One-Year Follow-Up of Conduction Abnormalities After Transcatheter Aortic Valve Implantation With the SAPIEN 3 Valve

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Long-term evolution of new-onset conduction abnormalities and need of permanent pacemaker implantation (PPI) after transcatheter aortic valve implantation (TAVI) have not been extensively evaluated. We describe the incidence and time course of new conduction abnormalities and the rate of PPI with the new-generation transcatheter aortic valve prosthesis Edwards SAPIEN 3 (S3). In total, 266 patients with severe aortic stenosis who underwent TAVI were retrospectively analyzed. Twelve-lead electrocardiograms at baseline, after TAVI, at discharge, at 1-, 6-, and 12-month follow-up were evaluated to identify conduction abnormalities and PPI requirements to investigate the correlates of PPI. After TAVI, a significant increase in PR interval duration and in QRS complex width was observed. New-onset left bundle branch block was observed in 65 patients (24%) after TAVI. The number of patients with left bundle branch block was maximum at hospital discharge and decreased at 12-month follow-up (39% and 32%, respectively). Thirty-five patients (13%) required PPI during the follow-up. However, paced rhythm was only observed in 7% of the patients with a complete 12-month follow-up. Patients who underwent PPI had a higher prevalence of first-degree atrioventricular block, complete right bundle branch block, and wider QRS complex at baseline. Baseline right bundle branch block and QRS width immediately after TAVI were the only variables independently associated with PPI. In conclusion, conduction disorders have a temporary nature after TAVI and showed a trend toward stabilization during the following months. With this new-generation device, the incidence of new conduction abnormalities requiring PPI is relatively low. **(Am J Cardiol 2019;124:1239−1245)**

Transcatheter aortic valve implantation (TAVI) has become the treatment of choice in patients with symptomatic severe aortic stenosis (AS) and contraindications or high risk for surgical aortic valve replacement.[1] Recently, this treatment has been extended to patients with intermediate operative risk.[2] The increased life expectancy of the population together with the current expansion of the indications for TAVI toward younger and lower surgical risk patients call for efforts to obtain similar (if not better) results than surgical aortic valve replacement which is currently the preferred treatment in these subpopulations.[3] The development of conduction abnormalities and the need for permanent pacemaker implantation (PPI) is a common complication of TAVI. Using the new-generation transcatheter aortic valves, the incidence of PPI ranges 2.3% to 36.1%.[4] This broad range of PPI incidence relies on the inclusion of patients with pre-existent conduction abnormalities, anatomical factors such as calcification of the left ventricular (LV) outflow tract, and procedural factors such as the design and depth of implantation of the transcatheter aortic valve prosthesis. Interestingly, the time course of TAVI-induced conduction abnormalities has not been fully elucidated and high-degree atrioventricular (AV) block may occur late (after 1 week) in a significant proportion of patients.[5] The present study describes the incidence of new conduction abnormalities after TAVI and their time course during 1-year follow-up using the Edwards SAPIEN S3 prosthesis (Edwards Lifesciences, Irvine, CA). Moreover, the need for PPI and factors associated with this complication are investigated.

Methods

Patients with severe AS or degenerated aortic surgical bioprosthesis who underwent TAVI with the balloon-expandable Edwards SAPIEN S3 valve between February 2014 and February 2018 at the Leiden University Medical Center (The Netherlands) were analyzed (n = 327). Patients with a permanent pacemaker at baseline were excluded (n = 61). The remaining 266 patients were included in this single-center retrospective analysis.

The indication for TAVI was established by the multidisciplinary heart team. Demographic and clinical characteristics were prospectively collected in the departmental Cardiology Information System (EPD-Vision; Leiden University Medical

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Center, Leiden, the Netherlands) and retrospectively analyzed. Twelve-lead electrocardiogram (ECG) acquired at baseline, immediately after the procedure, at hospital discharge, and at 1-, 6-, and 12-month follow-up, was evaluated. The occurrence of new cardiac conduction abnormalities after TAVI was recorded. These included any degree of new-onset AV block, left or right bundle branch block (LBBB and RBBB, respectively), unspecific ventricular conduction delay, atrial fibrillation (AF), and need for PPI. The changes over time in frequency of conduction abnormalities were analyzed during the follow-up. Among various clinical, electrocardiographic, and procedural variables, the associates of new PPI were investigated. The institutional review board approved this retrospective analysis of clinically acquired data and waived the need for patient-written informed consent.

