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ORIGINAL RESEARCH

Impact of New-Onset Right Bundle-Branch Block After Transcatheter Aortic Valve Replacement on Permanent Pacemaker Implantation

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BACKGROUND: A delayed and recurrent complete atrioventricular block (CAVB) is a life-threatening complication of transcatheter aortic valve replacement (TAVR). Post-TAVR evaluation may be important in predicting delayed and recurrent CAVB requiring permanent pacemaker implantation (PPI). The impact of new-onset right bundle-branch block (RBBB) after TAVR on PPI remains unknown.

METHODS AND RESULTS: In total, 407 patients with aortic stenosis who underwent TAVR were included in this analysis. Intraprocedural CAVB was defined as CAVB that occurred during TAVR. A 12-lead ECG was evaluated at baseline, immediately after TAVR, on postoperative days 1 and 5, and according to the need to identify new-onset bundle-branch block (BBB) and CAVB after TAVR. Forty patients (9.8%) required PPI, 17 patients (4.2%) had persistent intraprocedural CAVB, and 23 (5.7%) had delayed or recurrent CAVB after TAVR. The rates of no new-onset BBB, new-onset left BBB, and new-onset RBBB were 65.1%, 26.8%, and 4.7%, respectively. Compared with patients without new-onset BBB and those with new-onset left BBB, the rate of PPI was higher in patients with new-onset RBBB (3.4% versus 5.6% versus 44.4%, $P < 0.0001$). On post-TAVR evaluation in patients without persistent intraprocedural CAVB, the multivariate logistic regression analysis showed that new-onset RBBB was a statistically significant predictor of PPI compared with no new-onset BBB (odds ratio [OR], 18.0 [95% CI, 5.94–54.4]) in addition to the use of a self-expanding valve (OR, 2.97 [95% CI, 1.09–8.10]).

CONCLUSIONS: Patients with new-onset RBBB after TAVR are at high risk for PPI.

Key Words: complete atrioventricular block ■ new-onset right bundle-branch block ■ permanent pacemaker implantation ■ transcatheter aortic valve replacement

Transcatheter aortic valve replacement (TAVR) for severe aortic stenosis is a less invasive alternative to surgical aortic valve replacement.^{1,2} The favorable results of TAVR extend its indications to low- and intermediate-risk patients.^{3–6} Complete

atrioventricular block (CAVB) is a common complication of TAVR, resulting in permanent pacemaker implantation (PPI).^{5–7} During TAVR, CAVB can occur due to mechanical compression of the conduction system with a transcatheter heart valve (THV) and the insertion

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CLINICAL PERSPECTIVE

What Is New?

- Although the frequency of new-onset right bundle-branch block (RBBB) after transcatheter aortic valve replacement (TAVR) was 4.7%, patients with new-onset RBBB had a high rate (42%) of permanent pacemaker implantation (PPI) for delayed or recurrent complete atrioventricular block.
- New-onset RBBB was associated with PPI on post-TAVR evaluation in patients without persistent intraprocedural complete atrioventricular block.
- Prior RBBB was associated with PPI on pre-TAVR evaluation; however, it was not associated on post-TAVR evaluation.

What Are the Clinical Implications?

- New-onset RBBB is a rare conduction disturbance after TAVR but has a high risk of delayed or recurrent complete atrioventricular block requiring PPI.
- Post-TAVR findings of an ECG are effective to predict delayed and recurrent complete atrioventricular block after TAVR requiring PPI and may determine monitoring duration after TAVR; however, further studies are required.

Nonstandard Abbreviations and Acronyms

BBB	bundle-branch block
CAVB	complete atrioventricular block
PPI	permanent pacemaker implantation
TAVR	transcatheter aortic valve replacement
THV	transcatheter heart valve

of devices, including guidewires and balloon catheters.^{8,9} Intraprocedural CAVB is transient in most patients; however, some patients require PPI because of recurrent or delayed CAVB after TAVR. Delayed and recurrent CAVB requiring PPI can be life-threatening.¹⁰ It is important to predict such conditions, because they may occur after discharge. Evaluation based on an ECG after TAVR may be effective in predicting the need for PPI in patients without intraprocedural CAVB and in those who have recovered from intraprocedural CAVB.

