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3-Dimensional Aortic Annular Assessment by Multidetector Computed Tomography Predicts Moderate or Severe Paravalvular Regurgitation After Transcatheter Aortic Valve Replacement

A Multicenter Retrospective Analysis

Alexander B. Willson, MBBS, MPH,* John G. Webb, MD,* Troy M. LaBounty, MD,† Stephan Achenbach, MD,‡ Robert Moss, MBBS,* Miriam Wheeler, MBBS,* Christopher Thompson, MD,* James K. Min, MD,† Ronen Gurvitch, MBBS,* Bjarne L. Norgaard, MD,§ Cameron J. Hague, MD,* Stefan Toggweiler, MD,* Ronald Binder, MD,* Melanie Freeman, MBBS,* Rohan Poulter, MBBS,* Steen Poulsen, MD,§ David A. Wood, MD,* Jonathon Leipsic, MD*

Vancouver, Canada; Los Angeles, California; Giessen, Germany; and Aarhus, Denmark

Objectives This study sought to analyze multidetector computed tomography (MDCT) 3-dimensional aortic annular dimensions for the prediction of paravalvular aortic regurgitation (PAR) following transcatheter aortic valve replacement (TAVR).

Background Moderate or severe PAR after TAVR is associated with increased morbidity and mortality.

Methods A total of 109 consecutive patients underwent MDCT pre-TAVR with a balloon expandable aortic valve. Differences between transcatheter heart valve (THV) size and MDCT measures of annular size (mean diameter, area, and circumference) were analyzed concerning prediction of PAR. Patients with THV malposition ($n = 7$) were excluded. In 50 patients, MDCT was repeated after TAVR to assess THV eccentricity (1 – short diameter/long diameter) and expansion (MDCT measured THV area/nominal THV area).

Results Moderate or severe PAR (13 of 102) was associated with THV undersizing (THV diameter – mean diameter = –0.7 $\pm$ 1.4 mm vs. 0.9 $\pm$ 1.8 mm for trivial to mild PAR, $p < 0.01$). The difference between THV size and MDCT annular size was predictive of PAR (mean diameter: area under the curve [AUC]: 0.81, 95% confidence interval [CI]: 0.68 to 0.88; area: AUC: 0.80, 95% CI: 0.65 to 0.90; circumference: AUC: 0.76, 95% CI: 0.59 to 0.91). Annular eccentricity was not associated with PAR (AUC: 0.58, 95% CI: 0.46 to 0.75). We found that 35.3% (36 of 102) and 45.1% (46 of 102) of THVs were undersized relative to the MDCT mean diameter and area, respectively. THV oversizing relative to the annular area was not associated with THV eccentricity or underexpansion (oversized vs. undersized THVs; expansion: 102.7 $\pm$ 5.3% vs. 106.1 $\pm$ 5.6%, $p = 0.03$; eccentricity: median: 1.7% [interquartile range: 1.4% to 3.0%] vs. 1.7% [interquartile range: 1.1% to 2.7%], $p = 0.28$).

Conclusions MDCT-derived 3-dimensional aortic annular measurements are predictive of moderate or severe PAR following TAVR. Oversizing of THVs may reduce the risk of moderate or severe PAR. (J Am Coll Cardiol 2012;59: 1287–94) © 2012 by the American College of Cardiology Foundation

Paravalvular aortic regurgitation (PAR) remains an important limitation of transcatheter aortic valve replacement (TAVR) (1–3). Approximately 1 in 9 patients undergoing TAVR is left with moderate or severe PAR (3), which has

From the *Department of Medical Imaging and Division of Cardiology, St. Paul's Hospital, University of British Columbia, Vancouver, British Columbia, Canada; †Departments of Medicine, Imaging, and Biomedical Sciences, Division of Cardiology, Cedars-Sinai Medical Center, Los Angeles, California; ‡Department of Cardiology, University of Giessen, Giessen, Germany; and the §Department Cardiology B, Cardiac Imaging Center, Aarhus University Hospital Skejby, Aarhus, Denmark. Dr. Webb is a consultant for Siemens Medical and Edwards Lifesciences. Dr. Achenbach has received grant support from Siemens and Bayer Schering Pharma; and speaker honoraria from Siemens. Drs. Moss and Leipsic are consultants for Edwards Lifesciences. Dr. Min is on the Speaker's Bureau and medical advisory board of GE Healthcare; is a consultant for Edwards Lifesciences; and has equity interest in TC3. Drs. Toggweiler and Binder are supported by unrestricted grants from the Swiss National Foundation. Dr. Wood has relationships with Edwards Lifesciences and St. Jude Medical. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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Abbreviations and Acronyms

CI = confidence interval

IQR = interquartile range

kVp = peak kilovolts

MDCT = multidetector computed tomography

OR = odds ratio

PAR = paravalvular aortic regurgitation

TAVR = transcatheter aortic valve replacement

TEE = transesophageal echocardiography

THV = transcatheter heart valve(s)

been associated with increased morbidity and mortality (4). The 2 main causes of PAR are undersizing of the transcatheter heart valve (THV) relative to the aortic annulus and incorrect device positioning (5–7). Treatment of severe PAR due to THV undersizing is challenging and unsatisfactory.

