Comparison of Aortic Root Anatomy and Calcification Distribution Between Asian and Caucasian Patients Who Underwent Transcatheter Aortic Valve Implantation

Sung-Han Yoon, MD[a], Yohei Ohno, MD[b,c], Motoharu Araki, MD[d], Marco Barbanti, MD[b], Mao-Shin Lin, MD[e], Jung-Min Ahn, MD[a], Dong Hyun Yang, MD, PhD[f], Young-Hak Kim, MD, PhD[a], Sebastiano Immé, MD[b], Simona Gulino, MD[b], Claudia I. Tamburino, MD[b], Carmelo Sgroi, MD[b], Duk-Woo Park, MD, PhD[a], Soo-Jin Kang, MD, PhD[a], Seung-Whan Lee, MD, PhD[a], Cheol Whan Lee, MD, PhD[a], Seong-Wook Park, MD, PhD[a], Toshiya Muramatsu, MD[d], Hsien-Li Kao, MD[e], Corrado Tamburino, MD, PhD[b,g], and Seung-Jung Park, MD, PhD[a,*]

The current transcatheter aortic valve implantation (TAVI) devices have been designed to fit Caucasian and Latin American aortic root anatomies. We evaluated the racial differences in aortic root anatomy and calcium distribution in patients with aortic stenosis who underwent TAVI. We conducted a multicenter study of 4 centers in Asia and Europe, which includes consecutive patients who underwent TAVI with preprocedural multidetector computed tomography. Quantitative assessment of aortic root dimensions, calcium volume for leaflet, and left ventricular outflow tract were retrospectively performed in a centralized core laboratory. A total of 308 patients (Asian group, n = 202; Caucasian group, n = 106) were analyzed. Compared to Caucasian group, Asian group had smaller annulus area (406.3 ± 69.8 vs 430.0 ± 76.8 mm^2; p = 0.007) and left coronary cusp diameter (30.2 ± 3.2 vs 31.1 ± 3.4 mm; p = 0.02) and lower height of left coronary artery ostia (12.0 ± 2.5 vs 13.4 ± 3.4 mm; p <0.001). Of baseline anatomic characteristics, body height showed the highest correlation with annulus area (Pearson correlation *r* = 0.64; p <0.001). Co-existence of lower height of left coronary artery ostia (<12 mm) and small diameter of left coronary cusp (<30 mm) were more frequent in Asian group compared with Caucasian group (35.6% vs 20.8%; p = 0.02). In contrast, there were no differences in calcium volumes of leaflet (367.2 ± 322.5 vs 359.1 ± 325.7 mm^3; p = 0.84) and left ventricular outflow tract (8.9 ± 23.4 vs 10.1 ± 23.8 mm^3; p = 0.66) between 2 groups. In conclusion, judicious consideration will be required to perform TAVI for short patients with lower height of left coronary artery ostia and small sinus of Valsalva. **(Am J Cardiol 2015;116:1566−1573)**

Transcatheter aortic valve implantation (TAVI) has become the treatment of choice in inoperable or high-risk patients with severe aortic stenosis.[1−3] A number of studies demonstrated the safety and efficacy of TAVI.[4−6] TAVI has been generalized worldwide, and currently, more than 100,000 patients have been treated. For successful TAVI procedure, complete understanding of aortic root anatomy is of importance. Measurement of aortic annulus size, assessment of aortic root calcification, and selection of appropriate device size reduce the risk of device embolization, aortic root rupture, coronary obstruction, and paravalvular aortic regurgitation.[7−13] Of the imaging modalities, multidetector computed tomography (MDCT) is widely used because of the capability of 3-dimensional reconstruction that enables to appreciate the aortic root anatomy with high reproducibility and predictability of paravalvular aortic regurgitation.[12,13] Although the current TAVI devices have been designed to fit Caucasian and Latin American aortic root anatomies, the racial differences in aortic root anatomy and calcification of patients selected for TAVI have been poorly understood. The aim of the present study was to evaluate these racial differences and to identify the determinants of the aortic root dimensions in patients with severe aortic stenosis who underwent TAVI with MDCT.

Methods

From October 2012 to December 2014, consecutive patients who underwent TAVI at 4 heart centers in Asia and

[a]Department of Cardiology and [f]Department of Radiology, University of Ulsan, Asan Medical Center, Seoul, Korea; [b]Department of Cardiology, Ferrarotto Hospital, University of Catania, Catania, Italy; [c]Department of Cardiology, University of Tokai School of Medicine, Isehara, Japan; [d]Department of Cardiology, Saiseikai Yokohama City Eastern Hospital, Kanagawa, Japan; [e]Department of Cardiology, National Taiwan University Hospital, Taipei, Taiwan; and [g]Excellence Through Newest Advances Foundation, Catania, Italy. Manuscript received June 17, 2015; revised manuscript received and accepted August 18, 2015.

Funding: This study was supported by a grant from the Cardiovascular Research Foundation, Seoul, Republic of Korea.

Dr. Yoon and Dr. Ahn contributed equally to this article.

See page 1572 for disclosure information.

*Corresponding author: Tel: (+82) 2-3010-4812; fax: (+82) 2-475-6898.

E-mail address: sjpark@amc.seoul.kr (S.-J. Park).