Standard 12-lead ECGs were obtained at baseline and immediately after the procedure, at hospital discharge, and at 1-, 6-, and 12-month follow-up. Calibration of the ECG was set at 0.1 mV/mm and the paper speed was 25 mm/s. Heart rhythm, PR interval duration, QRS width, the presence of AV block, LBBB, RBBB, or unspecific ventricular conduction delay were assessed. A first-degree AV block was defined as a PR interval ≥200 milliseconds. RBBB was defined as a QRS width >120 milliseconds in the presence of typical RBBB morphology (rR' in V1). LBBB was defined as QRS duration >120 milliseconds and QRS complex negative in V1 with small R or no R. When the patient presented with paced rhythm, the duration of the QRS was not measured.

Preoperative transthoracic echocardiography was performed using commercially available ultrasound systems (Vivid 7, Vivid E9 and E95; General Electric Healthcare, Horten, Norway) equipped with 3.5 MHz or M5S-D transducers. Parasternal, apical, subcostal, and suprasternal views were obtained according to current recommendations.[6] The echocardiographic data were digitally stored in cine-loop format and data were retrospectively analyzed using commercially available software (EchoPac 112.0.1; GE Medical Systems, Horten, Norway). LV dimensions and ejection fraction (LVEF) were assessed as recommended.[6] Preoperative aortic valve function was evaluated using color, continuous and pulsed wave Doppler according to current recommendations.[6] Aortic valve area was calculated by the continuity equation and indexed for body surface area.[1] In addition, preoperative multidetector computed tomographic data were acquired to assess the aortic annulus dimensions, aortic valve calcification grade, and the feasibility of transfemoral access.

Edwards SAPIEN S3 transcatheter heart valves were used for all the patients. Selection of the device size was based on measurements of the aortic annulus obtained with multidetector row computed tomography. TAVI was performed via transfemoral access, if adequate iliofemoral arterial anatomy was present, or via transapical access otherwise. Balloon dilation was performed before implantation of the transcatheter valve in patients with severe native AS. Positioning and deployment of the device was achieved using fluoroscopic guidance. A temporary pacemaker was used for rapid right ventricular pacing during balloon predilatation as well as during implantation of the prosthesis.

Patients were followed up at the outpatient clinic at 1, 6, and 12 months. An ECG was performed at each outpatient visit. The decision to implant a permanent pacemaker was left at the discretion of the treating physician according to the current guidelines,[7,8] and the indication was reported for every patient.

Continuous variables are expressed as mean ± standard deviation or as the median (interquartile range [IQR]) and were compared using the unpaired Student *t* test or Mann-Whitney U test as appropriate. Categorical variables are presented as numbers and percentages and were compared with the chi-square test or Fisher's exact test as appropriate.

The Wilcoxon signed-rank test (for continuous variables) and the McNemar test (for binomial variables) were used to perform paired comparisons between 2 time-points. Univariable and multivariable logistic regression analyses were performed to identify independent clinical and ECG correlates of PPI. All variables with a p value <0.10 on univariable logistic regression analysis were included in the multivariable model. The odds ratio (OR) and 95% confidence interval (CI) were calculated and reported. All analyses were performed with the SPSS for Windows, version 23.0 (SPSS, Armonk, NY). All statistical tests were two-sided. A p value <0.05 was considered statistically significant.

Results

A total of 266 patients (mean age 80 ± 7, 52% male) were included in the present analysis. Baseline clinical, imaging, and procedural characteristics of the overall population are shown in Table 1.

The time course of cardiac conduction abnormalities after S3 valve implantation is presented in Table 2. Most patients were in sinus rhythm (SR) at baseline and the majority remained in SR during follow-up (Table 2). The mean changes in PR interval duration and in QRS complex width throughout the entire study period are shown in Figure 1. After TAVI, there was an increase in the PR interval duration and a significant increase in the QRS complex width compared with baseline. The PR interval duration showed its maximum values at hospital discharge (183 ± 32 milliseconds before treatment vs 195 ± 43 milliseconds at hospital discharge, p <0.001) and significantly decreased at follow-up (195 ± 43 milliseconds at hospital discharge vs 188 ± 40 milliseconds at 6-month follow-up, p = 0.039). At 12-month follow-up, the PR duration was slightly increased compared with 6 months (188 ± 40 milliseconds vs 192 ± 40 milliseconds, p = 0.045). Similarly, the QRS width was largest at discharge (111 ± 25 milliseconds at baseline vs 128 ± 30 milliseconds at discharge, p <0.001) and significantly decreased at follow-up (128 ± 30 milliseconds at discharge vs 121 ± 28 milliseconds at 1 month, p <0.001). Subsequently, the QRS width remained stable (Figure 1). The percentage of patients with first-degree AV block was significantly higher at discharge compared with baseline (18% at baseline vs 25% at hospital discharge, p = 0.002; Table 2). Of note, at 12-month follow-up, the number of patients with first-degree AV block increased (Table 2). New-onset complete LBBB was observed in 65 patients (24%) after TAVI. The number of patients with LBBB was maximum at hospital discharge and decreased at 12-month follow-up (from 39% to 32%, respectively).