Sizing THVs is traditionally performed using echocardiographic assessment of the aortic annulus relying on a single 2-dimensional measurement. The aortic annulus, however, is oval in configuration (8–10) and multidetector computed tomography (MDCT) offers a 3-dimensional alternative for image reconstruction of the aortic annulus in a proven reproducible fashion (9). However, questions remain as to whether MDCT annular measurements can predict significant PAR after TAVR and how MDCT should be integrated into THV-sizing protocols. This study aims to address this and to review the impact of annulus eccentricity and THV oversizing on valve expansion and circularity.

Methods

Patient selection. A total of 109 consecutive patients who underwent a screening MDCT before TAVR with a balloon expandable THV (Sapien XT or Sapien, Edwards Lifesciences, Irvine, California) were enrolled from 2 centers (90 from St. Paul's Hospital, Vancouver, Canada, and 19 from Aarhus University Hospital Skejby, Aarhus, Denmark) between January 2010 and June 2011. All patients gave informed written consent. Subjects with renal impairment (glomerular filtration rate <30 ml/min) did not undergo MDCT. The TAVR procedure has been previously described (11,12).

THV selection. During the course of this study, the Sapien valve was available in 23- and 26-mm nominal diameters and the Sapien XT in 20-, 23-, 26-, and 29-mm nominal diameters. In our institutions, THV sizing was multifactorial. In addition to transesophageal echocardiography (TEE) measures of the annulus, it was dependent on patient size, sex, left main height, and root calcification. For example, in our cohort, there are patients for whom the intraprocedural TEE supported the implantation of a different THV size than the operator elected to choose. MDCT was used for assessment of the iliofemoral system, coronary ostia height, and prediction of the fluoroscopic annular plane (13).

THV position. THV position was retrospectively reviewed independently by 2 experienced interventional cardiologists (J.W. and A.W.), who were blinded to the grade of aortic regurgitation, prosthesis size, and MDCT annular measurements. THV positioning was graded as correct, too high, or too low based on pre- and post-implant aortic root angiography. A prosthesis was considered high when the inflow of the prosthesis (and sealing cuff) was above the basal insertion of the native leaflets and low when the outflow portion of the sealing cuff was below the most basal insertion of the native leaflets (Fig. 1). Subjects in whom the prosthesis was implanted too high or low (n = 7) were not included in the analysis as malposition is a distinct and separate cause of PAR (6,7).

Assessment of aortic regurgitation by echocardiography. Pre-discharge transthoracic echocardiography was performed in all patients and interpreted by 3 experienced level III echocardiographers, who were unaware of the preoperative annulus dimensions and size of prosthesis. Aortic regurgitation was graded mild, moderate, or severe according to the Valve Academic Research Consortium criteria (14). Trivial jets were defined as those that were extremely

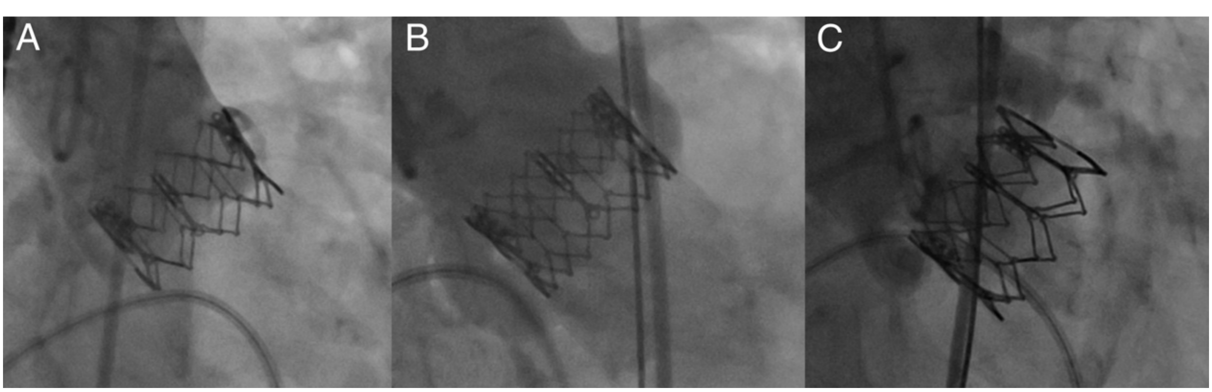

Figure 1 **Grading of THV Position**

(A) Correct, **(B)** too high, and **(C)** too low. THV = transcatheter heart valve(s).

narrow, limited to the distal left ventricular outflow tract, and judged to be hemodynamically insignificant. For the purposes of this analysis, trivial jets were grouped with no aortic regurgitation. Cases with discrepancies in grading among observers were resolved by consensus.

