Comparison of Aortic Root Dimensions and Geometries Before and After Transcatheter Aortic Valve Implantation by 2- and 3-Dimensional Transesophageal Echocardiography and Multislice Computed Tomography

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Background—3D transesophageal echocardiography (TEE) may provide more accurate aortic annular and left ventricular outflow tract (LVOT) dimensions and geometries compared with 2D TEE. We assessed agreements between 2D and 3D TEE measurements with multislice computed tomography (MSCT) and changes in annular/LVOT areas and geometries after transcatheter aortic valve implantations (TAVI).

Methods and Results—Two-dimensional circular ($\pi r^2$), 3D circular, and 3D planimetered annular and LVOT areas by TEE were compared with “gold standard” MSCT planimetered areas before TAVI. Mean MSCT planimetered annular area was 4.65 ± 0.82 cm² before TAVI. Annular areas were underestimated by 2D TEE circular (3.89 ± 0.74 cm², $P < 0.001$), 3D TEE circular (4.06 ± 0.79 cm², $P < 0.001$), and 3D TEE planimetered annular areas (4.22 ± 0.77 cm², $P < 0.001$). Mean MSCT planimetered LVOT area was 4.61 ± 1.20 cm² before TAVI. LVOT areas were underestimated by 2D TEE circular (3.41 ± 0.89 cm², $P < 0.001$), 3D TEE circular (3.89 ± 0.94 cm², $P < 0.001$), and 3D TEE planimetered LVOT areas (4.31 ± 1.15 cm², $P < 0.001$). Three-dimensional TEE planimetered annular and LVOT areas had the best agreement with respective MSCT planimetered areas. After TAVI, MSCT planimetered (4.65 ± 0.82 versus 4.20 ± 0.46 cm², $P < 0.001$) and 3D TEE planimetered (4.22 ± 0.77 versus 3.62 ± 0.43 cm², $P < 0.001$) annular areas decreased, whereas MSCT planimetered (4.61 ± 1.20 versus 4.84 ± 1.17 cm², $P = 0.002$) and 3D TEE planimetered (4.31 ± 1.15 versus 4.55 ± 1.21 cm², $P < 0.001$) LVOT areas increased. Aortic annulus and LVOT became less elliptical after TAVI.

Conclusions—Before TAVI, 2D and 3D TEE aortic annular/LVOT circular geometric assumption underestimated the respective MSCT planimetered areas. After TAVI, 3D TEE and MSCT planimetered annular areas decreased as it assumes the internal dimensions of the prosthetic valve. However, planimetered LVOT areas increased due to a more circular geometry. (Circ Cardiovasc Imaging. 2010;3:94-102.)

Key Words: computed tomography ■ echocardiography ■ transesophageal ■ aortic valve

Transcatheter aortic valve implantation (TAVI) has been demonstrated to be a feasible therapeutic alternative for high-risk surgical patients with symptomatic aortic stenosis.1-3 Noninvasive cardiac imaging plays a central role in TAVI because preoperative accurate measurements of aortic annular sizes are crucial for selection of appropriate prosthetic sizes. Currently, aortic annular and left ventricular outflow tract (LVOT) dimensions are assessed by 2D transthoracic or transesophageal echocardiography (TEE). However, compared with multislice computed tomography (MSCT) and 3D echocardiography, 2D echocardiography underestimates the aortic annular and LVOT dimensions.4,5 As the use of real-time 3D TEE to guide cardiac interventions has increased over the last few years, this imaging technique may constitute a valuable imaging tool during TAVI such as providing more accurate measurements of the aortic root and...
geometry. However, agreements between 3D TEE and MSCT-derived aortic annular and LVOT measurements are unknown. In addition, geometric changes in the aortic root after TAVI are unknown and may have important clinical implications during follow-up management of these patients. Thus, the aims of this study were (1) to compare aortic annular and LVOT areas derived from 2D and 3D TEE versus MSCT planimetered areas as “gold standard”; (2) to determine agreements between TEE and MSCT-derived aortic annular and LVOT areas; and (3) to examine changes in aortic annular and LVOT geometries after TAVI.

