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CLINICAL RESEARCH
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Multimodal Assessment of the Aortic Annulus Diameter

Implications for Transcatheter Aortic Valve Implantation

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Objectives We sought to compare 3 methods of measurements of the aortic annulus, transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), and multislice computed tomography (MSCT), and to evaluate their potential clinical impact on transcatheter aortic valve implantation (TAVI) strategy.

Background Exact measurement of the aortic annulus is critical for a patient's selection and successful implantation.

Methods Annulus diameter was measured using TTE, TEE, and MSCT in 45 consecutive patients with severe aortic stenosis referred for TAVI. The TAVI strategy (decision to implant and choice of the prosthesis' size) was based on manufacturer's recommendations (Edwards-Sapien prosthesis, Edwards Lifesciences, Inc., Irvine, California).

Results Correlations between methods were good but the difference between MSCT and TTE (1.22 ± 1.3 mm) or TEE (1.52 ± 1.1 mm) was larger than the difference between TTE and TEE (0.6 ± 0.8 mm; $p = 0.03$ and $p < 0.0001$, respectively). Regarding TAVI strategy, agreement between TTE and TEE overall was good (kappa = 0.68), but TAVI strategy would have been different in 8 patients (17%). Agreement between MSCT and TTE or TEE was only modest (kappa = 0.28 and 0.27), and a decision based on MSCT measurements would have modified the TAVI strategy in a large number of patients (40% to 42%). Implantation, performed in 34 patients (76%) based on TEE measurements, was successful in all but 1 patient with grade 3/4 regurgitation.

Conclusions In patients referred for TAVI, measurements of the aortic annulus using TTE, TEE, and MSCT were close but not identical, and the method used has important potential clinical implications on TAVI strategy. In the absence of a gold standard, a strategy based on TEE measurements provided good clinical results. (J Am Coll Cardiol 2010;55:186–94) © 2010 by the American College of Cardiology Foundation

Aortic stenosis (AS) is the most common valvular disorder in Western countries, and its prevalence is going to increase dramatically with the aging of the population (1,2). Surgical aortic valve replacement is the definitive therapy for patients with severe AS who have symptoms or left ventricular dysfunction (3,4). In the last few years, transcatheter aortic valve implantation (TAVI) has been developed as an alternative to surgical aortic valve replacement with promising results for patients with severe AS considered to be at high or prohibitive surgical risk (5–10). TAVI can be achieved by either a retrograde transfemoral or an anterograde transapical approach (7,11–14). For both approaches, an exact measurement of the aortic annulus is critical for appropriate patient selection and successful implantation. Annulus measurements usually are performed during transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE), but comparisons between these methods are rare and results are controversial (15,16). Recently, it has been suggested that multislice computed tomography (MSCT) also could provide detailed information on the shape and length of the aortic annulus (17), but comparisons between MSCT and TTE or TEE measurements are rare.

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In the absence of a validated gold standard, the most accurate method remained unclear, and whether the method of annulus measurement could affect the TAVI strategy (decision to implant and choice of the size of the prosthesis) had never been evaluated. Thus, the aim of the present study was to compare 3 methods of annulus measurements, namely TTE, TEE, and MSCT, and to evaluate their potential clinical impact on the procedure.

Methods

Study population. Patients with severe AS, referred to our center for TAVI between April 2007 and September 2008, were enrolled in the present study. Patients were included if they had undergone TTE, a TEE, and MSCT within 1 month in our institution. All examinations were indicated clinically as work-up for TAVI. Exclusion criteria were nonadequate echocardiographic or MSCT images precluding annulus measurements. Measurements were performed blindly from each other.

Two-dimensional echocardiography. All patients underwent a comprehensive TTE and TEE performed by 2 experienced echocardiographers (D.M.Z. and E.B.) using high-quality commercially available ultrasound systems (IE33 [Philips Medical Systems, Cleveland, Ohio] and Vivid 7 [General Electric Vingmed, Horten, Norway]). Annulus diameter was measured using the zoom mode at the insertion of the leaflets in midsystole from the parasternal long-axis view in TTE (Fig. 1A) or from the 120° to 140° long-axis view (3-chamber view) in TEE (Fig. 1B). Measurements were averaged from 3 to 5 beats. Evaluation of AS severity was based on mean transaortic gradient and the aortic valve area calculated using the continuity equation (18). The degree of aortic regurgitation was assessed semi-quantitatively according to current guidelines (19).

MSCT. SCANNING. All examinations were performed using a 64-multidetector computed tomography (CT) scanner (Lightspeed VCT, GE Healthcare, Milwaukee, Wisconsin), recently upgraded to allow low-dose step and shoot acquisitions (SnapShot Pulse, VCT-XT, GE Healthcare) under prospective electrocardiography gating. Technical parameters were axial field of view of 50 cm, longitudinal coverage of the entire aorta, iliac and common femoral arteries, gantry rotation time 350 ms, detector aperture 0.625 mm, axial coverage, 40 mm (64 × 0.625 mm), and temporal resolution 175 ms in single-sector reconstruction. Tube voltage parameters were chosen depending on patient body mass index, morphologic features, and mass repartition (55% with 120 kV, 45% with 100 kV), and 600 mA of tube current commonly was used. Contrast enhancement was achieved with 90 ml Iobitridol 350 mg/ml (Xenetix, Guerbet, Aulnay sous Bois, France). To ensure optimal synchronization between X-rays and injection, a bolus tracking was positioned and used at the aortic root level (Smartprep, GE Healthcare). Acquisition was centered at the 75% phase of R-R cardiac cycle when the heart rate was fewer than 65 beats/min and at 40% when the heart rate was more than 65 beats/min to ensure minimum motion artifacts. No beta-blockers were administered. Computed data were processed using a medium-soft tissue convolution kernel (standard). Thickness of reconstructed images was 0.625 mm. Data were sent to an external workstation (AW 4.3, GE Healthcare) where images were analyzed.