MDCT image acquisition. MDCT examinations were performed on either a 64-slice Discovery HD 750 High Definition scanner (GE Healthcare, Milwaukee, Wisconsin) or a Siemens Somatom Definition Flash Dual-Source scanner (Siemens Healthcare, Erlangen, Germany). Patients were injected with 80 to 120 ml of iodixanol 320 (GE Healthcare, Princeton, New Jersey) at 5 cc/s followed by 30 cc of normal saline. MDCT examinations were acquired in the craniocaudal direction with retrospective gating. Heart rate reduction with beta-blockade was not performed. MDCT scanner detector collimation width was 0.625 mm, detector coverage 40 mm, reconstructed slice thickness 1.25 mm, slice increment 1.25 mm, gantry rotation time 0.35 s, and the scan pitch 0.16 to 0.20 (adjusted per heart rate). Depending on patient size, maximum tube current ranged between 450 and 700 mA with a fixed tube voltage of 100 kVp for patients with a body mass index <30 kg/m^2 and 120 kVp used in larger patients. Electrocardiogram-gated dose modulation was used with tube current reduced to 60% of maximum tube current in systole.

MDCT image analysis. All MDCT examinations were evaluated by a single level III cardiac CT reader (J.L.). The datasets were reconstructed to achieve a double oblique transverse reconstruction at the level of the virtual basal ring (aortic annulus) in a fashion described previously (15–17). Image data were analyzed offline on a 3-dimensional workstation (AW 4.4, GE Healthcare, Waukesha, Wisconsin). To assess generalizability of MDCT annular measurements for the prediction of PAR, 70 cases were randomly selected and reviewed by 2 external readers (T.M.L. and S.A.). Cases were read offline on different workstations OSIRIX MD (version 3.9.4, Pixmeo, Geneva, Switzerland) and Leonardo (Siemens Medical Systems, Erlangen, Germany).

Measuring the difference between THV size and annular size for the prediction of PAR. Annular size was measured by TEE and MDCT. The TEE annular diameter was measured mid systole from the point of basal leaflet insertion as previously described (18). MDCT annular measurements include a mean diameter, area, and circumference (Fig. 2). The MDCT mean annular diameter was taken by averaging the short and long diameters. Aortic annular eccentricity was calculated as: 1 − short diameter/long diameter.

The difference between the nominal THV size and annular dimensions was measured by the following methods and then assessed for prediction of PAR:

1. THV diameter − TEE annular diameter
2. THV diameter − MDCT mean annular diameter
3. THV area/MDCT annular area
4. THV circumference/MDCT annular circumference

The external area of a fully expanded (i.e., nominal) THV is 3.14 cm^2 for the 20-mm THV, 4.15 cm^2 for the 23-mm THV, 5.31 cm^2 for a 26-mm THV, and 6.61 cm^2 for the 29-mm THV. Nominal circumference is 62.8 cm for the 20-mm THV, 72.3 cm for the 23-mm THV, 81.7 mm for the 26-mm THV, and 91.1 mm for the 29-mm THV.

Oversizing or undersizing a THV. A THV was deemed oversized when the THV diameter was greater than the MDCT mean annular diameter or when the THV nominal area was greater than the MDCT annular area. The percentage of oversizing (positive percentage) or undersizing (negative percentage) was calculated using the formula: (THV area/annular area − 1) × 100.

Post-implant geometry of the balloon expandable valves. In 50 patients, post-TAVR THV geometry was assessed before hospital discharge by MDCT. The THV was assessed at the level of the floor of the Sinus of Valsalva to

