Multimodality imaging to guide cardiac interventional procedures

Tops, L.F.

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Role of multislice computed tomography in transcatheter aortic valve replacement

David A. Wood[1]
Laurens F. Tops[2]
John R. Mayo[3]
Sanjeevan Pasupati[1]
Martin J. Schalij[2]
Karin Humphries[1]
May Lee[1]
Abdullah Al Ali[1]
Brad Munt[1]
Rob Moss[1]
Christopher R. Thompson[1]
Jeroen J. Bax[2]
John G. Webb[1]

[1]Division of Cardiology, St. Paul's Hospital, University of British Columbia, Vancouver, Canada
[2]Department of Cardiology, Leiden University Medical Center, Leiden, the Netherlands
[3]Department of Radiology, Vancouver General Hospital, University of British Columbia, Vancouver, Canada

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ABSTRACT

Transcatheter aortic valve replacement (TAVR) requires precise knowledge of the anatomic dimensions and physical characteristics of the aortic valve, annulus and aortic root. Most groups currently utilize angiography, transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE) to assess aortic annulus dimensions and anatomy. However, multislice computed tomography (MSCT) may allow more detailed 3-dimensional assessment of the aortic root. Twenty-six patients referred for TAVR underwent MSCT. Scans were also performed in 18 patients following TAVR. All patients underwent pre- and post-procedural aortic root angiograms, TTE and TEE. Mean differences in measured aortic annular diameters were 1.1 mm (95% CI 0.5, 1.8 mm) for calibrated angiography and TTE, 0.9 mm (95% CI -1.7, -0.1 mm) for TTE and TEE, 0.3 mm (95% CI -1.1, 0.6 mm) for MSCT (sagittal) and TTE, 1.2 mm (95% CI -2.2, -0.2 mm) for MSCT (sagittal) and TEE. The coronal systolic measurements on MSCT, which correspond to the angiographic orientation, were 3.2 mm (1^{st} and 3^{rd} quartiles 2.6, 3.9) larger than the sagittal systolic measurements, which are in the same anatomic plane as standard TTE and TEE views. There was no significant association between either the shape of the aortic annulus or the amount of AV calcium and the development of perivalvular aortic regurgitation. Following TAVR the prosthesis extended to or beyond the inferior border of the left main ostium in 9 of 18 patients (50%) and in 11 patients (61%) valvular calcium was <5mm from the left main ostium. In conclusion, MSCT identified that the aortic annulus is commonly eccentric and often oval. This may, in part, explain the small but clinically insignificant differences in measured aortic annular diameters with other imaging modalities. MSCT following TAVR demonstrated the close proximity of both the prosthesis and displaced valvular calcium to the left main ostium in most patients. Neither eccentricity nor calcific deposits appeared to contribute significantly to the severity of paravalvular regurgitation following TAVR.

INTRODUCTION

Transcatheter aortic valve replacement (TAVR) shows promise as an alternative to conventional open heart surgery for selected patients with severe symptomatic aortic stenosis (AS) (1-7). Transthoracic echocardiography (TTE), transesophageal echocardiography (TEE) and calibrated aortic angiography are commonly used to determine aortic annular size to assist in prosthesis selection (8). Recent work with multislice computed tomography (MSCT) provided detailed information on the shape of the aortic annulus and the relation between the annulus and the ostia of the coronary arteries (9). MSCT identified that the aortic annulus is oval, rather than circular, which might help explain the differences in measured aortic annular diameters with TTE, TEE, and calibrated angiography. We sought to determine if MSCT could provide clinically useful information beyond that available from angiographic and echocardiographic assessment that might influence patient selection and procedural issues during TAVR.

METHODS

Patients with severe symptomatic AS were referred to St. Paul's Hospital, University of British Columbia, Vancouver, Canada for TAVR due to a high risk of morbidity or mortality with conventional valve surgery. As part of their assessment 26 patients underwent screening MSCT in Vancouver between June 2005 and January 2007. These patients represent the study population. It was the consensus of a group of senior cardiac surgeons and cardiologists that the patients were unsuitable for conventional AVR due to excessive surgical risk. Of the initial 26 patients screened with MSCT, 23 subsequently underwent TAVR, 2 were determined not to be candidates for TAVR for technical reasons, and 1 patient was subsequently accepted for conventional surgery (Table 1). Of the 23 patients who underwent TAVR, 18 subsequently underwent evaluation with MSCT at a median of 4 (1^{st} and 3^{rd} quartiles 3, 6) months after TAVR. During this period an additional 52 patients underwent TAVR but did not undergo MSCT assessment due to renal dysfunction, poorly controlled arrhythmias or logistical issues.

