Transcatheter aortic valve implantation: role of multi-detector row computed tomography to evaluate prosthesis positioning and deployment in relation to valve function

Victoria Delgado1, Arnold C.T. Ng1, Nico R. van de Veire1, Frank van der Kley1, Joanne D. Schuijf1, Laurens F. Tops1, Arend de Weger1, Giuseppe Tavilla1, Albert de Roos2, Lucia J. Kroft2, Martin J. Schalij1, and Jeroen J. Bax1*

1Department of Cardiology and Cardiothoracic Surgery, Leiden University Medical Center, Albinusdreef 2, Leiden 2333 ZA, The Netherlands; and 2Department of Radiology, Leiden University Medical Center, The Netherlands

Aims
Aortic regurgitation after transcatheter aortic valve implantation (TAVI) is one of the most frequent complications. However, the underlying mechanisms of this complication remain unclear. The present evaluation studied the anatomic and morphological features of the aortic valve annulus that may predict aortic regurgitation after TAVI.

Methods and results
In 53 patients with severe aortic stenosis undergoing TAVI, multi-detector row computed tomography (MDCT) assessment of the aortic valve apparatus was performed. For aortic valve annulus sizing, two orthogonal diameters were measured (coronal and sagittal). In addition, the extent of valve calcifications was quantified. At 1-month follow-up after procedure, MDCT was repeated to evaluate and correlate the prosthesis deployment to the presence of aortic regurgitation. Successful procedure was achieved in 48 (91%) patients. At baseline, MDCT demonstrated an ellipsoid shape of the aortic valve annulus with significantly larger coronal diameter when compared with sagittal diameter (25.1 ± 2.4 vs. 22.9 ± 2.0 mm, P < 0.001). At follow-up, MDCT showed a non-circular deployment of the prosthesis in six (14%) patients. Moderate post-procedural aortic regurgitation was observed in five (11%) patients. These patients showed significantly larger aortic valve annulus (27.3 ± 1.6 vs. 24.8 ± 2.4 mm, P = 0.007) and more calcified native valves (4174 ± 1604 vs. 2444 ± 1237 HU, P = 0.005) at baseline and less favourable deployment of the prosthesis after TAVI.

Conclusion
Multi-detector row computed tomography enables an accurate sizing of the aortic valve annulus and constitutes a valuable imaging tool to evaluate prosthesis location and deployment after TAVI. In addition, MDCT helps to understand the underlying mechanisms of post-procedural aortic regurgitation.

Keywords
Transcatheter aortic valve implantation • Multi-slice computed tomography • Aortic stenosis

Introduction
In over 8000 high-risk severe aortic stenosis (AS) patients, transcatheter aortic valve implantation (TAVI) techniques have demonstrated to be a feasible alternative therapy to surgical aortic valve replacement.1 Successful implantation is reached in about 90% of cases in experienced centers.2-4 However, in 50% of the patients, mild aortic regurgitation, mostly paravalvular, can be observed, being one of the most frequent complications.3,4 To reduce the risk of aortic regurgitation after TAVI, the selection of the prosthetic valve size is of utmost importance. This selection is based on aortic valve annulus sizing and currently, echocardiography is the most used imaging modality for this purpose. However, with this two-dimensional imaging technique, the aortic valve annulus is

* Corresponding author. Tel: +31 71 526 2020, Fax: +31 71 526 6809, Email: j.j.bax@lumc.nl

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assumed to be circular and, recently, few studies, using three-dimensional imaging [multi-detector row computed tomography (MDCT) or magnetic resonance imaging] have demonstrated the ellipsoid geometry of the aortic valve annulus. These findings may have important implications for aortic valve annulus sizing. Better characterization of the aortic valve geometry may be of great value to select the prosthesis size and, subsequently, may reduce the frequency of aortic regurgitation.

In addition, MDCT is the ideal technique to evaluate the extent and location of calcifications in the aortic valve, an important feature that may determine the prosthesis deployment. In patients with heavily calcified valves, a non-circular deployment of the prosthesis has been reported. This less favourable deployment of the prosthesis may also contribute to an increased risk of aortic regurgitation. However, thus far, no study has evaluated the frequency of aortic regurgitation after TAVI in relation to the final deployed prosthesis shape.

Therefore, the aims of the present clinical evaluation were, first, to study the morphological and geometric characteristics of the aortic valve and aortic root that may predict a less favourable deployment of the prosthetic aortic valve during TAVI and, secondly, to evaluate the presence of significant (moderate-to-severe) aortic valve regurgitation after TAVI in relation to the deployed prosthesis shape. For these purposes, an extensive evaluation before and 1 month after TAVI was performed using MDCT.