New-onset bundle-branch block (BBB) is a conduction disturbance after TAVR, as well as CAVB. New-onset left BBB (LBBB) is the most common conduction disturbance after TAVR. Preexisting right BBB ([RBBB] before TAVR) is a risk factor of PPI.^{11,12}

The association between new-onset LBBB and PPI after TAVR is controversial.^{13–16} In contrast, new-onset RBBB is a rare conduction disturbance after TAVR,¹⁷ and there are no clinical data on its association with PPI. Though several studies have demonstrated that patients with new-onset conduction disturbances after TAVR have an increased risk of CAVB,^{18–20} the impact of new-onset RBBB after TAVR on PPI remains debatable. This study aimed to examine the association between new-onset RBBB after TAVR and PPI for delayed or recurrent CAVB.

METHODS

Study Population

This retrospective, observational, single-center study enrolled patients who underwent TAVR for severe aortic stenosis. The decision to perform TAVR was made after evaluation by a heart team at our institute. In this study, balloon-expandable (Sapien XT and 3 [Edwards Lifesciences, Irvine, CA]) and self-expanding (Evolut R, PRO and PRO+ [Medtronic, Minneapolis, MN]) valves were used based on preprocedural computed tomography. The need for pre- and postballoon dilatation was at the discretion of the treating physicians. We excluded patients with prior CAVB or PPI, valve-in-valve TAVR, unsuccessful THV deployment, or conversion to open-heart surgery. The primary end point was the incidence of PPI during hospitalization following TAVR. The Ethics Committee of Yokohama City University approved the study protocol. All patients provided written, comprehensive informed consent. The data that support the findings of this study are available from the corresponding author upon reasonable request.

ECG Analysis and Indication for PPI

A 12-lead ECG was evaluated at baseline, immediately after TAVR, on postoperative days 1 and 5, and as needed. In addition, continuous ECG monitoring was performed during hospitalization. New-onset BBB was defined as any new BBB that developed after the TAVR. Delayed BBB was defined as BBB occurring later in patients without new-onset BBB during the TAVR procedure. Intraprocedural CAVB was defined as a transient or persistent CAVB that occurred during TAVR. Recurrent CAVB was defined as CAVB recurring in patients who recovered from intraprocedural CAVB. Delayed CAVB was defined as CAVB occurring after TAVR in patients without intraprocedural CAVB. According to the clinical decision of the heart team, PPI was performed in patients who did not recover from intraprocedural, recurrent, or delayed CAVB (including advanced atrioventricular block and alternating BBB).

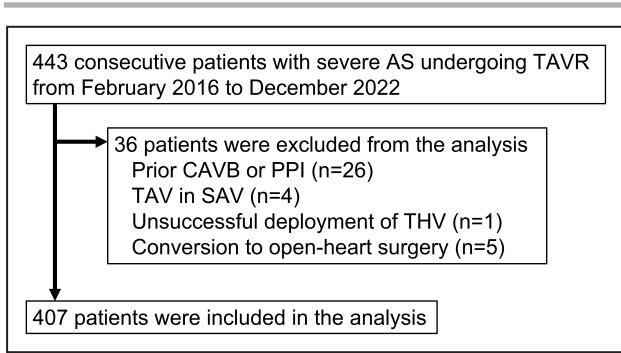


Figure 1. Patient flow diagram.

AS indicates aortic stenosis; CAVB, complete atrioventricular block; PPI, permanent pacemaker implantation; SAV, surgical aortic valve; TAV, transcatheter aortic valve; TAVR, transcatheter aortic valve replacement; and THV, transcatheter heart valve.

Statistical Analysis

Categorical variables were expressed as frequencies and percentages and compared using χ^2 or Fisher exact tests. Continuous values were expressed as mean±SD and compared using analysis of variance. Univariate and multivariate logistic regression analyses were performed to estimate the odds ratio (OR) and 95% CI. Because of the limited number of events, variables with $P<0.05$ or $P<0.10$ in univariate analysis were

entered into the multivariate models. Statistical significance was set at $P<0.05$. Statistical analyses were performed using JMP Pro 16 (SAS Institute, Cary, NC).

RESULTS

Among 443 consecutive patients with severe aortic stenosis who underwent TAVR between February 2016 and December 2022, a total of 407 patients were included in the analysis (Figure 1). The percentages of patients without BBB, those with prior LBBB, and those with prior RBBB were 78.6%, 5.4%, and 16.0%, respectively. Intraprocedural CAVB occurred in 79 patients (19.4%). Compared with patients without BBB and those with prior LBBB, patients with prior RBBB had a higher rate of intraprocedural CAVB (13.8% versus 13.6% versus 49.2%, $P<0.0001$).