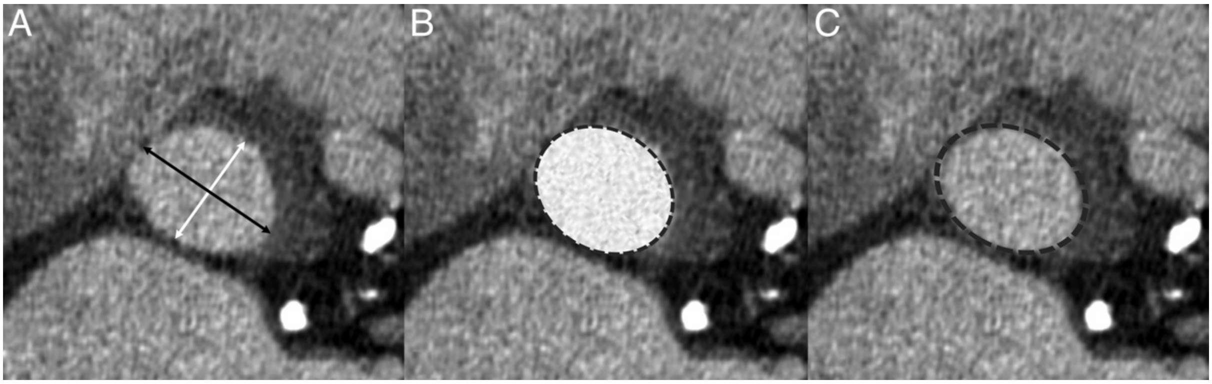

Figure 2 **Three-Dimensional MDCT Aortic Annular Measurements**

(A) Short and long diameters provide a mean annulus diameter and annular eccentricity. **(B)** Annular area. **(C)** Annular circumference. MDCT = multidetector computed tomography.

Table 1 Baseline Patient Characteristics (N = 102)

Age, yrs	81.3 ± 8.3
Female	51 (50.0%)
Diabetes	25 (24.5%)
GFR, ml/min	56.5 ± 21.6
STS PROM	6.6 (4.0–8.5)
Prior CABG	29 (28.4%)
LVEF, %	54.8 ± 12.8
Height, cm	166.7 ± 16.1
Weight, kg	76.7 ± 20.8
Mean aortic valve area, cm^2	0.70 ± 0.17
Mean transaortic gradient, mm Hg	43.5 ± 17.0
Moderate/severe MR	22 (22.5%)

Values are mean ± SD, n (%), or median (25th to 75th percentile).
CABG = coronary artery bypass graft surgery; GFR = glomerular filtration rate; MR = mitral regurgitation; STS PROM = Society of Thoracic Surgeons predicted risk of mortality.

approximate the annular level. Each THV was measured in cross section for a short and long external stent diameter. The external margins of the stent were traced to generate the post-TAVR MDCT THV area. THVs were assessed for eccentricity (1 − short diameter/long diameter) and expansion (MDCT measured THV external area/nominal THV area). A THV was circular when eccentricity was <10% (19,20) and 100% expansion represented a fully expanded THV. The effect of oversizing a THV relative to the MDCT annular area on THV eccentricity and expansion was assessed.

Statistical methods. Continuous variables are described as mean ± SD or median (interquartile range [IQR]). Categorical variables are described by frequencies and percentages. Continuous parametric variables were compared using unpaired and paired Student *t* test as appropriate. Continuous nonparametric variables were compared using the Mann-Whitney *U* test. Categorical variables were compared using Fisher exact test. Intraclass correlation coefficient was defined as the ratio of between-subject variance to the total. One-way analysis of variance was used to compare the difference in means from 3 groups of PAR grade. Area under the receiver-operating characteristic curves were performed to test discriminatory power of clinical characteristics, MDCT, and TEE measures for prediction of moderate or severe PAR. Analyses were performed using SAS (version 9.1.3, SAS Institute, Cary, North Carolina).

Results

Clinical characteristics are described in Table 1 and procedure characteristics in Table 2. The mean MDCT mean annular diameter was greater than the mean TEE annular diameter (23.9 ± 2.4 mm vs. 22.5 ± 1.9 mm, $p < 0.001$). Other mean MDCT systolic annular measurements include: short diameter: 21.1 ± 2.4 cm, long diameter: 26.8 ± 3.0 cm, eccentricity: 21.2 ± 7.1%, area: 4.7 ± 0.9 cm^2, and circumference: 79.6 ± 9.3 cm^2. The THV size was on average 2.2 ± 1.2 mm greater than the TEE diameter, 0.6 ± 1.9 mm greater than the MDCT mean annular diameter, 4.0 ± 16.6% greater than the MDCT annular area, and 1.0 ± 8.6% less than the MDCT annular circumference. Interobserver reliability of MDCT annular measurements as measured by the intraclass correlation coefficient are: mean annular diameter: 0.84 (IQR: 0.78 to 0.90), area: 0.81 (IQR: 0.60 to 0.90), long diameter: 0.78 (IQR: 0.68 to 0.85), circumference: 0.77 (IQR: 0.65 to 0.85), and short diameter: 0.70 (IQR: 0.49 to 0.82).

Prediction of PAR. Table 3 and Figure 3 show the receiver-operating characteristic curve analysis for MDCT, TEE, and demographic variables. Annular eccentricity, age, and sex were not predictive of PAR. The difference between THV diameter and TEE diameter provided moderate prediction of PAR (area under the curve: 0.70, 95% confidence interval [CI]: 0.51 to 0.88), whereas the relationship between THV size and 3-dimensional MDCT annular size (using diameter, area, and circumference measures) had moderate to good predictive value. These findings were consistent across all 3 MDCT readers.