Table 1
Baseline clinical, echocardiographic, and procedural characteristics

Variable	Overall population (n = 266)
Age (y)	80 ± 7
Men	139 (52%)
Body mass index (kg/m^2)	26 ± 5
NYHA functional class III or IV	164 (62%)
Hypertension	187 (70%)
Dyslipidemia	148 (56%)
Diabetes mellitus	75 (28%)
Peripheral artery disease	58 (22%)
Past smoker	46 (17%)
Prior myocardial infarction	59 (22%)
Chronic obstructive pulmonary disease	40 (15%)
Creatinine level (mmol/L)	94 [74-118]
Prior myocardial revascularization (PCI or CABG)	137 (52%)
Logistic EuroSCORE (%)	14.7±8.7
Medical treatment	
Beta-blocker	146 (55%)
Calcium antagonist	53 (20%)
Echocardiographic variables	
Left ventricular ejection fraction (%)	53 ± 15
Aortic valve area (cm^2)	0.7 ± 0.2
Mean transvalvular gradient (mmHg)	43 ± 17
Peak transvalvular gradient (mmHg)	69 ± 24
Computed tomography variables	
Aortic annulus area (mm^2)	475.7 ± 97.0
Aortic valve calcification (Hounsfield units)	3364.7 ± 1681.6
Eccentricity index	0.21 ± 0.07
Procedural variables	
Transfemoral access	223 (84%)
Transapical access	43 (16%)
Valve-in-valve procedure	4 (2%)
Prosthesis size (mm)	
23	84 (32%)
26	100 (38%)
29	82 (30%)
Need of balloon postdilation	34 (13%)
Grade of oversizing prosthesis (%)	13.2±11.4

Data are presented as mean value ± standard deviation or as frequencies and percentages.

The percentage of patients who remained free of any type of bundle branch block decreased from 74% at baseline to 47% at discharge.

After TAVI, 35 patients (13%) required PPI during a 12-month follow-up period. The median time from TAVI to PPI was 4 days (IQR: 3 to 25 days). The majority of the subjects were implanted before hospital discharge. Indications for PPI are shown in Table 3 and the precise timing of implantation is displayed in Figure 2. Importantly, paced rhythm was present in only 7% of the patients of the total population at hospital discharge. This proportion of patients remained unchanged during the entire follow-up period (9% at 6 months and 7% at 12 months, p = 1.000). There were no significant differences in clinical, imaging, and procedural characteristics between patients who underwent PPI versus patients who did not (Table 4). Patients who underwent PPI had a higher prevalence of first-degree AV block, complete RBBB and wider QRS complex at baseline compared with their counterparts (Table 5). Table 6 demonstrates the

Table 2
Electrocardiographic changes during 12-month follow-up

Variables		Pre-TAVI (n = 266)	Post-TAVI (n = 265)	Predischarge (n = 259)	1 month (n = 216)	6 months (n = 171)	12 months (n = 142)
Rhythm	Sinus rhythm	192 (72%)	191 (72%)	170 (66%)	155 (72%)	123 (72%)	99 (70%)
	Atrial fibrillation	74 (28%)	64 (24%)	69 (27%)	47 (22%)	33 (19%)	33 (23%)
	Idioventricular	0	0	1 (0.4%)	0	0	0
	Ventricular paced	0	10 (4%)	19 (7%)	14 (7%)	15 (9%)	10 (7%)
Atrioventricular block	First degree	49 (18%)	52 (20%)	64 (25%)	56 (26%)	39 (23%)	40 (28%)
Bundle branch block	Right	31 (12%)	25 (9%)	17 (7%)	13 (6%)	11 (6%)	13 (9%)
	Left	37 (14%)	102 (38%)	100 (39%)	69 (32%)	51 (30%)	45 (32%)
	None	198 (74%)	128 (48%)	123 (47%)	120 (55%)	94 (55%)	74 (52%)
Cumulative percentage of PPI implanted for each time interval		0	1 (0.4%)	29 (11%)	30 (11%)	35 (13%)	35 (13%)
New PPI for each time interval		0	1 (0.4%)	28 (11%)	1 (0.5%)	5 (3%)	0