Abbreviations and Acronyms

AS = aortic stenosis

CT = computed tomography

MSCT = multislice computed tomography

TAVI = transcatheter aortic valve implantation

TEE = transesophageal echocardiography

TTE = transthoracic echocardiography

IMAGE ANALYSIS. The measurement of the aortic annulus diameter was performed using 2 different methods. The first method was based on a double oblique multiplanar reconstruction. First, in each cross-sectional plane, insertion of the aortic leaflets into the aortic wall was selected manually, allowing a 3-dimensional representation of the aortic annulus (Fig. 2A). Second, a slice perpendicular to the aortic root including the 3 basal points of the annulus was obtained, and 2 orthogonal diameters (long- and short-axis diameters)

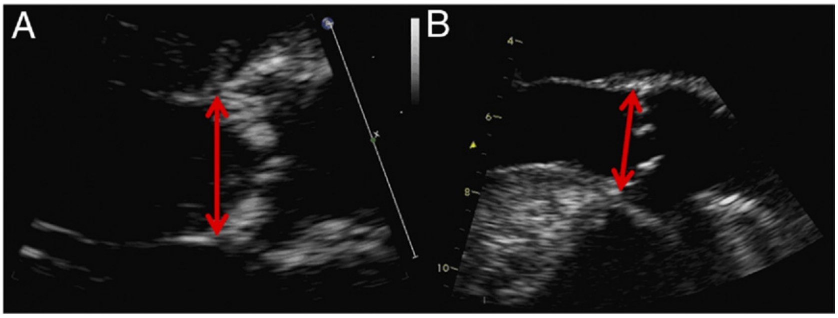

Figure 1 **Echocardiographic Measurements of the Aortic Annulus Diameter**

Examples of measurements of the annulus diameter by **(A)** transthoracic echocardiography and **(B)** transesophageal echocardiography.

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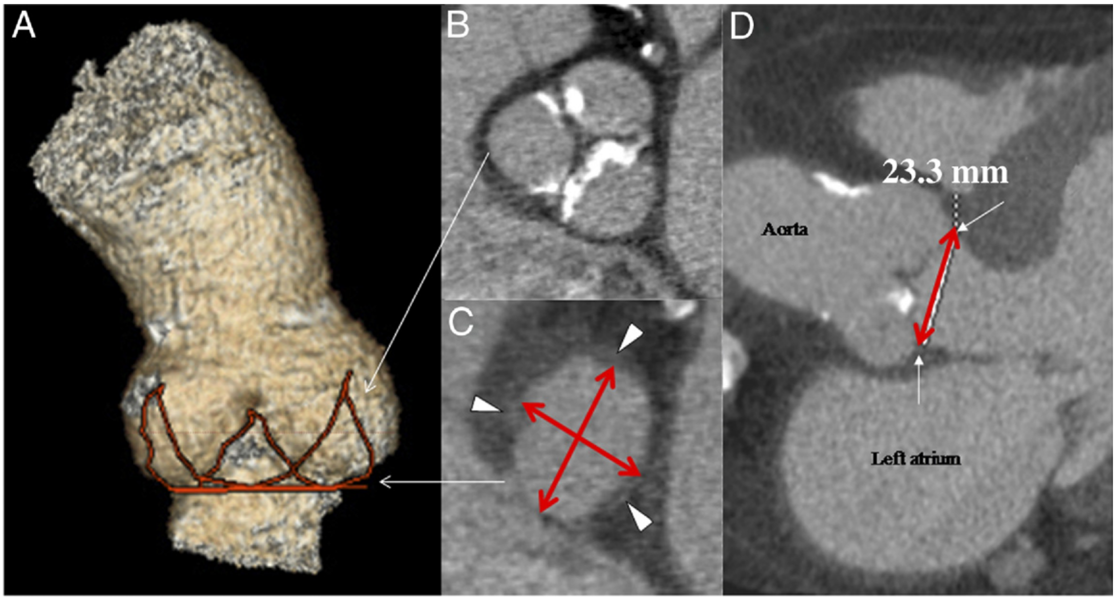

Figure 2 Three-Dimensional Reconstruction and Measurement of the Aortic Annulus Diameter Using Multislice Computed Tomography

(A) Aortic root with the 3-dimensional reconstruction of the aortic annulus showing its crown-like shape. **(B)** Short-axis view of the ascending aorta at the Valsalva level. **(C)** Short-axis view of the aortic root at the level of the basal attachment of the aortic leaflet. The **red arrows** show the long- and short-axis diameters measured at the level of this virtual basal ring. **(D)** Measurements of the aortic annulus in the 3-chamber view (plane similar to echocardiographic long-axis plane). The **small white arrows** represent the hinge point of the leaflet into the aortic wall.

of the aortic root were measured (Figs. 2B and 2C). For the second method, a plane including the aortic root, the left ventricular outflow tract, and the left atrium and ventricle (3-chamber view), similar to the long-axis echocardiographic plane, was reconstructed, and the diameter of the annulus at the hinge points of the leaflets was measured (Fig. 2D).