All MSCT scans were obtained using a cardiac gated Siemens Sensation 64 slice scanner (Siemens Medical Solutions, Erlangen, Germany) during suspended full inspiration. An initial non contrast enhanced coronary calcium scoring scan was performed using the following specifications: 120kVp, 123 effective mAs, ECG modulation on, pitch 0.2, rotation time 164 msec, detector aperture 0.6 mm, 180 degree B25f cardiac gated reconstruction algorithm at 75% R-R, 3 mm slice thickness, 3 mm spacing. A contrast enhanced bolus timing scan was performed at the level of the carina using a scan delay of 10 seconds. Twenty ml of Isovue 370 (Bracco Diagnostics, Mississauga, Ontario) contrast media was followed by 50 ml of normal saline delivered at 5 ml per second through an 18 gauge catheter in the antecubital fossa. Time-to-peak enhancement in the ascending aorta was used to determine the scan delay for

Table 1. Summary of TTE, TEE, MSCT and angiographic annular measurements

Age	MSCT Sagittal Diastole (mm)	MSCT Sagittal Systole (mm)	MSCT Corornal Diastole (mm)	MSCT Coronal Systole (mm)	Angiography (mm)	TTE (mm)	TEE (mm)	AVA (cm2)	MPG (mmHg)	EF (%)	MSCT post TAVR (mo follow-up)	Stent (mm)	MSCT Mid-stent Sagittal Systole (mm)	MSCT Mid-stent Coronal Systole (mm)
63	26	-	29	-	26	24	24	1.0	20	60	Died (before TAVR)	-	-	-
66	24	-	28	-	26	23	23	0.7	50	65	12	26	20	21
70	21	21	26	25	22	20	21	0.3	65	40	9	23	20	22
74	21	22	23	24	21	21	25	0.7	54	65	3	26	20	19
74	23	23	27	26	25	23	-	0.9	47	65	Accepted for surgery	-	-	-
77	20	-	20	-	23	22	21	0.6	43	65	3	26	20	21
77	24	24	30	29	25	24	28	0.6	40	20	8	26	23	23
79	20	24	30	27	27	26	25	0.7	37	50	6	26	24	25
80	23	-	27	-	26	22	-	0.8	41	65	Died	26	-	-
81	22	22	29	27	24	24	25	0.6	22	10	4	26	22	24
83	24	24	27	27	23	22	23	0.5	88	65	4	26	21	25
84	18	20	24	26	21	23	24	0.7	29	55	Declined follow-up	26	-	-
85	21	22	26	25	24	23	-	0.7	57	60	Declined procedure	-	-	-
85	23	23	25	25	23	21	-	0.5	74	65	Metastatic Cancer	-	-	-
86	23	25	26	27	23	24	24	0.5	42	55	4	26	21	24
86	19	22	24	25	25	23	23	0.7	64	65	3	26	20	25
87	23	23	27	27	25	24	21	0.3	46	45	3	23	23	24
88	18	20	24	23	22	21	21	0.6	41	65	6	23	19	20
89	21	22	25	26	25	24	24	0.6	55	60	Died	26	-	-
89	20	23	25	26	25	22	24	0.6	35	35	6	26	22	24
89	24	22	26	25	20	20	24	0.5	54	50	4	26	20	23
89	22	23	24	25	26	23	25	0.7	40	60	2	26	22	24
92	21	22	23	23	21	22	21	0.6	74	60	2	23	20	19
93	19	-	22	-	22	19	23	0.5	62	65	13	23	19	20
93	19	-	23	-	21	20	22	0.5	32	65	12	23	21	20
95	21	-	23	-	22	22	22	0.6	53	70	Died (before TAVR)	-	-	-

AVA = aortic valve area; EF = ejection fraction; MPG = mean pressure gradient (transaortic).

the subsequent diagnostic cardiac CT scan. This scan of the entire heart was acquired during the injection of 100 ml of 370 Isovue contrast media followed by 50 ml of normal saline at 5 ml per second. The scan acquisition used the following parameters: 120 kVp, 830-870 effective mAs, EKG modulation off, pitch 0.2, rotation time 330 msec, detector aperture 0.6 mm. Image reconstruction parameters included: 180 degree cardiac gated B30f reconstruction algorithm, 165 msec temporal resolution, timed to 30% and 70% of the R-R interval, 0.75 mm slice thickness, 0.4 mm spacing.

