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Annular versus supra-annular sizing for TAVI in bicuspid aortic valve stenosis

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KEYWORDS

- aortic stenosis
- miscellaneous
- MSCT
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Abstract

Aims: We sought to compare annular versus supra-annular sizing for transcatheter aortic valve implantation (TAVI) in patients with a bicuspid aortic valve (BAV).

Methods and results: In this retrospective single-centre analysis, we measured the aortic annulus (Ann) and intercommissural distance (ICD) on multidetector computed tomography scans in 217 BAV patients. With annular sizing being the default method for prosthesis size selection in all cases, we determined clinically relevant sizing errors and assessed the hypothetical impact of supra-annular sizing. Overall there was no significant difference between ICD and Ann (25.1 [23.5; 27.3] vs. 25.4 [23.6; 27.1] mm; p=0.24); intra-individually, ICD was similar to Ann in 26.7%, smaller in 40.1%, and larger in 33.2%. Annular sizing was appropriate in 96.3%, oversized in 0.5%, and undersized in 3.2% of cases. Supra-annular sizing would have resulted in a divergent size selection in 38.7% (smaller: 17.5%, larger: 19.8%, ICD out of range for TAVI prostheses: 1.4%) with potential improvement in a few cases with annular sizing errors, but potential worsening due to improper size selection in a much larger proportion of patients.

Conclusions: Annular sizing for TAVI in BAV is feasible and safe. The added value of supra-annular sizing is questionable.

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Abbreviations

Ann	annulus diameter
BAV	bicuspid aortic valve
ICD	intercommissural distance
MDCT	multidetector computed tomography
PVL	paravalvular leakage
TAVI	transcatheter aortic valve implantation
THV	transcatheter heart valve

Introduction

Transcatheter aortic valve implantation (TAVI) has become established as standard therapy for patients with severe aortic stenosis at high risk for surgical valve replacement[1]. The ongoing expansion of indications for TAVI to lower-risk populations will increasingly involve younger patients with bicuspid aortic valve (BAV)[2]. Concerns about performing TAVI in BAV relate to the complex aortic root anatomy with potentially increased procedural risks such as paravalvular leakage (PVL) and aortic root injury[3]. Even though recent evidence suggests that with the use of new-generation devices improved outcomes can be achieved in this subpopulation[4], there are some unresolved issues that need to be addressed further. These include the most appropriate sizing method for TAVI in BAV patients, something which is a matter of debate. Whereas in tricuspid aortic valves annular sizing using multidetector computed tomography (MDCT) is the standard of care for the selection of the proper transcatheter heart valve (THV) size, for BAV it has been suggested to determine the intercommissural distance (ICD) 4 or 5 mm above the annular plane to account for the more complex aortic root morphology in BAV that may have supra-annular narrowing[5]. However, evidence supporting this alternative approach is scarce, and thus far no systematic comparison of these different sizing methods has been reported. In the present analysis, we compared annular versus supra-annular sizing for TAVI in patients with BAV.

Methods

STUDY DESIGN

Consecutive patients undergoing TAVI for native aortic stenosis between June 2011 and August 2018 at our centre were analysed retrospectively. Exclusion criteria included the absence or insufficient image quality of preprocedural MDCT **(Figure 1)**. The procedures were performed using balloon-expandable or self-expanding/mechanically expandable THV **(Supplementary Table 1)**. Baseline data including demographics, comorbidities, and risk scores were drawn from a prospective database. The study was performed in accordance with the Declaration of Helsinki and was approved by the local ethics committee.

MULTIDETECTOR COMPUTED TOMOGRAPHY

MDCT examinations were performed with a 128-slice or a 384-slice dual-source scanner (SOMATOM® Definition or Force; Siemens Medical Solutions, Forchheim, Germany), as previously described[6]. Reconstructions were carried out using

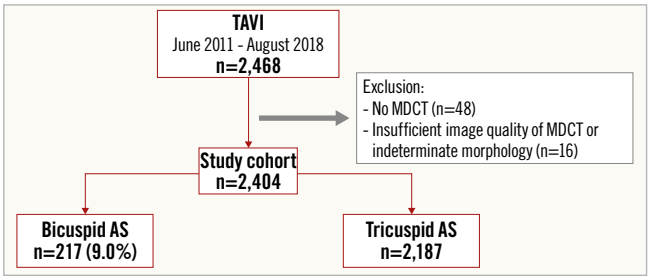

Figure 1. *Study population. AS: aortic stenosis; MDCT: multidetector computed tomography; TAVI: transcatheter aortic valve implantation*

a cardiac-gated B26f or I26f algorithm with a slice thickness of 0.6 mm in systole between 30% and 40% and in diastole at 70% of the cardiac cycle. For image analysis, dedicated software (3mensio; Pie Medical Imaging, Bilthoven, the Netherlands) was used. Image quality was estimated using a four-point scale. All scans were evaluated by a single cardiologist (W.K. Kim) with profound experience in cardiac imaging and were systematically analysed for the presence of BAV using diastolic and systolic reconstructions[7].