Methods

Patient population
A total of 53 consecutive patients with symptomatic, severe AS and at high risk for surgical aortic valve replacement were referred to our centre for TAVI. Inclusion criteria, according to recent recommendations, comprised: (i) symptomatic, severe AS defined by an aortic valve area < 1 cm² by echocardiographic continuity equation; (ii) diameter of the aortic valve annulus ⩾18 mm and ≤25 mm on transthoracic echocardiography; and (iii) increased risk for surgical valve replacement determined by a logistic European System for Cardiac Operative Risk Evaluation (logEuroSCORE) > 20% or the presence of concomitant comorbidities that increase the risk or contraindicates surgery. Exclusion criteria were: sepsis or active endocarditis, life-expectancy < 1 year, coagulopathy or bleeding diathesis and presence of left ventricular (LV) thrombus.

Clinical evaluation
The clinical evaluation consisted of risk assessment based on the logEuroSCORE associated comorbidities not accounted for in the score and frailty condition defined according to the criteria of Fried et al. In addition, comprehensive evaluation of aortic valve anatomy and function with transthoracic echocardiography and invasive coronary and aorto-ilio-femoral angiography, were performed according to current recommendations.

In addition, to characterize in detail the anatomy and dimensions of the aortic valve annulus and aortic root, MDCT was performed in all the patients. Specially, the extent of valve calcifications, aortic valve annulus sizing, and shape and location of the coronary ostia were carefully studied in order to anticipate potential procedural-related complications such as aortic regurgitation or coronary ostium occlusion.

At 1-month follow-up after TAVI, transthoracic echocardiography was clinically performed to evaluate the function of the prosthesis. The effective valve area and the transaortic pressure gradients were assessed. The presence of aortic regurgitation was also evaluated, grading the severity and indicating the mechanism and location of the regurgitant jet (paravalvular or central). Furthermore, cardiac MDCT was clinically performed to evaluate the positioning and deployment of the prosthetic valve and the findings were related to the presence of aortic regurgitation.

Transthoracic echocardiography
Patients were imaged in the left lateral decubitus position with a commercially available ultrasound system (Vingmed Vivid-7, General Electric Vingmed, Horten, Norway) equipped with a 3.5-MHz transducer. Standard grey-scale two-dimensional images were obtained in the parasternal (standard long- and short-axis) and apical views (two- and four-chamber and apical long-axis views). Left ventricular end-diastolic and end-systolic volumes were measured by biplane Simpson’s method and the ejection fraction was derived. Aortic valve morphology (tricuspid/bicuspid) was evaluated at the parasternal short-axis view. Left ventricular outflow tract diameter and aortic annulus, sinus and sinotubular junction diameters were measured at the parasternal long-axis view. Continuous-wave Doppler recordings through the aortic valve were obtained and peak and mean transaortic pressure gradients were calculated. Aortic valve area was calculated by continuity equation. Finally, colour Doppler echocardiography was performed after optimizing gain and Nyquist limit in order to evaluate the presence of regurgitant valve disease. According to current guidelines for the management of patients with valvular heart disease and current recommendations for echocardiographic assessment of valve stenosis, severe AS was defined by a mean transaortic pressure gradient > 40–50 mmHg or an aortic valve area < 1 cm².

Multi-detector row computed tomography data acquisition
Cardiac MDCT was performed with either a 64-detector row computed tomography scanner (Aquilion64, Toshiba Medical Systems, Otawara, Japan) or a volumetric 320-detector row computed tomography scanner (AquilionOne, Toshiba Medical Systems, Tochigi-ken, Japan) using dedicated protocols for each system: 120 kV, 300 mA, a rotation time of 400–500 ms (depending on the heart rate), and collimation of 64 × 0.5 mm for 64 system; and 100–120 kV, 400–580 mA with a minimum rotation time of 350 ms, and collimation of 320 × 0.5 mm for 320 system. All patients with a heart rate > 70 b.p.m. beats/min received oral beta-blockade, unless clinically contraindicated. The amount of non-ionic contrast media administered for MDCT examination was 80–100 mL (Iomeron 400, Bracco, Milan, Italy) at a flow of 5.0 mL/s when 64-detector row computed tomography was used. A tri-phasic injection of 60–80 mL of contrast media was administered when the 320-detector row computed tomography was used. First, 50–70 mL of contrast media was administered at a flow rate of 5.0 or 6.0 mL/s, followed by 20 mL of 50% contrast/saline. Subsequently, a saline flush of 25 mL was administered at a flow rate of 3.0 mL/s. In order to synchronize the arrival of the contrast media and the scan, bolus arrival was detected using automated peak enhancement detection in the left ventricle using a threshold of +100 Hounsfield Units (HU). The total amount of contrast used was dependent on the total scan time, body weight, and renal function. With a 64-detector row computed tomography scanner, data acquisition was performed gated to the electrocardiogram to allow retrospective gating and reconstruction of the data at desired phases of...
the cardiac cycle (at each 10% of RR interval and at 75–85% for diastole and 30–35% for systole). In contrast, with a 320-detector row computed tomography scanner, prospective ECG triggered dose modulation was applied, scanning an entire cardiac cycle and attaining maximal tube current at 75% (when stable heart rate ≤60 b.p.m.) or 65–85% (when heart rate ≥60 b.p.m.) of RR interval. When prospective dose modulation was used, the tube current outside of the predefined interval was 25% of the maximal tube current. The complete MDCT study protocol comprised prospective coronary calcium scan and coronary angiography. Coronary calcium scan was only performed at the baseline MDCT. For MDCT coronary angiography, data acquisition was performed triggered to the electrocardiogram to allow retrospective gating and reconstruction of the data at desired phases of the cardiac cycle (at each 10% of RR interval and at 75–85% for diastole and 30–35% for systole). Finally, axial dataset were transferred to an external workstation (Vitrea 2, Vital Images, Plymouth, Minnesota) for off-line analysis.