Non-contrast and contrast-enhanced images were transferred over the hospital's imaging network to the Multi Modality Workplace workstation (Version VE22A, Siemens Medical Solutions, Erlangen, Germany). Agatston method (10) aortic valve calcium scoring was performed using the Calcium Scoring software package (Syngo 2007C VE27B, Siemens Medical Solutions, Erlangen, Germany). Aortic valve measurements were made using electronic calipers within the Circulation software package (Syngo 2007C VE27B, Siemens Medical Solutions, Erlangen, Germany). Pre-implantation images were evaluated using window width of 1000 Hounsfield units (HU) and level of 150 HU. Due to artifact arising from the struts of the aortic valve prosthesis, post implantation images were evaluated using window width of 2500 HU and level of 1000 HU.

Images were analyzed using the workstation by consensus of two observers. The largest transverse diameter of the aortic annulus was measured in coronal and single oblique sagittal projections using the 30% (systole, or R-R with maximum leaflet excursion) and 70% (diastole) images. These proved to be the longest and shortest annular measurements in all patients. The correct orientation of these two orthogonal images was confirmed by inspection of the double oblique transverse (DOT) images of the aortic valve, which allowed confirmation of the level of insertion of the aortic valve leaflets (Figure 1). The single oblique sagittal view has the same orientation as both the parasternal long axis view on TTE and the midesophageal long axis view on TEE (11) (Figure 2). The coronal view has the same orientation as the anterior posterior view on aortic root angiography (Figure 3). The coronal view in diastole was used to measure the diameter of the sinus of Valsalva, the distance from the annulus to the inferior border of the left main coronary artery, and the length of the left coronary cusp leaflet (9). The coronal view in systole was used to measure the above leaflet length as well as the distance from the leaflet tip to the inferior border of the left main coronary artery (Figure 4). The DOT view was used to measure the maximum diameter of the sinus of Valsalva at the level of the inferior border of the left main coronary artery.

We subjectively graded the AV calcium using the scoring system of Willmann et al (12), which was adapted from Rosenhek et al. (13). Agatston method (10) calcium scores were obtained from the aortic valve leaflets using the Calcium Scoring program on the Siemens workstation from the non contrast enhanced images. Areas of AV calcium were highlighted and surrounding areas of calcium were excluded to generate a composite score for each valve.

MSCT scans performed post TAVR were analyzed using the same orthogonal viewing planes. Stent diameter was measured in systole in the single oblique sagittal and coronal planes at the

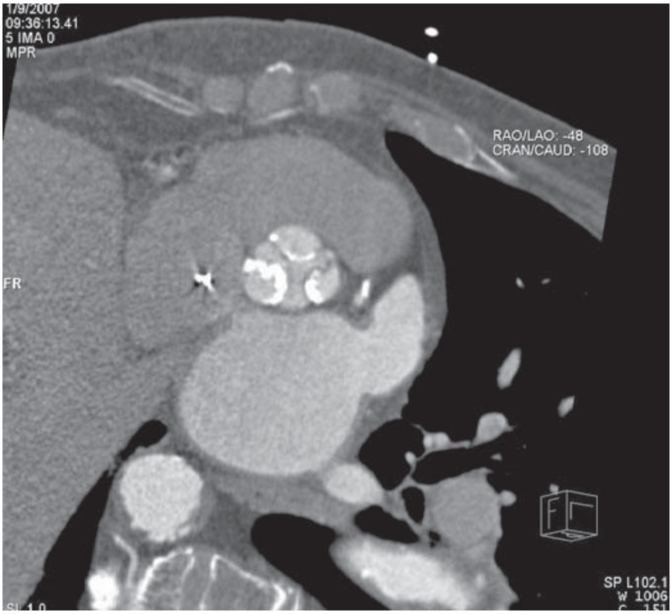

Figure 1. Double oblique transverse (DOT) view is used to derive the other standard orthogonal planes (single oblique sagittal and coronal projections). It is critical that the DOT view is parallel to the true valve plane. Calcium appears white in this projection.

level of the aortic annulus (Figure 5). The coronal view was used to measure the distance from the inferior border of the left main coronary artery to both the native valve calcification and the stent wall (Figure 6A). The distance from the superior edge of the stent to the inferior edge of the left main coronary artery was measured on an oblique coronal image that was rotated to pass through the origin of the left main artery and the centre of the stent (Figure 6A).