TAVI. In this series, TAVI was performed using a balloon-expandable valve (Edwards-Sapien, Edwards Lifesciences, Inc., Irvine, California) by transfemoral approach or by transapical approach when femoroiliac axes were not suitable. Technical aspects have been described elsewhere (5). Procedures were performed in the catheterization laboratory or in the operating room under general anesthesia and both fluoroscopic and transesophageal echocardiographic guidance.

Based on current knowledge (5,16), the decision of whether to perform the procedure and the choice of the prosthetic size were based on TEE measurements. The Edwards-Sapien valve currently is available in 2 sizes, 23 and 26 mm. According to the manufacturer's recommendations, a 23-mm prosthesis was implanted if the annulus was >18 and ≤21 mm, a 26-mm was implanted if the annulus diameter was >21 and ≤25 mm, and the procedure was not performed if the annulus diameter was ≤18 or >25 mm.

Statistical analysis. Continuous variables are expressed as mean ± SD. A paired *t* test without corrections for multiple comparisons and Pearson correlations were used for the comparisons of annulus measurement performed using TTE, TEE, or MSCT. To assess for error and bias, the Altman and Bland analysis method was used (20). Intraobserver and interobserver variability of annulus measurements were calculated as the absolute difference between the 2 measurements. The assessment of echocardiographic intraobserver and interobserver variability was performed off line on the same images. MSCT intraobserver and interobserver variability required new reconstructions. A contingency analysis was performed to assess the agreement between the different imaging methods with regard to the decision to implant and the choice of prosthesis' size and were expressed by the kappa value. Comparisons of agreement between methods were performed using the MacNemar test.

Results

Baseline characteristics. Fifty-one consecutive patients referred for TAVI between April 2007 and September 2008 underwent TTE, TEE, and MSCT in our hospital within 1 month. Six patients were excluded due to either echocardiographic (n = 2) or MSCT (n = 4) poor image quality. Forty-five patients finally were enrolled and constituted our study population. Mean age was 80 ± 8 years, and 26 patients (58%) were male. Atrial fibrillation was present in 9 patients (20%). All patients had a tricuspid aortic valve. Mean aortic valve area was 0.71 ± 0.17 cm^2, and mean gradient was 50 ± 16 mm Hg. Mean left ventricular ejection fraction was 46 ± 16% and was <50% in 18 patients (40%).

Echocardiographic measurements. Mean aortic annulus diameter was 23.9 ± 2.1 mm using TTE and 24.1 ± 2.1 mm using TEE ($p = 0.13$) (Table 1). Correlation between TTE and TEE was excellent ($r = 0.89$; $p < 0.00001$) (Fig. 3A), and the quality control plots using the Altman and Bland method showed that there was no trend for underestimation or overestimation using TTE (Fig. 3B) (mean difference, 0.22 mm; limits of agreement, −1.73 to 2.16). The absolute difference between methods was 0.6 ± 0.8 mm.

INTRAOBSERVER AND INTEROBSERVER VARIABILITY. Intraobserver and interobserver variability of the annulus diameter measurements, assessed in 20 patients, were 0.6 ± 0.8 mm and 1.0 ± 0.7 mm, respectively, for TTE and 0.6 ± 0.5 mm and 0.6 ± 1.0 mm, respectively, for TEE.

MSCT. 3-DIMENSIONAL RECONSTRUCTION OF THE AORTIC ANNULUS. Using multiplanar reconstruction and a manual selection of the hinge points of the aortic leaflets into the aortic wall, we were able to reconstruct the crown-like 3-dimensional shape of the aortic annulus with the semilunar implantation of the valve leaflets (Fig. 2A) (21). The leaflets were inserted up to the sinotubular junction, and their basal attachment defined the virtual basal ring (Fig. 2C).

GEOMETRY OF THE AORTIC ANNULUS. Long- and short-axis diameters of the aortic annulus at the level of the virtual basal ring were measured in all patients (Fig. 2C). The long-axis diameter was 27.5 ± 3.1 mm and the short-axis diameter 21.7 ± 2.3 mm. The 2 diameters were significantly different ($p < 0.0001$), demonstrating the oval shape of the aortic annulus. The mean of long- and short-axis diameters (24.6 ± 2.4 mm) tended to be significantly larger than TTE ($p = 0.004$) and TEE ($p = 0.07$) measurements (Table 1).