0002-9149/15/$ - see front matter
http://dx.doi.org/10.1016/j.amjcard.2015.08.021

Table 1
Baseline characteristics

Variables	All (N = 308)	Asian (N = 202)	Caucasian (N = 106)	p value
Age (year)	81.0 ± 6.1	80.8 ± 6.3	81.4 ± 5.8	0.45
Female	182 (59.1%)	118 (58.4%)	64 (60.4%)	0.74
Height (cm)	155.7 ± 9.2	153.4 ± 8.9	160.0 ± 9.2	< 0.001
Weight (kg)	60.8 ± 13.2	56.0 ± 10.4	70.1 ± 13.1	< 0.001
Body mass index (kg/m^2)	25.0 ± 4.3	23.7 ± 3.5	27.4 ± 4.7	< 0.001
Body surface area (m^2)	1.59 ± 0.19	1.53 ± 0.17	1.73 ± 0.17	< 0.001
NYHA Class III/IV	218 (70.8%)	135 (66.8%)	83 (78.3%)	0.04
Hypertension	264 (85.7%)	175 (86.6%)	89 (84.0%)	0.52
Diabetes mellitus	97 (31.5%)	62 (30.7%)	35 (33.0%)	0.68
Dyslipidemia	184 (59.7%)	126 (62.4%)	58 (54.7%)	0.19
Pulmonary disease	47 (15.3%)	27 (13.4%)	20 (18.9%)	0.21
Renal insufficiency*	159 (51.6)	124 (61.4%)	35 (33.0%)	< 0.001
Peripheral vascular disease	48 (15.6%)	38 (18.8%)	10 (9.4%)	0.03
Previous percutaneous coronary intervention	80 (26.0%)	65 (32.2%)	15 (14.2%)	0.001
Previous coronary artery bypass grafting	24 (7.8%)	14 (6.9%)	10 (9.4%)	0.44
Previous stroke	24 (7.8%)	19 (9.4%)	5 (4.7%)	0.15
Logistic EuroSCORE	20.6 ± 13.0	21.0 ± 13.6	19.4 ± 10.7	0.44
Society of Thoracic Surgeons score	5.9 ± 5.0	6.1 ± 5.2	5.1 ± 4.5	0.16

Values are expressed as N (%) or mean ± SD.
NYHA = New York Heart Association.
* Defined as estimated GFR ≤60 ml/min/1.73 m^2.

Europe (Asan Medical Center, Korea; Saiseikai Yokohama City Eastern Hospital, Japan; National Taiwan University Hospital, Taiwan; and Ferrarotto Hospital, Italy) were enrolled. Exclusion criteria were as follows: patients who did not undergo preprocedural MDCT; patients underwent TAVI for bicuspid aortic valve; patients underwent valve-in-valve TAVI for degenerated bioprostheses. Finally, 308 patients were included and compared between Asian group (patients from Asan Medical Center, Saiseikai Yokohama City Eastern Hospital, and National Taiwan University Hospital) and Caucasian group (patients from Ferrarotto Hospital).

In each center, the heart team determined TAVI eligibility on the basis of a systematic assessment with clinical condition as well as angiography, computed tomography, and echocardiography information. For the current analysis, patient data were pooled from 4 institutions, and all computed tomography Digital Imaging and Communications in Medicine data were collected and retrospectively analyzed at core laboratory in Asan Medical Center. Data collection was approved by the institutional review board at each center, and all patients provided written informed consent for analysis of their anonymized data.

All measurements of aortic root dimension were performed by SHY and DHY using 3mensio Structural Heart software (3mensio Structural Heart, version 6.0; 3mensio Medical Imaging BV, Bilthoven, The Netherlands), as previously described.[14,15] Three-dimensional MDCT annulus measurements included minimal diameter, maximal diameter, area, and perimeter. Annular eccentricity was described using the ellipticity index, defined as maximal diameter divided by minimal diameter. Aortic root measurements were performed as previously described.[16] In brief, the left ventricular outflow tract (LVOT) was defined as the plane 5 mm inferior to the annulus plane; the sinus was defined as the plane showing the largest cusp dimensions; the sinotubular junction defined as the distal end of the sinus portion; and the ascending aorta was defined as 30 mm superior to the annulus plane. All aortic root measurements were performed in midsystole. Retrieved from 20 randomly selected data files, annulus area measurements were performed by another observer to determine interobserver agreement and by the same observers subsequently to determine intraobserver agreement. All observers were blinded to previous measurements. Lower height of left coronary artery ostia was determined as <12 mm, and small sinus of Valsalva was determined as left coronary cusp diameter <30 mm according to reported study.[8]

For the assessment of calcification, calcium volume was measured using 3mensio Structural Heart software with the thresholds of 850 Hounsfield units.[17] Calcium in left, right, and noncoronary cusp was quantified separately using the "Mercedes Benz" tool for localization. For the calcium quantification, the aortic root was separated in the cranio-caudal axis along the double oblique long axis of the aortic root into the following parts: leaflet (from annulus plane to superior edge of leaflets); LVOT (from 5 mm inferior to annulus plane to annulus plane); and aortic root (from 5 mm inferior to annulus plane to superior edge of leaflets), as previously described.[11] Asymmetry was assessed using the maximum absolute difference in calcium volume between any 2 leaflets.

For the analysis of device sizing, the appropriate size was selected according to the published data for Edwards SAPIEN XT transcatheter heart valve and Medtronic CoreValve.[18−20] Briefly, device sizing for SAPIEN XT was based on a sizing algorithm with an optimal goal of modest annulus area oversizing (5% to 10%) with upper and lower limits of 1% to 20%. When >20% area oversizing was anticipated, intentional underexpansion of the device was suggested. Device sizing for Medtronic CoreValve was based on manufacture's recommendation: annulus area of 254.5 to 314.2 mm2, 314.2 to 415.5 mm2, 415.5 to 572.6 mm2, and 530.9 to 660.5 mm^2 for the 23-, 26-, 29-, and 31-mm CoreValve prosthesis.