Data are presented as frequencies and percentages. PPI = permanent pacemaker implantation; TAVI = transcatheter aortic valve implantation.

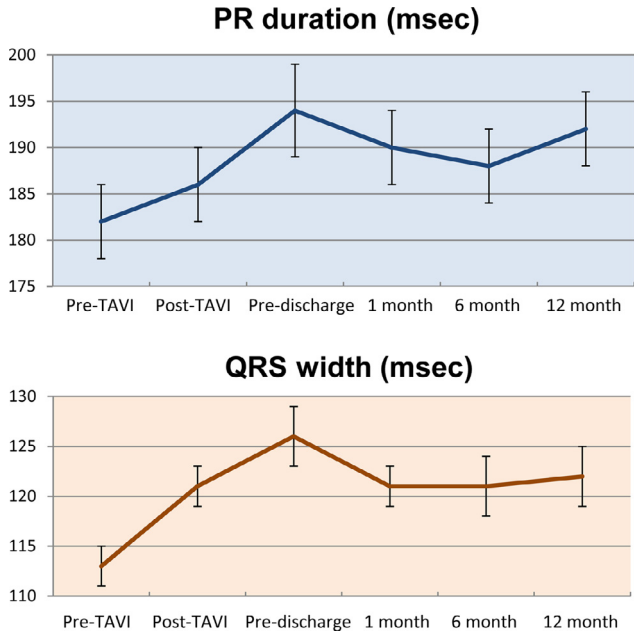

Figure 1. Changes in PR interval duration (A) and in QRS width (B) following TAVI. Error bars indicate standard errors. *p value stands for comparison between baseline values and predischarge values.

Table 3
Indications for permanent pacemaker implantation

Indication	N (%)
Atrioventricular block grade III	26 (74%)
Bradyarrhythmia with left bundle branch block	3 (8%)
Cardiac resynchronization therapia and His ablation	2 (6%)
Implantable cardioverter defibrillator	1 (3%)
Bradyarrhythmia	1 (3%)
Atrioventricular block grade II (Mobitz 2)	2 (6)

Data are presented as frequencies and percentages.

univariable and multivariable logistic regression analyses to identify correlates of PPI during 12-month follow-up after TAVI. The presence of RBBB, first-degree AV block, and a wider QRS complex at baseline together with a wider QRS complex at the ECG performed immediately after TAVI were included in the final multivariable model. Baseline RBBB and QRS width immediately after TAVI were the only variables independently associated with PPI.

Discussion

Cardiac conduction abnormalities are relatively frequent in patients with severe AS, as the aortic valve is in close anatomical proximity with the AV node and the origin of the left bundle branch, which can be affected by the degeneration and calcification processes that cause aortic valve stenosis.[9] In addition, both surgical aortic valve replacement and TAVI can induce conduction abnormalities.[10] In TAVI, direct trauma or compression of the AV node and left bundle branch can occur during balloon dilatation of the native valve and transcatheter valve deployment, leading to AV block and LBBB. Periprocedural edema of the left ventricular outflow tract is the most frequent cause of these conduction abnormalities.[4] Importantly, edema of the AV node and left bundle branch area is transient and conduction abnormalities may resolve over time. The design of the S3 prosthesis is characterized by a stent 3 to 4 mm longer than that of the earlier SAPIEN XT and an adaptive external tissue seal aiming at reducing paravalvular leak.[3] The greater length of S3 valve potentially extends the area of contact with the septum, potentially increasing the probability of AV block and other conduction disorders.[11] However, during the valve deployment, the stent shortens from the ventricular end, resulting in higher position and less damage of the AV node and low incidence of PPI.[12]

Several studies evaluated the ECG changes over time secondary to TAVI, demonstrating the transient nature of the new-onset conduction abnormalities.[13–15] Van Gils et al[13] demonstrated that in patients without conduction abnormalities before TAVI, a persistent QRS widening after procedure was able to identify patients at higher risk for PPI. However, the follow-up period was limited (14 days) and no distinction between different valve prosthesis