The impact of THV undersizing on PAR. Undersizing of a THV relative to the MDCT mean annular diameter (THV diameter < mean annular diameter) was present in 35.3% (36 of 102) of patients and in 45.1% (46 of 102) of patients by MDCT area (THV area < MDCT annular area). Moderate or severe PAR was associated with under-

Table 2 Procedural Characteristics (N = 102)

Valve type	
Sapien	10 (9.2%)
Sapien XT	92 (90.8%)
Valve diameter size, mm	
20	2 (2.0%)
23	46 (45.1%)
26	50 (49.0%)
29	4 (3.9%)
Access route	
Femoral	70 (68.6%)
Apical	32 (31.4%)
Mean aortic valve area after TAVR, cm^2	1.49 ± 0.27
Mean transaortic gradient after TAVR, mm Hg	11.0 ± 4.2
Aortic regurgitation	
Paravalvular	
None/trivial	47 (46.1%)
Mild	42 (41.2%)
Moderate	12 (11.8%)
Severe	1 (1.0%)
Transvalvular	
None/trivial	99 (97.0%)
Mild	2 (2.0%)
Moderate	0 (0%)
Severe	1 (1.0%)
Annular rupture	0 (0%)
Device embolization	0 (0%)
Procedural mortality	0 (0%)
30-day mortality	5 (4.9%)

Values are n (%) or mean ± SD.
TAVR = transcatheter aortic valve replacement.

Table 3 Area Under the Receiver-Operator Curve for the Prediction of Moderate or Severe PAR After TAVR

	MDCT Reader 1 (N = 102)		MDCT Reader 2 (n = 70)		MDCT Reader 3 (n = 70)	
	AUC	95% CI	AUC	95% CI	AUC	95% CI
THV diameter – mean diameter	0.81	0.68–0.88	0.85	0.72–0.96	0.84	0.63–0.97
THV area/annular area	0.80	0.65–0.90	0.79	0.58–0.94	0.86	0.70–0.97
THV circumference/annular circumference	0.76	0.59–0.91	0.76	0.54–0.96	0.86	0.73–0.97
THV diameter – TEE annulus diameter	0.70	0.51–0.88	NA		NA	
Female	0.62	0.50–0.77	NA		NA	
Age, yrs	0.59	0.50–0.72	NA		NA	
Annular eccentricity	0.58	0.46–0.75	0.61	0.49–0.81	0.57	0.49–0.73

AUC = area under the curve; CI = confidence interval; MDCT = multidetector computed tomography; NA = not applicable; PAR = paravalvular aortic regurgitation; TAVR = transcatheter aortic valve replacement; TEE = transesophageal echocardiography; THV = transcatheter heart valve(s).

sizing of the THV relative to the mean annular diameter and annular area by MDCT, whereas none or trivial PAR is associated with oversizing of the THV (Table 4, Fig. 4). Clinical, procedural, and echocardiographic characteristics for undersized versus oversized THV by MDCT area are displayed in Table 5.

We then dichotomized the difference between THV size and annular area and THV size and mean annular diameter at potentially clinically meaningful values. For patients with a THV diameter − mean annulus diameter <1 mm (56 of 102, 54.9%), the incidence of moderate or severe PAR was 21.4% versus 2.2% (odds ratio [OR]: 9.4, 95% CI: 2.15 to 88.8, $p < 0.01$) when the THV diameter − mean annular diameter ≥1 mm (46 of 102, 46.1%). For patients with a THV nominal area <10% greater than the annular area (68 of 102, 66.7%), the incidence of moderate or severe PAR was 19.1% versus 0% (OR: 18.4, 95% CI: 2.3 to >100, $p < 0.01$) for THVs with a nominal area >10% above the annular area (34 of 102, 33.3%).

The impact of annular eccentricity and THV oversizing on THV geometry. Fifty patients underwent post-TAVR MDCT (Fig. 5). THV circularity was present in 98% (49 of 50) and mean THV expansion of was 104.0 ± 5.6%. Eccentricity at the annular level was reduced following TAVR (21.5 ± 7.3% vs. 2.1 ± 1.7%, $p < 0.001$). Thirty-one (62%) patients received a THV that was oversized relative to the MDCT annular area (THV area > MDCT annular area). THV oversizing by area did not affect THV eccentricity (oversized vs. undersized: 1.7% [IQR: 1.4 to 3.0] vs. 1.7% [IQR: 1.1 to 2.7], $p = 0.28$). Oversized THVs had marginally less expansion than undersized THVs; however, on average, remained fully expanded (102.7 ± 5.3% vs. 106.1 ± 5.6%, $p = 0.03$). The 2 patients with the largest percentage of THV oversizing (THV area was 59.8% and 47.8% greater than the annular area) had the lowest THV expansion at 90.3% and 91.7%, respectively. Despite THV underexpansion, hemodynamics were satisfactory. (Case 1: aortic valve area 1.3 cm^2, mean gradient 9 mm Hg in a 23-mm valve; Case 2: aortic valve area 1.8 cm^2 and mean gradient 15 mm Hg in a 26-mm valve).