Continuous variables are presented as mean ± standard deviation, whereas categorical variables are expressed as counts and percentages. Between-group comparisons were performed using the Pearson bivariate test and the chi-square or Fisher's exact test for categorical variables and the Student *t* test for continuous variables. Pearson correlation was used to compare the aortic root measurements and anatomic characteristics. The Kolmogorov−Smirnov test was used to compare the distribution of aortic root calcium volume. Linear regression analysis was used to estimate the annulus area. Interobserver and intraobserver agreement was evaluated by calculating intraclass

Table 2
Aortic root dimensions

Variables	All (N = 308)	Asian (N = 202)	Caucasian (N = 106)	p value
Annulus				
Area (mm^2)	414.5 ± 73.1	406.3 ± 69.8	430.0 ± 76.8	0.007
Perimeter	73.7 ± 6.4	73.0 ± 6.2	75.1 ± 6.5	0.008
Diameter maximal	26.0 ± 2.5	25.6 ± 2.4	26.7 ± 2.6	< 0.001
Diameter minimal	20.6 ± 2.1	20.5 ± 2.0	20.7 ± 2.1	0.40
Diameter mean	23.3 ± 2.1	23.1 ± 2.0	23.7 ± 2.2	0.009
Ellipticity index*	1.26 ± 0.10	1.25 ± 0.10	1.29 ± 0.10	0.001
Left ventricular outflow tract				
Area (mm^2)	393.1 ± 90.5	385.1 ± 88.3	408.4 ± 93.0	0.03
Perimeter	72.9 ± 8.1	71.8 ± 7.8	74.9 ± 8.2	0.001
Diameter maximal	26.9 ± 3.0	26.4 ± 2.8	27.6 ± 3.1	0.001
Diameter minimal	18.9 ± 2.8	18.8 ± 2.8	19.0 ± 2.7	0.60
Diameter mean	22.9 ± 2.8	22.6 ± 2.5	23.3 ± 2.6	0.02
Ellipticity index*	1.44 ± 0.19	1.42 ± 0.18	1.47 ± 0.20	0.03
Sinus of Valsalva				
Area (mm^2)	761.0 ± 162.7	753.4 ± 158.4	775.5 ± 170.4	0.26
Perimeter	100.9 ± 11.1	100.5 ± 11.1	101.5 ± 11.2	0.46
Diameter, left coronary cusp	30.5 ± 3.3	30.2 ± 3.2	31.1 ± 3.4	0.02
Diameter, right coronary cusp	29.2 ± 3.5	29.2 ± 3.1	29.4 ± 4.2	0.58
Diameter, non-coronary cusp	30.9 ± 4.1	30.7 ± 4.3	31.5 ± 3.7	0.11
Diameter mean	30.2 ± 3.2	30.0 ± 3.1	30.7 ± 3.3	0.09
Height, left coronary cusp	16.9 ± 2.7	16.3 ± 2.6	18.0 ± 2.8	< 0.001
Height, right coronary cusp	18.7 ± 2.8	18.5 ± 2.7	19.1 ± 2.9	0.046
Height, non-coronary cusp	16.5 ± 2.5	16.0 ± 2.4	17.5 ± 2.5	< 0.001
Height mean	17.4 ± 2.3	16.9 ± 2.2	18.2 ± 2.3	< 0.001
Sino-tubular junction				
Area (mm^2)	594.6 ± 142.6	581.5 ± 134.2	628.4 ± 153.4	0.006
Perimeter	86.6 ± 10.0	85.6 ± 9.3	88.6 ± 10.8	0.01
Diameter maximal	28.3 ± 3.3	27.8 ± 3.1	29.1 ± 3.6	0.002
Diameter minimal	26.8 ± 3.2	26.5 ± 3.0	27.3 ± 3.4	0.03
Diameter mean	27.5 ± 3.2	27.2 ± 3.0	28.2 ± 3.5	0.007
Ascending aorta				
Area (mm^2)	752.5 ± 154.0	753.0 ± 139.8	751.6 ± 178.5	0.94
Perimeter	97.0 ± 10.7	97.2 ± 8.9	96.6 ± 13.5	0.70
Diameter maximal	31.6 ± 3.2	31.5 ± 2.9	31.8 ± 3.6	0.43
Diameter minimal	30.3 ± 3.0	30.4 ± 2.8	30.0 ± 3.5	0.37
Diameter mean	30.9 ± 3.1	30.9 ± 2.8	30.9 ± 3.5	0.30
Coronary ostia				
Height, left coronary ostia	12.5 ± 2.9	12.0 ± 2.5	13.4 ± 3.4	< 0.001
Height, right coronary ostia	16.8 ± 3.0	16.8 ± 2.6	16.9 ± 3.6	0.82
Leaflet				
Left coronary cusp	102.8 ± 104.3	96.7 ± 103.9	115.7 ± 104.4	0.15
Right coronary cusp	104.9 ± 109.0	101.6 ± 112.2	112.0 ± 102.2	0.45
Non-coronary cusp	171.5 ± 156.2	168.8 ± 153.4	177.3 ± 162.6	0.67
Total	364.4 ± 323.1	367.2 ± 322.5	359.1 ± 325.7	0.84
Asymmetry	124.2 ± 109.1	127.7 ± 106.4	117.5 ± 114.3	0.44
Left ventricular outflow tract				
Left coronary cusp	5.0 ± 17.1	4.1 ± 15.6	7.1 ± 20.0	0.16
Right coronary cusp	1.6 ± 8.1	1.6 ± 8.1	1.6 ± 8.3	0.95
Posterior-coronary cusp	3.0 ± 13.3	3.1 ± 14.3	2.7 ± 11.0	0.81
Total	9.3 ± 23.5	8.9 ± 23.4	10.1 ± 23.8	0.66
Asymmetry	8.4 ± 21.4	8.0 ± 21.3	9.1 ± 21.6	0.65
Aortic root				
Left coronary cusp	107.8 ± 109.9	100.8 ± 108.5	122.8 ± 111.9	0.11
Right coronary cusp	106.5 ± 113.3	103.3 ± 116.5	113.5 ± 106.4	0.47
Posterior-coronary cusp	174.5 ± 158.3	172.0 ± 156.3	180.0 ± 163.3	0.68
Total	388.9 ± 331.4	376.1 ± 332.3	416.4 ± 329.6	0.33
Asymmetry	131.5 ± 110.0	130.2 ± 109.2	134.4 ± 112.3	0.76

Values are expressed as mean ± SD.
Values are millimeters, unless otherwise indicated.
* Defined as Maximum diameter/Minimal diameter.

