brought the importance of accurate noninvasive assessment of the aortic annulus to a new spotlight. Previous work has shown that TEE diameters can underestimate the true diameter as measured at surgery by a mean of 1.2 mm and frequently underestimate it by >2 mm (21). Despite this, operators have become accustomed to echocardiography-guided TAVI with good results. Current implantation guidelines use TEE diameters to determine the size of the prosthesis to be implanted. However, aortic regurgitation, valve embolization, annular rupture, and patient prosthetic mismatch continue to occur, underscoring the importance of accurate annular evaluation. Even though MDCT appears to provide data on the true anatomical shape and dimensions of the aortic annulus, its applicability has remained limited due partly to uncertainty in incorporating the additional information into the clinical context.

Most useful MDCT measurements. In this study, we evaluated previously described MDCT-derived annular dimensions, including the area-derived diameter (11). The latter considers the entire directly measured circumferential area of the complex shape of the annulus, and the mathematically derived diameter attempts to provide a "diameter of best fit" when provided a circular geometry as seen with a balloon expandable transcatheter valve. We found that in

Table 6. Valve Size Chosen According to Mode of Annulus Assessment by TEE Versus MDCT Using Area-Derived Diameter

Imaging Modality and Sizing Criteria	Valve Size Chosen		
	23 mm	26 mm	29 mm
TEE-guided	15	23	3
MDCT unadjusted	5	26	10
MDCT using adjusted criteria	13	23	5

In the top row, valve sizes were chosen according to TEE measurements and the following guidelines for implantation: 23-mm valve for annulus ≥18.0 to ≤21.0 mm; 26-mm valve for >21.0 to ≤25.0 mm; and 29-mm valve for >25.0 to ≤28.0 mm. In the middle row, valve sizes were chosen from the MDCT area-derived diameter according to the same cutoff guidelines for implantation. In the bottom row, valve sizes were chosen from the MDCT area-derived diameter but adjusted by 1.5 mm to account for the mean difference in this measurement from TEE, hence: 23-mm valve for annulus ≥19.5 to ≤22.5 mm; 26-mm valve for >22.5 to ≤26.5 mm; and 29-mm valve for >26.5 to ≤29.5 mm.

Abbreviations as in Table 5.

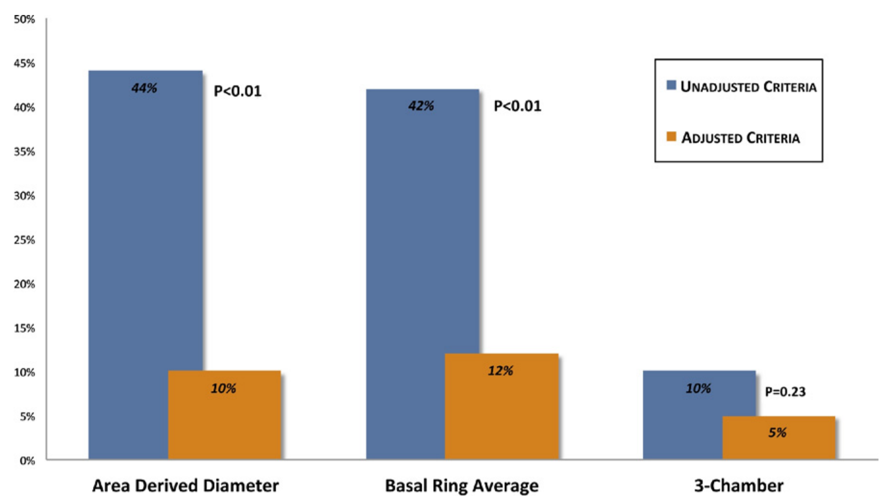

Figure 7. Impact on Valve Size Choice of Unadjusted Versus Adjusted Cutoffs

The graph demonstrates the effect of using MDCT-derived diameters on valve size choice according to current TEE-based cutoffs (unadjusted criteria **[blue]**) versus cutoffs in which the mean difference between MDCT and TEE has been incorporated (adjusted criteria **[brown]**). Abbreviations as in Figure 5.

fact this area-derived diameter and the basal ring average diameter were the most reproducible and reliable measurements obtained by MDCT. The 3-chamber measurement was less reproducible, and the sagittal oblique diameter had the lowest interobserver reliability with an ICC of 0.54 (95% CI: 0.39 to 0.69).

While the 3-chamber measurement was not as reproducible, it had the best correlation with TEE diameters. This is to be expected given that the 3-chamber MDCT projection in essence is an attempt to replicate the echocardiographic plane of measurement. However, in understanding MDCT dimensions, we need to move beyond attempting to replicate the more familiar TEE measurements. The lower correlation for the area-derived diameter and the basal ring average diameter is simply explained: they are measuring different things and provide more anatomical information than does echocardiography.