The patient flow according to CAVB and PPI is shown in Figure 2. Among 79 patients with intraprocedural CAVB, 62 patients (78.5%) recovered from intraprocedural CAVB (ie, transient CAVB). Conversely, 17 patients (21.5%) did not recover from intraprocedural CAVB (ie, persistent CAVB), resulting in PPI. The association between the ECG findings before and after TAVR is shown in Table 1. The rate of persistent intraprocedural CAVB was higher in patients with prior

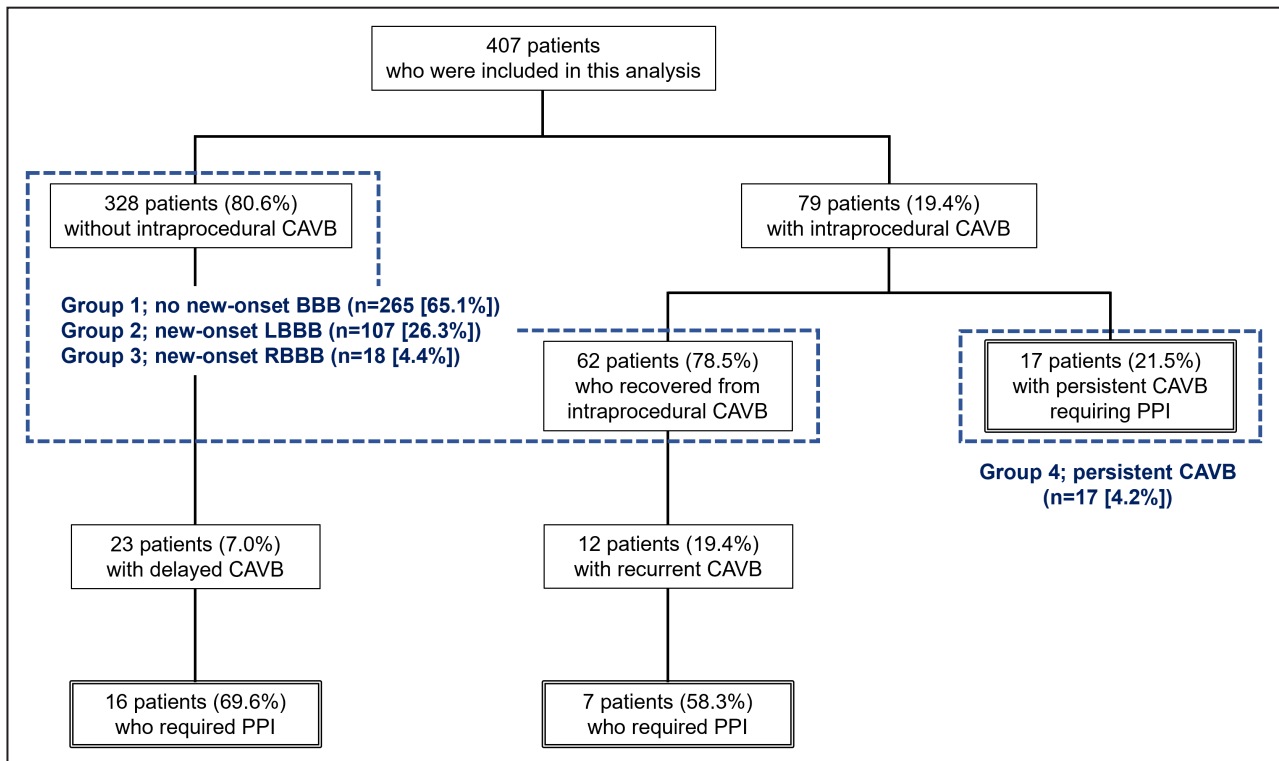


Figure 2. Patient flow according to CAVB and PPI.

BBB indicates bundle-branch block; CAVB, complete atrioventricular block; LBBB, left bundle-branch block; PPI, permanent pacemaker implantation; and RBBB, right bundle-branch block.

