Balloon Filling Algorithm for Optimal Size of Balloon Expandable Prosthesis During Transcatheter Aortic Valve Replacement

Gerhard Schymik, MD[a,*], Milos Radakovic, MD[a], Peter Bramlage, MD[b], Claus Schmitt, MD[a], and Panagiotis Tzamalis, MD[a]

Aim is to report on the results of an optimized balloon filling algorithm and suggest a refinement of the implantation approach to maximize safety. Appropriate sizing of balloon expandable valves during transcatheter aortic valve implantation is crucial. Study comprised 370 consecutive patients receiving SAPIEN 3 valve between 2015 and 2018. Valve expansion/recoil measurement in the inflow area, annular area, and outflow area was performed previously and postimplantation. Nominal balloon filling resulted in underexpansion—23 mm (20.96 mm), 26 mm (23.88 mm), and 29 mm (27.56 mm) SAPIEN 3 valves at the annular level. Increased balloon filling by 2 cc resulted in a gradual increase in valve diameter reaching 97.35% (23 mm), 96.50% (26 mm), and 96.11% (29 mm) of the nominal valve diameter. Final diameters were usually higher in the valvular inflow and outflow tracts. The 29 mm valve did not reach its nominal diameter with 2 cc overfilling and in none of inflow area (95.48%), annular area (96.11%), or outflow area (96.86%). Device success (by VARC II) was 96.2%. No root or septal rupture, device migration, mitral valve injury, coronary obstruction, or dissection occurred. Rate of new permanent pacemaker implantation was 8.3%. Paravalvular leakage was none or trace in most patients. Mean valve gradient was 10.77 mm Hg postprocedure. 1.9% of the patients had a maximum gradient of >40 mm Hg, 2.2% >20 mm Hg. In conclusion, an optimized balloon filling algorithm resulted in appropriate valve gradients, low levels of paravalvular leakage, low rates of permanent pacemaker implantation and no annular rupture. **(Am J Cardiol 2020;134:108−115)**

Appropriate sizing of balloon expandable valves during transcatheter aortic valve replacement (TAVR) is crucial. An oversized prosthesis valve may result in conduction disturbances requiring permanent pacemaker implantation (PPI), coronary obstruction, peri-aortic hematoma, mitral valve injury, septal, or root rupture.[1−4] Undersizing may result in paravalvular leakage (PVL).[2,5−8] As the inflow, annular and outflow areas of the aortic valve may differ in their size and the degree of calcification, a valve may even be oversized, appropriately sized or undersized at any level. Rather than choosing the prosthesis valve size based on the nominal valve area as commonly performed, it may make more sense to gradually adjust the filling of the implantation balloon which will result in varying degrees of valve expansion to accommodate different patient aortic annular areas and dimensions. We assumed that gradually adjusting the balloon filling volume based on procedural angiography may help to identify an appropriate valve expansion minimizing the risk of PVL, PPI, and annular rupture alike. The aim of the present manuscript, therefore, is to report on the results of an optimized balloon filling algorithm and suggest a refinement of the implantation approach in an attempt to maximize patient safety.

Methods

We used the prospective TAVI-Karlsruhe registry of consecutive patients who underwent TAVR in our institution between 2015 and 2018 as the basis for this analysis. Design characteristics of this registry have been published previously.[9−11] The local Ethics Committee approved the study and patients gave informed consent.

Patients included in this study had been diagnosed with severe symptomatic aortic stenosis and been assigned to undergo TAVR by the Karlsruhe Heart Team. The 2 principle criteria used to determine suitability for TAVR in our institution were a logistic EuroSCORE of ≥15 or age ≥75 years with a logistic EuroSCORE of <15. The presence of additional co-morbidities not considered in the EuroSCORE, such as malignancy (but with a life expectancy of more than 1 year), liver cirrhosis, severe pulmonary disease with long-term provision of oxygen, frailty, and porcelain aorta were also evaluated. In addition, we considered patients who were unwilling to undergo surgical aortic valve replacement. An unsuitable native aortic valve annulus was a contraindication for TAVR, as was a life-expectancy or quality-of-life that was seriously affected by co-morbidities (such as dementia with disability, a previous major stroke, uncontrolled congestive heart failure, or

[a]Medical Clinic IV − Department of Cardiology, Municipal Hospital Karlsruhe, Academic Teaching Hospital of the University of Freiburg, Germany; and [b]Institute for Pharmacology and Preventive Medicine, Cloppenburg, Germany. Manuscript received June 8, 2020; revised manuscript received and accepted July 28, 2020.

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*Corresponding author. Tel.: +49 721 9742960; fax: +49 721 9742909.
E-mail address: g.schymik@gmx.de (G. Schymik).

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cardiogenic shock). All consecutive patients were considered for our study if they had an appropriate Computed Tomography data for valve size determinations. Patients in which the valve/frame was not rectangular to the imaging plane were excluded.