Clinical Perspective on p 102

Methods

Patient Population

Fifty-three patients who underwent TAVI with the Edwards-Sapien valve (Edwards Lifesciences, Inc, Irvine, Calif) for treatment of severe symptomatic aortic stenosis were prospectively included. Based on the consensus of a group of cardiothoracic surgeons and cardiologists, all these patients underwent TAVI due to excessive surgical morbidity and mortality risks from conventional aortic valve replacement. Operative risk was calculated according to the logistic EuroSCORE as previously published.6 Similarly, selection of the transfemoral versus transapical approaches was based on consensus agreements between the surgeons and cardiologists. Briefly, the transfemoral approach is selected based on the size, tortuosity, and extent of calcifications of the femoral arteries, the transcatheter aortic valve and sheath sizes to be implanted, and ease of valve positioning during the procedure. Technical descriptions for the transfemoral and transapical TAVI procedure have been previously described.3 All the authors hereby declare that all data in the present study cohort of patients has not been previously published.

All patients clinically underwent preoperative transthoracic echocardiography to assess left ventricular (LV) function and aortic stenosis severity, and intraoperative TEE to assist the TAVI procedure (including evaluation of operative complications) as indicated in the position statement by the European Association of Cardio-Thoracic Surgery, European Society of Cardiology and European Association of Percutaneous Cardiovascular Interventions.5 Similarly, preoperative and postoperative MSCT were clinically performed to determine aortic root dimensions before selection of the appropriate prosthetic valve size and to evaluate transcatheter aortic valve deployment (including complications such as device migration and vascular injury), respectively.3

From the various pre-TAVI TEE images, aortic annular and LVOT areas (each comprising the calculated 2D circular area, calculated 3D circular area, and 3D planimetered area) were compared with MSCT planimetered aortic annular and LVOT areas, respectively; MSCT was used as the gold standard. In addition, changes in planimetered aortic annular and LVOT areas after TAVI (as compared with baseline) were evaluated with MSCT and 3D TEE. After TAVI, as the internal dimensions of the prosthetic valve becomes the “new effective” annulus, its internal dimensions were measured as representative of the post-TAVI aortic annular dimensions.

Transthoracic Echocardiography

Transthoracic echocardiography was performed in all subjects preoperatively at rest using commercially available ultrasound transducer and equipment (M3S probe, Vivid 7, GE-Vingmed, Horten, Norway). All images were digitally stored on hard disks for offline analysis (EchoPAC version BT 07.00, GE-Vingmed). A complete 2D, color, pulsed and continuous-wave Doppler echocardiogram was performed according to standard techniques.7,8 LV end-diastolic volume index (EDVI) and end-systolic volume index (ESVI) were calculated using the Simpson blipole method of discs and corrected for body surface area, and LV ejection fraction was derived.8 Mean transaortic pressure gradient was measured by continuous-wave Doppler and aortic valve area was calculated by the continuity equation.10

TEE Imaging

Intraoperative TEE was performed in all subjects using commercially available fully sampled matrix-array TEE transducer and ultrasound system (X7-2t Live 3D TEE transducer, iE33, Philips Medical Systems, Andover, Mass). All images were digitally stored for offline analysis (QLAB cardiac 3DQ, Philips Medical Systems). During acquisition of full volume images, gain and compression settings were optimized to display a magnified zoomed image of the aortic root in the 30° short-axis or 120° long-axis view.

TEE Image Analysis

Measurements of the 2D TEE aortic root dimensions were performed during early systole as recommended by the American Society of Echocardiography for quantification of stroke volume and aortic stenosis severity.10 Determinations of 2D TEE aortic annular and LVOT diameters were performed in the 3-chamber long-axis view at approximately the 120° angle. Briefly, the aortic annular diameter was measured from the junction of the aortic leaflet with the septal endocardium to the junction of the leaflet with the mitral valve posteriorly, using the inner edge to inner edge. The LVOT diameter was obtained 5 mm into the LVOT from the level of the annulus. During the 2D TEE image acquisition, every attempt was made to ensure the largest annulus diameter was obtained (Figure 1).

Similarly, off-line cropping of the 3D aortic root datasets were performed using 3 multiplanar reformations (MPR) planes during early systole. Cropping of the images were first performed using 2 orthogonal MPR planes bisecting the long axis of the LVOT in parallel and a third transverse plane bisecting the aortic annulus directly beneath the lowest insertion points of all 3 aortic cusps to obtain the short-axis aortic annular view. The transverse MPR plane was then moved 5 mm into the LVOT to obtain a representative short-axis LVOT view (Figure 2).