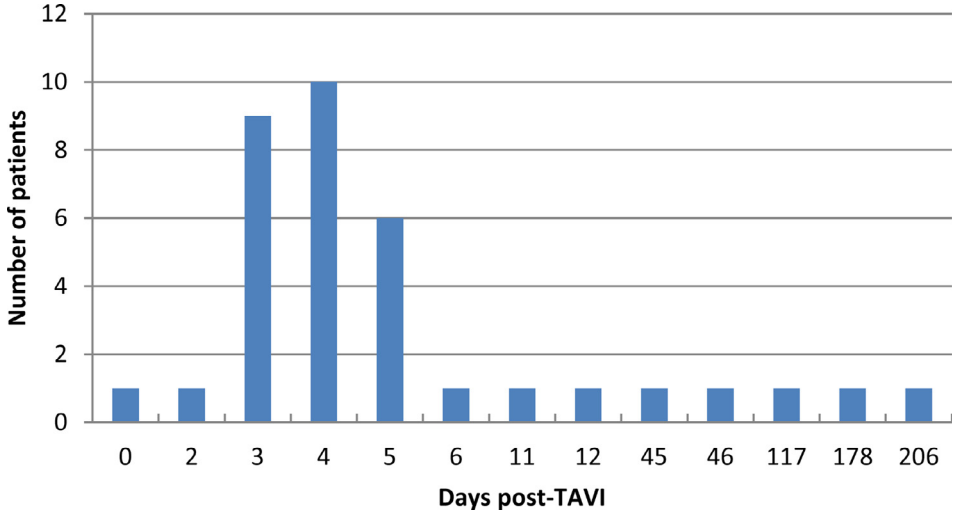

Figure 2. Timing of permanent pacemaker implantation after TAVI. TAVI = transcatheter aortic valve implantation.

Table 4
Clinical, procedural, and echocardiographic parameters in patient receiving permanent pacemaker versus patients without

Variable	Permanent pacemaker implantation		p Value
	Yes (n = 35)	No (n = 231)	
Age (y)	79 ± 8	80 ± 7	0.586
Men	19 (54%)	120 (52%)	0.796
Body mass index (kg/m^2)	26 ± 5	26 ± 5	0.477
New York Heart Association functional class III or IV	11 (31%)	62 (27%)	0.772
Hypertension	25 (71%)	162 (70%)	0.904
Dyslipidemia	19 (54%)	129 (56%)	0.842
Diabetes mellitus	8 (23%)	67 (29%)	0.443
Peripheral artery disease	6 (17%)	52 (23%)	0.466
History of smoking	7 (20%)	39 (17%)	0.658
Prior myocardial infarction	8 (23%)	51 (22%)	0.928
Chronic obstructive pulmonary disease	4 (11%)	36 (16%)	0.421
Creatinine level (mmol/L)	127 ± 125	108 ± 66	0.156
Prior myocardial revascularization (percutaneous coronary intervention or coronary artery by-pass graft)	19 (54%)	118 (52%)	0.688
Logistic EuroSCORE (%)	13 ± 8	15 ± 9	0.214
Echocardiographic variables			
Left ventricular ejection fraction (%)	52 ± 15	53 ± 15	0.770
Aortic valve area (cm^2)	0.72 ± 0.20	0.75 ± 0.19	0.325
Mean gradient (mm Hg)	44 ± 14	43 ± 16	0.628
Peak gradient (mm Hg)	70 ± 20	68 ± 25	0.700
Computed tomography variables			
Aortic annulus area (mm^2)	468.1 ± 91.2	476.8 ± 97.9	0.648
Aortic valve calcification (Hounsfield units)	3234.4 ± 1696.3	3381.7 ± 1685.5	0.739
Eccentricity index	0.21 ± 0.08	0.20 ± 0.07	0.454
Procedural variables			
Transfemoral access	31 (89%)	192 (83%)	0.622
Transapical access	4 (11%)	39 (17%)	0.622
Prosthesis size (mm)			
23	9 (26%)	75 (32%)	0.423
26	13 (37%)	87 (38%)	0.953
29	13 (37%)	69 (30%)	0.385
Grade of oversizing prosthesis (%)	16.3 ± 13.4	12.8 ± 11.0	0.119
Need of postballoon dilation	5 (14%)	29 (13%)	0.775

Data are reported as mean and standard deviation or as frequencies and percentages as appropriate.