We analyzed the actual expansion of 370 SAPIEN 3 (S3) implantations (valve size: 91 × 23 mm, 161 × 26 mm, and 118 × 29 mm) using angiography during/postimplantation. The inflow area (IFA), the tightest narrowing at the height of the annulus (annulus area [AA]) and the outflow area (OFA) were determined (Philipps, Heart Navigator, Release 7.3). Angiographic calibration was performed with the maximum filled S3 implantation balloon in an orthogonal view using the inner diameter of the outer marker under the S3 (using the Allura Xper FD20C, Release 7.2). Measurement of the valve expansion/recoil was performed before postdilation of the implanted valve and at the end of the procedure. In case the angiography determined that the artificial valve diameter was smaller than the diameter of the native valve, postdilation was performed to reduce PVL in case of any leakage. For this purpose the same balloon was used with added 1 or 2 cc of saline.

We defined oversizing as a prosthesis valve area that is larger than the patient aortic valve area. Overfilling was defined as a more-than-nominal filling of the implantation balloon. Overexpansion was defined as an expansion of the valve beyond its nominal diameter and area. Undersizing, underfilling, and underexpansion were defined as the opposite of the aforementioned terms.

Categorical variables are presented as absolute numbers with frequencies (%) and were compared using the Chi-square test (or Fisher's exact test where appropriate). Continuous variables were compared using the student's *t* test or Wilcoxon rank sum test. Pairwise results were corrected using the Bonferroni−Holm−Shaffer procedure for multiple comparisons. An analysis of variance was used for multiple comparisons of continuous variables in groups, using the Games−Howell as a post hoc test. Pearson correlation coefficients were applied to associate the annular area with the valve expansion. All tests were 2-sided and a p-value of <0.05 was considered statistically significant. Data analysis was conducted using SPSS version 20 (IBM, Chicago, Illinois).

Results

The mean patient age was 83.6 years, 56.8% were male, and the mean surgical risk based on the logistic EuroSCORE I of 29.3%. Further patient characteristics and comorbid conditions are presented in Table 1.

Of the 370 patients included in this study, 91 patients received a 23 mm valve, 161 patients a 26 mm valve, and 118 patients a 29 mm valve. The implantation procedure started with underfilling of the balloon in 148 patients, normal filling in 137 patients, and overfilling of the balloon in 85 patients ($p < 0.001$) (Table 2). Postdilation of the implanted valve was performed in 23.0% patients (28.6% of 23 mm vs 19.9% of 26 mm vs 12.7% of 29 mm valve, $p = 0.006$); 71 patients were treated with 1 postdilation and 14 patients received postdilation twice. At the end of the procedures, overfilled balloons (at the start or postdilation) were used in 116 (31.4%) patients (41.8% of 23 mm vs 28.0% of 26 mm vs 28.0% of 29 mm valve, $p = 0.048$).

Table 1
Patient characteristics at baseline (n = 370 patients)

Variable	mean±SD / %
Age (years)	83.6 ± 5.4
Men	56.8%
Left ventricular ejection fraction (%)	55.6 ± 13.6
New York Heart Association III/IV	94.5%
Coronary artery disease	61.3%
Chronic obstructive pulmonary disease (moderate/severe)	21.5%
Peripheral arterial disease	10.3%
Previous myocardial infarction, (<90 days)	9.2%
Major neurological deficits	14.8%
Carotid artery stenosis	8.2%
Pulmonary hypertension (moderate/severe)	23.8%
Renal failure (including dialysis)	17.3%
"Porcelain" aorta	11.1%
Previous coronary artery bypass grafting	10.3%
Previous valve surgery	0.8%
Frailty	8.6%
Mitral valve disease (>II°)	16.5%
Log. European System for cardiac operative risk evaluation I	29.3 ± 1.3

Recoil of valves (Table 3) after implantation was 0.52 mm in IFA, 0.70 in the AA, and 0.69 in OFA ($p < 0.001$ respectively). In absolute terms, recoil was smaller with 23 mm valves compared with the 26 mm and 29 mm valves, but comparable as a proportion of the nominal valve diameter.

The 23 mm valve reached 97.35% of its nominal diameter in the AA, only if the balloon was filled with 2 cc more than its nominal filling (Table 4, Figure 1). At nominal filling it reached a mean diameter of 20.9 mm. The diameter was gradually adjusted to accommodate desired diameters of as little as 19.30 mm by 2 cc underfilling. With 2 cc overfilling, the 23 mm valve reached 100% of its nominal value in the IFA and the OFA. The same pattern was true for the 26 mm valve. It reached 96.50% of its desired diameter in the AA whereas desired diameters were reached in IFA and OFA (99 and 100%, respectively). Within a range of −2 cc and up to +2 cc, it was able to accommodate desired sizes between 22.75 and 25.09 mm in the AA, 13.95 and 25.79 mm in the IFA, and 24.00 to 26.03 mm in the OFA. The 29 mm valve, however, did not completely reach its desired diameter even with 2 cc overfilling and in none of IFA (95.48%), AA (96.11%), or OFA (96.86%). It was able to accommodate desired sizes between 25.79 and 27.87 mm in the AA, 27.21 and 27.69 mm in the IFA, and 27.26 to 28.09 mm in the OFA.

Figure 2 illustrates the relation between the valve expansion after implantation and the annular area with a Pearson correlation coefficient of 0.898 ($p < 0.001$). The set of 23, 26, and 29 mm valves were able to span a desired range between 18 and 29 mm as determined by balloon inflation. As such, annular areas requiring diameters between 18 and 29 mm were suited.