**Multi-detector row computed tomography data analysis: aortic valve evaluation**

**Aortic valve morphology**

The correct orientation of the reconstructed coronal and single oblique sagittal views through the aortic valve yields the reconstructed double oblique transverse view of the aortic valve, as previously described. From this view, the anatomy of the aortic valve can be defined (tricuspid/bicuspid) as well as the extent and location of the calcifications. The Agatston calcium score of the aortic valve was obtained from the prospective calcium scan and, additionally, the amount of aortic valve calcification was graded qualitatively (grade 1—no calcification, grade 2—mild calcification, grade 3—moderately calcified, and grade 4—heavily calcified) as previously described. In addition, the location of the calcifications was evaluated by dividing the aortic valve in three different areas: hinge point between the leaflets and the annulus, commissures and free edge of the leaflets.

**Aortic valve annulus sizing**

The aortic valve annulus was measured at the coronal and the single oblique sagittal views providing the coronal and the sagittal diameters, respectively (Figure 1). The eccentricity index of the aortic valve annulus was calculated as 1 (sagittal diameter/coronal diameter). The closer to 0, the more circular the annulus is. Ellipsoid-shaped aortic annulus was considered when the eccentricity index was ≥0.1.

**Aortic root dimensions and relative position of the coronary ostia to the aortic valve annulus**

The aortic root dimensions included the diameters at the level of the sinus of Valsalva and at the level of the sinotubular junction measured at the single oblique sagittal views. The position of the coronary ostia was evaluated by measuring the height of the right and the left coronary ostia relative to the aortic valve annulus plane (Figure 2).

**Positioning and deployment of prosthetic aortic valve**

One month after the TAVI, MDCT was repeated. The position of the aortic valve prosthesis was evaluated in relation to the aortic valve annular plane, measuring the distance between the lower rim of the prosthesis and the aortic valve annulus. In addition, the position of the aortic valve prosthesis was evaluated in relation to the left and right coronary ostia: positioned at the same level of one of the ostia, over passing their height or positioned below the ostia (Figure 3). Furthermore, the deployment of the prosthesis was evaluated: two orthogonal diameters were measured and the internal area was assessed by planimetry at the ventricular side and the aortic side. Non-circular deployment was defined when the eccentricity index was ≥0.1 (Figure 4). Finally, the aortic valve annulus area covered by the deployed prosthesis was evaluated and the net difference between the native aortic valve annulus area and the area of the deployed prosthesis at the ventricular level was calculated.

**Transcatheter aortic valve implantation**

Technical description of TAVI using either transfemoral or transapical approach has been previously described. The balloon-expandable prosthesis Edwards Sapien (Edwards Lifesciences, Inc., CA, USA) was...
used in all patients. According to transthoracic echocardiography, 23-mm prosthesis was used in patients with an aortic valve annulus size between 18 and 21 mm, and 26-mm prosthesis when the aortic valve annulus was 22–25 mm. In addition, transapical approach was used when the diameter of the iliofemoral arteries was 7 mm, for 23-mm prosthesis, or 8 mm, for 26-mm prosthesis, or when tortuosity and bulky calcifications of the peripheral arteries or porcelain aorta existed. The procedure was performed at the catheterization laboratory with transesophageal echocardiography and fluoroscopy guidance. Balloon valvuloplasty was performed in all patients before valve implantation. Both processes, balloon valvuloplasty and valve implantation, were performed under rapid right ventricular pacing to minimize transvalvular flow and risk for valve embolization. Immediately after valve implantation, the position within the aortic valve annulus and the function of the prosthetic valve were assessed with aortography and transesophageal echocardiography.