3-CHAMBER VIEW. Mean aortic annulus diameter was 23.8 ± 2.6 mm (Fig. 2D). The MSCT measurements did not differ from the TTE measurements ($p = 0.73$; mean difference, −0.10 mm; limits of agreement, −3.76 to 3.57), and correlation between the methods was good ($r = 0.71$; $p < 0.0001$) (Figs. 4A and 4B). The MSCT measurements also did not differ from TEE measurements ($p = 0.26$; mean difference, −0.32 mm; limits of agreement, −4.03 to 3.40) and correlated well with TEE measurements ($r = 0.70$; $p < 0.0001$) (Figs. 4C and 4D, Table 1). However, the absolute difference between MSCT and TTE (1.22 ± 1.3 mm) or TEE (1.52 ± 1.1 mm) was significantly larger than the absolute difference between TTE and TEE (0.6 ± 0.8 mm; $p = 0.03$ and $p < 0.0001$, respectively), as illustrated by the wider scatter of the Altman and Bland plots (Figs. 4B and 4D vs. Fig. 3B).

INTRAOBSERVER AND INTEROBSERVER VARIABILITY. Intraobserver and interobserver variability of annulus diameter measurements, assessed in 25 patients, were 0.5 ± 0.4 mm and 0.7 ± 0.6 mm for the mean of long- and short-axis diameters, respectively, and 1.3 ± 0.9 mm and 1.3 ± 1.4 mm, respectively, for the 3-chamber view.

Theoretical impact of the method of measurement of the annulus diameter on the procedure. We evaluated the theoretical impact of the measurement of the annulus diameter using TTE, TEE, or MSCT on TAVI strategy (decision to perform the procedure and choice of the prosthesis size). Results are summarized in Table 2.

Agreement between TTE and TEE was good overall (kappa = 0.68), but the decision to implant or the choice of the prosthetic size would have been different in 8 patients (17%; TEE measurements being larger in 5 patients and smaller in 3 patients; a difference of more than 1 mm was observed in 5 patients).

Using the mean of the long- and short-axis diameters measured by MSCT at the virtual basal ring, agreement with TTE or TEE was modest (kappa = 0.32 and 0.34, respectively), and MSCT measurements would have modified the TAVI strategy in a large number of patients (17 patients [38%] compared with either TTE or TEE vs. 8 patients [17%] between TTE and TEE; both $p = 0.05$). Among these 17 patients, MSCT measurements were larger than TTE or TEE measurements in 12 and 10 patients, respectively. Agreement between MSCT and TTE or TEE using the short- or the long-axis diameter was even worse (kappa range 0.03 to 0.13) (Table 2).

Table 1 Comparison Between Echocardiographic and MSCT Measurements

	Mean Annulus Diameter (mm)	Median	Range	p Value vs. TTE	R vs. TTE	p Value vs. TEE	R vs. TEE
Echocardiographic measurements							
TTE	23.9 ± 2.1	24	19–30	—	—	0.13	0.89
TEE	24.1 ± 2.1	24.5	20–30	0.13	0.89	—	—
MSCT measurements							
Virtual basal ring							
Long-axis	27.5 ± 3.1	27	22–34	<0.0001	0.69	<0.0001	0.67
Short-axis	21.7 ± 2.3	22	17.5–28	<0.0001	0.73	<0.0001	0.69
Mean	24.6 ± 2.4	24	19.8–29.5	0.004	0.80	0.07	0.77
3-chamber view	23.8 ± 2.6	24	18–29	0.73	0.71	0.26	0.70

Data presented are mean ± SD. R is coefficient of correlation.
MSCT = multislice computed tomography; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.

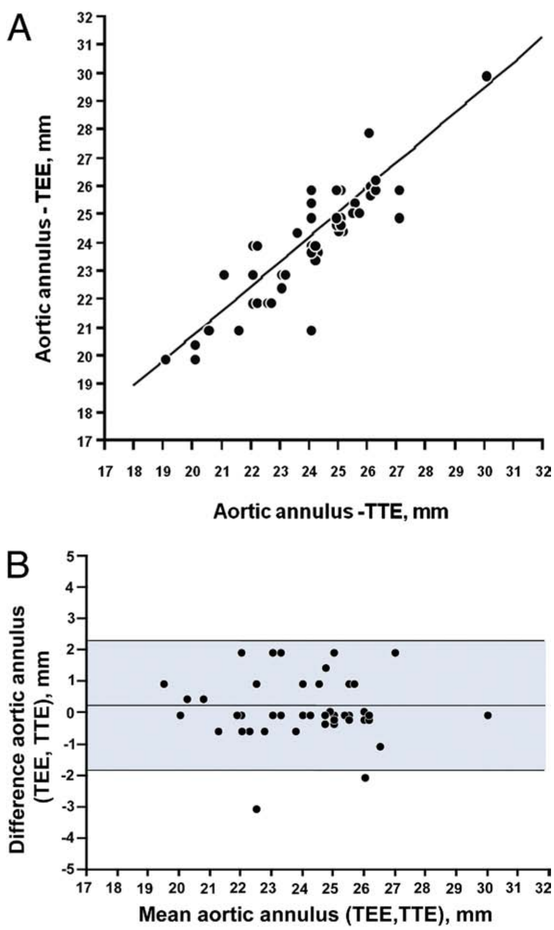

Figure 3 **Correlations Between Echocardiographic Measurements of the Aortic Annulus Diameter**

(A) Correlation between the annulus diameter measured by transthoracic echocardiography (TTE) and by transesophageal echocardiography (TEE). The **solid line** indicates the regression line. **(B)** Quality control plots using Bland-Altman analysis for the 2 methods. The **middle line** represents the mean, the **upper line** represents +2 SDs, and the **lower line** represents −2 SDs.