From the various 2D and 3D TEE images, the following aortic annular and LVOT areas were obtained: (1) 2D circular annular area approximated by \(\pi r^2\) (diameter derived from 3-chamber view using the 2D TEE images); (2) 3D circular annular area approximated by \(\pi r^2\) (diameter derived from 3-chamber view using the 3D TEE data set, representing the largest possible diameter obtainable in

Figure 1. Two-dimensional TEE image of the aortic root, long-axis view. The aortic annular and LVOT diameters were obtained as the largest possible diameter during systole using the inner edge to inner edge as recommended by the American Society of Echocardiography. The LVOT diameter was obtained exactly 5 mm below the level of the aortic annulus.
an idealized long-axis view of the heart (Figure 2); 3D planimetered annular area (from the 3D TEE MPR short-axis view, Figure 2); 2D circular LVOT area approximated by $\pi \times r^2$; (3) 3D circular LVOT area approximated by $\pi \times r^2$; and (4) 3D planimetered LVOT area.

These aortic annular and LVOT areas from 2D and 3D TEE were subsequently compared with the MSCT “gold standard” planimetered aortic annular and LVOT areas, respectively.

**MSCT Imaging**

All patients clinically underwent preoperative and postoperative evaluations of the aortic root and transcatheter aortic valve deployment by MSCT using either a 64-slice or 320-slice MSCT scanner (Aquilion 64 and Aquilion ONE, respectively, Toshiba Medical Systems, Otawara, Japan). Accordingly, data were acquired with a collimation of either $64 \times 0.5$ mm or $320 \times 0.5$ mm and a gantry rotation time of 400 ms or 350 ms, respectively. For the Acquilion 64, the tube current was 300 to 400 mA and the tube voltage was 120 kV or 135 kV as determined by the patient’s body mass index. Similarly for the Acquilion ONE, the tube current was 400 to 580 mA, and tube voltage was 100 kV, 120 kV, or 135 kV, as determined by the patient’s body mass index.

The patient’s heart rate and blood pressure were monitored before each scan, and $\beta$-blockers (50 to 100 mg metoprolol orally) were administered in the absence of contraindications if heart rate exceeded a threshold of 65 bpm. All scans were performed during mid-inspiratory breath-hold, and 80 to 90 mL of nonionic contrast (Iomeron 400, Bracco, Milan, Italy) was injected into the antecubital vein. Subsequently, data sets were reconstructed and off-line post-processing of MSCT images were performed on dedicated workstations (Vitrea2, Vital Images, Minneapolis, Minn). The median time from the TAVI procedure to follow-up MSCT imaging was 1.2 months (interquartile range, 1.1 to 1.9 months).

**MSCT Image Analysis**

Early systolic images of the aortic root at 30% to 35% of R-R interval were selected and using the 3 MPR planes, a long-axis image analogous to the 120° long-axis view of the aortic annulus/LVOT on TEE were obtained. In a manner similar to the 3D TEE image analysis, 2 orthogonal MPR planes bisect the long axis of the LVOT in parallel, and a third transverse plane bisects the aortic annulus directly beneath the lowest insertion points of all 3 aortic cusps to obtain the short-axis aortic annular view. The transverse MPR plane was then moved 5 mm into the LVOT to obtain a representative short-axis LVOT view (Figure 3). Planimetered areas for both the aortic annulus and LVOT were obtained from the various MSCT short-axis MPR views and represent the “gold standard” cross-sectional aortic annular/LVOT areas.

**Measurement of Aortic Annular and LVOT Eccentricity**

An eccentricity index was used to assess the aortic annular and LVOT geometries before and after TAVI using the short-axis MSCT and 3D TEE images. An eccentricity index of zero would represent a perfect circle while progressively higher eccentricity index represent progressively more ellipsoid geometry.

**Statistical Analysis**

Continuous variables were presented as mean±1 SD unless otherwise stated. The paired t test was used to compare 2 groups of paired data of Gaussian distribution with Bonferroni corrections performed for multiple comparisons. Repeated-measures analysis of variance (ANOVA) was used to compare ≥3 groups of paired data, and post hoc analysis was performed with Bonferroni correction. The method of Bland and Altman was used for agreement analysis between 2D TEE, 3D TEE, and MSCT-derived aortic annular/LVOT areas. Intraobserver and interobserver agreement for TEE and MSCT derived aortic root cross-sectional areas were performed by 2 independent, blinded observers and evaluated by intraclass correlation, with good agreement being defined as $>0.80$. A 2-tailed probability value of $<0.05$ was considered significant. All statistical analyses were performed using SPSS for Windows (SPSS Inc, Chicago, Ill), version 16.