**Statistical analysis**

Continuous variables have been checked for normal distribution with the Kolmogorov–Smirnov test and are presented as mean and standard deviation or as median and interquartile range (IQR: 25–75%), as appropriate. Categorical variables are presented as number and frequencies. Comparisons between baseline and at follow-up were performed with two-sided Student t-test for paired data or Wilcoxon signed rank test (continuous variables) or McNemar–Bowker test (categorical variables), as appropriate. Comparisons between patients with circular deployment and non-circular deployment of the prosthesis and between patients with none or mild aortic regurgitation and patients with moderate-to-severe aortic regurgitation after TAVI were performed with the non-parametric Mann–Whitney U-test and Fisher’s exact test. All statistical analyses were performed with SPSS software (version 15.0, SPSS, Inc., Chicago, IL, USA). A P-value less than 0.05 was considered statistically significant.
Results

Patient characteristics
Baseline characteristics of the 53 included patients [mean age 80 ± 8 years, 29 (55%) male] are presented in Table 1. The majority of the patients had dyspnoea (n = 48, 91%), and 22 (42%) patients had angina. Mean logEuroSCORE was 22 ± 12%. Forty-three (81%) patients had known coronary artery disease and 34 (64%) patients had prior revascularization with coronary by-pass surgery (n = 23, 43%) or percutaneous coronary intervention (n = 11, 21%). Previous history of myocardial infarction was recorded in 12 (23%) patients. Medication included β-blockers (n = 30, 57%), angiotensin-converting enzyme inhibitors (n = 30, 57%), calcium-receptor antagonists (n = 14, 26%), diuretics (n = 42, 79%), statins (n = 39, 74%), oral anticoagulation/aspirin (n = 48, 91%).

Baseline transthoracic echocardiography
Table 2 summarizes the echocardiographic characteristics of the study population at baseline. The majority of the patients had a tricuspid aortic valve (n = 51, 96%). Two patients showed a bicuspid valve. Maximum and mean transaortic pressure gradients were 64 ± 25 and 40 ± 17 mmHg, respectively, and the median aortic valve area was 0.7 cm² (IQR: 0.5–0.8 cm²) (Table 2). Moderate aortic regurgitation was present in five (9%) patients. Concomitant valvular heart disease included: moderate-to-severe mitral regurgitation in 13 (25%) patients and severe-to-moderate tricuspid regurgitation in 9 (17%) patients. Median systolic pulmonary artery pressure was 42 mmHg (IQR: 34–48 mmHg).

Baseline multi-detector row computed tomography data
Table 3 presents the baseline measurements performed on MDCT data. Aortic valve anatomy was confirmed, being tricuspid in 51 (96%) patients and bicuspid in 2 (4%) patients. The majority of the patients showed heavily calcified aortic valve, with 39 (74%)...
patients scoring 3–4 and with a mean Agatston score of 2624 ± 1413 HU. Aortic valve calcifications were located at the hinge point, the commissures, and the free edge of the leaflets in 34 (64%), 35 (66%), and 39 (74%) patients, respectively. The aortic annulus usually had a significantly larger coronal diameter than the sagittal diameter (25.1 ± 2.4 vs. 22.9 ± 2.0 mm, \(P < 0.001\)), resulting in pronounced ellipsoid morphology in 26 (49%) patients, with a mean eccentricity index of 0.1 ± 0.06. In addition, both MDCT-derived diameters were significantly larger than the diameter measured on echocardiography, resulting in an underestimation by echocardiography of 1 mm when compared with the MDCT-derived sagittal diameter and up to 3.3 mm when compared with MDCT-derived coronal diameter (\(P < 0.001\)). Finally, the left coronary ostium was located at a mean distance from the aortic valve annulus plane of 16.5 ± 3.2 mm, whereas the right coronary ostium was located at a mean distance of 17.4 ± 3.3 mm.

### Table 2 Transthoracic echocardiography: changes after transcatheter aortic valve implantation

<table>
<thead>
<tr>
<th></th>
<th>Baseline (n = 53)</th>
<th>1-Month follow-up (n = 46)</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean transaortic pressure gradient (mmHg)</td>
<td>40 ± 17</td>
<td>9 ± 7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Maximum transaortic pressure gradient (mmHg)</td>
<td>64 ± 25</td>
<td>16 ± 10</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aortic valve area (cm²)</td>
<td>0.7 (0.5, 0.8)</td>
<td>1.8 (1.6, 2.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LV outflow tract (mm)</td>
<td>19.7 ± 2.4</td>
<td>20.0 ± 2.3</td>
<td>0.014</td>
</tr>
<tr>
<td>Aortic valve annulus diameter (mm)</td>
<td>21.9 ± 2.3</td>
<td>21.4 ± 2.5</td>
<td>0.277</td>
</tr>
<tr>
<td>Sinus of Valsalva diameter (mm)</td>
<td>32.9 ± 3.9</td>
<td>32.4 ± 3.6</td>
<td>0.187</td>
</tr>
<tr>
<td>Sinotubular junction diameter (mm)</td>
<td>25.7 ± 3.6</td>
<td>25.5 ± 3.5</td>
<td>0.220</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aortic regurgitation (%)</th>
<th></th>
<th></th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>15 (28%)</td>
<td>10 (22%)</td>
<td>0.390</td>
</tr>
<tr>
<td>Mild</td>
<td>33 (63%)</td>
<td>31 (67%)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>5 (9%)</td>
<td>5 (11%)</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| LV end-diastolic volume (mL) | 100 (78, 128) | 120 (75, 154) | 0.131       |
| LV end-systolic volume (mL)  | 48 (29, 78)     | 45 (27, 89)    | 0.706       |
| LV ejection fraction (%)    | 51 ± 15          | 54 ± 16         | 0.469       |