Device success, defined by VARC II, was 96.2%. No root or septal rupture, device migration, mitral valve injury, coronary obstruction, or dissection occurred. A total of 45 of the 370 patients had a pacemaker before the

Table 2
Procedural characteristics (n = 370 patients)

	Total	Valve size (mm)			p-value
		23	26	29	
Annulus area	n.a.	385.26 ± 27.82	488.03 ± 35.39	605.33 ± 37.49	<0.001
Predilation	70/370	18/91 (19.8%)	27/161 (16.8%)	21/118 (17.8%)	0.711
First balloon filling					
Underfilling	148/370	27/91 (29.7%)	73/161 (45.3%)	48/118 (40.7%)	0.050
Normal filling	137/370	36/91 (39.6%)	58/161 (36.0%)	43/118 (36.4%)	0.844
Overfilling	85/370	28/91 (30.8%)	30/161 (18.6%)	27/118 (22.9%)	0.088
Postdilation	85/370	31/91 (34.1%)	39/161 (24.2%)	16/118 (13.6%)	0.001
One dilation	71/85	26/91 (28.6%)	32/161 (19.9%)	13/118 (12.7%)	0.006
Two dilations	14/85	6/91 (6.6%)	6/161 (3.7%)	2/118 (1.7%)	0.184
No postdilation	285/370	60/91 (65.9%)	122/161 (75.8%)	102/118 (86.4%)	0.001
Overfilling (pre- or post- dilation)	116/370	38/91 (41.8%)	45/161 (28.0%)	33/118 (28.0%)	0.048

Start of implantation was with normal filling 137/370, underfilling 148/370, overfilling 85/370 (<0.001).

Table 3
Valve recoil (n = 468 measurements in 370 patients)

	Total	23 mm (n = 129)	26 mm (n = 204)	29 mm (n = 135)	p-value across valve sizes
Recoil IFA (mm)	0.52 ± 0.48 (p <0.001)	0.45 ± 0.39 (p <0.001)	0.51 ± 0.50 (p <0.001)	0.62 ± 0.51 (p <0.001)	0.014
		2.0%	2.0%	2.1%	
Recoil AA (mm)	0.70 ± 0.47 (p <0.001)	0.66 ± 0.40 (p <0.001)	0.70 ± 0.51 (p <0.001)	0.74 ± 0.48 (p <0.001)	0.363
		2.9%	2.7%	2.6%	
Recoil OFA (mm)	0.69 ± 0.49 (p <0.001)	0.66 ± 0.49 (p <0.001)	0.71 ± 0.51 (p <0.001)	0.70 ± 0.48 (p <0.001)	0.669
		2.9%	2.7%	2.4%	

AA = annulus area, tightest narrowing at the height of the annulus; IFA = inflow area; OFA = outflow area.

Table 4
SAPIEN 3 Expansion (n = 450 measurements in 370 patients)

23 mm	-2 cc filling (n = 5)	-1 cc filling (n = 27)	Nominal filling (n = 48)	+1 cc filling (n = 34)	+2 cc filling (n = 14)	p-value
IFA (mm)	20.56 ± 0.86	21.34 ± 0.50	21.97 ± 0.64	22.40 ± 0.53	23.01 ± 0.48	<0.001
(of nominal)	89.39%	92.78%	95.52%	97.39%	100.04%	
AA (mm)	19.30 ± 0.45	20.17 ± 0.78	20.96 ± 0.65	21.65 ± 0.59	22.39 ± 0.50	<0.001
(of nominal)	83.91%	87.70%	91.13%	94.13%	97.35%	
OFA (mm)	20.50 ± 0.34	21.32 ± 0.83	21.84 ± 0.62	22.55 ± 0.59	23.12 ± 0.45	<0.001
(of nominal)	89.13%	92.70%	94.96%	98.04%	100.52%	
26 mm	(n = 39)	(n = 42)	(n = 66)	(n = 38)	(n = 16)	
IFA (mm)	23.95 ± 0.72	24.68 ± 0.92	24.71 ± 0.78	25.07 ± 0.54	25.79 ± 0.69	<0.001
(of nominal)	92.12%	94.92%	95.04%	96.42%	99.19%	
AA (mm)	22.75 ± 0.69	23.73 ± 0.89	23.88 ± 0.77	24.48 ± 0.63	25.09 ± 0.77	<0.001
(of nominal)	87.50%	91.27%	91.85%	94.15%	96.50%	
OFA (mm)	24.00 ± 0.70	24.82 ± 0.85	24.94 ± 0.74	25.51 ± 0.72	26.03 ± 0.74	<0.001
(of nominal)	92.31%	95.46%	95.92%	98.12%	100.12%	
29 mm	(n = 22)	(n = 20)	(n = 46)	(n = 19)	(n = 14)	
IFA (mm)	27.21 ± 0.66	27.72 ± 0.57	27.69 ± 0.75	28.36 ± 0.94	27.69 ± 0.75	<0.001
(of nominal)	93.83%	95.59%	95.48%	97.79%	95.48%	
AA (mm)	25.79 ± 0.55	26.51 ± 0.36	26.74 ± 0.70	27.56 ± 0.87	27.87 ± 0.63	<0.001
(of nominal)	88.93%	91.41%	92.21%	95.03%	96.11%	
OFA (mm)	27.26 ± 0.72	27.89 ± 0.60	28.09 ± 0.74	28.59 ± 0.69	28.09 ± 0.74	<0.001
(of nominal)	94.00%	96.17%	96.86%	98.59%	96.86%	