**Results**

**Baseline Characteristics**

The mean age was 80.0±7.7 years; 28 were men. Table 1 outlines the baseline clinical parameters. Mean LVEDVI, LVESVI, and LV ejection fraction were 61.1±27.7 mL/m².
32.8±24.7 mL/m², and 51.4±14.7%, respectively. The mean transaortic pressure gradient and aortic valve area were 40.1±16.9 mm Hg and 0.69±0.18 cm², respectively. All patients had severe aortic stenosis based on the calculated aortic valve area as indicated by current guidelines. The mean logistic EuroSCORE was 21.5±12.0%.

Table 1. Baseline Clinical Parameters of Patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>80.0±7.7</td>
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<tr>
<td>Sex, male/female</td>
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<tr>
<td>Body surface area, m²</td>
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<td>Diabetes mellitus</td>
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<tr>
<td>Hypertension</td>
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<tr>
<td>Smoking</td>
<td>18.9</td>
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<tr>
<td>Hypercholesterolemia</td>
<td>41.5</td>
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<tr>
<td>Positive family history</td>
<td>22.6</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>26.4</td>
</tr>
<tr>
<td>Previous coronary artery bypass surgery</td>
<td>35.8</td>
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<tr>
<td>Aortic stenosis symptoms, %</td>
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<tr>
<td>Dyspnea</td>
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<tr>
<td>Angina pectoris</td>
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<tr>
<td>Syncope</td>
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<tr>
<td>Logistic EuroSCORE, %</td>
<td>21.5±12.0</td>
</tr>
</tbody>
</table>

Transcatheter Aortic Valve Implantation Procedure

The transfemoral and transapical approaches were performed in 31 (58.5%) and 22 (41.5%) patients, respectively. The 23-mm and 26-mm Edwards-Sapien valves were successfully implanted in 12 (22.6%) and 37 (69.8%) patients, respectively. In 2 patients, the procedure was aborted because of unstable position of the dilatation balloon through a transfemoral approach and in 1 patient, the procedure was aborted because of high risk of LV apical tearing from a transapical approach. There were 3 intraoperative deaths (2 from electromechanical dissociation and 1 from extensive aortic dissection), and 4 additional patients died before hospital discharge from hemodynamic deterioration.

Assessment of Aortic Annulus and LVOT Before TAVI

Before TAVI, the mean MSCT planimeted annular area was 4.65±0.82 cm². Cross-sectional aortic annular areas were significantly underestimated by 2D TEE circular annular area (3.89±0.74 cm², P<0.001), 3D TEE circular annular area (4.06±0.79 cm², P<0.001), and 3D TEE planimeted annular area (4.22±0.77 cm², P<0.001). The method of Bland and Altman was used to assess the agreements between 2D TEE circular annular areas versus MSCT planimeted annular areas, 3D TEE circular annular areas versus MSCT planimeted annular areas, and 3D TEE planimeted annu-
Figure 4. Bland and Altman plots comparing 2D TEE calculated circular annular areas versus MSCT planimetered annular areas (top panel), 3D TEE circular annular areas versus MSCT planimetered annular areas (middle panel), and 3D TEE planimetered annular areas versus MSCT planimetered annular areas (bottom panel). Three-dimensional TEE planimetered annular area had the narrowest limits of agreement and least bias.

Figure 5. Bland and Altman plots comparing 2D TEE calculated circular LVOT areas versus MSCT planimetered LVOT areas (top panel), 3D TEE circular LVOT areas versus MSCT planimetered LVOT areas (middle panel), and 3D TEE planimetered LVOT areas versus MSCT planimetered LVOT areas (bottom panel). Three-dimensional TEE planimetered LVOT area had the narrowest limits of agreement and least bias.
lar areas versus MSCT planimetered annular areas. Figure 4 showed that 3D TEE derived planimetered annular areas had the narrowest limits of agreement and least bias. The mean differences between 2D TEE circular annular area, 3D TEE circular annular area, and 3D TEE planimetered annular area versus MSCT planimetered annular area were −0.77 ± 0.44 cm² (95% CI, −0.89 cm² to −0.64 cm²), −0.61 ± 0.44 (95% CI, −0.73 cm² to −0.49 cm²), and −0.45 ± 0.28 cm² (95% CI, −0.53 cm² to −0.37 cm²), respectively. On average, 2D TEE circular annular areas, 3D TEE circular annular areas, and 3D TEE planimetered annular areas underestimated the MSCT cross-sectional annular area by 16.4%, 12.9%, and 9.6%, respectively.