Table 3
Correlation between anatomical characteristics and annulus size

	Annulus area		Annulus perimeter		Annulus mean diameter	
	Pearson r correlation	p value	Person r correlation	p value	Pearson r correlation	p value
Weight	0.35	< 0.001	0.35	< 0.001	0.36	< 0.001
Height	0.64	< 0.001	0.64	< 0.001	0.65	< 0.001
Body mass index	0.03	0.65	0.02	0.70	0.03	0.64
Body surface area	0.47	< 0.001	0.47	< 0.001	0.48	< 0.001

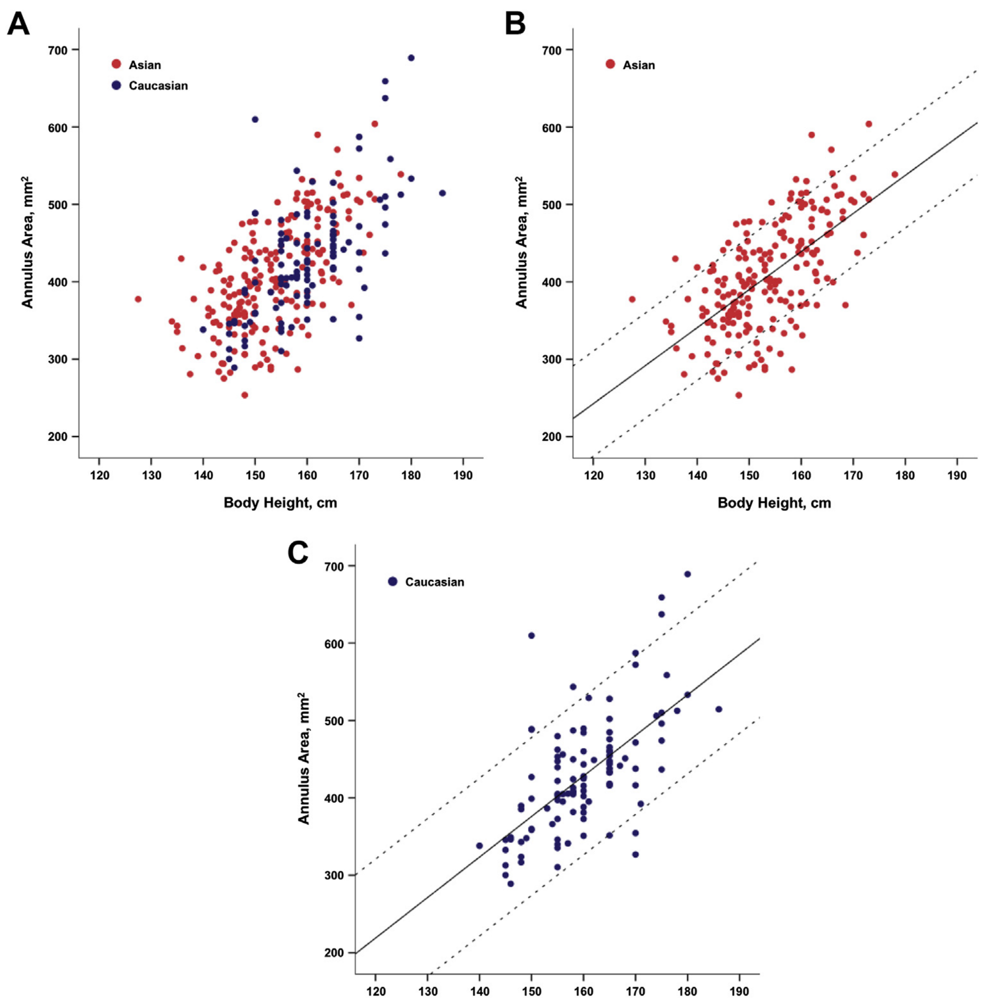

Figure 1. Correlation of aortic root dimensions and body height. Correlations between body height and the annulus area for overall *(A)*, Asian *(B)*, and Caucasian *(C)* are shown. *Fitted lines* present the predicted values from the linear regression, and *dotted lines* present the predicted values ± standard deviation.

correlation coefficients. All p values reported are 2-sided, and p values <0.05 were considered significant. All data were analyzed using the Statistical Package for the Social Science (SPSS) software version 20 (SPSS Inc., Chicago, Illinois).

Results

A total of 308 patients with mean age of 81.0 ± 6.1 years and 182 women (59.1%) were included in this study. Compared to Caucasian group, Asian group was smaller in height, weight, body mass index, and body surface area (Table 1). Renal insufficiency, peripheral vascular disease, and previous percutaneous coronary intervention were more frequent, and NYHA classes III or IV was less common in Asian group compared with Caucasian group.

Overall and race-specific dimensions of the aortic root are provided in Table 2. We demonstrated satisfactory interobserver and intraobserver reproducibility for aortic root measurement (interobserver intraclass correlation coefficients = 0.97 and intraobserver intraclass correlation coefficients = 0.98). Compared to Caucasian group, annulus

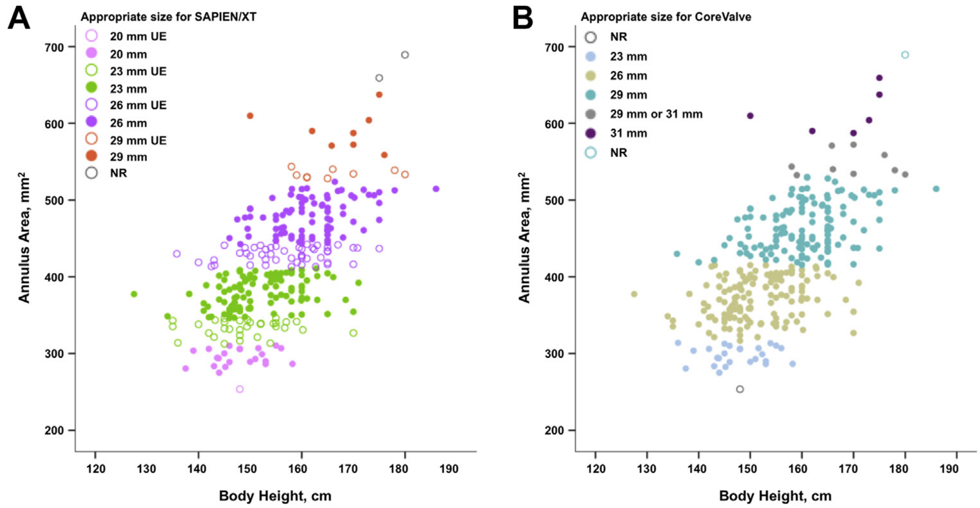

Figure 2. Association of body height and annulus size or appropriate device size. The appropriate device size was associated with body height for Edwards SAPIEN or SAPIEN XT *(A)* and Medtronic CoreValve *(B)*. NR = not recommended; UE = underexpansion.