There were 18 implantations with -3 or +3/+4 that are not described in this table.

procedure (12.2%) and 27 of 325 (8.3%) received a new PPI thereafter. PVL was either none or trace in the majority of patients after the procedure, with 1 patient receiving a 29 mm valve being classified as suffering from mild regurgitation (0.3% of all patients). Rates of PVL marginally increased by day 30 (1.3% mild or

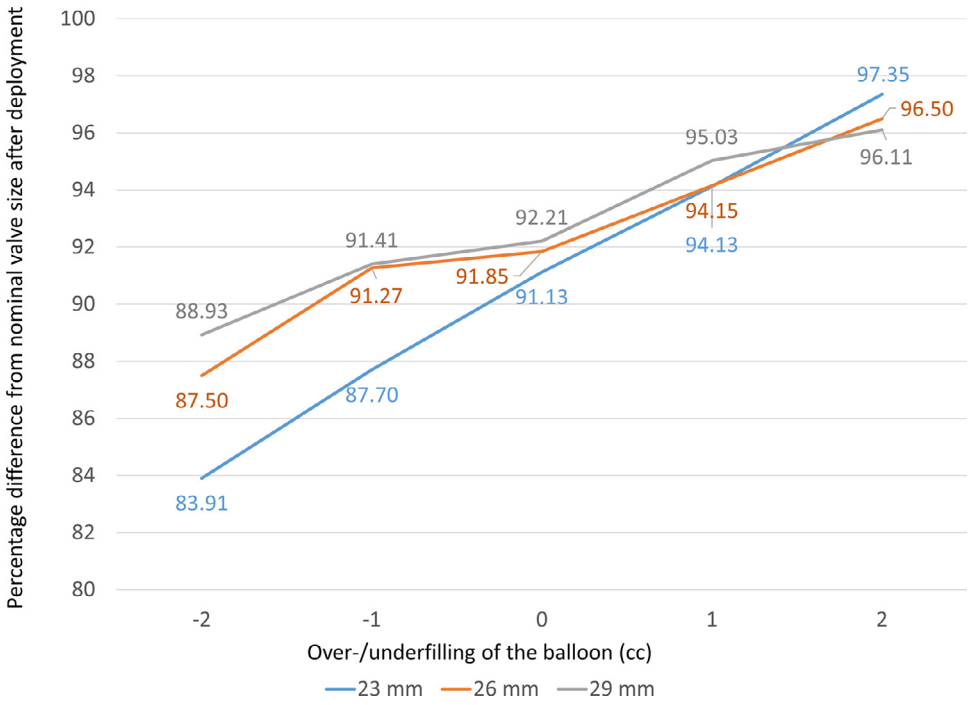

Figure 1. Mean SAPIEN 3 expansion at the narrowest point (AA); n = 468.

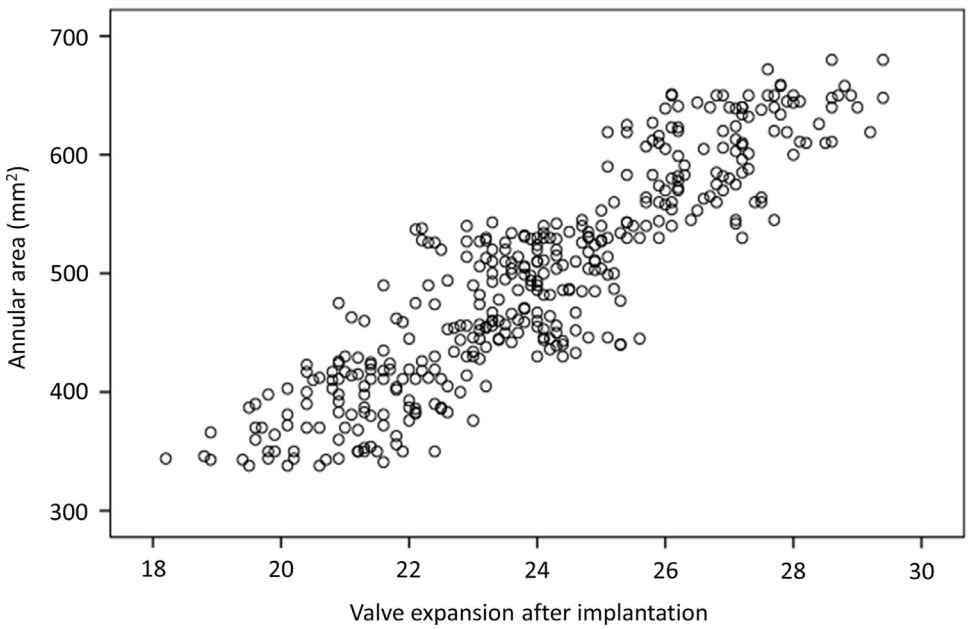

Figure 2. Mean valve expansion at the narrowest point. Pearson correlation coefficient 0.898 ($p < 0.001$); mean annular area 495.23 ± 89.11 mm^2; mean expansion in AA 23.99 ± 2.41 mm; n = 300 implantations, n = 383 SAPIEN 3-expansion values.

moderate) and 1 year (3.3% with mild or moderate); no severe regurgitation was observed (Table 5).