Three-chamber view measurements using MSCT would have influenced the procedure in 18 patients (40%) compared with TTE and in 19 patients (42%) compared with TEE (vs. 17% between TTE and TEE; $p = 0.03$ and $p = 0.01$, respectively), and kappa values also were modest (0.28 and 0.27, respectively). In these patients, MSCT measurements were larger than TTE or TEE measurements in 8 and 7 patients, respectively.

Results of implantation. In this series, the decision of whether to perform the procedure and the choice of prosthesis size were based on TEE measurements according to current knowledge and recommendations (5). TAVI was not performed in 11 patients (24%) due to the following reasons (not exclusive): acceptable surgical risk and patients redirected toward surgery (n = 3), patients medically managed because of nonsevere (relative) AS after dobutamine stress echo (n = 3), annulus too large (n = 3), poor life expectancy (n = 1), and small femoroiliac diameter in patient not otherwise suitable for the transapical approach (n = 1).

TAVI was performed in 34 patients (76%), using the transfemoral approach in 25 patients (74%) and the transapical approach in 9 patients (26%). A 23-mm valve was implanted in 5 patients and a 26-mm was implanted in 29 patients. Four patients with a borderline aortic annulus diameter between 25 and 25.5 mm finally were implanted because of a prohibitive surgical risk and a strong clinical demand. Implantation was successful in all but 1 patient with a final grade 3/4 periprosthetic aortic regurgitation (TEE annulus diameter, 24 mm; 26-mm prosthesis). Aortic regurgitation grade 2/4 was observed in 5 patients, grade 1/4 was observed in 20 patients, and trace or none was observed in 19 patients. There was no malpositioning, migration, or annulus rupture.

Discussion

Principal findings. In the present study, in a consecutive group of patients with AS referred for TAVI, we measured the aortic annulus using multiple methods and modalities. Results were close but not identical. The TTE and TEE measurements did not differ, with a low intraobserver and interobserver variability and overall a good but not absolute agreement regarding the decision to implant and the choice of the prosthesis size. Cardiac MSCT offered the unique opportunity to assess the complex 3-dimensional structure of the aortic annulus, and we confirmed its oval shape. MSCT also could provide plane orientation and views similar to that of echocardiography, and close measurements of the annulus diameter were observed. However, absolute difference between MSCT and TTE or TEE was larger than in-between both echocardiographic measurements, resulting in only a modest agreement between MSCT and echocardiography regarding the TAVI strategy. Thus, the method used for the measurement of the annulus diameter may have important implications for TAVI. The best method—or the most accurate—remains to be determined, but the use of TEE as reference was associated with good clinical results.

Aortic annulus geometry. The aortic annulus is a 3-dimensional structure much more complex than a simple circular ring. The aortic leaflets are supported in a crown-like fashion within the aortic root (21). The attachment of the aortic leaflets is semilunar and extends throughout the aortic root, running from their basal attachment within the left ventricle to their distal attachment at the sinotubular junction. These semilunar attachments cross the so-called anatomic ventriculo-aortic junction. Two rings usually are defined, an inferior virtual basal ring formed by joining the basal attachment of the leaflets and a superior ring at the top of the crown, which is a true ring corresponding to the sinotubular junction. Using 64-slice MSCT, we were able to reconstruct the 3-dimensional crown-like structure of the aortic annulus with the semilunar implantation of the aortic