Standard 2 dimensional TTE was performed as part of our screening assessment. Images were obtained with patients in the left lateral decubitus position with a commercially available system (Sonos 5500, Philips Medical Systems) interfaced with an S3 compound probe and stored on a digital archive system. The diameter of the aortic annulus was measured by an independent viewer in systole in the parasternal long axis view at the site of leaflet attachment (Figure 2B).

TEE was performed immediately before and after TAVR. Images were obtained with patients intubated and sedated in the supine position with the same system interfaced with a T6210 omniplane probe. The diameter of the aortic annulus was measured by an independent viewer in systole in the midesophageal long axis view at the site of leaflet attachment (Figure 2C). Aortic regurgitation (AR) severity immediately post implantation and at hospital discharge was the consensus grade of two senior echocardiographers using the ratio of regurgitation jet to left ventricular outflow tract height and regurgitation pressure half-time determination (8,14,15). The site of AR was judged to be either valvular (through the valve) or perivalvular (around the valve).

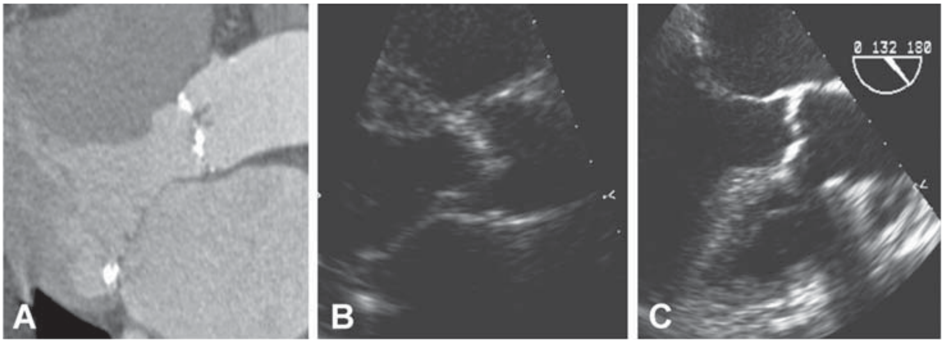

Figure 2. The (A) single oblique sagittal view on MSCT is equivalent to the (B) parasternal long axis-view on TTE and the (C) midesophageal long-axis view on TEE. The aortic annular measurements for this patient were 23, 23, and 24 mm respectively.

Calibrated angiographic annular measurements were performed by two independent viewers as part of the screening assessment. The diameter at the leaflet hinge point at the presumed level of the aortic annulus was measured in systole in the anterior posterior view (Figure 3B).

Continuous data are presented as mean values ± standard deviation (SD) or median values with 1st and 3rd quartiles, as appropriate. Categorical data are presented as percentages. Bland-Altman plots were used to compare annular measurements obtained using different techniques (angiographic, echocardiographic and MSCT) (16). All statistical analyses were performed with SPSS TM software (version 13.0, SPSS Inc., Chicago, Illinois). All statistical tests were 2 sided. A p value of < 0.05 was considered statistically significant.