The mean valve gradient was 10.77 mm Hg after the procedure with a mean maximum of 20.8 mm Hg (Table 6). Overall, 1.9% of the patients had a maximum gradient of >40 mm Hg and 2.2% had a mean gradient of >20 mm Hg. Gradient slightly varied at 30 days and 1 year, but without a clinically meaningful impact on the rates of increased mean or maximum pressure gradients in a critical range. For the 12 patients who had a high P_{max} and/or P_{mean} at 1 year, valve sizes were equally represented (n = 4 for each valve).

Discussion

There has been a long-standing interest in appropriate expansion of the SAPIEN valve family. Barbanti et al[12] reviewed the effects of underexpansion of the SAPIEN XT (accomplished by underfilling of the implantation balloon

Table 5
Aortic valve regurgitation (n = 370)

	AI I° (mild)	AI I–II° (mild-moderate)	AI II° (moderate)
Angiography postprocedure			
23 mm (n = 91)	10 (10.0%)	0	0
26 mm (n = 161)	5 (3.1%)	0	0
29 mm (n = 118)	3 (2.5%)	1 (0.8%)	0
Total (n = 370)	18 (4.8%)	1 (0.3%)	0
Echo 30 days			
23 mm (n = 78)	20 (25.6%)	0	1 (1.3%)
26 mm (n = 132)	11 (8.3%)	1 (0.8%)	2 (1.5%)
29 mm (n = 97)	8 (8.2%)	0	0
Total (n = 307)	39 (12.7%)	1 (0.3%)	3 (1.0%)
Echo 365 days			
23 mm (n = 72)	21 (29.2%)	2 (2.8%)	0
26 mm (n = 115)	9 (7.8%)	1 (0.9%)	4 (3.5%)
29 mm (n = 87)	7 (8.0%)	1 (1.1%)	1 (1.1%)
Total (n = 274)	37 (13.5%)	4 (1.5%)	5 (1.8%)

Table 6
Gradients (n = 370)

	mean ± SD	P_{max} >40 mm Hg	P_{mean} >20 mm Hg
Postprocedure/discharge (n = 363)			
P_{max} (mm Hg)	20.8 ± 9.1	7 (1.9%)	
P_{mean} (mm Hg)	10.77 ± 4.8		8 (2.2f%)
30 days (n = 363)			
P_{max} (mm Hg)	19.8 ± 7.2	5 (1.4%)	
P_{mean} (mm Hg)	10.3 ± 3.8		6 (1.6%)
365 days (n = 273)			
P_{max} (mm Hg)	18.9 ± 7.5	10 (2.7%)	
P_{mean} (mm Hg)	11.3 ± 4.3		7 (1.9%)

by 10%) in patients with high-risk features or anatomies. The study compared the results of implantations with underfilled balloons to patients with nominal balloon expansion and found no differences in the echocardiographic area, paravalvular regurgitation, and in-hospital outcomes. Postdilation, however, was required in 10.6% of patients with an initially underexpanded valve compared with 4.6% of patients with nominal expansion. The approach and the outcomes of Barbanti are in line with our strategy of underexpansion when needed. Although Barbanti regarded nominal filling as nominal expansion, however, we found that valves do not open completely with nominal filling but require 2 cc overfilling to achieve this.

Shivaraju et al[13] investigated whether overexpansion of the S3 valve would result in an improved valve seal and reduced rates of PVL. Valves for patients with annuli in the border zone between 2 valve sizes were intentionally 'overexpanded' by overfilling of the deployment balloon. They saw no central insufficiency in any of their 130 patients treated according to their suggestion. They believed that with this strategy an annulus size of up to 740 mm2 with a mean diameter of 31 mm can be treated safely depending on the stiffness and degree of calcification of the native valve and annulus. We partially disagree with their conclusions. In contrast to their data, we implanted, for example, a 23 mm valve 14 times with 2 cc overfilling which resulted in a mean annular area of 393.5 mm2 based on a mean diameter of 22.39 mm. This is smaller than the 430 mm2 in the annular plane they measured in one of their patients. Thus, we would not consider overfilling the implantation balloon for a 23 mm valve with 2 cc as overexpansion. Furthermore, we believe that actual overexpansion of a valve may compromise valve integrity and do not pursue this strategy. In addition, we do not think that implanting a 29 mm valve into a 31 mm annular ring is feasible because of overexpansion of the valve, which should be avoided in any case. The 29 mm valve may be adequate for these patients in case the native valve above the annulus is heavily calcified and because the left ventricular outflow tract (LVOT) may be smaller than the annulus and thus anchor the valve.