<table>
<thead>
<tr>
<th>Concomitant valvular heart disease (%)</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral regurgitation</td>
<td></td>
<td></td>
<td>0.120</td>
</tr>
<tr>
<td>None</td>
<td>11 (21%)</td>
<td>17 (37%)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>29 (55%)</td>
<td>22 (48%)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>10 (19%)</td>
<td>6 (13%)</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>3 (6%)</td>
<td>1 (2%)</td>
<td></td>
</tr>
<tr>
<td>Tricuspid regurgitation</td>
<td></td>
<td></td>
<td>0.777</td>
</tr>
<tr>
<td>None</td>
<td>19 (36%)</td>
<td>16 (35%)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>25 (47%)</td>
<td>24 (52%)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>6 (11%)</td>
<td>5 (11%)</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>3 (6%)</td>
<td>1 (2%)</td>
<td></td>
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</tbody>
</table>

| Pulmonary artery pressure (mmHg)       | 42 (34, 48)          | 41 (37, 45)                   | 0.155       |

Transcatheter aortic valve implantation

In 30 (57%) patients, a transfemoral approach was performed, whereas a transapical approach was performed in the remaining 23 (43%) patients. A 23-mm prosthesis was implanted in 11 (21%) patients and a 26-mm prosthesis was implanted in 39 (74%) patients. Procedural success rate was 91% (48 patients of 53). In two patients, the procedure was aborted because of unstable position of the dilatation balloon through a transfemoral approach, and in one patient, the procedure was aborted because of high risk of LV apical tearing using a transapical approach. Three (6%) procedural deaths were registered and four (7%) patients died before hospital discharge (because of haemodynamic deterioration).

### Aortic valve function and aortic root geometry evaluation with multi-detector row computed tomography at 1-month follow-up

At 1-month follow-up, patients were imaged with transthoracic echocardiography (n = 46) and MDCT (n = 42). A significant decrease of mean and maximum transaortic pressure gradients and a significant increase of aortic valve area were observed (Table 2). Mild aortic regurgitation was noted in 31 (67%) patients...
Table 3  Multi-slice computed tomography analysis: changes after transcatheter aortic valve implantation

<table>
<thead>
<tr>
<th></th>
<th>Baseline (n = 53)</th>
<th>1-Month follow-up (n = 42)</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>Aortic valve annulus diameter (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronal</td>
<td>25.1 ± 2.4</td>
<td>24.6 ± 2.4</td>
<td>0.283</td>
</tr>
<tr>
<td>Sagittal</td>
<td>22.9 ± 2.0</td>
<td>23.3 ± 2.0</td>
<td>0.018</td>
</tr>
<tr>
<td>Aortic valve annulus area (cm²)</td>
<td>4.6 ± 0.7</td>
<td>4.3 ± 0.8</td>
<td>0.162</td>
</tr>
<tr>
<td>Eccentricity of the aortic valve annulus</td>
<td>0.10 ± 0.06</td>
<td>0.06 ± 0.04</td>
<td>0.001</td>
</tr>
<tr>
<td>Sinus of Valsalva diameter (mm)</td>
<td>34.1 ± 3.1</td>
<td>33.5 ± 3.6</td>
<td>0.314</td>
</tr>
<tr>
<td>Sinotubular junction diameter (mm)</td>
<td>27.9 ± 2.9</td>
<td>27.8 ± 2.9</td>
<td>0.809</td>
</tr>
<tr>
<td>Distance between left coronary ostium–aortic annulus plane (mm)</td>
<td>16.5 ± 3.2</td>
<td>16.2 ± 2.7</td>
<td>0.467</td>
</tr>
<tr>
<td>Distance between right coronary ostium–aortic annulus plane (mm)</td>
<td>17.4 ± 3.3</td>
<td>16.5 ± 3.0</td>
<td>0.303</td>
</tr>
</tbody>
</table>

and moderate aortic regurgitation was observed in 5 (11%) patients. The location of the regurgitant jet was central in 18 (37%) patients and paravalvular in 18 (37%) patients.

On MDCT, the geometry of the aortic valve annulus changed due to a significant increase in sagittal diameter (from 22.9 ± 2.0 to 23.3 ± 2.0 mm, P = 0.018), whereas the coronal diameter remained unchanged (Table 3). Consequently, the eccentricity index of the aortic valve annulus reduced significantly (from 0.1 ± 0.06 to 0.06 ± 0.04, P = 0.001) indicating a more circular geometry of the aortic valve annulus.