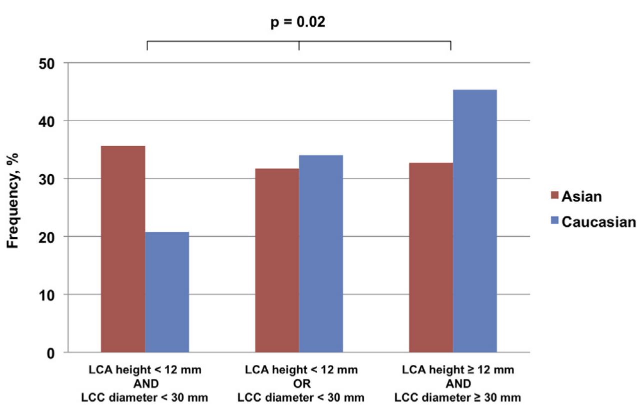

Figure 3. Comparison of left coronary artery (LCA) height and left coronary cusp (LCC) diameter. Comparison of frequency of lower height of LCA ostia and small LCC between Asian and Caucasian. Lower height of LCA ostia was determined by height of LCA ostia <12 mm and small LCC was determined by LCC diameter < 30 mm.

area, perimeter, and maximal and mean diameter were smaller in Asian group. Similarly, LVOT area, perimeter, and maximal and mean diameter were smaller in Asian group than in Caucasian group. In terms of other parts of aortic root, diameter of left coronary cusp, height of all 3 cusps, and sinotubular junction dimension (area, perimeter, and maximal/minimal/mean diameter) were smaller in Asian group than in Caucasian group, but the ascending aorta dimensions were similar between 2 groups. With respect to height of coronary ostium, height of left coronary artery ostia was shorter in Asian group than in Caucasian group (12.0 ± 2.5 vs 13.4 ± 3.4 mm; $p < 0.001$), but there were no differences in right coronary artery ostia between 2 groups (16.8 ± 2.6 mm vs 16.9 ± 3.6 mm; $p = 0.82$).

Among the baseline anatomic characteristics including weight, height, body mass index, and body surface area, height showed the highest linear association with aortic annulus dimensions (annulus area, Pearson correlation $r = 0.64$; $p < 0.001$; annulus perimeter, Pearson correlation $r = 0.64$; $p < 0.001$; annulus mean diameter, Pearson correlation $r = 0.65$; $p < 0.001$; Table 3 and Figure 1). On linear regression analysis, annulus area was estimated as following formulas: (annulus area for Asian) = 4.93 × (height) − 350 ± 66 mm^2; (annulus area for Caucasian) = 5.24 × (height) − 410 ± 102 mm^2 (Figure 1). Regardless of the type of devices, the appropriate device size showed continuous distribution pattern, with association with body height (Figure 2).

The number of patients with lower height of left coronary artery ostia (<12 mm) was 146 (47.4%) in overall, 107 (53.0%) in Asian group, and 39 (36.8%) in Caucasian group ($p = 0.007$). Similarly, the number of patients with small sinus of Valsalva (left coronary cusp diameter <30 mm) was 142 (46.1%) in overall, 101 (50.0%) in Asian group, and 41 (38.7%) in Caucasian group ($p = 0.058$). Co-existence of lower height of left coronary artery ostia and small sinus of Valsalva was more common in Asian group than in Caucasian group (35.6% vs 20.8%; $p = 0.02$; Figure 3).

The measurements of calcium quantification were summarized in Table 4. There were no differences in mean calcium volume of leaflet, LVOT, and aortic root between 2 groups (leaflet 367.2 ± 322.5 vs 359.1 ± 325.7 mm^3, $p = 0.84$; LVOT 8.9 ± 23.4 vs 10.1 ± 23.8 mm^3, $p = 0.66$; and aortic root 376.1 ± 332.3 vs 416.4 ± 329.6 mm^3, $p = 0.33$). Similarly, asymmetry of leaflet, LVOT, and aortic root calcium volume were similar between 2 groups (leaflet 127.7 ± 106.4 vs 117.5 ± 114.3 mm^3, $p = 0.44$; LVOT 8.0 ± 21.3 vs 9.1 ± 21.6 mm^3, $p = 0.65$; and aortic root 130.2 ± 109.2 vs 134.4 ± 112.3 mm^3, $p = 0.76$). In addition, distribution pattern of aortic root calcium volume was not significantly different between 2 groups ($p = 0.35$; Figure 4).

Discussion

The present study demonstrated 2 following findings: aortic root dimensions were smaller in Asian group than in Caucasian group, especially lower height of left coronary artery ostia and small sinus of Valsalva in Asian group; there were no significant differences in calcium volume