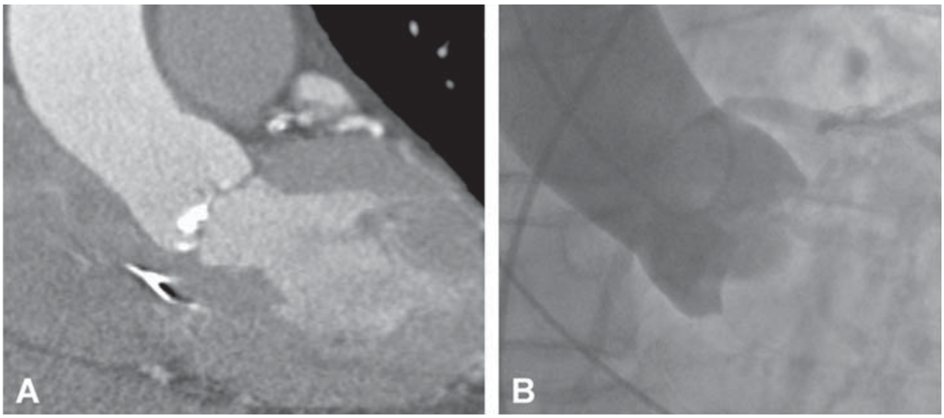

Figure 3. The (A) coronal view on MSCT has the same orientation as the (B) anterior posterior view on aortic root angiogram. Images from the same patient as Figure 2 are displayed with aortic annular measurements of 25 and 26 mm respectively.

RESULTS

Mean age of the 26 patients was 82 ± 9 years. A balloon expandable valve was implanted in 23 patients, utilizing the femoral approach in 21 and the apical approach in 2 due to the presence of femoral artery disease. Coronary artery disease was present in 83%, with 30% having

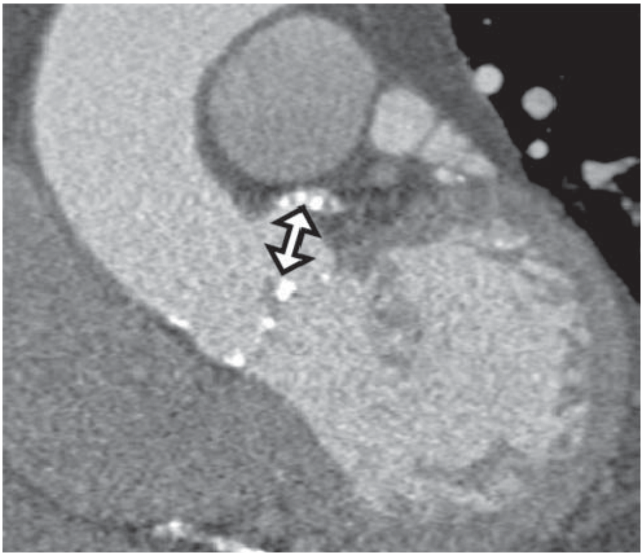

Figure 4. The coronal view in systole on MSCT was used to measure the distance from the left coronary cusp leaflet tip to the inferior border of the left main coronary artery.

undergone prior percutaneous intervention and 39% having had prior coronary artery bypass graft surgery. The logistic EuroSCORE (17,18) estimate of operative mortality was 31.5 ± 19.7%.

Screening MSCT measurements were applied to our 26 patients with severe AS. The average left coronary cusp leaflet length in systole, from leaflet insertion to leaflet tip, was 14.8 ± 1.3 mm. The mean distance from the aortic annulus to the inferior border of the left main coronary artery was 15 ± 3.0 mm. The maximum diameter of the sinus of Valsalva in the DOT view was 32.5 ± 3.0 mm.

The differences in aortic annular dimensions for calibrated angiography, TTE, TEE, and MSCT are listed in Table 1 and selected Bland-Altman plots are shown in Figure 7. The mean differences in measured aortic annular diameters were 1.1 mm (95% CI 0.5, 1.8 mm) for calibrated angiography and TTE, 0.9 mm (95% CI -1.7, -0.1 mm) for TTE and TEE, 0.3 mm (95% CI -1.1, 0.6 mm) for MSCT (sagittal) and TTE, 1.2 mm (95% CI -2.2, -0.2 mm) for MSCT (sagittal) and TEE (Figure 7). In the systolic phase, the mean diameter of the aortic annulus on the coronal view was 25.7 ± 1.5 mm and 22.4 ± 1.3 mm in the sagittal view. The mean difference between the coronal and sagittal diameters was 3.2 mm (95% CI 2.6, 3.9). In the diastolic phase, the mean diameter of the aortic annulus on the coronal view was 25.5 ± 2.5 mm and 21.5 ± 2.1 mm in the sagittal view. The mean difference between the coronal and sagittal diameters was 4.0 mm (95% CI 3.1, 4.8).