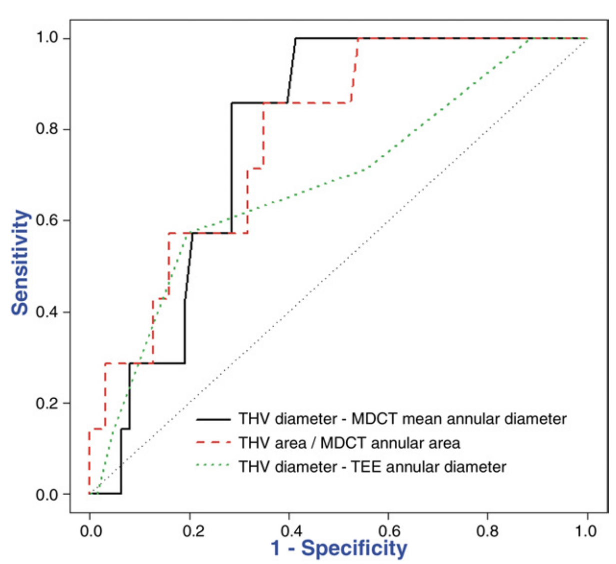

Figure 3 Area Under the Receiver-Operating Characteristic Curves for Prediction of PAR

MDCT mean diameter (0.81, 95% confidence interval [CI]: 0.68 to 0.88), MDCT area (0.80, 95% CI: 0.65 to 0.90), and transesophageal echocardiography (TEE) diameter (0.70, 95% CI: 0.51 to 0.88). PAR = paravalvular aortic regurgitation; other abbreviations as in Figures 1 and 2.

Table 4 The Relationship Between Undersizing a THV Relative to the MDCT Annular Size and Increasing Grade of PAR

Grade of PAR	THV Diameter – Mean Annular Diameter (mm)	Percentage Difference Between the THV Area and Annular Area*
None/trivial	1.5 ± 1.8	14.2 ± 18.3
Mild	0.4 ± 1.8	4.3 ± 14.2
Moderate/severe	−0.7 ± 1.4	−7.0 ± 9.5
p value	<0.01	<0.01

Values are mean ± SD and measured in systole. *A positive percentage represents the amount that the THV area is greater than the annular area. Conversely, a negative percentage represents the amount that the THV area is less than the annular area. Calculated by (THV area/annular area − 1) × 100.

Abbreviations as in Table 3.

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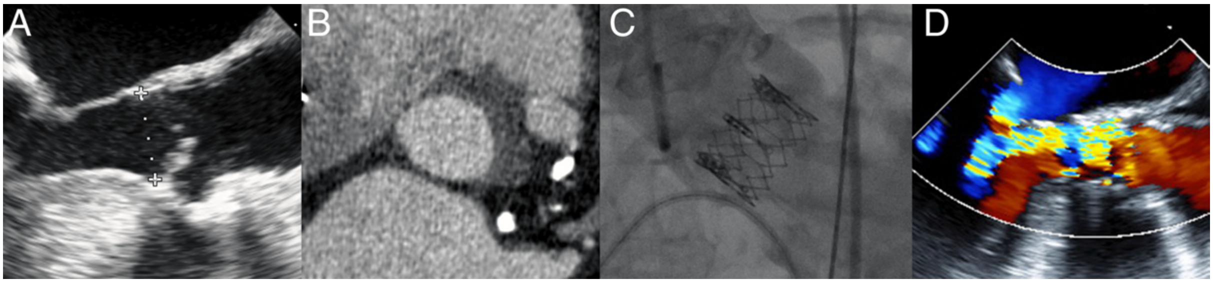

Figure 4 Case Example of THV Undersizing Causing Significant PAR

(A) A 23-mm Sapien XT (Edwards Lifesciences, Irvine, California) valve was selected based on a TEE annular diameter of 22 mm. **(B)** The MDCT mean annular diameter is 25 mm (22 × 28 mm) and area 4.90 cm^2. The THV is undersized by 2 mm relative to the mean diameter and by 15% relative to the annular area. **(C)** The THV appears undersized on aortic root angiography. **(D)** Moderate PAR on echocardiography. Abbreviations as in Figures 1, 2, and 3.

Discussion

This study demonstrates that MDCT annular measurements have good predictive value of moderate or severe PAR following TAVR. Differences between nominal THV size and MDCT mean annular diameter and area demonstrated the strongest relationship. Importantly, these findings were consistent across multiple MDCT readers from different institutions and countries using a variety of workstations, suggesting that these findings are generalizable.