Table 5
Electrocardiographic characteristics between patients with and without permanent pacemaker implantation

		PPI (n = 35)	No PPI (n = 231)	p Value
Rhythm	Sinus rhythm	26 (74%)	166 (72%)	0.766
	Atrial fibrillation	9 (26%)	65 (28%)	0.766
PR duration (ms)		196 ± 37	182 ± 32	0.078
QRS width (ms)		125 ± 30	110 ± 24	0.005
Atrioventricular block	1st degree	11 (31%)	38 (16%)	0.032
	2nd degree	1 (3%)	1 (0.4%)	0.127
Bundle branch block	Right	12 (34%)	17 (7%)	<0.001
	Left	3 (9%)	38 (16%)	0.229

Data are presented as frequencies and percentages.

implanted was performed. Piazza et al[14] studied only patients treated with the self-expanding Medtronic CoreValve prosthesis and reported that patients who developed new-onset LBBB had persisting LBBB at 6 months of follow-up. Leire et al[15] analyzed exclusively 59 patients who received the S3 valve and showed that advanced AV block requiring PPI occurred in 2 patients. Conversely, the incidence of minor conduction abnormalities was relatively high (39% of patients demonstrated new-onset LBBB). In half of these cases, the new conduction abnormality was transient, although the time course of conduction disorders was analyzed only until hospital discharge. This difference may be due to technical factors and design of the balloon-expandable valve compared with the self-expandable prosthesis. Of note, a recent work of De Torres Alba et al[16] analyzed 606 patients receiving the S3 valve and demonstrated that the risk of PPI remained high beyond 7 days after TAVI and that this risk cannot be accurately predicted

Table 6
Determinants of PPI during 12-month follow-up after TAVI

Variables	Univariate analysis			Multivariate analysis		
	Odds ratio	95% Confidence interval	p Value	Odds ratio	95% Confidence interval	p Value
Age (y)	0.986	0.939-1.036	0.585			
Pre-TAVI sinus rhythm	1.131	0.503-2.544	0.766			
Pre-TAVI atrial fibrillation	0.884	0.393-1.988	0.766			
Pre-TAVI right bundle branch block	6.568	2.793-15.444	<0.001	5.029	1.163-21.750	0.031
Pre-TAVI left bundle branch block	0.476	0.774-3.232	0.238			
Pre-TAVI first-degree atrioventricular block	2.509	0.139-1.635	0.036	2.209	0.833-5.862	0.111
Pre-TAVI QRS width	1.021	1.008-1.034	0.001	0.975	0.947-1.005	0.099
Post-TAVI left bundle branch block	1.581	0.774-3.232	0.209			
New-onset post TAVI left bundle branch block	2.034	0.959-4.315	0.064	0.897	0.271-2.974	0.859
Post-TAVI QRS width	1.041	1.024-1.057	<0.001	1.042	1.016-1.068	0.001

TAVI = transcatheter aortic valve implantation.

based on clinical or electrocardiographic factors: 23.5% of the patients requiring PPI at a late stage did not show any previous conduction abnormalities. This suggests that the conduction abnormalities requiring PPI at a late stage after TAVI may be due to progression of degeneration of the conduction system rather than the effect of the procedure or of the presence of the prosthetic valve. Our study also demonstrated that in a small proportion of patients, the need for PPI may develop even months after TAVI. Therefore, repeat ECG at long-term follow-up is recommended.

Initial experiences with the S3 device showed an increased risk of PPI compared with the previous iterations of Edwards SAPIEN balloon-expandable prostheses.[3] In our study, the rate of PPI was 13%, which is in line with previously reported incidences.[3,17] Vahanian et al recently reported an incidence of PPI of 4.3% in 101 patients treated with the S3 prosthesis.[12] The lower incidence of PPI reported in this study was achieved through a careful positioning of the S3 prosthesis, high in the left ventricular outflow tract, following current recommendations for implantation to minimize the damage to the AV node and left bundle branch.[18] Nevertheless, the present study also shows that the need for pacemaker implantation may decrease over time as a significant proportion of patients receiving a pacemaker before hospital discharge did not show paced rhythm during follow-up. This emphasizes the need for frequent surveillance of these patients as they may not need PPI, and the settings of the pacemaker can be adjusted to allow intrinsic rhythm. The predictors of PPI after S3 implantation have been previously investigated.[19,20] In the present study, wider QRS, presence of RBBB, and first-degree AV block at baseline were associated with an increased risk for PPI after TAVI. These findings are corroborated by previous studies evaluating the association between the S3 prosthesis and the need for PPI.[19,20] Alternatively, in the present study, new-onset LBBB was not associated with the requirement for PPI. This finding is similar to the study by Gonska et al,[19] who showed that only first-degree AV block and RBBB before procedure were independently associated with PPI.