In addition to standard aortic root measurements, the ICD_{max} was determined as surrogate for supra-annular sizing 4 mm above the annular plane using the respective maximum value from systolic (ICD_{sys}) and diastolic (ICD_{dia}) reconstructions **(Figure 2)**. According to the relation between the annulus size (Ann) and ICD, we defined a cylindrical (ICD=Ann±Ann*0.02), trapezoid (ICD<Ann*1.02), or inverse trapezoid shape (ICD>Ann*0.98) of the aortic root. The calcium score of the device landing zone was measured according to the Agatston method[8].

SIZING

As the selection of the prosthesis size was commonly based on the maximum annulus diameter (Ann_{max}) of systolic and diastolic reconstructions, for supra-annular sizing, the respective maximum value of systolic and diastolic ICD values was used (ICD_{max}). To estimate prosthesis sizing, we calculated the cover index annular sizing: CI_{Ann}=100*([prosthesis size-Ann_{max}]/prosthesis size) and the supra-annular sizing: CI_{ICD}=100*([prosthesis size-ICD_{max}]/prosthesis size). Nominal thresholds for correct sizing, undersizing, and oversizing of the various prostheses were derived from official recommendations[9].

To account for cases of prosthesis size selection that were divergent from official recommendations, including systematic oversizing when using the ACURATE *neo*™ device (Boston Scientific, Marlborough, MA, USA)[10], overfilling or underfilling of the SAPIEN 3 balloon (Edwards Lifesciences, Irvine, CA, USA), or undersizing in patients with severe device landing zone calcification, we took into consideration procedural outcomes to obtain a comprehensive clinical evaluation of sizing. Hence, a nominal oversizing or undersizing was only categorised as a clinically relevant sizing error in the presence of procedural complications

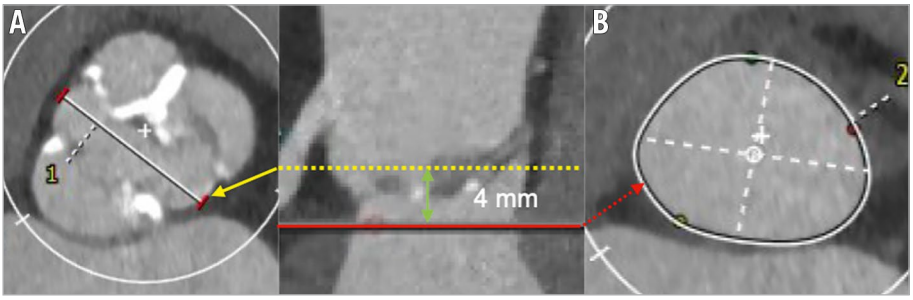

Figure 2. *Aortic annulus and intercommissural distance on MDCT. Measurement of (A) the intercommissural distance 4 mm above the annular plane and (B) the aortic annulus in a bicuspid aortic valve.*

potentially related to an inappropriate selection of the THV size (including PVL ≥2°, device embolisation, permanent pacemaker implantation, and annular rupture). Furthermore, we determined the hypothetical prosthesis size that would have been chosen when employing supra-annular sizing. In cases with complications due to annular oversizing, the selection of a smaller valve size according to supra-annular sizing was rated as potential improvement and vice versa. On the other hand, in cases with good procedural outcomes using annular sizing and discordant supra-annular sizing, we assumed an inappropriate size selection which hence was rated as potential worsening.

ECHOCARDIOGRAPHY AND AORTOGRAPHY

PVL was assessed on discharge transthoracic echocardiography according to established criteria[11]. All images were reviewed independently by two cardiologists with expert competence in imaging who were blinded to clinical parameters; in cases of disagreement mutual consensus was achieved. The position of the first implanted prosthesis was determined by measuring the distance between the annulus and ventricular aspect at the non-coronary and left-coronary cusps, as described earlier[12].

OUTCOMES OF INTEREST

Procedural results were evaluated according to updated Valve Academic Research Consortium (VARC-2) criteria[13]. The primary outcome of interest was the rate of appropriate sizing. Secondary outcomes of interest were complications related to sizing, device success, and all-cause mortality at 30 days; mortality data were obtained from follow-up visits, via telephone interview, or from medical reports.

STATISTICAL ANALYSIS

Continuous variables are expressed as median and interquartile range (IQR), and categorical data are given as numbers and percentages. Continuous variables were compared with the Wilcoxon test or Kruskal-Wallis H test, and categorical data were analysed with the chi-square test or Fisher's exact test. A two-sided p-value <0.05 was considered significant. All statistical data were calculated using SPSS, Version 21 (IBM Corp., Armonk, NY, USA).