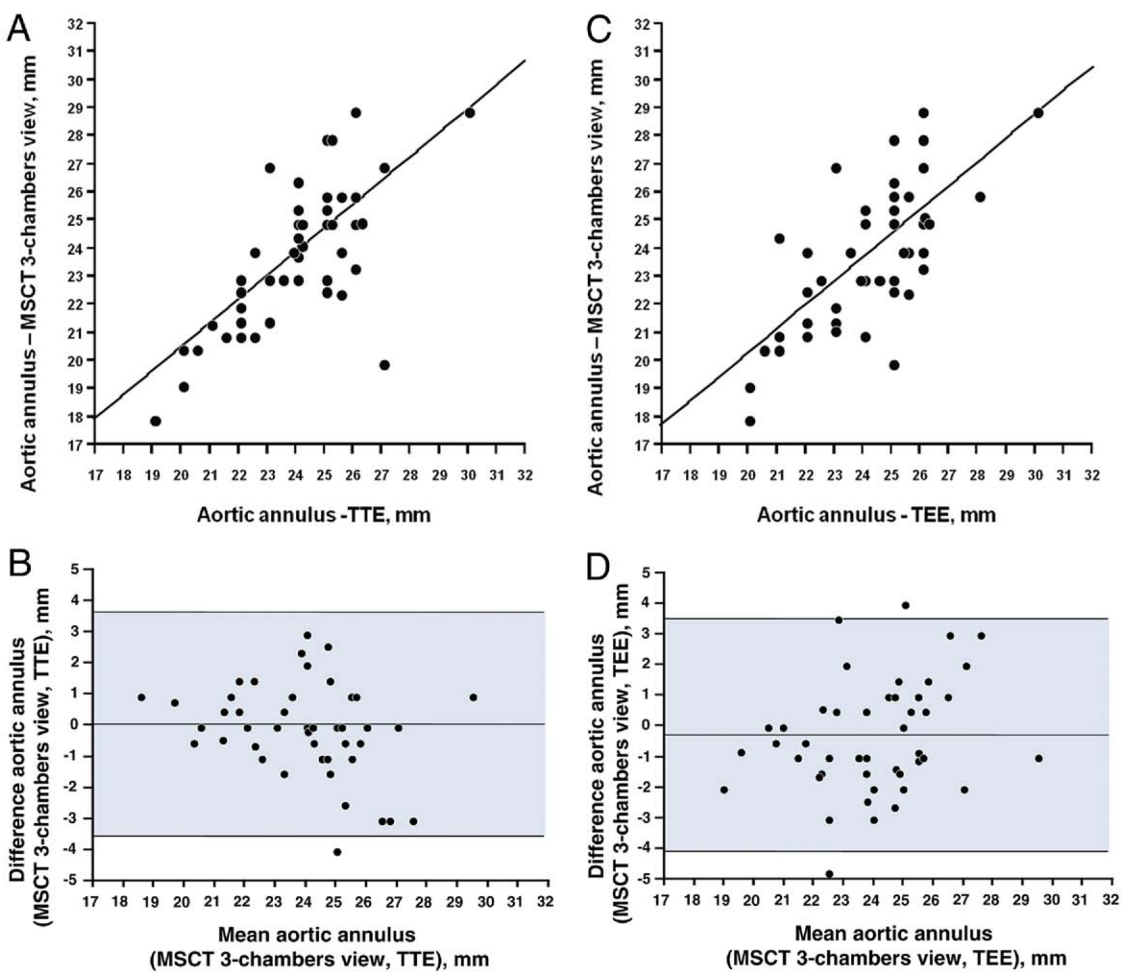

Figure 4 **Correlations Between Echocardiographic and MSCT Measurements of the Aortic Annulus Diameter**

Correlations between the aortic annulus measured by multislice computed tomography (MSCT) using the 3-chamber view and **(A)** TTE and **(B)** TEE. The **solid line** indicates the regression line. Quality control plots using Bland-Altman analysis for the 2 methods, **(C)** TTE and **(D)** TEE. The **middle line** represents the mean, the **upper line** represents +2 SDs, and the **lower line** represents −2 SDs. Abbreviations as in Figure 3.

leaflets. In our study, the long- and short-axis aortic annulus diameters in the plane passing through the lowest point of the aortic leaflet insertion (virtual basal ring) were significantly different, demonstrating that the aortic annulus is not only a complex 3-dimensional structure, but also that its shape is oval and not circular. Our results are in agreement with those of others (17). Using MSCT, they measured the aortic annulus in a sagittal and coronal plane and observed significant differences. It is worth noting that the plane of our long- and short-axis diameters corresponded grossly but not exactly to the coronal and sagittal views mentioned above. Others have also shown that the left ventricular outflow tract is elliptical (22,23). This may have important clinical implications for the calculation of the aortic valve area using the continuity equation (misevaluation of AS severity). Thus, diameter of the aortic annulus may vary according to the location where it is measured, and its shape may explain the smaller diameters (up to 3 mm) obtained using TEE compared with surgical measurements recently reported (24).

Challenges of the measurement of the aortic annulus in TAVI. TAVI is an emerging technology to treat high-risk patients with AS. Accurate annulus measurements and the selection of the appropriate prosthesis size is critical. Undersizing or oversizing of the prosthesis may lead to dramatic events such as valve embolization, severe paravalvular leaks, or annulus rupture. In addition, a larger prosthesis may not be able to be advanced in patients with borderline vascular access or may induce profound vascular injuries.

Aortic annulus can be assessed using multiple methods. Echocardiography plays a key role in a patient's evaluation before TAVI and during the procedure (16). It is widely available, repeatable, and easy to perform even if TEE is semi-invasive and usually requires sedation or general anesthesia. MSCT also can be used for the measurement of the

Table 2 Impact of the Method of Aortic Annulus Measurement on TAVI Strategy

	TAVI Strategy			Agreement With TTE		Agreement With TEE	
	23-mm Prosthesis	26-mm Prosthesis	No Implantation	n (%)	Kappa	n (%)	Kappa
Echocardiographic measurements							
TTE	5	29	11	—	—	37 (83)	0.68
TEE	6	25	14	37 (83)	0.68	—	—
MSCT measurements							
Virtual basal ring							
Long-axis	0	10	35	16 (36)	0.03	19 (42)	0.07
Short-axis	16	21	8	21 (47)	0.13	19 (42)	0.09
Mean	4	24	17	28 (62)	0.32	28 (62)	0.34
3-chamber view	7	25	13	27 (60)	0.28	26 (58)	0.27

Data presented as number of patients.
TAVI = transcatheter aortic valve implantation; other abbreviations as in Table 1.

aortic annulus. Radiation exposure and iodine injection are important MSCT limitations, but they also may provide useful additional information such as the anatomy of the coronary arteries (25,26), the aortic valve area and anatomy (27–29), and the plane of the valve and the importance and distribution of aortic valve calcifications (30). To the best of our knowledge, this is the first study aimed at comparing multiple methods of annulus measurements (TTE, TEE, MSCT) and at evaluating their potential clinical impact on TAVI strategy.