Patients were considered to have an oval annulus if the difference between their coronal and sagittal annular measurements was ≥ 3 mm (9). Twenty patients (77 %) had an oval annulus. Eight patients had ≥ moderate perivalvular AR on TEE immediately post implantation. There was no significant association between the shape of the aortic annulus and the proportion of

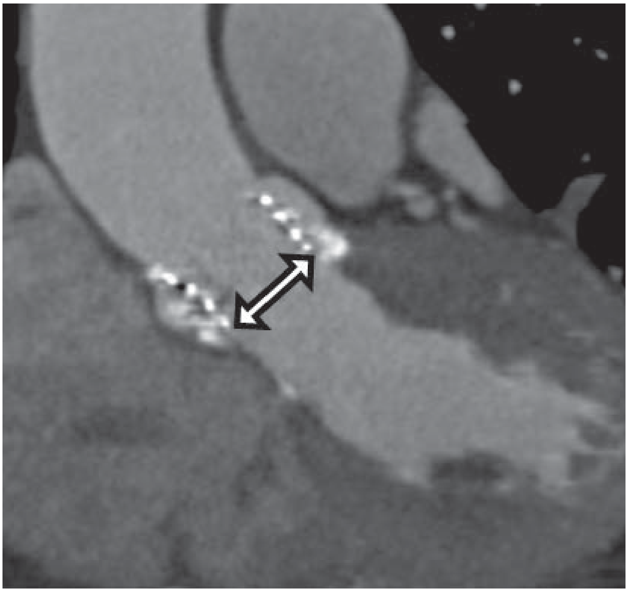

Figure 5. The coronal view in systole on MSCT was used to measure the stent diameter at the level of the aortic annulus.

patients that developed moderate perivalvular AR (Fisher's exact test, p=1.0). Seven of these patients went on to have successful re-dilation of their balloon expandable aortic valve immediately following implantation with a reduction in perivalvular leak.

Seventeen patients had grade 4, 6 grade 3, and none grade 1 or 2 AV calcific deposits. There was no significant association between the grade of calcium and the proportion of patients that developed moderate perivalvular AR (Fisher's exact test, p=0.35). AV calcium scores were also stratified above and below 3500, corresponding to subjective AV calcium scores of 3 or 4. There was no significant association between the stratified objective calcium scores and the proportion of patients that developed moderate perivalvular AR (Fisher's exact test, p=0.37).

Post TAVR the prosthesis was observed to extend above the inferior border of the left main coronary artery in 50% of patients (n=9) (Figure 6A); extending a median of 0.5 mm (1st and 3rd quartiles 0, 8) above the left main ostium. The median distance from the left main coronary artery to the displaced native valve calcium was 4 mm (1st and 3rd quartiles 3, 5). Eleven patients (61%) had displaced calcium that was <5mm from the left main ostium (Figure 6A).

The stent diameter was measured at the level of the aortic annulus (Figure 5). The implanted stent was considered circular if the difference between the coronal and sagittal annular measurements was <3 mm. By this definition, 14 patients (78%) had a circular annulus post implantation and 4 (22%) had a non-circular annulus. Of those with a non-circular annulus, 3 of the 4 patients had an oval annulus prior to TAVR.

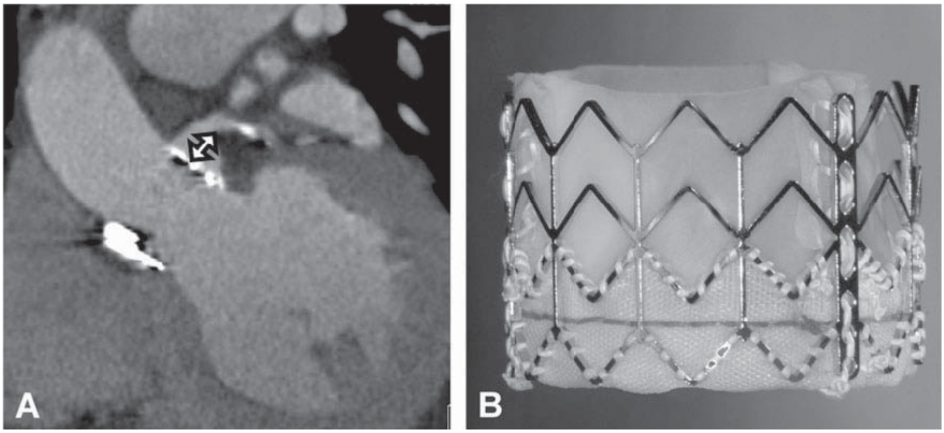

Figure 6. The (A) coronal view in systole on MSCT was used to measure the distance from the inferior border of the left main coronary artery to both the native valve calcium and the stent wall. The distance the stent was placed above or below the inferior border of the left main coronary artery was also recorded. Panel B: A digital picture of a 23 mm balloon expandable prosthesis (Cribier-EdwardsTM , Edwards Lifesciences Inc., Irvine, CA) demonstrates the fabric cuff that covers the bottom third of the stent.