Results

STUDY COHORT

Between June 2011 and August 2018, a total of 2,468 patients with severe native aortic stenosis underwent TAVI consecutively at our centre. After exclusion of 48 cases without preprocedural MDCT and 16 cases with indeterminate bicuspid phenotype (due to insufficient image quality or complex anatomy), the TAVI cohort consisted of 2,404 patients **(Figure 1)** with excellent, good, and acceptable image quality in 31.4%, 45.1%, and 23.4% of cases, respectively. Using MDCT criteria, we diagnosed 217 (9.0%) patients with BAV (median age 80.0 years [76.4-83.5], STS PROM 3.9% [2.4-5.6]). Baseline characteristics and procedural details are shown in **Table 1** and **Table 2**. Results according to THV generation are illustrated in **Figure 3**.

ICD AND ANNULUS MEASUREMENTS

On average, ICD_{max} was similar to Ann_{max} (25.1 [23.5; 27.3] vs. 25.4 [23.6; 27.1] mm; p=0.24). Intra-individually, ICD_{max} was similar to Ann_{max} in 26.7% (cylindrical shape), smaller in 40.1% (trapezoid shape), and larger in 33.2% (inverse trapezoid shape). ICD_{max} and the ICD_{max}/Ann_{max} ratio differed according to the BAV subtype **(Figure 4)**; the difference was greatest in patients with bicommissural non-raphe type ($BiC_{Non\text{-}Raphe}$) (27.0 mm [25.8; 27.5]; 1.04 [0.99; 1.12]), followed by patients with bicommissural raphe type (BiC_{Raphe}) (25.9 mm [24.2; 27.9]; 1.01 [0.97; 1.05]) and tricommissural incomplete raphe type (TriC) (24.2 mm [22.3; 25.9]; 0.98 [0.94; 1.02]; p<0.001 for both comparisons).

PROSTHESIS SIZE SELECTION

Supplementary Table 2 summarises complications potentially related to sizing errors (n=48, four patients had multiple complications). Using the aforementioned criteria, a small number of primarily sizing-related complications were identified among BAV (8/48; 16.7%). Under this premise, annular sizing in BAV was deemed to be appropriate in 96.3%, oversized in 0.5%, and undersized in 3.5% of cases.

Compared with annular sizing, supra-annular sizing would have resulted in a selection of similar sizes in 61.3%, upsizing in 19.8%, and downsizing in 17.5%, while in 1.4% the ICD_{max} would have been too large for currently available TAVI prostheses **(Table 3)**.

Table 1. Baseline characteristics and MDCT measurements.

		BAV (n=217)
Age, years		80.0 [76.4; 83.5]
Female sex		98 (45.2%)
Logistic EuroSCORE I, %		17.2 [10.2; 25.7]
STS PROM, %		3.9 [2.4; 5.5]
Estimated glomerular filtration rate, ml/min		70.2 [55.0; 86.5]
Hypertension		188 (86.6%)
Diabetes		63 (29.0%)
Hyperlipidaemia		67 (30.9%)
Chronic obstructive lung disease		43 (19.8%)
Coronary artery disease		103 (47.5%)
Prior CABG		19 (8.8%)
Peripheral artery disease		27 (12.4%)
Prior stroke		26 (12.0%)
Prior atrial fibrillation		84 (38.7%)
Prior permanent pacemaker		23 (10.6%)
Left ventricular ejection fraction, %		60.0 [50.0; 65.0]
Mean transaortic gradient, mmHg		45.0 [37.5; 55.0]
Aortic valve area, cm^2		0.7 [0.5; 0.8]
MDCT		
Ann_{max}, mm		25.1 [23.4; 26.8]
ICD_{max}, mm		24.9 [23.1; 27.0]
Annulus min diameter, mm		21.3 [19.8; 23.1]
Annulus max diameter, mm		27.4 [25.5; 29.6]
Annular eccentricity		1.29 [1.21; 1.37]
Annulus area, mm^2		490 [426; 550]
Annulus perimeter, mm		80.2 [74.5; 85.3]
Left ventricular outflow tract diameter, mm		24.6 [22.1; 26.6]
Sinotubular junction diameter, mm		29.9 [27.7; 33.2]
Sinus of Valsalva diameter, mm		33.2 [31.1; 36.1]
Ascending aorta diameter, mm		36.1 [32.6; 40.2]
Aortic valve calcium score, AU		3,247 [2,106; 4,364]
Aortic valve calcification	mild	34 (15.7%)
	moderate	108 (49.8%)
	severe	75 (34.6%)
Bicuspid anatomy		
Sievers classification	Type 0	7 (3.2%)
	Type 1	207 (95.4%)
	Type 2	3 (1.4%)
Jilaihawi classification[17]	Bicommissural non-raphe type	7 (3.2%)
	Bicommissural raphe type	114 (52.5%)
	Tricommissural incomplete raphe type	96 (44.2%)

Values denote numbers (percentage) or median [IQR]. Ann_{max}: maximum area- or perimeter-derived annulus diameter; BAV: bicuspid aortic valve; CABG: coronary artery bypass graft; ICD: intercommissural distance; STS PROM: Society of Thoracic Surgeons predicted risk of mortality

Table 2. Procedural outcomes.