To evaluate the clinical significance of underestimating the aortic annular cross-sectional areas, preoperative aortic valve areas for all patients were recalculated using 3D TEE circular annular area, 3D TEE planimetered annular area, and MSCT planimetered annular area. A respective 10%, 25%, and 25% of patients were recategorized into moderate aortic stenosis, based on current guidelines definition. No patients were recategorized into mild aortic stenosis.

The mean MSCT planimetered LVOT area was 4.61 ± 1.20 cm² before TAVI. Cross-sectional LVOT areas were significantly underestimated by 2D TEE circular LVOT area (3.41 ± 0.89 cm², P < 0.001), 3D TEE circular LVOT area (3.89 ± 0.94 cm², P < 0.001), and 3D TEE planimetered LVOT area (4.31 ± 1.15 cm², P < 0.001). Similarly, the method of Bland and Altman was used to test the agreement between 2D TEE circular LVOT areas versus MSCT planimetered annular areas, 3D TEE circular LVOT areas versus MSCT planimetered annular areas, and 3D TEE planimetered LVOT areas versus MSCT planimetered annular areas. Three-dimensional TEE-derived planimetered LVOT areas had the narrowest limits of agreement and least bias (Figure 5). The mean difference between 2D TEE circular LVOT area, 3D TEE circular LVOT area, and 3D TEE planimetered LVOT area versus MSCT planimetered LVOT area were −1.26 ± 0.84 cm² (95% CI, −1.50 cm² to −1.03 cm²), −0.78 ± 0.82 cm² (95% CI, −1.01 cm² to −0.78 cm²), and −0.37 ± 0.37 cm² (95% CI, −0.47 cm² to −0.26 cm²), respectively. On average, 2D TEE circular LVOT areas, 3D TEE circular LVOT areas, and 3D TEE planimetered LVOT areas underestimated the MSCT cross-sectional LVOT area by 26.3%, 15.2%, and 7.7%, respectively.

To increase clinical utility, linear regression equations were formulated to correct for the underestimations by 2D TEE circular annular/LVOT areas versus their respective “true” cross-sectional areas by MSCT.

\[
\text{Planimetered annular area (cm}^2\text{)} = 1.01 + 0.94 \\
\times 2D \text{ TEE circular annular area (cm}^2\text{)} \\
\text{r} = 0.85, P < 0.001
\]

\[
\text{Planimetered LVOT area (cm}^2\text{)} = 1.39 + 0.96 \\
\times 2D \text{ TEE circular LVOT area (cm}^2\text{)} \\
\text{r} = 0.72, P < 0.001
\]

**Assessment of Aortic Annulus and LVOT After TAVI**

After TAVI, both MSCT planimetered annular area (4.65 ± 0.82 versus 4.20 ± 0.46 cm², P < 0.001) and 3D TEE planimetered annular area (4.22 ± 0.77 versus 3.62 ± 0.43 cm², P < 0.001) decreased. In contrast, both MSCT planimetered LVOT area (4.61 ± 1.20 versus 4.84 ± 1.17 cm², P = 0.002) and 3D TEE planimetered LVOT area (4.31 ± 1.15 versus 4.52 ± 1.21 cm², P < 0.001) increased after TAVI.

Table 2 shows the different aortic annular/LVOT areas calculated according to various TEE methods before and after TAVI. In regard to the aortic annulus, the mean reduction in 2D TEE circular annular area, 3D TEE circular annular area and 3D TEE planimetered area from pre-TAVI to post-TAVI were 0.13 ± 0.48 cm², 0.42 ± 0.61 cm², and 0.57 ± 0.58 cm², respectively (P < 0.001 by repeated-measures ANOVA). Post hoc analysis showed significant differences in the change in aortic annular areas post-TAVI between 3D TEE circular versus 2D TEE circular area methods (P = 0.005) and between 3D TEE planimetered versus 2D TEE circular area methods (P < 0.001). However, there was a nonsignificant trend between the 3D TEE planimetered and 3D TEE circular area methods (P = 0.051). In contrast, in regard to the LVOT, the mean increase in 2D TEE circular area, 3D TEE circular area, and 3D TEE planimetered area after TAVI were 0.17 ± 0.57 cm², 0.18 ± 0.85 cm², and 0.22 ± 0.34 cm², respectively (P = 0.73 by repeated-measures ANOVA).