Some limitations have to be acknowledged. First, this is a single-center retrospective study. Second, we also included patients who underwent a valve-in-valve procedure. As an advantage, this reflects a real-life population in clinical practice.

In conclusion, in a large population of patients treated with the S3 valve, new-onset conduction abnormalities exhibit a temporary nature after TAVI and showed a trend toward stabilization during 1-year follow-up. The presence of baseline RBBB and the QRS width after TAVI were significantly associated with the need for PPI.

Disclosure

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1. Baumgartner H, Falk V, Bax JJ, De Bonis M, Hamm C, Holm PJ, Iung B, Lancellotti P, Lansac E, Rodriguez Munoz D, Rosenhek R, Sjogren J, Tornos Mas P, Vahanian A, Walther T, Wendler O, Windecker S, Zamorano JL, Group ESCSD. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. *Eur Heart J* 2017;38:2739–2791.
2. Leon MB, Smith CR, Mack MJ, Makkar RR, Svensson LG, Kodali SK, Thourani VH, Tuzcu EM, Miller DC, Herrmann HC, Doshi D, Cohen DJ, Pichard AD, Kapadia S, Dewey T, Babaliaros V, Szeto WY, Williams MR, Kereiakes D, Zajarias A, Greason KL, Whisenant BK, Hodson RW, Moses JW, Trento A, Brown DL, Fearon WF, Pibarot P, Hahn RT, Jaber WA, Anderson WN, Alu MC, Webb JG, Investigators P. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. *New Engl J Med* 2016;374:1609–1620.
3. Webb J, Gerosa G, Lefevre T, Leipsic J, Spence M, Thomas M, Thielmann M, Treede H, Wendler O, Walther T. Multicenter evaluation of a next-generation balloon-expandable transcatheter aortic valve. *J Am Coll Cardiol* 2014;64:2235–2243.
4. van Rosendael PJ, Delgado V, Bax JJ. Pacemaker implantation rate after transcatheter aortic valve implantation with early and new-generation devices: a systematic review. *Eur Heart J* 2018;39:2003–2013.
5. Toggweiler S, Stortecky S, Holy E, Zuk K, Cuculi F, Nietlispach F, Sabti Z, Suciu R, Maier W, Jamshidi P, Maisano F, Windecker S, Kobza R, Wenaweser P, Luscher TF, Binder RK. The electrocardiogram after transcatheter aortic valve replacement determines the risk for post-procedural high-degree AV block and the need for telemetry monitoring. *JACC Cardiovasc Intervent* 2016;9:1269–1276.
6. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang

W, Voigt JU. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1–39. e14.