		BAV (n=217)
Access	Transthoracic	40 (18.4%)
	Transvascular	177 (81.6%)
Predilatation		98 (45.2%)
Post-dilatation		59 (27.2%)
Prosthesis type	Self-expanding/mechanically expandable	97 (44.7%)
	Balloon-expandable	120 (55.3%)
Prosthesis generation	First	31 (14.3%)
	New	186 (85.7%)
Procedural duration, min		39.0 [31.0; 51.5]
Fluoroscopy time, min		9.4 [6.7; 13.9]
Contrast agent, ml		80 [60; 120]
Left ventricular ejection $fraction_{post}$, %		60.0 [53.5; 65.0]
Mean transvalvular $gradient_{post}$, mmHg		11.0 [7.0; 14.0]
Aortic valve $area_{post}$, cm^2		1.6 [1.3; 1.8]
Paravalvular leakage ≥2°		12/206 (5.8%)
Implantation depth NCC, mm		5.0 [3.0; 7.0]
Implantation depth LCC, mm		4.0 [2.0; 6.0]
Prosthesis position	Appropriate	178/216 (82.4%)
	High	14/216 (6.5%)
	Deep	24/216 (11.1%)
30-day all-cause mortality		8/217 (3.7%)
Device success (VARC-2)		181 (83.4%)
Device embolisation		3 (1.4%)
Second valve implantation		6 (2.8%)
Aortic root injury		3 (1.4%)
Cardiopulmonary bypass		6 (2.8%)
Conversion to sternotomy		4 (1.8%)
Acute kidney injury stage 2 and 3		15 (6.9%)
Major vascular complication		15 (6.9%)
Major bleeding		13 (6.0%)
Major stroke		9 (4.1%)
Permanent pacemaker implantation		33 (15.2%)

Values denote numbers (percentage) or median [IQR]. BAV: bicuspid aortic valve; LCC: left coronary cusp; NCC: non-coronary cusp

Table 3. Annular versus supra-annular sizing.

		BAV (n=217)
Ratio ICD_{max}/Ann_{max}		0.99 [0.96; 1.04]
Cover index Ann_{max}, %		3.7 [0.7; 6.9]
Cover index ICD_{max}, %		4.4 [-0.2; 10.0]
ICD_{max} vs. Ann_{max} diameter	Similar	58 (26.7%)
	Smaller	87 (40.1%)
	Larger	72 (33.2%)
Clinical estimation of annular sizing	Appropriate	209 (96.3%)
	Oversizing	1 (0.5%)
	Undersizing	7 (3.2%)
Supra-annular vs. annular sizing	Similar	133 (61.3%)
	Smaller (downsizing)	38 (17.5%)
	Larger (upsizing)	43 (19.8%)
	CD_{max} too large for TAVI	3 (1.4%)

Values denote numbers (percentage) or median [IQR]. Ann: annulus diameter; BAV: bicuspid aortic valve; ICD: intercommissural distance

The proportion of upsizing was highest in $BiC_{Non\text{-}Raphe}$-type valves (57.1%), whereas the proportion of downsizing was highest in TriC-type valves (27.1%) **(Figure 4)**.

Among the cases with complications suggestive of annular sizing errors, supra-annular sizing would potentially have led to a more appropriate valve size selection in a few cases (n=5;

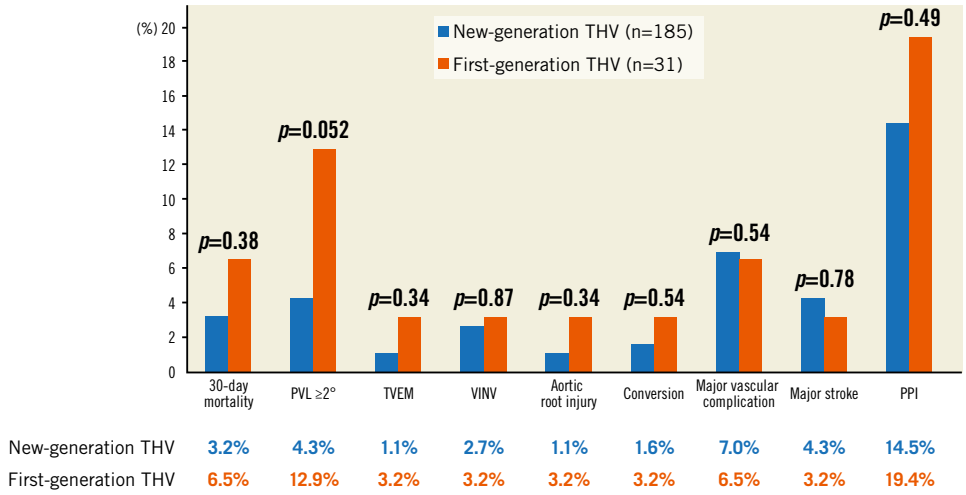

Figure 3. *Outcomes of first- versus new-generation transcatheter heart valves. PPI: permanent pacemaker implantation; PVL: paravalvular leak; TVEM: transcatheter valve embolisation and migration; VINV: valve-in-valve*