Table 5 Clinical, Procedural, and Echocardiographic Characteristics of Undersized (THV Nominal Area < MDCT Area) Versus Oversized THV (THV Nominal Area > MDCT Area)

	Undersized (n = 46)	Oversized (n = 56)	p Value
Clinical characteristics			
Age, yrs	80.1 ± 9.2	82.2 ± 7.5	0.22
Sex			0.05
Female	19 (41.3%)	32 (57.1%)	
Male	27 (58.7%)	24 (42.9%)	
STS PROM	6.9 ± 3.7	6.4 ± 3.3	0.47
GFR, ml/min	53.6 ± 22.1	58.7 ± 21.2	0.25
Height, cm	167.1 ± 22.6	166.4 ± 11.0	0.86
Weight, kg	80.7 ± 24.2	74.3 ± 18.3	0.20
Procedural characteristics			
Access route			0.03
Femoral	28 (60.8%)	44 (78%)	
Apical	18 (39.1%)	12 (21.4%)	
Mean THV diameter size, mm	24.5 ± 1.98	24.8 ± 1.69	0.38
Echocardiographic characteristics			
Mean aortic valve area, cm^2	0.70 ± 0.19	0.70 ± 0.17	0.96
Mean transaortic gradient, mm Hg	43.3 ± 17.0	43.6 ± 17.2	0.92
Post-TAVR mean aortic valve area, cm^2	1.45 ± 0.26	1.55 ± 0.31	0.13
Post-TAVR mean aortic gradient, mm Hg	11.5 ± 4.7	10.8 ± 4.0	0.48
PAR			
None/trivial	13 (28.3%)	34 (60.7%)	<0.01
Mild	24 (52.2%)	18 (32.1%)	0.02
Moderate or severe	9 (19.6%)	4 (7.1%)	0.04

Values are mean ± SD or n (%).
Abbreviations as in Tables 1 and 3.

Aortic annular measurements: which to use in clinical practice? Accurate and reproducible measurements of the aortic annulus are crucial for optimum sizing of THVs. It is well established that the aortic annulus is a noncircular structure (8–10), and, in our cohort, the mean difference between the short and long annular diameters was 5.7 mm (21%). Two-dimensional TEE annular diameters are on average 1.4 mm less than the mean annular diameter on MDCT. We do not intend to suggest that MDCT is superior to TEE but rather that MDCT with 3-dimensional measures can provide complementary and additive information in the assessment of patients undergoing TAVR. However, we do believe that the 2-dimensional TEE annular diameter may underestimate the "true" annular size. MDCT with its isotropic voxels and multiplanar reformat capabilities offers the ability to routinely reconstruct the annulus in its true plane with double oblique transverse projections. With this reconstruction, there are multiple annular measurements that can be taken including mean diameter, area, and circumference. An area-derived diameter, circumference-derived diameter, and annular eccentricity index can also be calculated. This extensive information has the potential to create confusion. The present data establish that the 2 most reproducible and predictive MDCT annular measurements of PAR are mean diameter and area.

Our data suggest that in order to minimize the risk of significant PAR, the implanted THV size should be greater than the 3-dimensional annular size by MDCT. THVs that were oversized relative to the MDCT mean annular diameter by at least 1 mm and annular area by at least 10% had a significantly reduced risk of moderate or severe PAR. However, THV oversizing may come at a cost, with a potential greater risk of coronary occlusion or annular rupture, and future studies are warranted to assess the safety and feasibility before intentional oversizing should be performed.

When considering what THV size to implant, it is worth considering the increase in THV area when going from the smaller to larger THV (Fig. 6). Upsizing from a 23-mm to

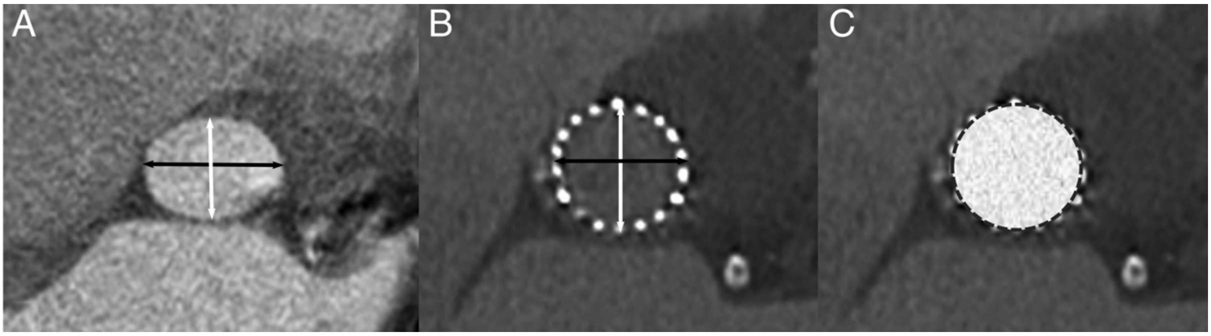

Figure 5 **The Effect of Aortic Annular Eccentricity and THV Oversizing on THV Expansion and Eccentricity as Demonstrated by Matched Pre- and Post-TAVR MDCT in an Individual Patient**