Prosthesis deployment evaluated with multi-detector row computed tomography and relation to aortic valve function

The aortic valve prosthesis was implanted at a mean distance of 3.9 ± 2.8 mm below the aortic valve annular plane. In the majority of the patients (89%), the prosthesis was placed below the coronary ostia. However, in five (11%) patients, the upper edge of the prosthesis reached the left coronary ostium height. Nonetheless, the struts of the prosthesis at that level allow for a normal coronary inflow. Figure 4 illustrates some examples of different positions of the prosthesis.

In addition, the prosthesis showed a circular deployment in 36 (86%) patients, with a mean eccentricity index of 0.05 ± 0.03. The mean internal area of the prosthetic valve at the ventricular level was 3.7 ± 0.5 cm², whereas the mean internal area at the aortic level was 4.1 ± 0.5 cm². The mean difference between the aortic valve annulus area and the internal area of the deployed prosthesis was 0.77 ± 0.51 cm². Interestingly, six (14%) patients had a non-circular deployment of the prosthesis with a mean eccentricity index of 0.13 ± 0.01. These patients with non-circular deployment had significantly larger baseline aortic valve annulus in the coronal plane (27.7 ± 1.6 vs. 24.3 ± 2.3 mm, P = 0.001) and the sagittal plane (24.4 ± 1.2 vs. 22.5 ± 1.9 mm, P = 0.012) when compared with patients with circular deployment. Consequently, the aortic valve annulus area was significantly larger when compared with patients with circular deployment (5.3 ± 0.4 vs. 4.3 ± 0.7 cm², P = 0.001). In addition, the extent of valve calcifications was also significantly higher in patients with non-circular deployment (3862 ± 1837 vs. 2321 ± 1196 HU, P = 0.040).

As reported above, the frequency of moderate aortic regurgitation was 11% (n = 5), and the regurgitant jet was paravalvular in all these patients. When compared with patients with none or mild aortic regurgitation, patients with moderate aortic regurgitation had significantly larger coronal and sagittal aortic valve annulus diameters at baseline (coronal: 27.3 ± 1.6 vs. 24.8 ± 2.4 mm, P = 0.007; sagittal: 24.9 ± 1.6 vs. 22.7 ± 2.0 mm, P = 0.003). Consequently, the aortic valve annulus area assessed with MDCT was significantly larger in patients with moderate aortic regurgitation (5.3 ± 0.5 vs. 4.4 ± 0.7 cm², P = 0.001). More important, patients with moderate aortic regurgitation showed more calcified native valves as quantified by Agatston calcium score when compared with patients with none–mild aortic regurgitation (4174 ± 1604 vs. 2444 ± 1237 HU, P = 0.005). In addition, all the patients with moderate aortic regurgitation showed heavily calcified aortic valve commissures when compared with patients without moderate aortic regurgitation (100 vs. 59%, P = 0.07), whereas calcifications of the hinge points and the free edge of the leaflets were observed with similar frequency in both groups of patients (63 vs. 57%, P = 0.751 and 71 vs. 73%, P = 0.942, respectively). Interestingly, patients with moderate aortic regurgitation showed on follow-up MDCT a significantly more ellipsoid prosthetic valve, with a higher eccentricity index (0.14 ± 0.02 vs. 0.05 ± 0.03, P < 0.001). In addition, the net difference between the aortic valve annulus area and the internal area of the deployed prosthesis at the ventricular level was higher in patients with moderate aortic regurgitation when compared with patients with none or mild aortic regurgitation (1.37 ± 0.62 vs. 0.69 ± 0.45 cm², P = 0.028). This finding indicates that a higher mismatch between native aortic valve annulus area and deployed prosthesis area may determine a higher risk of significant aortic regurgitation. In contrast, there were no differences in the position of the prosthesis relative to the aortic valve annular plane (3.1 ± 3.8 vs. 4.0 ± 2.7 mm, P = 0.822).

Discussion

The present clinical evaluation demonstrated that in the majority of the patients undergoing TAVI, circular deployment of the valved stent was achieved. However, in a substantial percentage of patients, a non-circular deployment of the prosthesis was noted. These patients had significantly larger aortic valve annular dimensions and greater amount of calcifications. Finally, moderate post-procedural aortic regurgitation was observed more frequently in patients with significantly larger aortic valve annulus, more calcified native valves at baseline and less favourable deployment of the
prosthesis after TAVI. Multi-slice computed tomography allows exact characterizations of the native aortic valve apparatus and may predict the results of TAVI in terms of prosthesis deployment and valvular leakage.