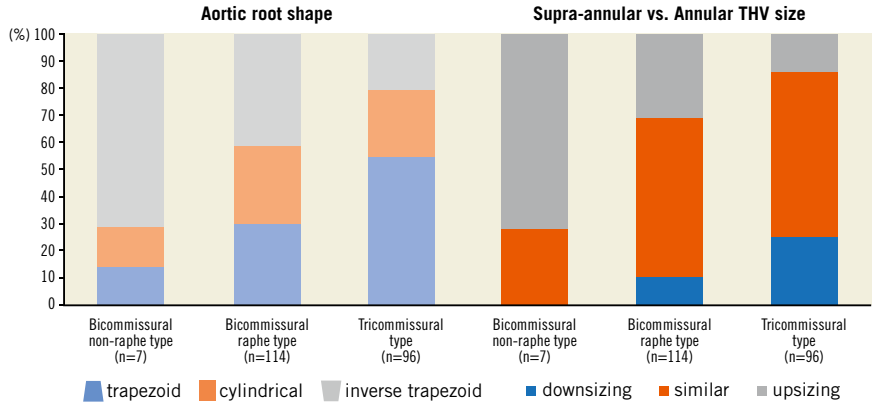

Figure 4. *Intercommissural distance vs. annulus diameter. The proportion of patients with an inverse trapezoid shape of the aortic root (ICD larger than Ann) is more prevalent in bicommissural phenotypes, whereas a trapezoid shape (ICD smaller than Ann) is more common in tricommissural phenotypes. Accordingly, supra-annular sizing would lead more frequently to upsizing in bicommissural types and to downsizing in tricommissural phenotypes. Upsizing included three cases with ICD being too large for TAVI prostheses.*

2.3%), exclusively in non-cylindrical aortic root shapes. In cases with good outcomes according to annular sizing, supra-annular sizing was divergent in a much larger proportion of patients (n=79; 36.4%) and may have resulted in a potential worsening due to inappropriate valve size selection, regardless of the underlying aortic root shape **(Figure 5)** or the THV type **(Supplementary Figure 1)**.

CYCLIC VARIATIONS OF ICD AND ANNULUS

Systolic and diastolic MDCT reconstructions were available in 214 (98.6%) and 211 (97.2%) patients, respectively. ICD_{sys} (24.9 mm [23.1; 27.0]) was larger than ICD_{dia} (24.4 mm [22.3; 26.4]; p<0.001). Furthermore, ICD_{sys} in general was similar to Ann_{sys} (25.1 mm [23.4-26.8]; p=0.08), whereas ICD_{dia} was significantly smaller than Ann_{dia} (24.8 mm [23.3; 26.8]; p=0.001). In detail, ICD_{sys} was similar to Ann_{sys} in 34.6% of the cases, larger in 29.3%, and smaller in 36.1%. ICD_{dia} was similar to Ann_{dia} in 26.3%, larger in 28.7%, and smaller in 45.0%.

Discussion

The main findings of the present study are:

1) In BAV, the relation between the diameter of the annulus and ICD varied according to the BAV subtype and resulted in different aortic root shapes (cylindrical, trapezoid, inverse trapezoid).
2) Annular sizing for TAVI in patients with BAV using various THV was feasible and safe and yielded good procedural outcomes in >95% of patients.
3) Supra-annular sizing would have resulted in divergent size selection in approximately 40% of cases with potential improvement in a few cases with complications due to annular sizing errors, but potential worsening due to improper size selection in a much larger proportion of patients.

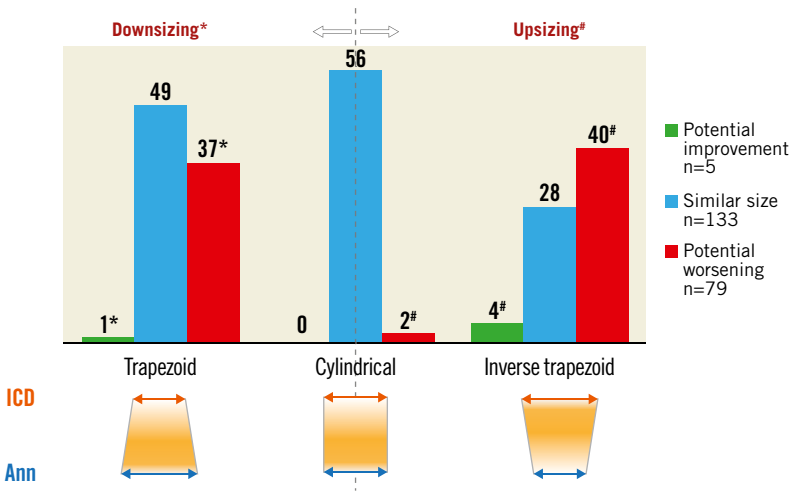

Figure 5. *Aortic root shape and impact on sizing. Supra-annular sizing would have led to a potentially improved size selection in a few cases with non-cylindrical aortic root shape, but the proportion of cases with potential worsening due to supra-annular sizing was much larger irrespective of the aortic root shape. Downsizing occurred exclusively in patients with a trapezoid shape, whereas upsizing was more common in patients with an inverse trapezoid shape. The latter group included three cases in which the ICD was too large for currently available TAVI prostheses.*