Table 1. Association Between ECG Findings Before and After TAVR

	ECG findings after TAVR			
	No BBB after TAVR (n=193, 47.4%)	LBBB after TAVR (n=130, 31.9%)	RBBB after TAVR (n=73, 17.9%)	Persistent intraprocedural CAVB (n=17, 4.2%)
ECG findings before TAVR				
Prior no BBB (n=320, 78.6%)	192 (60.0)	106 (33.1)* (new-onset LBBB)	19 (5.9)* (new-onset RBBB)	6 (1.9)
Prior LBBB (n=22, 5.4%)	0 (0)	21 (95.5)	0 (0)	1 (4.6)
Prior RBBB (n=65, 16.0%)	1 (1.5)	3 (4.6)† (new-onset LBBB)	54 (83.1)	10 (15.4)

BBB indicates bundle-branch block; CAVB, complete atrioventricular block; LBBB, left bundle-branch block; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

*Three patients without prior BBB had new-onset LBBB and RBBB.

†Three patients with prior incomplete RBBB had transient new-onset LBBB.

RBBB, compared with those without BBB and prior LBBB (15.4% versus 1.9% versus 4.6%, $P<0.0001$). Three patients without prior BBB who had both new-onset LBBB and RBBB after TAVR, and 3 patients with prior incomplete RBBB who had transient new-onset LBBB after TAVR are shown in Table 2. The rates of no new-onset BBB, new-onset LBBB, and new-onset RBBB were 65.1%, 26.8%, and 4.7%, respectively. Therefore, we divided the patients into 4 groups according to the ECG findings after TAVR: patients without new-onset BBB (Group 1, n=265 [65.1%]), patients with new-onset LBBB (Group 2, n=107 [26.3%]), patients with new-onset RBBB (Group 3, n=18 [4.4%]), and patients with persistent intraprocedural CAVB (Group 4, n=17 [4.2%]). Patients with both new-onset LBBB and RBBB were categorized as shown in Table 2. There were no significant differences in the baseline characteristics among the groups, except for left ventricular ejection fraction, aortic annulus size, percent oversizing value in patients who received a

balloon-expandable valve, and rate of intraprocedural CAVB (Table 3).

Thirty-five patients (8.6%) had delayed or recurrent CAVB; among them, 23 patients (65.7%) required PPI (Figure 2). Of the 328 patients without intraprocedural CAVB, 23 (7.0%) had delayed CAVB; among them, 16 (69.6%) required PPI. Conversely, among 62 patients with transient intraprocedural CAVB, 12 (19.4%) had recurrent CAVB; among them, 7 (58.3%) required PPI. Overall, 40 patients (9.8%) required PPI. The reasons were that 17 patients (4.2%) had persistent intraprocedural CAVB, and 23 (5.7%) had delayed or recurrent CAVB after TAVR. The mean time from the TAVR procedure to delayed or recurrent CAVB was 2.6 ± 1.4 days. The mean time from TAVR procedure to PPI was 6.9 ± 3.7 and 8.2 ± 3.1 days in patients with persistent intraprocedural CAVB (Group 4) and those without (Groups 1–3), respectively.

Compared with patients without new-onset BBB (Group 1) and those with new-onset LBBB (Group 2),

Table 2. Details of Patients With Both LBBB and RBBB After TAVR

Case	Age, y	Sex	Valve type	Prior BBB	Intraprocedural CAVB	New-onset LBBB	New-onset RBBB	Group	Delayed or recurrent CAVB	PPI
1	80	Female	Evolut	No	No	Delayed and transient	Immediately after TAVR	2	No	No
2	85	Female	Evolut	No	Yes	Immediately after TAVR	Delayed	3	Recurrent (alternating BBB)	Yes
3	93	Female	Sapien	No	Yes	Immediately after TAVR	Delayed	3	Recurrent	Yes
4	90	Female	Evolut	IRBBB	Yes	Delayed and transient	No	2	Recurrent	No
5	75	Female	Sapien	IRBBB	No	Immediately after TAVR and transient	No	2	No	No
6	85	Female	Evolut	IRBBB	No	Delayed and transient	No	2	No	No