To assess the geometric shape change in the aortic annulus and LVOT before and after TAVI, the eccentricity index was derived using the short-axis longest and shortest diameters. Both the aortic annulus and LVOT became less elliptical after TAVI (Table 3). The mean change in aortic annular eccentricity index from pre-TAVI to post-TAVI by MSCT and 3D TEE was 0.11 ± 0.08 and 0.08 ± 0.10, respectively. The mean

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**Table 2. Aortic Annular and LVOT Areas Derived From Different Methods by TEE Before and After Transcatheter Aortic Valve Implantations**

<table>
<thead>
<tr>
<th>Method</th>
<th>Before TAVI</th>
<th>After TAVI</th>
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<tbody>
<tr>
<td><strong>Aortic Annulus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D TEE Circular</td>
<td>3.89±0.74*</td>
<td>3.41±0.89*</td>
</tr>
<tr>
<td>Area, cm²</td>
<td>4.06±0.79*</td>
<td>3.89±0.94*</td>
</tr>
<tr>
<td>3D TEE Circular</td>
<td>4.22±0.77</td>
<td>3.41±1.15</td>
</tr>
<tr>
<td>Area, cm²</td>
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<td></td>
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<tr>
<td>3D TEE Planimetered</td>
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<tr>
<td>Area, cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LVOT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D TEE Circular</td>
<td>4.31±0.84*</td>
<td>3.98±0.98*</td>
</tr>
<tr>
<td>Area, cm²</td>
<td>4.06±1.10*</td>
<td>4.06±1.10*</td>
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<tr>
<td>3D TEE Circular</td>
<td>3.62±0.43</td>
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<tr>
<td>Area, cm²</td>
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<tr>
<td>3D TEE Planimetered</td>
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<tr>
<td>Area, cm²</td>
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</table>

*P<0.05 versus respective 3D TEE planimetered annular/LVOT areas by paired t test with Bonferroni corrections for multiple comparisons.

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**Assessment of Aortic Annulus and LVOT After TAVI**

After TAVI, both MSCT planimetered annular area (4.65 ± 0.82 versus 4.20 ± 0.46 cm², P < 0.001) and 3D TEE planimetered annular area (4.22 ± 0.77 versus 3.62 ± 0.43 cm², P < 0.001) decreased. In contrast, both MSCT planimetered LVOT area (4.61 ± 1.20 versus 4.84 ± 1.17 cm², P = 0.002) and 3D TEE planimetered LVOT area (4.31 ± 1.15 versus 4.52 ± 1.21 cm², P < 0.001) increased after TAVI.

Table 2 shows the different aortic annular/LVOT areas calculated according to various TEE methods before and after TAVI. In regard to the aortic annulus, the mean reduction in 2D TEE circular annular area, 3D TEE circular annular area and 3D TEE planimetered area from pre-TAVI to post-TAVI were 0.13 ± 0.48 cm², 0.42 ± 0.61 cm², and 0.57 ± 0.58 cm², respectively (P < 0.001 by repeated-measures ANOVA). Post hoc analysis showed significant differences in the change in aortic annular areas post-TAVI between 3D TEE circular versus 2D TEE circular area methods (P = 0.005) and between 3D TEE planimetered versus 2D TEE circular area methods (P < 0.001). However, there was a nonsignificant trend between the 3D TEE planimetered and 3D TEE circular area methods (P = 0.051). In contrast, in regard to the LVOT, the mean increase in 2D TEE circular area, 3D TEE circular area, and 3D TEE planimetered area after TAVI were 0.17 ± 0.57 cm², 0.18 ± 0.85 cm², and 0.22 ± 0.34 cm², respectively (P = 0.73 by repeated-measures ANOVA).

To assess the geometric shape change in the aortic annulus and LVOT before and after TAVI, the eccentricity index was derived using the short-axis longest and shortest diameters. Both the aortic annulus and LVOT became less elliptical after TAVI (Table 3). The mean change in aortic annular eccentricity index from pre-TAVI to post-TAVI by MSCT and 3D TEE was 0.11 ± 0.08 and 0.08 ± 0.10, respectively. The mean
change in LVOT eccentricity index from pre-TAVI to post-
TAVI by MSCT and 3D TEE was 0.05±0.08 and 0.03±0.07,
respectively. There were no significant differences between
MSCT or 3D TEE–derived eccentricity indices. Figure 6
illustrates an example of a patient with a smaller, elliptical
LVOT before TAVI (left panel) and subsequent change to a
less elliptical geometry after TAVI (right panel).

Intraobserver and interobserver agreements for TEE and
MSCT derived cross-sectional areas were expressed by intra-
class correlation and summarized in Table 4.