Existing data on supra-annular measurement and sizing are scarce and conflicting, and the optimal sizing methodology in BAV remains a matter of debate. Only a few reports have demonstrated the feasibility of supra-annular sizing with measurement of a smaller ICD that would lead to the selection of a smaller prosthesis size, but these studies were limited by small sample sizes and confounding factors[14,15]. Another shortcoming of supra-annular sizing is that there is no standard of how to perform the measurement. The ICD is commonly determined 4 to 5 mm above the annular plane, where implanted THVs have been shown to be mostly constrained, but there are also reports of circumscribing the border of the leaflets which would more or less correspond to the aortic valve area and therefore will commonly be smaller than annular dimensions[16]. Furthermore, it remains unclear in which phase of the cardiac cycle the ICD should be measured.

ANNULUS AND INTERCOMMISSURAL DISTANCE

In the present cohort, ICD_{max} was similar overall to Ann_{max}, in contrast to previous studies in which the ICD was smaller than annulus dimensions[14,15]. This may be explained by cyclic variations of the ICD that we observed in the present analysis, but which in most previous studies were not taken into consideration systematically. In a series by Jilaihawi et al, systolic reconstructions were available for the determination of the ICD, but their proportion was not further specified[17]. Conversely, in the present study systolic and diastolic reconstructions were available in the vast majority, thus we noted a difference between ICD and Ann only when considering diastolic reconstructions (ICD_{dia}, Ann_{dia}), whereas ICD and Ann were similar when using systolic images (ICD_{sys}, Ann_{sys}) or the respective maximum values (ICD_{max}, Ann_{max}). These cyclic differences of the ICD should be taken into consideration for future studies on supra-annular sizing.

In addition, the ICD varied depending on the BAV subtype, showing larger values in bicommissural phenotypes and smaller values in tricommissural phenotypes **(Figure 4)**, which is consistent with previous reports[17].

ANNULAR AND SUPRA-ANNULAR SIZING

Using stringent criteria, we identified only a few cases with primarily sizing-related complications **(Supplementary Table 2)**; hence, annular sizing was deemed to be appropriate in >95% of cases. On the other hand, supra-annular sizing in approximately 40% would have led to a divergent sizing strategy, with presumably improved size selection in only a few cases and conceivably improper size selection in a much larger proportion of patients **(Figure 5)**. As supra-annular sizing was only hypothetical and we were not able to determine if and how a divergent size selection would have affected procedural outcomes, our observations are at best hypothesis-generating. Nonetheless, it is unlikely that two different sizes of a prosthesis could be implanted in the same patient with similarly good results. Even though we cannot prove superiority of annular sizing over supra-annular sizing, our results demonstrate that annular sizing is feasible and safe for TAVI in BAV, questioning the need for an alternative sizing approach. A recent registry on THV sizing in BAV demonstrated the feasibility of annular sizing in 88% of cases, whereas it was recommended to integrate supra-annular sizing only in borderline situations[5].

Supra-annular sizing and high positioning of the prosthesis in BAV, as promoted by some TAVI operators, appears intuitive and could be useful in certain scenarios, but it is unclear how to select those patients who would benefit from supra-annular

sizing. An unselected implementation of this alternative sizing approach in routine clinical practice does not seem to be justified, as the potentially detrimental effects could outweigh the benefits. Importantly, the underlying aortic root shape does not necessarily allow prediction of whether supra-annular sizing would be beneficial over annular sizing, for instance by systematic downsizing in cases with a trapezoid-shaped aortic root, as one would assume.

Limitations

This is a retrospective analysis with its inherent limitations as mentioned above. The variety of different THVs that were implanted may have had an impact on the divergent size selection when employing supra-annular sizing, as sizing charts vary with respect to the covered annulus range, available sizes, and overlapping of valve sizes. Assessment of PVL by means of echocardiography was not core lab-adjudicated and was performed without distinction between transvalvular and paravalvular regurgitation, although the proportion of transvalvular regurgitation is usually small[18].

Conclusions

Annular sizing for TAVI in bicuspid aortic valves is feasible and safe and is associated with good outcomes, in particular with the use of new-generation devices. Our results suggest that an incremental benefit due to an altered sizing regimen seems unlikely.

Impact on daily practice

Annular sizing should be considered the default approach for TAVI in patients with bicuspid aortic valve, whereas our results do not support the additional or even exclusive implementation of supra-annular sizing in this subset.