Three patients without prior BBB had both new-onset LBBB and RBBB (Cases 1–3). Among them, 1 patient had new-onset RBBB immediately after TAVR and transient delayed LBBB; however, delayed CAVB was not observed. In contrast, the remaining 2 patients with new-onset LBBB immediately after TAVR had complications with alternative BBB or CAVB due to delayed new-onset RBBB, resulting in PPI. Among 3 patients with prior incomplete RBBB and new-onset LBBB (Cases 4–6), 1 patient had recurrent CAVB; however, in each patient, LBBB was transient, and PPI was not required. Patients with both new-onset LBBB and RBBB were included in the group, with new-onset BBB observed in the later period. For example, when new-onset LBBB was followed by new-onset RBBB, the patients were included in Group 3 (Cases 2 and 3). BBB indicates bundle-branch block; CAVB, complete atrioventricular block; IRBBB, incomplete right bundle-branch block; LBBB, left bundle-branch block; PPI, permanent pacemaker implantation; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

Table 3. Baseline Characteristics

Characteristic	Group 1: no new-onset BBB (n=265)	Group 2: new-onset LBBB (n=107)	Group 3: new-onset RBBB (n=18)	Group 4: persistent CAVB (n=17)	P value
Clinical					
Age, y	84.1±4.7	84.3±4.1	86.1±5.1	84.2±4.5	0.35
Men	92 (35)	26 (24)	3 (17)	7 (41)	0.093
Body mass index, kg/m ²	22.6±3.7	22.6±3.4	23.4±4.8	22.4±2.8	0.79
Hypertension	219 (83)	91 (85)	16 (89)	14 (82)	0.87
Diabetes	73 (28)	21 (20)	4 (22)	4 (24)	0.45
Dyslipidemia	166 (63)	80 (75)	9 (50)	12 (71)	0.068
Chronic kidney disease	186 (70)	74 (69)	10 (56)	12 (71)	0.63
Coronary artery disease	92 (35)	26 (24)	7 (39)	6 (35)	0.23
Previous PCI	78 (29)	23 (22)	5 (28)	5 (29)	0.48
Previous CABG	9 (3)	3 (3)	0 (0)	0 (0)	0.74
Previous myocardial infarction	23 (9)	4 (4)	0 (0)	1 (6)	0.23
STS score	7.2±4.9	6.2±4.1	7.3±3.9	6.6±3.0	0.31
Baseline ECG					
Sinus	223 (84)	96 (90)	16 (89)	15 (88)	0.54
First-degree AVB	38 (17)	13 (14)	3 (19)	2 (13)	0.85
AF/AFL	42 (16)	11 (10)	2 (11)	2 (12)	0.54
Prior LBBB	21 (8)	–	0 (0)	1 (6)	0.45
Prior RBBB	52 (20)	3 (3)	–	10 (59)	<0.0001
Baseline TTE					
IVSd, mm	12.8±2.4	12.8±2.2	12.8±1.8	13.1±2.2	0.97
PWd, mm	11.8±2.2	11.9±2.1	11.7±2.3	11.5±2.1	0.91
LVDd, mm	44.1±6.3	42.5±6.4	43.6±5.1	42.3±5.7	0.12
LVEF, %	66.0±14.4	69.2±12.5	70.7±11.4	73.6±8.3	0.026
LVEF <60%	71 (27)	17 (16)	2 (11)	1 (6)	0.023
Peak jet velocity, cm/s	454±80	463±81	456±58	487±71	0.35
Mean pressure gradient, mmHg	48.6±17.2	50.2±19.1	48.9±12.6	55.7±16.3	0.39
AVA, cm ²	0.65±0.15	0.66±0.16	0.70±0.18	0.72±0.16	0.12
CT analysis					
Mean annulus diameter, mm	22.9±2.1	22.3±2.1	22.4±2.2	22.1±2.3	0.035
Annulus area, mm ²	417±79	394±76	399±80	388±86	0.049
Bicuspid aortic valve	8 (3)	2 (2)	1 (6)	1 (6)	0.71
LVOT calcification	60 (23)	26 (24)	3 (17)	4 (24)	0.91
TAVR procedure					
Predilatation	158 (60)	64 (60)	10 (56)	12 (71)	0.81
Postdilatation	78 (29)	38 (36)	2 (11)	5 (29)	0.20
Valve type					0.28
Balloon-expandable valve	146 (55)	51 (48)	7 (39)	7 (41)	
Self-expanding valve	119 (45)	56 (52)	11 (61)	10 (59)	
Balloon-expandable valve (n=211)					0.11
20mm	19 (13)	8 (16)	1 (14)	1 (14)	
23mm	76 (52)	34 (67)	5 (71)	2 (29)	
26mm	41 (28)	8 (16)	0 (0)	2 (29)	
29mm	10 (7)	1 (2)	1 (14)	2 (29)	
% Oversizing	3.0±4.3	5.2±4.7	5.8±3.3	6.2±4.3	0.0049
Self-expanding valve (n=196)					0.54
23mm	9 (8)	7 (13)	1 (9)	2 (20)	