7. Brignole M, Auricchio A, Baron-Esquivias G, Bordachar P, Boriani G, Breithardt OA, Cleland J, Deharo JC, Delgado V, Elliott PM, Gorenek B, Israel CW, Leclercq C, Linde C, Mont L, Padeletti L, Sutton R, Vardas PE, Guidelines ESCCfP, Zamorano JL, Achenbach S, Baumgartner H, Bax JJ, Bueno H, Dean V, Deaton C, Erol C, Fagard R, Ferrari R, Hasdai D, Hoes AW, Kirchhof P, Knuuti J, Kolh P, Lancellotti P, Linhart A, Nihoyannopoulos P, Piepoli MF, Ponikowski P, Sirnes PA, Tamargo JL, Tendera M, Torbicki A, Wijns W, Windecker S, Document R, Kirchhof P, Blomstrom-Lundqvist C, Badano LP, Aliyev F, Bansch D, Baumgartner H, Bsata W, Buser P, Charron P, Daubert JC, Dobreanu D, Faerestrand S, Hasdai D, Hoes AW, Le Heuzey JY, Mavrakis H, McDonagh T, Merino JL, Nawar MM, Nielsen JC, Pieske B, Poposka L, Ruschitzka F, Tendera M, Van Gelder IC, Wilson CM. 2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy: the Task Force on cardiac pacing and resynchronization therapy of the European Society of Cardiology (ESC). Developed in collaboration with the European Heart Rhythm Association (EHRA). *Eur Heart J* 2013;34:2281–2329.
8. Epstein AE, DiMarco JP, Ellenbogen KA, Estes NA 3rd, Freedman RA, Gettes LS, Gillinov AM, Gregoratos G, Hammill SC, Hayes DL, Hlatky MA, Newby LK, Page RL, Schoenfeld MH, Silka MJ, Stevenson LW, Sweeney MO, Tracy CM, Epstein AE, Darbar D, DiMarco JP, Dunbar SB, Estes NA 3rd, Ferguson TB Jr., Hammill SC, Karasik PE, Link MS, Marine JE, Schoenfeld MH, Shanker AJ, Silka MJ, Stevenson LW, Stevenson WG, Varosy PD, American College of Cardiology F, American Heart Association Task Force on Practice G, Heart Rhythm S. 2012 ACCF/AHA/HRS focused update incorporated into the ACCF/AHA/HRS 2008 guidelines for device-based therapy of cardiac rhythm abnormalities: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Heart Rhythm Society. *J Am Coll Cardiol* 2013;61:e6–75.
9. Friedman HS, Zaman Q, Haft JI, Melendez S. Assessment of atrioventricular conduction in aortic valve disease. *Br Heart J* 1978;40:911–917.
10. Karyofillis P, Kostopoulou A, Thomopoulou S, Habibi M, Livanis E, Karavolias G, Voudris V. Conduction abnormalities after transcatheter aortic valve implantation. *J Geriatr Cardiol* 2018;15:105–112.
11. Binder RK, Rodes-Cabau J, Wood DA, Mok M, Leipsic J, De Larochelliere R, Toggweiler S, Dumont E, Freeman M, Willson AB, Webb JG. Transcatheter aortic valve replacement with the SAPIEN 3: a new balloon-expandable transcatheter heart valve. *JACC Cardiovasc Intervent* 2013;6:293–300.
12. Vahanian A, Urena M, Walther T, Treede H, Wendler O, Lefevre T, Spence MS, Redwood S, Kahlert P, Rodes-Cabau J, Leipsic J, Webb J. Thirty-day outcomes in patients at intermediate risk for surgery from the SAPIEN 3 European approval trial. *EuroIntervention* 2016;12:e235–e243.
13. van Gils L, Baart S, Kroon H, Rahhab Z, El Faquir N, Rodriguez Olivares R, Aga Y, Maugenest AM, Theuns DA, Boersma E, Szili Torok T, De Jaegere PP, Van Mieghem NM. Conduction dynamics after transcatheter aortic valve implantation and implications for permanent pacemaker implantation and early discharge: the CONDUCT-study. *Europace* 2018;20:1981–1988.
14. Piazza N, Nuis RJ, Tzikas A, Otten A, Onuma Y, Garcia-Garcia H, Schultz C, van Domburg R, van Es GA, van Geuns R, de Jaegere P, Serruys PW. Persistent conduction abnormalities and requirements for pacemaking six months after transcatheter aortic valve implantation. *EuroIntervention* 2010;6:475–484.
15. Leire U, Eulogio G, Francisco Jose RR, Francisco Javier PJ, Juan MP, Belen DA, Miguel RDR, Adolfo F, Rodrigo T, Belen RA. Electrocardiographic changes and conduction disturbances after transfemoral aortic valve implantation with Edwards Sapien 3 prosthesis. J Electrocardiol 2018;51:416–421.
16. De-Torres-Alba F, Kaleschke G, Vormbrock J, Orwat S, Radke R, Feurle M, Diller GP, Reinecke H, Baumgartner H. Delayed pacemaker requirement after transcatheter aortic valve implantation with a new-generation balloon expandable valve: should we monitor longer. *Int J Cardiol* 2018;273:56–62.
17. Wendler O, Schymik G, Treede H, Baumgartner H, Dumonteil N, Ihlberg L, Neumann FJ, Tarantini G, Zamarano JL, Vahanian A. SOURCE 3 registry: Design and 30-day results of the European Post-approval Registry of the Latest Generation of the SAPIEN 3 transcatheter heart valve. *Circulation* 2017;135:1123–1132.
18. 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.
19. 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.
20. 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 Intervent* 2016;9:244–254.