Table 4
Quantification of calcium

Calcium volume, mm^3	All (N = 308)	Asian (N = 202)	Caucasian (N = 106)	p value
Leaflet				
Left coronary cusp	102.8 ± 104.3	96.7 ± 103.9	115.7 ± 104.4	0.15
Right coronary cusp	104.9 ± 109.0	101.6 ± 112.2	112.0 ± 102.2	0.45
Non-coronary cusp	171.5 ± 156.2	168.8 ± 153.4	177.3 ± 162.6	0.67
Total	364.4 ± 323.1	367.2 ± 322.5	359.1 ± 325.7	0.84
Asymmetry	124.2 ± 109.1	127.7 ± 106.4	117.5 ± 114.3	0.44
Left ventricular outflow tract				
Left coronary cusp	5.0 ± 17.1	4.1 ± 15.6	7.1 ± 20.0	0.16
Right coronary cusp	1.6 ± 8.1	1.6 ± 8.1	1.6 ± 8.3	0.95
Posterior-coronary cusp	3.0 ± 13.3	3.1 ± 14.3	2.7 ± 11.0	0.81
Total	9.3 ± 23.5	8.9 ± 23.4	10.1 ± 23.8	0.66
Asymmetry	8.4 ± 21.4	8.0 ± 21.3	9.1 ± 21.6	0.65
Aortic root				
Left coronary cusp	107.8 ± 109.9	100.8 ± 108.5	122.8 ± 111.9	0.11
Right coronary cusp	106.5 ± 113.3	103.3 ± 116.5	113.5 ± 106.4	0.47
Posterior-coronary cusp	174.5 ± 158.3	172.0 ± 156.3	180.0 ± 163.3	0.68
Total	388.9 ± 331.4	376.1 ± 332.3	416.4 ± 329.6	0.33
Asymmetry	131.5 ± 110.0	130.2 ± 109.2	134.4 ± 112.3	0.76

Values are expressed as mean ± SD.

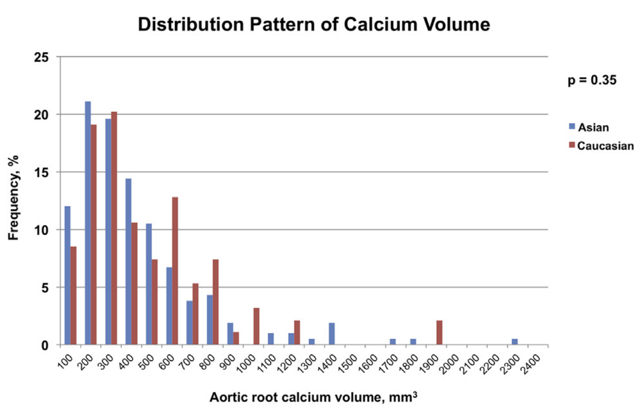

Figure 4. Distribution of aortic root calcium volume in Asian and Caucasian groups. Distribution pattern of aortic root calcium volume in Asian and Caucasian groups are shown.

and its asymmetry of leaflet, LVOT, and aortic between 2 groups.

In healthy population, aortic annulus size measured by 2-dimensional transesophageal echocardiogram was augmented with the increase of body weight, body height, and body surface area; and body surface area showed the highest correlation.[21] In contrast, our study demonstrated that annulus size in patients with severe aortic stenosis had the highest correlation with body height. Because the assumption formulas were similar between Asian and Caucasian, racial difference in annulus dimensions might be attributable to the difference in body height. Similarly, the sexual difference in annulus dimensions might be due to the difference in body height (Supplementary Figure 1).[16]

Our study firstly reported the lower height of left coronary artery ostia in Asian group than in Caucasian group. Note that 1/3 of Asian patients had both lower height of left coronary artery ostia and small sinus of Valsalva. According to reported study, lower height of left coronary artery ostia and small sinus of Valsalva were associated with coronary obstruction after TAVI.[8] Therefore, TAVI practice for patients with small annulus will increase the risk of coronary obstruction. In contrast, small annulus was associated with decreased risk of paravalvular aortic regurgitation.[22–24] The impact of these anatomic differences on clinical outcomes needs further investigation.

Several studies demonstrated the association between the amount of calcium volume and higher incidence of paravalvular aortic regurgitation after TAVI.[11,17] Accurate device sizing with MDCT measurement in the current practice will emphasize the impact of aortic valve calcification on clinical outcome. Several studies described the racial difference in the prevalence of calcification of coronary artery and extracoronary including aortic and mitral valves and thoracic aorta in the prospective cohort of asymptomatic subjects.[25,26] However, our analysis demonstrated that there were no differences in the mean calcium volume and its asymmetry of leaflet, LVOT, and aortic root between 2 groups. This discrepancy might be explained by that the patients with severe aortic stenosis who underwent TAVI were highly selected population with old age and multiple co-morbidities and entirely different from the previous cohort population. Furthermore, the similar severity and distribution of calcification despite the racial difference in aortic root dimensions indicates that the aortic valve calcification was independent from baseline characteristics and other co-morbidities and thus should be assessed individually.

The following limitations of the present study need to be acknowledged: First, this study enrolled patients who underwent TAVI during selected period and preprocedural MDCT with adequate quality and does not provide the information for patients who underwent TAVI at different period or those without preprocedural MDCT. Second, only calcium volume on contrast CT is assessed in this study, and calcium volume on noncontrast CT is not assessed. The calcium volume on noncontrast CT is more accurate for the assessment of calcification; however, given the association between location of calcium and paravalvular aortic regurgitation, quantification of calcium on contrast CT will provide important information. Finally, both groups do not adequately represent their races. Korean patients might be taller in Asian countries, and Italian patients might be shorter in European countries. The results from this study need to be investigated in other countries.

Disclosures

The authors have no conflicts to disclose.

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.amjcard.2015.08.021.