(A) At baseline, the aortic annulus is eccentric (29%) with a mean diameter of 20.5 mm (17.0 mm × 24.1 mm) and area of 3.45cm^2. **(B)** Following implantation of a 23-mm THV, MDCT shows a circular implant (23.2 mm × 23.5 mm, eccentricity 1.3%). **(C)** Despite the THV being oversized relative to the annular area by 20%, the THV is fully expanded with an expansion ratio of 103.6% (THV area = 4.30 cm^2). TAVR = transcatheter aortic valve replacement; other abbreviations as in Figures 1 and 2.

a 26-mm balloon expandable THV is associated with an exponential 28% increase in external valve area. In the future, as sizing of THVs becomes more meticulous through 3-dimensional measurements, it seems likely that a greater range of THV sizes will become available.

Post-implant THV geometry and the impact of oversizing and annular eccentricity on THV expansion and eccentricity. Balloon expandable THVs have excellent rates of circularity and complete expansion. Modest oversizing of a THV relative to the annular area did not affect THV expansion, whereas extreme oversizing (i.e., THV area 50% greater than annular area) did result in underexpansion of the THV. The clinical importance of this is unknown. The low eccentricity of the THV despite annular eccentricity suggests the aortic annulus is somewhat compliant and conformable to the THV. This may explain why annular eccentricity was not predictive of PAR.

Study limitations. Despite a large cohort, the prevalence of significant PAR in this study was relatively low. Aortic annular calcification was not measured by MDCT. Severe calcification may have an impact on PAR severity, annular measurement, and THV geometry. There were no cases of aortic root rupture following TAVR, so risk of this through oversizing of a THV could not be assessed. MDCT accuracy in assessing the annulus may be affected by motion artifact, which may reduce accuracy of measurements. In addition, when dose modulation is used, image quality may be reduced. Nevertheless, in this study where patients were not rate controlled before MDCT, and in whom dose modulation was used, we observed high inter-reader correlation. Finally, the current study did not assess the utility of 3-dimensional TEE measurements, which, in principle, may provide similar measurements to 3-dimensional MDCT.

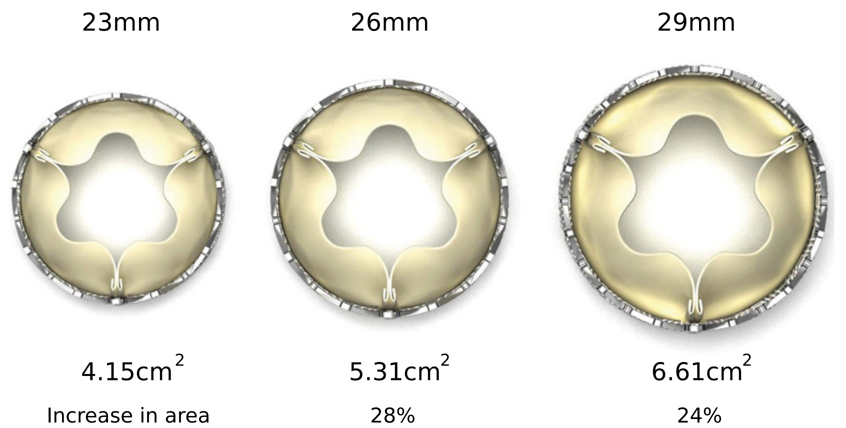

Figure 6 **Area as a Measure of Balloon Expandable THV Size**

Nominal external valve area can be used for sizing of balloon expandable THVs. A THV is defined as oversized when the external valve area is greater than the MDCT annular area. Nominal THV area increases by 28% from a 23- to 26-mm THV and by 24% from a 26- to 29-mm THV. Abbreviations as in Figures 1 and 2.

Conclusions

MDCT annular measurements are reproducible and strongly predictive of significant PAR. THVs that are oversized relative to the MDCT mean annular diameter by at least 1 mm and annular area by at least 10% have a significantly reduced risk of moderate or severe PAR. Modest THV oversizing relative to MDCT annular area was not associated with THV eccentricity or underexpansion. Future studies assessing whether intentional oversizing by MDCT criteria reduces PAR without an increased risk of complications is warranted.

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Reprint requests and correspondence: Dr. Jonathon Leipsic, St. Paul's Hospital, 1081 Burrard Street, Vancouver, British Columbia V6Z 1Y6, Canada. E-mail: JLeipsic@providencehealth.bc.ca.

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