Comparison between methods. Echocardiography is the most widely used method for annulus measurement and thus is considered as the reference method. The anteroposterior diameter of the annulus can be measured either using TTE or TEE, but comparisons between these 2 methods are rare and results conflicting (15,16). In a recent study, in 37 patients with AS referred for TAVI, a discrepancy between TTE and TEE was observed, the annulus diameter being larger using TEE. In the present study, we did not observe any significant difference between these 2 echocardiographic methods. Two explanations can be proposed. First, all of our measurements were performed using the zoom and high-quality commercial ultrasound systems (IE33 by Philips and Vivid 7 by General Electric vs. Philips Sonos 5500 in the aforementioned study). Second, we excluded patients with nonadequate TTE image quality. It is worth noting that acoustic blooming may affect TTE as well as TEE measurements when calcifications are posteriorly located.

MSCT allows a 3-dimensional acquisition of the entire heart throughout the cardiac cycle and multiple plane reconstructions with a high spatial resolution. The 3-chamber view has the same orientation as the parasternal long-axis view on TTE and the 120° long-axis view on TEE. Others have compared, in 169 patients, the annulus diameter measured using TTE and using MSCT in the so-called sagittal view (17). They reported good agreement between both methods despite a trend toward smaller results with TTE. However, only 19 patients with moderate to severe AS were enrolled and no comparison with TEE was presented. In the present study, in a larger number of patients with severe AS, MSCT measurements did not differ from and correlated well with echocardiographic measurements despite an absolute difference larger than the absolute difference between TTE and TEE. Of note, our 3-chamber measurements were close to those presented in this study (23.5 ± 2.7 mm vs. 23.8 ± 2.6 mm, respectively).

Clinical implications. A good correlation between the different methods was observed, but results were not identical. Whatever the explanation for these discrepancies, the TAVI strategy would have been changed in a substantial number of patients (17% to 64%). There is no gold standard, and thus it is not possible to define which method is the most accurate. From a clinical perspective, the most accurate method is the one that allows performing the procedure most effectively with the lowest rate of complications.

Based on current knowledge, TEE is considered by most experts as the reference method. Our strategy based on TEE measurements gave good results, but nevertheless on a limited number of patients. Whether a strategy based on another method could achieve better results is difficult to demonstrate because ideally it would require a randomized study.

Study limitations. First, although the rate of patients excluded from the analysis is provided, this was not a feasibility study. Patients with nonadequate echocardiographic or MSCT images were excluded from the present study because our aim was to evaluate the clinical impact on TAVI strategy of annulus measurements using multiple methods. Second, CT and echocardiographic measurements were not performed exactly at the same time (end-systole to mid-diastole vs. mid-systole, respectively). However, variations of the annulus size during the cardiac cycle are limited (17,31), especially in patients with severe AS with severe calcifications of the aortic valve and the aortic wall and annulus. Dual CT, faster CT with 83-ms temporal resolution, may overcome this limitation and allow low radiation prospective acquisition in mid-systole. Third, 9 patients were in atrial fibrillation. Atrial fibrillation may induce motion artifacts precluding accurate measurements. In the present study, patients with inadequate CT images (including patients with AF) were excluded. However, patients in atrial fibrillation with good images were not excluded, but this small sample size precludes subgroup analysis. In addition, exclusion of the 9 patients in AF did not affect our conclusions with a poor to modest agreement between CT and echocardiographic measurements (kappa value range, 0.07 to 0.38). Fourth, iodine injection and radiation exposure are important MSCT limitations. In the present study, all MSCT were indicated clinically to assess not only the aortic annulus, but also the entire aorta and the femoro-iliac arteries. Finally, only the balloon-expandable Edwards-Sapien prosthesis was used in the present study. Annulus thresholds and prosthesis size are slightly different with the CoreValve Revalving System (Medtronic CV, Luxembourg, Luxembourg) but the modest agreement between methods regarding the TAVI strategy is not dependent on the type of device.

Conclusions

In a consecutive group of patients with AS referred for TAVI, we assessed the aortic annulus diameter using TTE, TEE, and MSCT. Measurements were close but not identical, possibly due to the complex 3-dimensional structure and elliptical shape of the aortic annulus, and the method used had important potential clinical implications on TAVI strategy. In the absence of a gold standard, our strategy based on TEE measurements provided good results. Identification of specific determinants of valve-related complications in larger studies and prospective registries will improve our clinical practice.