1. Kodali SK, Williams MR, Smith CR, Svensson LG, Webb JG, Makkar RR, Fontana GP, Dewey TM, Thourani VH, Pichard AD, Fischbein M, Szeto WY, Lim S, Greason KL, Teirstein PS, Malaisrie SC, Douglas PS, Hahn RT, Whisenant B, Zajarias A, Wang D, Akin JJ, Anderson WN, Leon MB; Partner Trial Investigators. Two-year outcomes after transcatheter or surgical aortic-valve replacement. *N Engl J Med* 2012;366:1686–1695.
2. Makkar RR, Fontana GP, Jilaihawi H, Kapadia S, Pichard AD, Douglas PS, Thourani VH, Babaliaros VC, Webb JG, Herrmann HC, Bavaria JE, Kodali S, Brown DL, Bowers B, Dewey TM, Svensson LG, Tuzcu M, Moses JW, Williams MR, Siegel RJ, Akin JJ, Anderson WN, Pocock S, Smith CR, Leon MB; Partner Trial Investigators. Transcatheter aortic-valve replacement for inoperable severe aortic stenosis. *N Engl J Med* 2012;366:1696–1704.
3. Adams DH, Popma JJ, Reardon MJ, Yakubov SJ, Coselli JS, Deeb GM, Gleason TG, Buchbinder M, Hermiller J Jr, Kleiman NS, Chetcuti S, Heiser J, Merhi W, Zorn G, Tadros P, Robinson N, Petrossian G, Hughes GC, Harrison JK, Conte J, Maini B, Mumtaz M, Chenoweth S, Oh JK; U.S. CoreValve Clinical Investigators. Transcatheter aortic-valve replacement with a self-expanding prosthesis. *N Engl J Med* 2014;370:1790–1798.
4. Gilard M, Eltchaninoff H, Iung B, Donzeau-Gouge P, Chevreul K, Fajadet J, Leprince P, Leguerrier A, Lievre M, Prat A, Teiger E, Lefevre T, Himbert D, Tchetche D, Carrie D, Albat B, Cribier A, Rioufol G, Sudre A, Blanchard D, Collet F, Dos Santos P, Meneveau N, Tirouvanziam A, Caussin C, Guyon P, Boschat J, Le Breton H, Collart F, Houel R, Delpine S, Souteyrand G, Favereau X, Ohlmann P, Doisy V, Grollier G, Gommeaux A, Claudel JP, Bourlon F, Bertrand B, Van Belle E, Laskar M; France 2 Investigators. Registry of transcatheter aortic-valve implantation in high-risk patients. *N Engl J Med* 2012;366:1705–1715.
5. Hamm CW, Mollmann H, Holzhey D, Beckmann A, Veit C, Figulla HR, Cremer J, Kuck KH, Lange R, Zahn R, Sack S, Schuler G, Walther T, Beyersdorf F, Bohm M, Heusch G, Funkat AK, Meinertz T, Neumann T, Papoutsis K, Schneider S, Welz A, Mohr FW; GARY-Executive Board. The German Aortic Valve Registry (GARY): in-hospital outcome. *Eur Heart J* 2014;35:1588–1598.
6. Moat NE, Ludman P, de Belder MA, Bridgewater B, Cunningham AD, Young CP, Thomas M, Kovac J, Spyt T, MacCarthy PA, Wendler O, Hildick-Smith D, Davies SW, Trivedi U, Blackman DJ, Levy RD, Brecker SJ, Baumbach A, Daniel T, Gray H, Mullen MJ. Long-term outcomes after transcatheter aortic valve implantation in high-risk patients with severe aortic stenosis: the U.K. TAVI (United Kingdom Transcatheter Aortic Valve Implantation) Registry. *J Am Coll Cardiol* 2011;58:2130–2138.
7. Barbanti M, Yang TH, Rodes Cabau J, Tamburino C, Wood DA, Jilaihawi H, Blanke P, Makkar RR, Latib A, Colombo A, Tarantini G, Raju R, Binder RK, Nguyen G, Freeman M, Ribeiro HB, Kapadia S, Min J, Feuchtner G, Gurtvich R, Alqoofi F, Pelletier M, Ussia GP, Napodano M, de Brito FS Jr, Kodali S, Norgaard BL, Hansson NC, Pache G, Canovas SJ, Zhang H, Leon MB, Webb JG, Leipsic J. Anatomical and procedural features associated with aortic root rupture during balloon-expandable transcatheter aortic valve replacement. *Circulation* 2013;128:244–253.
8. Ribeiro HB, Webb JG, Makkar RR, Cohen MG, Kapadia SR, Kodali S, Tamburino C, Barbanti M, Chakravarty T, Jilaihawi H, Paradis JM, de Brito FS Jr, Canovas SJ, Cheema AN, de Jaegere PP, del Valle R, Chiam PT, Moreno R, Pradas G, Ruel M, Salgado-Fernandez J, Sarmento-Leite R, Toeg HD, Velianou JL, Zajarias A, Babaliaros V, Cura F, Dager AE, Manoharan G, Lerakis S, Pichard AD, Radhakrishnan S, Perin MA, Dumont E, Larose E, Pasian SG, Nombela-Franco L, Urena M, Tuzcu EM, Leon MB, Amat-Santos IJ, Leipsic J, Rodes-Cabau J. Predictive factors, management, and clinical outcomes of coronary obstruction following transcatheter aortic valve implantation: insights from a large multicenter registry. *J Am Coll Cardiol* 2013;62:1552–1562.
9. Jilaihawi H, Kashif M, Fontana G, Furugen A, Shiota T, Friede G, Makhija R, Doctor N, Leon MB, Makkar RR. Cross-sectional computed tomographic assessment improves accuracy of aortic annular sizing for transcatheter aortic valve replacement and reduces the incidence of paravalvular aortic regurgitation. *J Am Coll Cardiol* 2012;59:1275–1286.
10. Willson AB, Webb JG, Labounty TM, Achenbach S, Moss R, Wheeler M, Thompson C, Min JK, Gurvitch R, Norgaard BL, Hague CJ, Toggweiler S, Binder R, Freeman M, Poulter R, Poulsen S, Wood DA, Leipsic J. 3-dimensional aortic annular assessment by multidetector computed tomography predicts moderate or severe paravalvular regurgitation after transcatheter aortic valve replacement: a multicenter retrospective analysis. *J Am Coll Cardiol* 2012;59:1287–1294.
11. Khalique OK, Hahn RT, Gada H, Nazif TM, Vahl TP, George I, Kalesan B, Forster M, Williams MB, Leon MB, Einstein AJ, Pulerwitz TC, Pearson GD, Kodali SK. Quantity and location of aortic valve complex calcification predicts severity and location of paravalvular regurgitation and frequency of post-dilation after balloon-expandable transcatheter aortic valve replacement. *JACC Cardiovasc Interv* 2014;7:885–894.
12. Gurvitch R, Webb JG, Yuan R, Johnson M, Hague C, Willson AB, Toggweiler S, Wood DA, Ye J, Moss R, Thompson CR, Achenbach S, Min JK, Labounty TM, Cury R, Leipsic J. Aortic annulus diameter determination by multidetector computed tomography: reproducibility, applicability, and implications for transcatheter aortic valve implantation. *JACC Cardiovasc Interv* 2011;4:1235–1245.
13. Willson AB, Webb JG, Freeman M, Wood DA, Gurvitch R, Thompson CR, Moss RR, Toggweiler S, Binder RK, Munt B, Cheung A, Hague C, Ye J, Leipsic JA. Computed tomography-based sizing recommendations for transcatheter aortic valve replacement with balloon-expandable valves: comparison with transesophageal echocardiography and rationale for implementation in a prospective trial. *J Cardiovasc Comput Tomogr* 2012;6:406–414.
14. Watanabe Y, Morice MC, Bouvier E, Leong T, Hayashida K, Lefevre T, Hovasse T, Romano M, Chevalier B, Donzeau-Gouge P, Farge A, Cormier B, Garot P. Automated 3-dimensional aortic annular assessment by multidetector computed tomography in transcatheter aortic valve implantation. *JACC Cardiovasc Interv* 2013;6:955–964.
15. de Heer LM, Budde RP, Mali WP, de Vos AM, van Herwerden LA, Kluin J. Aortic root dimension changes during systole and diastole: evaluation with ECG-gated multidetector row computed tomography. *Int J Cardiovasc Imaging* 2011;27:1195–1204.
16. Buellesfeld L, Stortecky S, Kalesan B, Gloekler S, Khattab AA, Nietlispach F, Delfine V, Huber C, Eberle B, Meier B, Wenaweser P, Windecker S. Aortic root dimensions among patients with severe aortic stenosis undergoing transcatheter aortic valve replacement. *JACC Cardiovasc Interv* 2013;6:72–83.
17. Jilaihawi H, Makkar RR, Kashif M, Okuyama K, Chakravarty T, Shiota T, Friede G, Nakamura M, Doctor N, Rafique A, Shibayama K, Mihara H, Trento A, Cheng W, Friedman J, Berman D, Fontana GP. A revised methodology for aortic-valvar complex calcium quantification for transcatheter aortic valve implantation. *Eur Heart J Cardiovasc Imaging* 2014;15:1324–1332.
18. Binder RK, Webb JG, Willson AB, Urena M, Hansson NC, Norgaard BL, Pibarot P, Barbanti M, Larose E, Freeman M, Dumont E, Thompson C, Wheeler M, Moss RR, Yang TH, Pasian S, Hague CJ,