DISCUSSION

Anderson et al. first noted that the site of attachment of the three aortic valvar leaflets is not circular, as the term "annulus" implies (19). Recently, studies using both MSCT and magnetic resonance imaging have supported these observations (9,20). The word "annulus" is actually a misnomer as the aortic valvar complex consists of several small rings within the aortic root that do not all correspond to discrete anatomic structures. We have used the term "annulus" for simplicity. The mean difference between the coronal and sagittal annular diameters was 3.2 mm (95% CI 2.6, 3.9) during the systolic phase and 4.0 mm (95% CI 3.1, 4.8) during the diastolic phase and is similar to the results we obtained with a larger cohort (169 patients) with and without AS (9). There was no significant difference between the systolic and diastolic measurements in either study. An oval aortic annulus helps explain the differences in annular measurements seen with imaging modalities that are restricted to a single plane or a limited field of view (Table 1). The current practice of routinely oversizing the prosthesis by 10 to 20% makes the small

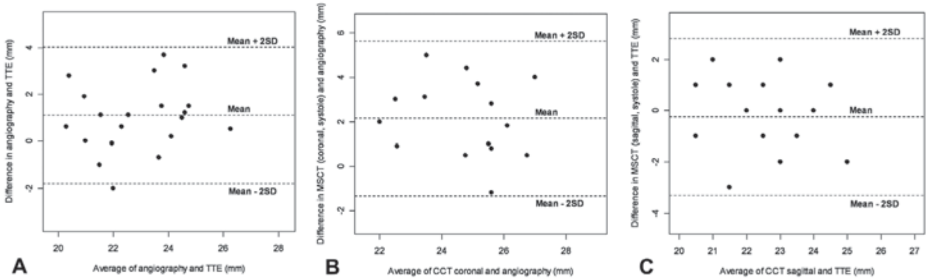

Figure 7. Bland-Altman plots comparing (A) annular measurements using angiography and TTE, (B) the coronal view obtained in systole on MSCT and angiography, and (C) the sagittal view obtained in systole on MSCT and TTE.

differences in measured aortic annular diameters with TTE, TEE, and calibrated angiography clinically insignificant. An oval annulus also has important implications for echocardiography as the parasternal short axis view assumes a circular annulus as a point of reference. Physicians should be aware of this potential limitation.

There was no significant association between the shape of the aortic annulus and the proportion of patients that developed moderate perivalvular AR. It is possible that an association may become apparent with a larger cohort over a longer time period although this has not been observed (7). Our routine practice of oversizing the prosthesis by 10 to 20% may have also obscured any potential association (4,8).

There was no significant association between either the calcium grade or the AV calcium score and the proportion of patients that developed moderate perivalvular AR. It is possible that an association may become apparent with a larger cohort although this does not appear to be a major concern in the majority of patients. This is consistent with the clinical impression that severe native AV calcium is not a major contraindication to TAVR (3).

In one half of the current cohort (n=9) the prosthesis was observed to extend to or beyond the level of the ostium of the left main coronary artery (Figure 6A). Currently available balloon expandable transcatheter valves incorporate a sealing cuff in the portion of the prosthesis that lies within the annulus. The portion of the valve extending to or beyond the left main typically consists of an open mesh that does not interfere with coronary perfusion (Figure 6B). Cell size is sufficiently large to permit catheter access to the coronaries although a leaflet support strut may be problematic. However, obstruction of the left main ostium due to a displaced bulky native valve leaflet has been an infrequent occurrence (3,4). Our finding of native calcified tissue in relatively close proximity to the left main ostium argues for careful screening and surveillance.

CONCLUSIONS

MSCT prior to TAVR may be useful to assess aortic valve morphology, annular dimensions, assist in prosthesis selection and assess the potential for coronary compromise. That the annulus is commonly oval rather than circular has implications with regards to the interpretation of other imaging modalities. MSCT following TAVR may be useful to assess prosthesis positioning and adequacy of deployment.

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