From an analysis of the PARTNER II data, Blanke et al[14] suggested that actual oversizing may be a feasible strategy with the S3. Their definition subtracted the 3-dimensional annular area from the transcatheter heart valve (THV) nominal area to determine oversizing. They concluded that oversizing, based on their definition, was a feasible approach to reduce PVL without compromising safety. Based on our own data, which demonstrated underexpansion of the valve with nominal filling of the balloon, we speculate that Blanke et al actually described a strategy to overfill the balloon and arrived at nominal expansion but not overexpansion and, thus, not oversizing. Pellegrini et al[1] had the same misconception as they took the prosthesis nominal area and regarded any value

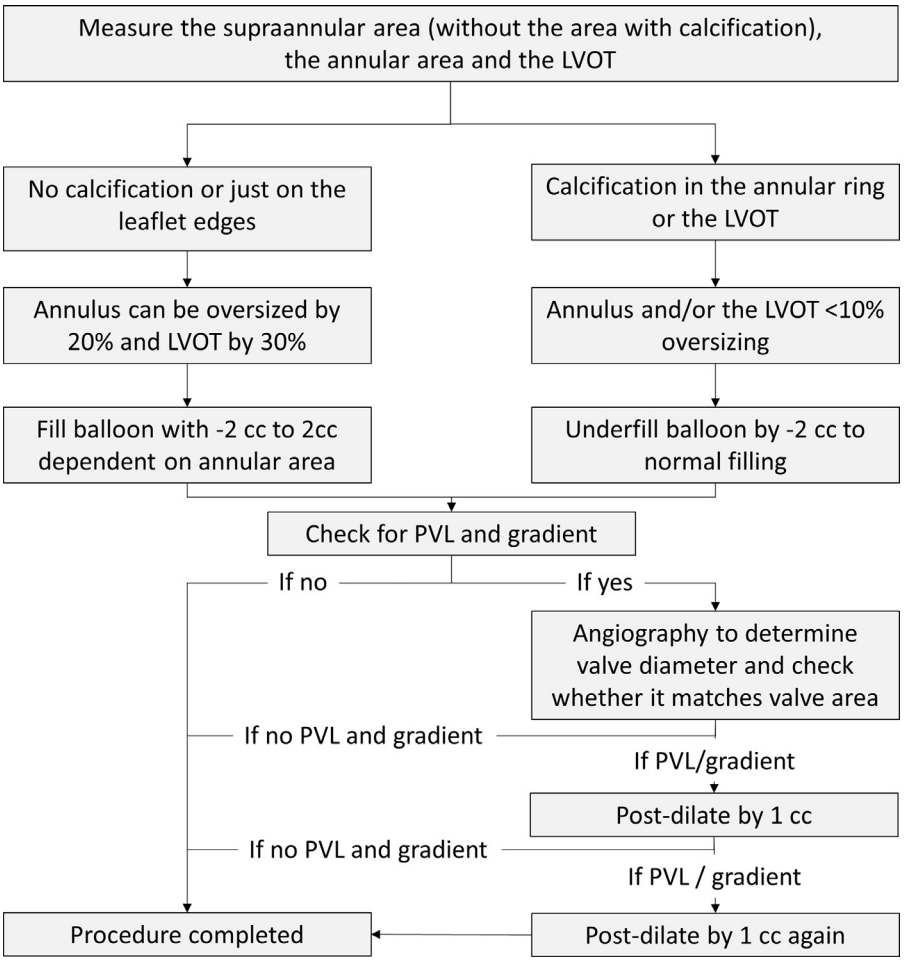

Figure 3. Implantation algorithm. LVOT, left ventricular outflow tract; PVL, paravalvular leak.

above the patient aortic annular area as indicative of oversizing.

As opposed to the strategy of previous authors we foster no general strategy of overexpansion. We suggest that each patient anatomy, degree, and location of calcification and selected valve size needs a tailored with potentially stepwise balloon filling, in an effort to arrive at the appropriate expansion of the selected valve. We suggest that the achieved valvular area should always be determined and compared with the valvular area of the native valve. A pure reference to the nominal opening area of the selected valve appears not to be appropriate.

We also documented that the valve diameter in both the in- and outflow of the valve is higher across valve sizes and balloon filling volumes than in the annular area, which is a well-documented phenomenon for the SAPIEN and, particularly, the SAPIEN XT valves.[13,15] This may be the result of the higher recoil of the valve after implantation which was generally highest compared with the in- and outflow tract. The recoil itself is potentially determined by the more rigid structure of the annular ring, which may have an elastic component moving back toward the center of the valve. This observation was also documented by Shivaraju et al[13] who observed the in- and out-flow part of the overexpanded S3 valves to be flared and reaching the maximum diameter, which is about 10% larger by area than the stated nominal size of the THV.

None of the authors observed relevant complications with their strategy and no annular ruptures were observed in any of the case series reported.[1,12–14] This is less surprising but not exactly reassuring as Barbanti reported his results based on a group of 47 patients and Shivaraju included "more than 30 patients with initial deliberate overexpansion of the THV and 100 patients with subsequent postdilation of a nominally deployed valve."[13] Taking into consideration that annular ruptures occurs in 0.6% of patients who underwent valve implantation, it makes the observation of such an untoward event extremely unlikely in small case series.[4] Larger case series, such as our study with 370 documented patients and the study by Blanke et al[14] that reported the events in 835 patients, add to these investigations, where approximately 3 and 5 cases, respectively, of annular ruptures would be expected.