Multi-detector row computed tomography before transcatheter aortic valve implantation

The number of TAVI procedures has increased significantly in the last years. Although procedural success rate is ~90%, several complications related to prosthesis over- or undersizing have been reported (paravalvular aortic regurgitation or prosthesis migration). To reduce the frequency of these complications, accurate sizing of the aortic valve annulus is crucial. To date, a gold standard method for aortic valve annulus sizing has not been defined yet. Echocardiography is the most widely used imaging technique for this purpose. However, with this imaging modality, the aortic valve annulus is assumed to be circular, although it has been demonstrated that this structure has an ellipsoid shape. In this regard, Babaliaros et al. studied 23 patients with severe AS and demonstrated that transthoracic or transesophageal echocardiography underestimated the size of the aortic valve annulus by >1.7 and >1.2 mm, respectively, when compared with the measurement performed intraoperatively with surgical sizers. The authors addressed the ellipsoid shape of the aortic valve annulus, and not an inaccuracy of this two-dimensional imaging technique, as the main cause of these differences.

In contrast, MDCT provides a three-dimensional assessment of the aortic valve annulus and may provide a more accurate sizing. In the present study, MDCT demonstrated the ellipsoid shape of the aortic valve annulus, with a coronal diameter significantly larger than the sagittal diameter. In addition, both MDCT-derived diameters were significantly larger than the diameter measured on echocardiography. A decision making based on MDCT measurements may result in less mismatch between the self- or balloon-expandable prosthesis and the native aortic valve annulus and therefore, post-procedural complications derived from an over- or undersizing could be observed less frequently.

Assessment of transcatheter aortic valve implantation results with multi-detector row computed tomography

Echocardiography is also the cornerstone technique to evaluate the results of TAVI. Prosthesis function can be evaluated immediately, demonstrating a significant decrease in transaortic pressure gradients and an increase in aortic valve area. In addition, post-procedural aortic regurgitation can be evaluated, determining the severity and the location of the leakage (central or paravalvular). However, the pathophysiological reasons for the presence of post-procedural aortic regurgitation, such as prosthesis misdeployment, may be difficult to determine from echocardiography. In a series of 35 patients with severe AS, Zegdi et al. demonstrated a high incidence of prosthesis misdeployment, being 30% in patients with tricuspid native aortic valve. A less favourable deployment determined the presence of gap—contact between the prosthesis and the host aortic valve annulus and the presence of paravalvular leak. In addition, Wood et al. studied 26 patients with severe AS treated with TAVI using Edwards Sapien valve. Moderate-to-severe paravalvular aortic leak was observed in eight patients. On MDCT studies performed at 1-month follow-up, a non-circular prosthesis deployment was observed in 22% of the patients (4 patients of 26). However, no relation was observed between the presence of significant paravalvular leak and the geometry of the native aortic valve annulus, extent of valvular calcifications, and prosthesis deployment. In the present study, MDCT provided exact information on prosthesis deployment at 1-month follow-up in the largest cohort of patients to date. Circular deployment was observed in the majority of the patients. However, six (14%) patients showed a non-circular deployment. Importantly, when compared with patients with circular deployment of the prosthesis, patients with non-circular deployment had at baseline a more severe calcification of the aortic valve reflected by a higher Agatston score index. This finding would confirm the hypothesis of Zegdi et al.

Last but not least, paravalvular, moderate aortic regurgitation was observed in 11% of the patients. When compared with patients with none or mild aortic regurgitation, patients with moderate paravalvular leakage had significantly larger aortic valve annulus dimensions and higher amount of valve calcifications at baseline. More important, at 1-month follow-up, MDCT demonstrated that these patients had more ellipsoid prosthesis deployment and the aortic valve annulus area covered by the deployed prosthesis was less than in patients with none or mild aortic regurgitation. Either with self-expandable or balloon-expandable prosthesis, the reported incidence of moderate aortic regurgitation is 13–18%. Prosthesis-aortic annulus mismatch has been postulated as one of the causes of this complication. The present evaluation demonstrates that several factors may determine the presence of paravalvular aortic regurgitation: larger aortic valve annulus dimensions, higher amount of valvular calcifications at the commissures and non-circular deployment of the prosthesis. Multi-detector row computed tomography, by providing an accurate sizing and characterization of the aortic valve annulus, may help in the selection of the prosthesis size, which may reduce prosthesis-aortic annulus mismatch. In addition, this imaging technique may be of importance to design the procedural strategy by predicting in which patients a less favourable deployment of the prosthesis could be observed and redilatation of the prosthesis may be needed. At follow-up, MDCT may indicate the underlying mechanism of paravalvular aortic regurgitation by demonstrating the apposition and deployment of the prosthesis.