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Conflict of interest statement

W.K. Kim reports receiving proctor fees and/or lecture honoraria from Boston Scientific, Abbott, Edwards Lifesciences, and Medtronic. C. Liebetrau reports receiving lecture honoraria from Abbott, AstraZeneca, Bayer, Berlin-Chemie, Boehringer Ingelheim, Daiichi Sankyo, and Pfizer – Bristol-Myers Squibb, and meeting expenses from Bayer, and Daiichi Sankyo. M. Renker reports receiving lecture honoraria from Abbott. A. Rolf reports receiving lecture honoraria from AstraZeneca, Boehringer, Pfizer, MSD, and Bristol-Myers Squibb. M. Doss reports receiving proctor fees and/or lecture honoraria from Boston Scientific, and Abbott. C. Hamm reports being on the advisory board of Medtronic. H. Möllmann reports receiving proctor fees and/or speaker honoraria from Abbott, Biotronik, Boston Scientific, and Edwards Lifesciences. The other authors have no conflicts of interest to declare.

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Supplementary data

Supplementary Figure 1. Potential impact of supra-annular sizing according to THV type.

Supplementary Table 1. Overview of implanted prostheses.

Supplementary Table 2. Causes of potential sizing-related complications.

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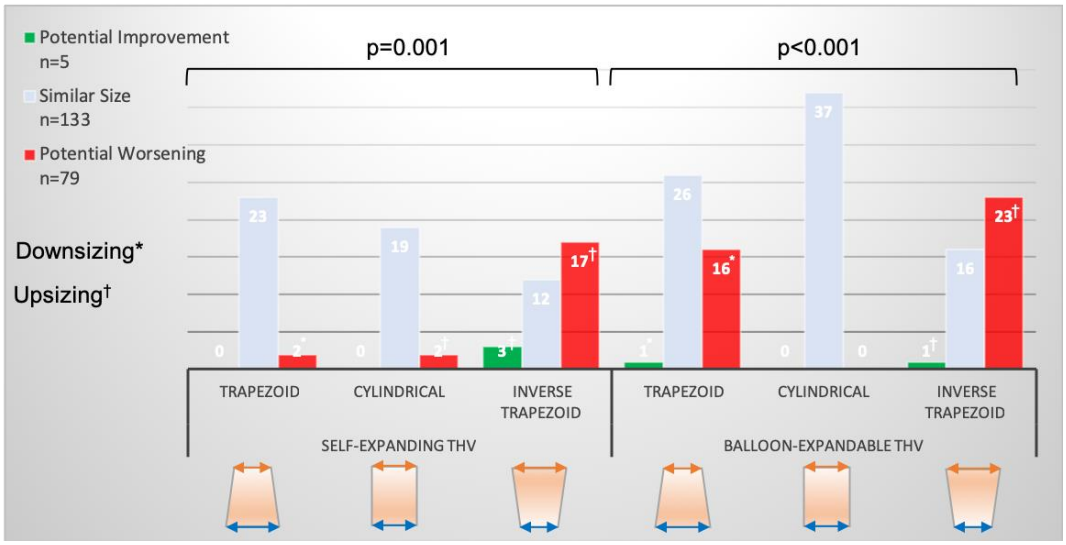
Supplementary data

Supplementary Figure 1. Potential impact of supra-annular sizing according to THV type.



The proportion of cases with similar sizing, potential improvement or worsening due to supra-annular sizing is similar between patients treated with self-expanding or balloon-expandable THV.

Supplementary Table 1. Overview of implanted prostheses.

Prosthesis	**Generation**	**BAV (n=217)**
Balloon-expandable		
SAPIEN XT	Early	13 (6.0%)
SAPIEN 3	New	107 (49.3%)
Self-expanding/Mechanically expandable		
ACURATE TA	Early	8 (3.7%)
ACURATE *neo*	New	48 (22.1%)
CoreValve	Early	12 (5.5%)
CoreValve Evolut R	New	13 (6.0%)
Lotus	New	4 (1.8%)
Portico	New	12 (5.5%)

Values denote numbers (percentage).

BAV: bicuspid aortic valve

Supplementary Table 2. Causes of potential sizing-related complications.