Increased rates of PPI may be an additional concern after prosthesis oversizing. Pellegrini et al[1] observed increased PPI rates with oversizing and concluded that there is no ideal range of oversizing to minimize both device failure and PPI. Seth et al[16] suggested that selective balloon-overfilling, rather than choosing a larger valve size, may be an appropriate strategy to confine rates of PPI. With our

strategy, we observed a PPI rate of 8.3% for a series of cases performed between 2015 and 2018. This is low compared with a number of case series specifically looking at PPI rates with the S3, which observed rates between 14.4% and 20.4%. [17–23] Beyond oversizing being identified as one of the variables associated with increased PPI rates, preexisting conduction disturbance, aortic valve calcification, and implantation depth have been identified as further relevant variables that are unrelated to the expansion of valves.

Based on the reported experience we developed an Implantation Algorithm (Figure 3) that serves to optimize the THV size, reduce the risk of PVL, PPI, and annular rupture. As a first step, the annular area, the supraannular area and the LVOT dimensions are obtained. If calcification is found in the annular ring or LVOT this is a concern, as calcification cannot be displaced and will be pushed into the annular ring wall with the potential for rupture. Calcification only at the leaflet edges has no impact on the implantation procedure with normal but not shallow sinus. If there is no annular/LVOT calcium, the annulus can be oversized by 20% and the LVOT by 30%. For example, a patient with an annular area of 420 mm2 would receive a 23 mm valve straight with a higher filling volume, as the valve will not expand properly with nominal filling. In case of annular calcification and an annular area of, for example, 360 mm2, implantation will be more cautious. In a first step the balloon would be underfilled by 1 to 2 ml. Following these initial steps, the implantation result is inspected. If there is no PVL and no gradient the procedure is regarded complete. Should there be a PVL, the size of the valve is determined. If the expansion of the valve matches the previously determined valve area it will not be postdilated. If, however, the valve expansion is below the previously determined valve area it will be postdilated (even in the presence of calcium) to minimize PVL; the additional filling volume is dependent on the available space and may even be performed in 2 steps.

Conclusion

In conclusion, expansion of the S3 valve is highly dependent on the filling volume of the implantation balloon. At nominal filling, the difference to the normal size is 7.8% to 8.9%. Only when the implantation balloon is overfilled by 2 cc does the S3 valve almost reaches nominal size. An optimized balloon filling algorithm resulted in appropriate valve gradients and low levels of PVL, low rates of PPI and no annular rupture.

Authors Contribution

Gerhard Schymik: conceptualization, methodology, investigation, writing − original draft, writing review & editing, visualization. Milos Radakovic: investigation, writing review & editing, visualization. Peter Bramlage: conceptualization, methodology, investigation, writing − original draft, visualization. Claus Schmitt: investigation, writing review & editing, visualization. Panagiotis Tzamalis: conceptualization, methodology, investigation, writing − review & editing, visualization.

Conflict of Interest

Gerhard Schymik is a proctor and Peter Bramlage consultant for Edwards Lifesciences. No conflict of interest was declared by the other authors.

Data availability statement

The aggregated data used to support the findings of this study are available from the corresponding author upon reasonable request.

1. Pellegrini C, Kim WK, Holzamer A, Walther T, Mayr NP, Michel J, Rheude T, Nunez J, Kasel AM, Trenkwalder T, Kaess BM, Joner M, Kastrati A, Schunkert H, Hilker M, Mollmann H, Hengstenberg C, Husser O. Multicenter evaluation of prosthesis oversizing of the SAPIEN 3 transcatheter heart valve. Impact on device failure and new pacemaker implantations. *Rev Esp Cardiol (Engl Ed)* 2019;72:641–648.
2. 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.
3. 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.
4. Schymik G, Heimeshoff M, Bramlage P, Wondraschek R, Suselbeck T, Gerhardus J, Luik A, Posival H, Schmitt C, Schrofel H. Ruptures of the device landing zone in patients undergoing transcatheter aortic valve implantation: an analysis of TAVI Karlsruhe (TAVIK) patients. *Clin Res Cardiol* 2014;103:912–920.
5. Stundl A, Rademacher MC, Descoups C, Weber M, Sedaghat A, Grube M, Hammerstingl C, Mellert F, Vasa-Nicotera M, Welz A, Grube E, Werner N, Nickenig G, Sinning JM. Balloon post-dilation and valve-in-valve implantation for the reduction of paravalvular leakage with use of the self-expanding CoreValve prosthesis. *EuroIntervention* 2016;11:1140–1147.
6. Webb JG, Binder RK. Post-dilating transcatheter heart valves. *JACC Cardiovasc Interv* 2012;5:513–514.
7. Takagi K, Latib A, Al-Lamee R, Mussardo M, Montorfano M, Maisano F, Godino C, Chieffo A, Alfieri O, Colombo A. Predictors of moderate-to-severe paravalvular aortic regurgitation immediately after CoreValve implantation and the impact of postdilatation. *Catheter Cardiovasc Interv* 2011;78:432–443.
8. Kleczynski P, Dziewierz A, Daniec M, Bagienski M, Rzeszutko L, Sorysz D, Trebacz J, Sobczynski R, Tomala M, Dudek D. Impact of post-dilatation on the reduction of paravalvular leak and mortality after transcatheter aortic valve implantation. *Kardiol Pol* 2017;75:742–748.
9. Tzamalis P, Herzberger V, Bergmann J, Wuerth A, Bramlage P, Schroefel H, Schmitt C, Schymik G. The association of diabetes mellitus treated with oral antidiabetic drugs and insulin with mortality after transcatheter valve implantation: a 3-year follow-up of the TAVIK registry. *Cardiovasc Diabetol* 2019;18:63.
10. Schymik G, Bramlage P, Herzberger V, Bergmann J, Conzelmann LO, Wurth A, Luik A, Schrofel H, Tzamalis P. Impact of dialysis on the prognosis of patients undergoing transcatheter aortic valve implantation. *Am J Cardiol* 2019;123:315–322.
11. Schymik G, Herzberger V, Bergmann J, Bramlage P, Conzelmann LO, Wurth A, Luik A, Schrofel H, Tzamalis P. Evolution of transcatheter aortic valve implantation over 7 years: results of a prospective single-centre registry of 2000 patients in a large municipal hospital (TAVIK Registry). *BMJ Open* 2018;8:e022574.