Continued

Table 3. Continued

Characteristic	Group 1: no new-onset BBB (n=265)	Group 2: new-onset LBBB (n=107)	Group 3: new-onset RBBB (n=18)	Group 4: persistent CAVB (n=17)	P value
26mm	50 (42)	21 (38)	3 (27)	6 (60)	
29mm	52 (44)	23 (41)	7 (64)	2 (20)	
34mm	8 (7)	5 (9)	0 (0)	0 (0)	
% Oversizing	21.8±5.0	22.3±5.7	22.6±3.0	23.4±4.8	0.71
Cusp overlap technique	26 (22)	13 (23)	4 (36)	1 (10)	0.54
Intraprocedural CAVB	42 (16)	14 (13)	6 (33)	17 (100)	<0.0001

Data are expressed as mean±SD or n (%). Chronic kidney disease was defined as estimated glomerular filtration rate ≤60 mL/min per 1.73 m². AF indicates atrial fibrillation; AFL, atrial flutter; AVA, aortic valve area; AVB, atrioventricular block; BBB, bundle-branch block; CABG, coronary artery bypass grafting; CAVB, complete atrioventricular block; CT, computed tomography; IVSd, interventricular septum thickness at diastole; LBBB, left bundle-branch block; LVDd, left ventricular diastolic dimension; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; PCI, percutaneous coronary intervention; PWd, posterior wall thickness at diastole; RBBB, right bundle-branch block; STS, Society of Thoracic Surgeons; TAVR, transcatheter aortic valve replacement; and TTE, transthoracic echocardiography.

patients with new-onset RBBB (Group 3) had a higher rate of PPI (3.4% versus 5.6% versus 44.4%, $P<0.0001$) (Figure 3). Among 19 patients with new-onset RBBB, all patients with delayed RBBB (n=3) required PPI because of recurrent or delayed CAVB and tended to have a higher rate of PPI than those without (100% versus 32%, $P=0.058$).

The pre-TAVR evaluation of PPI predictors in all patients (Groups 1–4) is shown in Table 4. Univariate

logistic regression analysis showed that prior RBBB and use of a self-expanding valve were associated with the need for PPI. In the multivariate logistic regression analysis, prior RBBB (OR, 3.41 [95% CI, 1.64–7.08]) and use of a self-expanding valve (OR, 2.56 [95% CI, 1.27–5.19]) were statistically significant predictors of PPI. Among patients who received a balloon-expandable valve (n=211), older age and left ventricular outflow tract calcification tended to be associated with PPI in the univariate analysis (Table S1). Among patients who received a self-expanding valve (n=196), only prior RBBB was associated with PPI in the univariate analysis (Table S2).

The post-TAVR evaluation of PPI predictors in patients without persistent intraprocedural CAVB (Groups 1–3) is shown in Table 5. We added the following variables: post-balloon dilatation, intraprocedural CAVB, new-onset LBBB, and new-onset RBBB on post-TAVR evaluation. Univariate logistic regression analysis showed that use of a self-expanding valve and new-onset RBBB were associated with PPI. Older age, left ventricular outflow tract calcification, and intraprocedural CAVB tended to be associated with PPI. In contrast, prior RBBB was not associated with PPI. Multivariate logistic regression analysis showed that new-onset RBBB was a statistically significant predictor of PPI compared with no new-onset BBB (OR, 18.0 [95% CI, 5.94–54.4]), in addition to use of a self-expanding valve (OR, 2.97 [95% CI, 1.09–8.10]). There was no significant interaction between new-onset RBBB and the valve type (balloon-expandable valve versus self-expanding valve) with respect to PPI ($P=0.17$). Among patients who received a balloon-expandable valve (n=204), new-onset RBBB was a statistically significant predictor of PPI compared with no new-onset BBB (OR, 61.9 [95% CI, 3.12–1229.1]), in addition to age (OR, 1.34 [95% CI, 1.03–1.74]) (Table S3). Among patients who received a self-expanding valve (n=186), new-onset RBBB was also statistically significantly