Table 3. Eccentricity Indices for Aortic Annulus and LVOT by
MSCT and 3D TEE Before and After Transcatheter Aortic Valve
Implantation

<table>
<thead>
<tr>
<th></th>
<th>Pre-TAVI</th>
<th>Post-TAVI</th>
<th>P Value</th>
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<tr>
<td><strong>MSCT</strong></td>
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<tr>
<td>Aortic annulus</td>
<td>0.17±0.08</td>
<td>0.05±0.03</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVOT</td>
<td>0.26±0.09</td>
<td>0.20±0.08</td>
<td>&lt;0.001</td>
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<tr>
<td><strong>3D TEE</strong></td>
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<tr>
<td>Aortic annulus</td>
<td>0.15±0.09</td>
<td>0.07±0.05</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVOT</td>
<td>0.24±0.09</td>
<td>0.19±0.09</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Discussion
The present study demonstrated that before TAVI, the aortic
annular and LVOT circular geometric assumption (by either
2D or 3D TEE) resulted in significant underestimation of
their respective MSCT planimetered areas. Using MSCT
planimetered areas as “gold standard,” 3D TEE planimetered
aortic annular and LVOT areas showed the least underesti-
mation and narrowest limits of agreements compared with
their respective calculated circular areas. After TAVI, both
3D TEE and MSCT demonstrated significant decrease in
planimetered aortic annular areas as the “new effective”
aortic annulus assumes the internal dimensions of the circular
prosthetic valve. In contrast, the planimetered LVOT areas
increased due to a more circular geometry after TAVI.

Aortic Annular and LVOT Geometries and
Cross-Sectional Areas by 3D TEE and MSCT
Current recommendations by the American Society of Echo-
cardiography advocate either the aortic annular or LVOT
diameters to be used during calculation of aortic stenosis
severity by continuity equation.10 Although caution was
recommended regarding underestimating the LVOT cross-
sectional area due to its elliptical geometry, no suggestions
were provided to resolve any difficulties. Often in clinical
practice, the aortic annular or LVOT diameters measured on
TEE long-axis views are clinical “gold standards” for calcu-
lating their respective circular cross-sectional areas (Figure
1). However, these echocardiographically derived diameters
are often the minor diameters of an elliptically shaped
annulus/LVOT, resulting in significant underestimations of
the true cross-sectional areas (Figures 2 and 3). In the present
study, we quantified the degree of underestimation caused by
the TEE geometric assumption as ranging from 12.9% to
26.3% when compared with the respective “gold standard”
MSCT planimetered areas. As the velocity time integrals do
not change in the continuity equation, underestimating the
aortic annular/LVOT cross-sectional areas by 12.9% to
26.3% will automatically equate to similar degrees of under-

Table 4. Intraobserver and Interobserver Agreements for
Transesophageal and MSCT-Derived Cross-Sectional Areas

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intraclass Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intraobserver agreement</strong></td>
<td></td>
</tr>
<tr>
<td>2D TEE circular area</td>
<td>0.952</td>
</tr>
<tr>
<td>3D TEE circular area</td>
<td>0.947</td>
</tr>
<tr>
<td>3D TEE planimetered area</td>
<td>0.986</td>
</tr>
<tr>
<td>MSCT planimetered area</td>
<td>0.988</td>
</tr>
<tr>
<td><strong>Interobserver agreement</strong></td>
<td></td>
</tr>
<tr>
<td>2D TEE circular area</td>
<td>0.911</td>
</tr>
<tr>
<td>3D TEE circular area</td>
<td>0.891</td>
</tr>
<tr>
<td>3D TEE planimetered area</td>
<td>0.976</td>
</tr>
<tr>
<td>MSCT planimetered area</td>
<td>0.994</td>
</tr>
</tbody>
</table>

Figure 6. MSCT example of a smaller, elliptical LVOT before transcatheter aortic valve implantation (left panel, eccentricity index=0.23)
and subsequent change to a less elliptical geometry after transcatheter aortic valve implantation (right panel, eccentricity index=0.19).
estimations for the calculated aortic valve areas. Furthermore, this error in the calculation of aortic valve area is likely to be more pronounced in the presence of suboptimal images by 2D transthoracic echocardiography. This was reflected in a respective 10%, 25%, and 25% of patients being reclassified as having moderate aortic stenosis based on calculated aortic valve areas using 3D TEE circular annular area, 3D TEE planimetered annular area, and MSCT planimetered annular area.