Nguyen G, Raju R, Toggweiler S, Min JK, Wood DA, Rodes-Cabau J, Leipsic J. The impact of integration of a multidetector computed tomography annulus area sizing algorithm on outcomes of transcatheter aortic valve replacement: a prospective, multicenter, controlled trial. *J Am Coll Cardiol* 2013;62:431−438.

19. Barbanti M, Leipsic J, Binder R, Dvir D, Tan J, Freeman M, Norgaard B, Hansson N, Cheung A, Ye J, Yang TH, Maryniak K, Raju R, Thompson A, Blanke P, Lauck S, Wood D, Webb J. Underexpansion and ad hoc post-dilation in selected patients undergoing balloon-expandable transcatheter aortic valve replacement. *J Am Coll Cardiol* 2014;63:976−981.
20. Kasel AM, Cassese S, Bleiziffer S, Amaki M, Hahn RT, Kastrati A, Sengupta PP. Standardized imaging for aortic annular sizing: implications for transcatheter valve selection. *JACC Cardiovasc Imaging* 2013;6:249−262.
21. Zhu D, Zhao Q. Dynamic normal aortic root diameters: implications for aortic root reconstruction. *Ann Thorac Surg* 2011;91:485−489.
22. Van Belle E, Juthier F, Susen S, Vincentelli A, Iung B, Dallongeville J, Eltchaninoff H, Laskar M, Leprince P, Lievre M, Banfi C, Auffray JL, Delhaye C, Donzeau-Gouge P, Chevreul K, Fajadet J, Leguerrier A, Prat A, Gilard M, Teiger E; FRANCE 2 Investigators. Postprocedural aortic regurgitation in balloon-expandable and self-expandable transcatheter aortic valve replacement procedures: analysis of predictors and impact on long-term mortality: insights from the FRANCE2 Registry. *Circulation* 2014;129:1415−1427.
23. De Carlo M, Giannini C, Fiorina C, Bedogni F, Napodano M, Klugmann S, Tamburino C, Maisano F, Santoro G, Ettori F, Petronio AS. Paravalvular leak after CoreValve implantation in the Italian Registry: predictors and impact on clinical outcome. *Int J Cardiol* 2013;168:5088−5089.
24. Ali OF, Schultz C, Jabbour A, Rubens M, Mittal T, Mohiaddin R, Davies S, Di Mario C, Van der Boon R, Ahmad AS, Amrani M, Moat N, De Jaegere PP, Dalby M. Predictors of paravalvular aortic regurgitation following self-expanding Medtronic CoreValve implantation: the role of annulus size, degree of calcification, and balloon size during pre-implantation valvuloplasty and implant depth. *Int J Cardiol* 2015;179:539−545.
25. Nasir K, Katz R, Takasu J, Shavelle DM, Detrano R, Lima JA, Blumenthal RS, O'Brien K, Budoff MJ. Ethnic differences between extra-coronary measures on cardiac computed tomography: multi-ethnic study of atherosclerosis (MESA). *Atherosclerosis* 2008;198: 104−114.
26. Bild DE, Detrano R, Peterson D, Guerci A, Liu K, Shahar E, Ouyang P, Jackson S, Saad MF. Ethnic differences in coronary calcification: the Multi-Ethnic Study of Atherosclerosis (MESA). *Circulation* 2005;111: 1313−1320.