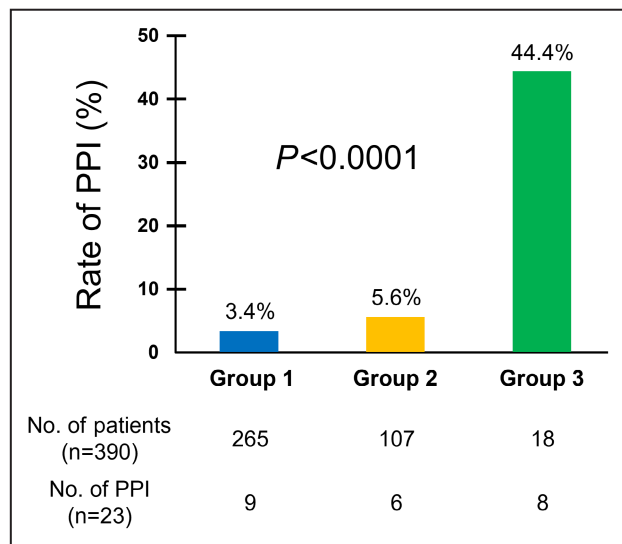


Figure 3. PPI rate according to new-onset BBB after TAVR. The patients were divided into the following groups according to ECG findings after TAVR: patients without new-onset BBB (Group 1), patients with new-onset LBBB (Group 2), and patients with new-onset RBBB (Group 3). Patients with both new-onset LBBB and RBBB were included in the group with new-onset BBB observed later (Table 3, Cases 1–3). For example, when new-onset LBBB was followed by new-onset RBBB, the patients were included in the new-onset RBBB group. BBB indicates bundle-branch block; LBBB, left bundle-branch block; PPI, permanent pacemaker implantation; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

Table 4. Pre-TAVR Evaluation of PPI Predictors in All Patients (Groups 1–4, n=407)

Variables	Univariate			Multivariate		
	OR	95% CI	P value	OR	95% CI	P value
Age (per 1 y)	1.05	0.97–1.13	0.20			
Men	1.06	0.53–2.12	0.88			
Prior LBBB (vs no prior BBB)	0.56	0.073–4.35	0.58			
Prior RBBB (vs no prior BBB)	3.24	1.58–6.65	0.0013	3.41	1.64–7.08	0.0010
LVEF <60%	0.59	0.24–1.44	0.24			
Annulus diameter (per 1 mm)	0.94	0.80–1.10	0.41			
Bicuspid aortic valve	1.88	0.40–8.89	0.43			
LVOT calcification	1.72	0.85–3.49	0.13			
Self-expanding valve	2.43	1.22–4.86	0.012	2.56	1.27–5.19	0.0089
Predilatation	1.63	0.80–3.31	0.18			

BBB indicates bundle-branch block; LBBB, left bundle-branch block; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; OR, odds ratio; PPI, permanent pacemaker implantation; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

associated with PPI compared with no new-onset BBB (OR, 8.87 [95% CI, 2.35–33.4]) (Table S4).

DISCUSSION

The main findings of this study are: (1) The rates of no new-onset BBB, new-onset LBBB, and new-onset RBBB after TAVR were 65.1%, 26.8%, and 4.7%, respectively. (2) Among the patients, 8.6% had recurrent or delayed CAVB, leading to a high rate of PPI (65.7%). (3) Compared with patients without new-onset BBB and those with new-onset LBBB, the rate of PPI for delayed or recurrent CAVB was higher in patients with

new-onset RBBB (3.4% versus 5.6% versus 44.4%, $P<0.0001$). (4) New-onset RBBB was a statistically significant predictor of PPI on post-TAVR evaluation in patients without persistent intraprocedural CAVB. (5) Prior RBBB was a statistically significant predictor of PPI on pre-TAVR evaluation; however, it was not associated with PPI on post-TAVR evaluation. (6) Prior and new-onset LBBB was not associated with PPI on pre- and post-TAVR evaluation.