12. 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.
13. Shivaraju A, Kodali S, Thilo C, Ott I, Schunkert H, von Scheidt W, Leon MB, Kastrati A, Kasel AM. Overexpansion of the SAPIEN 3 transcatheter heart valve: a feasibility study. *JACC Cardiovasc Interv* 2015;8:2041–2043.
14. Blanke P, Pibarot P, Hahn R, Weissman N, Kodali S, Thourani V, Parvataneni R, Dvir D, Naoum C, Norgaard BL, Douglas P, Jaber W, Khalique OK, Jilaihawi H, Mack M, Smith C, Leon M, Webb J, Leipsic J. Computed tomography-based oversizing degrees and incidence of paravalvular regurgitation of a new generation transcatheter heart valve. *JACC Cardiovasc Interv* 2017;10:810–820.
15. Nombela-Franco L, Ribeiro HB, Urena M, Pasian S, Allende R, Doyle D, Delarochelliere R, Delarochelliere H, Laflamme L, Laflamme J, Jerez-Valero M, Cote M, Pibarot P, Larose E, Dumont E, Rodes-Cabau J. Incidence, predictive factors and haemodynamic consequences of acute stent recoil following transcatheter aortic valve implantation with a balloon-expandable valve. *EuroIntervention* 2014;9:1398–1406.
16. Sheth T, Natarajan MK, Kreatsoulas C, Whitlock R, Parry D, Chu V, Smith A, Velianou JL. Avoiding S3 Valve Over-Sizing by Deployment Balloon Over-Filling: Impact on Rates of Permanent Pacemaker and Other Procedural Complications During TAVR. *J Invasive Cardiol* 2018;30:23–27.
17. Fujita B, Kutting M, Seiffert M, Scholtz S, Egron S, Prashovikj E, Borgermann J, Schafer T, Scholtz W, Preuss R, Gummert J, Steinseifer U, Ensminger SM. Calcium distribution patterns of the aortic valve as a risk factor for the need of permanent pacemaker implantation after transcatheter aortic valve implantation. *Eur Heart J Cardiovasc Imaging* 2016;17:1385–1393.
18. Maeno Y, Abramowitz Y, Kawamori H, Kazuno Y, Kubo S, Takahashi N, Mangat G, Okuyama K, Kashif M, Chakravarty T, Nakamura M, Cheng W, Friedman J, Berman D, Makkar RR, Jilaihawi H. A highly predictive risk model for pacemaker implantation after TAVR. *JACC Cardiovasc Imaging* 2017;10:1139–1147.
19. Tarantini G, Mojoli M, Purita P, Napodano M, D'Onofrio A, Frigo A, Covolo E, Facchin M, Isabella G, Gerosa G, Iliceto S. Unravelling the (arte)fact of increased pacemaker rate with the Edwards SAPIEN 3 valve. *EuroIntervention* 2015;11:343–350.
20. Mauri V, Reimann A, Stern D, Scherner M, Kuhn E, Rudolph V, Rosenkranz S, Eghbalzadeh K, Friedrichs K, Wahlers T, Baldus S, Madershahian N, Rudolph TK. Predictors of permanent pacemaker implantation after transcatheter aortic valve replacement with the SAPIEN 3. *JACC Cardiovasc Interv* 2016;9:2200–2209.
21. De Torres-Alba F, Kaleschke G, Diller GP, Vormbrock J, Orwat S, Radke R, Reinke F, Fischer D, Reinecke H, Baumgartner H. Changes in the pacemaker rate after transition from Edwards SAPIEN XT to SAPIEN 3 transcatheter aortic valve implantation: the critical role of valve implantation height. *JACC Cardiovasc Interv* 2016;9:805–813.
22. Husser O, Pellegrini C, Kessler T, Burgdorf C, Thaller H, Mayr NP, Kasel AM, Kastrati A, Schunkert H, Hengstenberg C. Predictors of permanent pacemaker implantations and new-onset conduction abnormalities with the SAPIEN 3 balloon-expandable transcatheter heart valve. *JACC Cardiovasc Interv* 2016;9:244–254.
23. Gonska B, Seeger J, Kessler M, von Keil A, Rottbauer W, Wohrle J. Predictors for permanent pacemaker implantation in patients undergoing transfemoral aortic valve implantation with the Edwards Sapien 3 valve. *Clin Res Cardiol* 2017;106:590–597.