Clinical implications

Aortic regurgitation after TAVI is a common complication which mechanisms and future implications remain unclear. Accurate aortic valve annulus sizing is crucial to reduce the incidence of paravalvular aortic regurgitation. The aortic valve annulus dimensions obtained with MDCT are larger than the dimensions obtained with echocardiography. The aortic valve annulus dimensions obtained with MDCT are larger than the dimensions obtained with echocardiography. Furthermore, heavily calcified valves may pose resistance to prosthesis deployment, resulting in an ellipsoid-shaped valved stent and a higher incidence of paravalvular aortic regurgitation. To date, the presence of significant paravalvular regurgitation immediately after TAVI is commonly treated...
with balloon redilatation and oversizing the prosthesis. However, the risk of aortic valve annulus rupture should be counterbalanced. In light of these results, aortic valve annulus sizing based on MDCT may shift current cut-off values to select prosthesis size and manufacturers should consider providing a wider range of prosthesis sizes keeping a low profile to improve the results and reduce the incidence of complications. In addition, pre-procedural MDCT examination provides also exact information on the amount of calcium and may predict which patients would probably show this complication. Finally, after TAVI, MDCT may constitute a valuable and complementary modality imaging to better evaluate the procedural results (deployment and location of the prosthesis) and to understand the underlying mechanisms of post-procedural aortic regurgitation. Additional studies are needed in order to establish a reference method to measure the aortic valve annulus and to demonstrate that the risks of MDCT imaging (radiation exposure) are superseded by a better outcome (lower post-procedural aortic regurgitation rate) in these patients.

Study limitations

The results of the present study are limited to one type of catheter-mounted valve: the balloon-expandable Edwards Sapien valve (Edwards Lifesciences, Inc., CA, USA). However, a recent study evaluating the appraisal and deployment of the self-expandable CoreValve Revalving System (CRS, Medtronic, Luxembourg, Luxembourg) with MDCT has demonstrated a symmetrical expansion of the functionally important middle part, whereas the other parts of the frame showed an incomplete and non-uniform expansion.21

Conclusions

In patients undergoing TAVI, an accurate characterization of the aortic valve apparatus, comprising sizing of the aortic annulus and evaluation of calcification extent, is crucial to achieve a high success rate and low frequency of complications. Prosthesis misdeployment was related to higher amount of aortic valve calcifications, whereas moderate aortic regurgitation was related to prosthesis-aortic annulus mismatch, more calcified native valve and non-circular deployment of the prosthesis. Multi-detector row computed tomography, by providing a three-dimensional view of the aortic valve, enables an accurate sizing of the aortic valve annulus and an exact characterization of the extent of calcifications before the procedure. At follow-up, MDCT constitutes a valuable imaging tool to illustrate the procedural results, in terms of prosthesis location and deployment, and helps to understand the underlying mechanisms of aortic regurgitation.

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Fibrous skeleton endocarditis causing septated aneurysm on the anterior mitral leaflet

Yang Gi Ryu and Man-Jong Baek*

Department of Thoracic and Cardiovascular Surgery, Guro Hospital, Korea University Medical Center, Guro 2-Dong, Guro-Gu, Seoul, Republic of Korea

* Corresponding author. Tel: +82 2 2626 3105, Fax: +82 2 866 6377, Email: mdpbaek@korea.ac.kr

A 26-year-old male was diagnosed to active aortic valve endocarditis extending the fibrous skeleton, caused by Streptococcus sanguinis. A transthoracic echocardiography showed multiple, highly mobile vegetations on all three cusps of the aortic valve with mild-to-moderate aortic regurgitation and a 2.7 × 1.2 cm-sized septated aneurysm on the anterior mitral leaflet with moderate-to-severe mitral regurgitation (Panels A—C). On emergent surgery, a septated aneurysm invaded to the anterior mitral leaflet (Panel D). The aortic cusps were destroyed with numerous vegetations, but the infection was not spread into the aortic annulus or surrounding structures. The excised mass was white to dark brown, with smooth and glistening appearance in atrial surface and septation in ventricular surface (Panels E and F). With the fibrous skeleton reconstruction using a bovine pericardium, both aortic and mitral valves were replaced with mechanical valves under support of extracorporeal circulation. Intravenous antibiotics with ceftriaxone and gentamicin were continued for approximately 4 more weeks postoperatively after which, the patient was discharged uneventfully.

Aneurysmal change of the anterior mitral leaflet is a well-known, but rare complication of aortic valve endocarditis. Once an aneurysm has developed, it is prone to rupture, resulting either in fatal embolic events or acute severe systolic mitral regurgitation. The extension of the infectious process is thought to be either due to the contiguous spread or due to the aortic regurgitant jet striking the subvalvular structures.

Panels A and B. Parasternal long-axis view of transthoracic echocardiography showing irregular, septated, round-shaped mass like an aneurysm (An) on the anterior mitral leaflet at end-systole. LV, left ventricle; LA, left atrium.

Panel C. Parasternal long-axis view of transthoracic echocardiography at end-diastole. LV, left ventricle; LA, left atrium; An, aneurysm on the anterior mitral leaflet; V, aortic valve vegetation.

Panel D. The intraoperative view of the mass attached to the anterior mitral valve.

Panel E. Atrial surface of the excised mass.

Panel F. Ventricular surface of the excised mass.

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