The unifying feature of the less reproducible measures (sagittal, coronal, or 3-chamber) is that unlike the basal ring measurements, they represent single-plane dimensions of what is usually a more complex oval structure. Subtle obliquity or tilting of the root can easily result in significant variability. Given the elliptical nature of the aortic annulus, even minor changes in orientation can result in potentially significant differences. The 3-chamber reconstruction requires additional dataset manipulation to generate and is subject to the same limitations as the coronal and sagittal oblique measures regarding orientation.

Application of MDCT measurements. We found that if MDCT area-derived diameter or basal ring average diameter were used to guide valve size choice, a different valve size might have been selected in 10% to 12% of patients. In a previous study, Messika-Zeitoun et al. (9) evaluated the theoretical impact of the method of measurement of the annulus diameter on the procedure, finding that when using the basal ring average diameter, MDCT measurements would have modified the TAVI strategy in 38% of patients. Similarly, Tzikas et al. (10) found a change of strategy in 36% of cases if the coronal dimension was used, and Schultz et al. (11) found that 39% would not be candidates for a CoreValve prosthesis (Medtronic Inc., Minneapolis, Minnesota) if the long-axis diameter of the basal ring was used. An important difference in our study is that having demonstrated MDCT measurements to be consistently larger than TEE measurements, these differences were integrated before applying diameter criteria that are accepted for TEE measurements. Using this strategy, we found that when MDCT was used "unadjusted," the TAVI strategy might have been altered in similar frequencies to the previous studies (42% to 44%), but when the criteria were "adjusted" to incorporate these differences, these were significantly reduced to 10% to 12% ($p < 0.01$). These particular cases appear to be especially important. We found in the cases with residual discrepancies between MDCT and TEE that exceeded these criteria, the frequency of moderate paravalvular aortic regurgitation following TAVI was very high. For example, moderate regurgitation was noted in 3 of 4 cases in which a larger valve size was indicated by MDCT as evaluated by "adjusted" area-derived diameter cutoffs. Although the cause of aortic regurgitation following TAVI is multifactorial, this nevertheless raises the possibility that, in specific cases, TEE may underestimate the true annular dimensions, thus contributing to selection of undersized prostheses and important paravalvular regurgitation.

Based on these findings, we propose that given the consistent differences in certain measurements, current manufacturer-recommended sizing cutoffs that are based on TEE diameters might not be appropriate to directly translate to MDCT cutoffs. For example, 22 mm measured by TEE is *not* the same as 22 mm measured by the area-derived diameter from MDCT. The aim of our study is to help clinicians understand how to best apply MDCT measurements and help put them into practical clinical context to aid decision making. We propose that if MDCT measurements are used to help guide valve size choice, new strategies taking into account the differences in specific annular dimensions compared with TEE measurements are required. Such strategies should use adjusted criteria utilizing the most reproducible MDCT measurements of the area-derived diameter or basal ring average diameter.

Study limitations. Although we conducted an analysis of the theoretical choice of valve size according to different annular measurements, the choice of valve size is multifactorial. Factors, including annular diameter, degree and extent of calcification, symmetry of the leaflets, distance to the coronaries, diameter of the sinotubular ridge, and curvature of the sinuses of Valsalva might all affect final valve choice. We could not incorporate these factors into our analysis as this would be beyond the scope of this study, and we considered valve size choice by annular dimensions alone. Also, our study used only the balloon expandable valve and the results with regards to AR may not be applicable in the same way to the self-expanding model. However, annulus determination is crucial regardless of the valve type chosen.

The MDCT scans and echocardiographic assessments were not always performed at exactly the same time of the cardiac cycle for each patient. The MDCT measurements were, however, taken during systolic phases of the cardiac cycle at the point of maximum valve opening. As well, annulus size variation during the cardiac cycle is minimal (7,22), especially in patients with severely stenotic and restricted valves.

Not all patients underwent valve implantation: 9 patients are still awaiting a procedure. This relates to practical considerations of our current waiting list as opposed to any specific factors that may affect the results or conclusions of this study.

Conclusions

MDCT imaging provides significant anatomical information regarding the complex elliptical shape of the aortic annulus. The most reproducible MDCT measurements are the area-derived diameter and basal ring average diameter, with derived values generally larger than those obtained with echocardiography. For MDCT to be used for valve selection, a strategy incorporating these differences might be important. MDCT using these easily derived measurements might be ideally suited to sizing transcatheter aortic valves as they account for the eccentricity of the aortic annulus, are reproducible, and are noninvasive. Further larger studies are required to define the specific cutoffs of annular dimensions as obtained by different imaging modalities for selection of valve size.

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Key Words: aortic annulus ■ aortic stenosis ■ computed tomography ■ transcatheter aortic valve implantation.