No.	Complication	Prosthesis	Device position	Cover index, % [official sizing range]	Main causes
1	PVL ≥2° PPI	CV 29 mm	deep	4.2 [10.3-20.7]	PVL: undersizing, malpositioning PPI: malpositioning
2	PVL ≥2° PPI	CV 29 mm	deep	14.9 [10.3-20.7]	PVL: malpositioning PPI: malpositioning, RBBB
3	PVL ≥2°	CV 29 mm	correct	13.7 [10.3-20.7]	Device related
4	PVL ≥2°	Neo 25 mm	correct	6.9 [0-8.0]	Other[1]
5	PVL ≥2°	Neo 25 mm	correct	9.2 [0-8.0]	Severe calcification
6	PVL ≥2°	Neo 25 mm	deep	1.7 [0-8.0]	Malpositioning
7	PVL ≥2°	Neo 25 mm	correct	4.4 [0-8.0]	Other[1]
8	PVL ≥2°	POR 25 mm	deep	11.0 [8.0-16.0]	Malpositioning
9	PVL ≥2°	SXT 26 mm	correct	2.2 [0-11.5]	Asymmetric calcification
10	PVL ≥2°	Lotus 25 mm	deep	-5.4 [0-8.0]	Undersizing, malpositioning
11	PVL ≥2°	S3 23 mm	correct	-7.0 [-1.7-10.0]	Undersizing
12	PVL ≥2°	POR 29 mm	correct	6.9 [6.9-13.8]	Undersizing, severe calcification
13	PVL ≥2°	CV 31 mm	deep	3.2 [6.5-16.1]	Undersizing, malpositioning[2]
14	TVE PPI	Neo 25 mm	deep	3.7 [0-8.0]	TVE: malpositioning PPI: malpositioning
15	TVE	Neo 27 mm	high	6.7 [0-7.4]	Malpositioning
16	TVE	SXT 26 mm	deep	-4.3 [0-11.5]	Undersizing, malpositioning
17	ARI PPI	S3 29 mm	correct	10.3 [-1.7-9.7][3]	ARI: oversizing PPI: oversizing, RBBB
18	ARI	SXT 29 mm	correct	9.4 [0-10.3]	Severe calcification

19	ARI	S3 29 mm	correct	1.7 [-1.7-9.7][3]	Severe calcification
20	PPI	Neo 27 mm	correct	2.0 [0-7.4]	RBBB
21	PPI	S3 29 mm	correct	3.4 [-1.7-9.7][3]	RBBB
22	PPI	S3 29 mm	correct	3.1 [-1.7-9.7][3]	RBBB
23	PPI	POR 23 mm	correct	8.0 [8.7-17.4]	Undetermined
24	PPI	EvoR 34 mm	correct	18.6 [11.8-23.5]	Undetermined
25	PPI	CV 29 mm	deep	11.4 [10.3-20.7]	Device related, malpositioning
26	PPI	Neo 25 mm	correct	5.9 [0-8.0]	Undetermined
27	PPI	S3 29 mm	correct	6.2 [-1.7-9.7][3]	Undetermined
28	PPI	S3 26 mm	deep	-1.0 [-1.5-10.0]	RBBB, malpositioning
29	PPI	Neo 25 mm	correct	3.6 [0-8.0]	Undetermined
30	PPI	EvoR 29 mm	correct	14.8 [10.3-20.7]	RBBB
31	PPI	EvoR 34 mm	correct	19.6 [11.8-23.5]	RBBB
32	PPI	AC_{TA} 23 mm	deep	8.8 [0-8.0]	Malpositioning
33	PPI	S3 26 mm	correct	-1.1 [-1.5-10.0]	Undetermined
34	PPI	S3 29 mm	correct	6.3 [-1.7-9.7][3]	RBBB
35	PPI	S3 26 mm	correct	3.4 [-1.5-10.0]	Undetermined
36	PPI	Lotus 27 mm	correct	0.5 [0-7.4]	Device related, RBBB
37	PPI	S3 29 mm	correct	-2.4 [-1.7-9.7][3]	Undetermined
38	PPI	S3 29 mm	correct	-2.0 [-1.7-9.7][3]	Undetermined
39	PPI	CV 29 mm	deep	8.7 [10.3-20.7]	Device related, malpositioning
40	PPI	POR 23 mm	correct	6.9 [8.7-17.4]	Undetermined
41	PPI	S3 29 mm	high	0.1 [-1.7-9.7][3]	RBBB
42	PPI	POR 27 mm	deep	13.7 [7.4-14.8]	Malpositioning
43	PPI	S3 29 mm	correct	5.1 [-1.7-9.7][3]	RBBB
44	PPI	CV 26 mm	correct	11.9 [11.5-23.1]	Device related

45	PPI	S3 26 mm	correct	4.5 [-1.5-10.0]	Undetermined
46	PPI	S3 23 mm	correct	-1.7 [-1.7-10.0]	Undetermined
47	PPI	S3 26 mm	correct	7.7 [-1.5-10.0]	Undetermined
48	PPI	S3 29 mm	correct	0.2 [-1.7-9.7][3]	Undetermined

[1]Paravalvular leakage was underestimated in the aortogram (rated as mild paravalvular leakage), therefore no post-dilatation was performed. Discharge echocardiogram revealed a moderate paravalvular leakage.

[2]Due to moderate paravalvular leakage, a second valve was implanted (valve-in-valve), which led to a reduction to mild paravalvular leakage at discharge.

[3]Undersizing up to -10.3% possible.

AC_{TA}: ACURATE TA; ARI: aortic root injury; CV: CoreValve; EvoR: Evolut R; Neo: ACURATE *neo*; POR: Portico; PVL: paravalvular leakage; RBBB: right bundle branch block; S3: SAPIEN 3; SXT: SAPIEN XT; TVE: transcatheter valve embolisation