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REFERENCES

1. Iung B, Baron G, Butchart EG, et al. A prospective survey of patients with valvular heart disease in Europe: the Euro Heart Survey on Valvular Heart Disease. Eur Heart J 2003;24:1231–43.
2. Nkomo VT, Gardin JM, Skelton TN, Gottdiener JS, Scott CG, Enriquez-Sarano M. Burden of valvular heart diseases: a population-based study. Lancet 2006;368:1005–11.
3. Bonow RO, Carabello BA, Kanu C, et al. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease). J Am Coll Cardiol 2006;48:e1–148.
4. Vahanian A, Baumgartner H, Bax J, et al. Guidelines on the management of valvular heart disease: the Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. Eur Heart J 2007;28:230–68.
5. Vahanian A, Alfieri O, Al-Attar N, et al. Transcatheter valve implantation for patients with aortic stenosis: a position statement from the European Association of Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). Eur Heart J 2008;29:1463–70.
6. Cribier A, Eltchaninoff H, Bash A, et al. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. Circulation 2002;106:3006–8.
7. Cribier A, Eltchaninoff H, Tron C, et al. Treatment of calcific aortic stenosis with the percutaneous heart valve: mid-term follow-up from the initial feasibility studies: the French experience. J Am Coll Cardiol 2006;47:1214–23.
8. Cribier A, Eltchaninoff H, Tron C, et al. Early experience with percutaneous transcatheter implantation of heart valve prosthesis for the treatment of end-stage inoperable patients with calcific aortic stenosis. J Am Coll Cardiol 2004;43:698–703.
9. Descoutures F, Himbert D, Lepage L, et al. Contemporary surgical or percutaneous management of severe aortic stenosis in the elderly. Eur Heart J 2008;29:1410–7.
10. Webb JG, Chandavimol M, Thompson CR, et al. Percutaneous aortic valve implantation retrograde from the femoral artery. Circulation 2006;113:842–50.
11. Lichtenstein SV, Cheung A, Ye J, et al. Transapical transcatheter aortic valve implantation in humans: initial clinical experience. Circulation 2006;114:591–6.
12. Walther T, Falk V, Borger MA, et al. Minimally invasive transapical beating heart aortic valve implantation—proof of concept. Eur J Cardiothorac Surg 2007;31:9–15.
13. Walther T, Simon P, Dewey T, et al. Transapical minimally invasive aortic valve implantation: multicenter experience. Circulation 2007; 116:I240–5.
14. Webb JG, Pasupati S, Humphries K, et al. Percutaneous transarterial aortic valve replacement in selected high-risk patients with aortic stenosis. Circulation 2007;116:755–63.
15. Fan CM, Liu X, Panidis JP, Wiener DH, Pollack PS, Addonizio VP. Prediction of homograft aortic valve size by transthoracic and transesophageal two-dimensional echocardiography. Echocardiography 1997;14:345–8.
16. Moss RR, Ivens E, Pasupati S, et al. Role of echocardiography in percutaneous aortic valve implantation. J Am Coll Cardiol Img 2008;1:15–24.
17. Tops LF, Wood DA, Delgado V, et al. Noninvasive evaluation of the aortic root with multislice computed tomography. Implications for transcatheter aortic valve replacement. J Am Coll Cardiol Img 2008; 1:321–30.
18. Baumgartner H, Hung J, Bermejo J, et al. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. J Am Soc Echocardiogr 2009;22:1–23.
19. Zoghbi WA, Enriquez-Sarano M, Foster E, et al. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. J Am Soc Echocardiogr 2003;16:777–802.
20. Altman D, Bland J. Measurement in medicine: the analysis of method comparison studies. The Statistician 1983;32:307.
21. Piazza N, De Jaegere P, Schultz C, Becker AB, Serruys PW, Anderson RH. Anatomy of the aortic valvar complex and its implications for transcatheter implantation of the aortic valve. Circ Cardiovasc Intervent 2008;1:74–81.
22. Akhtar M, Tuzcu EM, Kapadia SR, et al. Aortic root morphology in patients undergoing percutaneous aortic valve replacement: evidence of aortic root remodeling. J Thorac Cardiovasc Surg 2009;137:950–6.
23. Doddamani S, Grushko MJ, Makaryus AN, et al. Demonstration of left ventricular outflow tract eccentricity by 64-slice multi-detector CT. Int J Cardiovasc Imaging 2009;25:175–81.
24. Babaliaros VC, Liff D, Chen EP, et al. Can balloon aortic valvuloplasty help determine appropriate transcatheter aortic valve size? J Am Coll Cardiol Intv 2008;1:580–6.
25. Gilard M, Cornily JC, Pennec PY, et al. Accuracy of multislice computed tomography in the preoperative assessment of coronary disease in patients with aortic valve stenosis. J Am Coll Cardiol 2006;47:2020–4.
26. Reant P, Brunot S, Lafitte S, et al. Predictive value of noninvasive coronary angiography with multidetector computed tomography to detect significant coronary stenosis before valve surgery. Am J Cardiol 2006;97:1506–10.
27. Bouvier E, Logeart D, Sablayrolles JL, et al. Diagnosis of aortic valvular stenosis by multislice cardiac computed tomography. Eur Heart J 2006;27:3033–8.

28. Feuchtner GM, Dichtl W, Friedrich GJ, et al. Multislice computed tomography for detection of patients with aortic valve stenosis and quantification of severity. J Am Coll Cardiol 2006;47:1410–7.
29. Laissy JP, Messika-Zeitoun D, Serfaty JM, et al. Comprehensive evaluation of preoperative patients with aortic valve stenosis: usefulness of cardiac multidetector computed tomography. Heart 2007;93:1121–5.
30. Messika-Zeitoun D, Aubry MC, Detaint D, et al. Evaluation and clinical implications of aortic valve calcification by electron beam computed tomography. Circulation 2004;110:356–62.
31. Shiran A, Adawi S, Ganaeem M, Asmer E. Accuracy and reproducibility of left ventricular outflow tract diameter measurement using transthoracic when compared with transesophageal echocardiography in systole and diastole. Eur J Echocardiogr 2009;10:319–24.

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