Although 3D TEE can avoid this geometric assumption limitation by permitting direct planimetry of the cross-sectional annular/LVOT areas, the present study demonstrated that 3D TEE planimetered annular/LVOT areas still underestimated their respective MSCT planimetered areas by up to 9.6%. This was most likely due to a lower spatial resolution associated with 3D TEE volumetric imaging. However, Bland-Altman analyses showed the least bias and narrowest limits of agreement when comparing planimetered annular/LVOT areas by 3D TEE and MSCT, and the absolute difference in the planimetered annular/LVOT areas between both imaging modalities was small. In contrast, agreements were lower when comparing 2D TEE or 3D TEE–derived circular annular/LVOT areas with their respective MSCT planimetered areas. Thus, underestimation of aortic annular/LVOT cross-sectional areas due to a lower echocardiographic spatial resolution is probably not as clinically important as the erroneous geometric assumption of a circular aortic root.

Changes in Aortic Annular and LVOT Geometries After TAVI

In the present study, both MSCT and 3D TEE demonstrated an elliptical aortic annular/LVOT geometry before TAVI, leading to significant underestimations of their “true” cross-sectional areas when assuming a circular geometry. However, after TAVI, the “new effective” aortic annulus assumes the smaller circular internal dimensions of the deployed prosthetic valve. Consequently, aortic annular area is smaller after TAVI, and the near circular geometry of the deployed prosthetic valve resulted in no significant difference between the calculated circular versus planimetered annular areas. In contrast, the planimetered LVOT area increased after TAVI due to a less elliptical geometry (Figure 6). However, LV reverse remodeling with regression of hypertrophy could have contributed to a larger LVOT measurement by MSCT at 1-month follow-up.

Clinical Implications

Transcatheter aortic valve implantation is a feasible therapeutic alternative for high-risk surgical patients with severe symptomatic aortic stenosis. 1–3 3D volumetric imaging by 3D TEE is an ideal preoperative imaging modality to assess the native aortic root dimensions before TAVI. The ability to noninvasively measure cross-sectional aortic annular/LVOT areas by 3D TEE has important clinical implications such as selection of appropriate prosthetic valve size and more accurate calculations of stroke volumes. Postoperatively, as the aortic annulus assumes a more circular geometry, calculated circular annular area by transthoracic echocardiography is an accurate and inexpensive method to follow the progress of transcatheter aortic valve function.

Study Limitations

One study limitation is the lack of phantom imaging by 3D TEE and MSCT to determine their “true accuracy.” However, the present study was performed as part of the preoperative and postoperative assessment of patients who underwent TAVI as part of their ongoing clinical management. Furthermore, MSCT had superior spatial signal-to-noise ratio compared with echocardiography and was thus used as a “clinical gold standard.”

Conclusion

Before TAVI, echocardiographic assumption of a circular aortic annular/LVOT geometry leads to significant underestimation of their “true” cross-sectional area. Direct planimetry of the aortic annular/LVOT areas by 3D TEE volumetric imaging showed the best agreement with MSCT “gold standard.” After TAVI, aortic annular area decreased as the “new effective” annulus assumes the internal dimensions of the prosthetic valve whereas the LVOT area increased due to a more circular geometry. These changes can be accurately assessed by 3D TEE.

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Disclosures

None.

References

CLINICAL PERSPECTIVE

Current 2D echocardiographic techniques assume circular aortic root geometry when calculating cross-sectional areas. Previous studies have demonstrated that the aortic annulus and left ventricular outflow tract have an ellipsoid geometry but failed to quantify the extent of underestimation caused by this geometric assumption. This may have important clinical implications for selection of appropriate transcatheter aortic valve sizes, which is currently based on 2D echocardiographic measurements. Furthermore, changes in the aortic root dimensions and geometries after transcatheter aortic valve implantations are unknown. Using multislice computed tomography as the “clinical gold standard,” the present study quantified the degree of aortic root cross-sectional area underestimation caused by the assumption of circular aortic annular and left ventricular outflow tract geometry. Furthermore, we demonstrated that 3D transesophageal echocardiography had the best agreement with multislice computed tomography. Finally, after transcatheter aortic valve implantations, the left ventricular outflow tract and aortic valve annulus became more circular-shaped. The use of 3D imaging may have implications in the calculation of aortic valve area by continuity equation and the selection of appropriate transcatheter aortic valve sizes.
Comparison of Aortic Root Dimensions and Geometries Before and After Transcatheter Aortic Valve Implantation by 2- and 3-Dimensional Transesophageal Echocardiography and Multislice Computed Tomography


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