New-Onset RBBB and LBBB

Anatomically, the left bundle branch is easier to block after THV implantation than the right bundle branch.⁷

Table 5. Post-TAVR Evaluation of PPI Predictors in Patients Without Persistent Intraoperative CAVB (Groups 1–3, n=390)

Variables	Univariate			Multivariate		
	OR	95% CI	P value	OR	95% CI	P value
Age (per 1 y)	1.09	0.98–1.20	0.098			
Men	0.77	0.30–2.01	0.60			
Prior LBBB (vs no prior BBB)			
Prior RBBB (vs no prior BBB)	1.22	0.40–3.73	0.73			
LVEF <60%	1.09	0.39–3.01	0.88			
Annulus diameter (per 1 mm)	0.99	0.81–1.20	0.90			
Bicuspid aortic valve	1.62	0.20–13.3	0.65			
LVOT calcification	2.30	0.96–5.50	0.062			
Self-expanding valve	3.32	1.28–8.61	0.014	2.97	1.09–8.10	0.033
Predilatation	1.60	0.64–3.98	0.31			
Postdilatation	0.80	0.31–2.09	0.65			
Intraoperative CAVB	2.48	0.98–6.31	0.056			
New-onset LBBB (vs no new-onset BBB)	1.88	0.72–4.96	0.20			
New-onset RBBB (vs no new-onset BBB)	19.4	6.59–57.3	<0.0001	18.0	5.94–54.4	<0.0001

BBB indicates bundle-branch block; CAVB, complete atrioventricular block; LBBB, left bundle-branch block; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; OR, odds ratio; PPI, permanent pacemaker implantation; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

In this study, the rates of new-onset LBBB and new-onset RBBB were 26.8% and 4.7%, respectively. The rate of new-onset LBBB has been reported to be 11% to 30% in patients who received balloon expandable valves^{12,21-23} and 37% to 45% in those who received self-expanding valves.^{24,25} A recent study using both balloon-expandable and self-expanding valves demonstrated that the rate of new-onset LBBB was 39%.²⁶ New-onset LBBB is the most frequent conduction disturbance after TAVR^{11,12}; therefore, patients with prior RBBB are at high risk of PPI. Meanwhile, few studies have reported new-onset RBBB after TAVR because of its rarity. Jorgensen et al demonstrated the rate of new-onset RBBB was 3.5%,¹⁷ which is consistent with our results.

Prior and New-Onset RBBB and PPI

In this study, the rate of PPI was extremely high (42.1% [8/19]) in patients with new-onset RBBB. Furthermore, new-onset RBBB was a statistically significant predictor of PPI on post-TAVR evaluations of patients without persistent intraprocedural CAVB. A case series by Wang et al suggested that new-onset RBBB after TAVR may be associated with PPI.²⁷ To our knowledge, this was the first study to investigate the association between new-onset RBBB and PPI after TAVR. The left bundle branch may be partially damaged in patients with new-onset RBBB, even if their ECGs did not reveal LBBB. This could potentially explain the high rate of PPI after TAVR in patients with new-onset RBBB. In the present study, prior RBBB was a predictor of PPI on pre-TAVR evaluation, consistent with findings from previous studies.^{28,29} However, post-TAVR evaluation in patients without persistent intraprocedural CAVB revealed that prior RBBB was not a predictor of PPI. Although patients with prior RBBB have an increased rate of persistent intraprocedural CAVB, the risk of PPI may not be high in patients with prior RBBB who did not have persistent intraprocedural CAVB. For the risk management of delayed and recurrent CAVB, patients with RBBB after TAVR should be categorized into those with new-onset RBBB and those with prior RBBB. New-onset RBBB may be associated with damage to the right bundle branch and partial left bundle branch, whereas prior RBBB without persistent intraprocedural CAVB may be associated with minimal or no damage of the conduction system.

Prior and New-Onset LBBB and PPI

Few studies have examined the impact of prior LBBB on PPI because patients with prior LBBB were excluded from the analysis in most studies reporting conduction disturbances after TAVR. Fischer et al reported that prior LBBB was associated with early PPI after TAVR,³⁰ whereas Saito et al recently reported that

there was no association between prior LBBB and PPI.³¹ The association between new-onset LBBB and PPI after TAVR also remains controversial.^{7,13-16} Urena et al demonstrated that new-onset LBBB is associated with the incidence of PPI,¹² whereas Schymik et al demonstrated absence of any association.¹³ Despite the conflicting conclusions of the 2 studies, the rate of PPI was similar (13.1% versus 14.2%, respectively).^{12,13} These rates were higher than the rate of PPI in patients with new-onset LBBB (7.3% [8/109]) in our study. In addition, our results showed that prior and new-onset LBBB were not associated with PPI on either pre- and post-TAVR evaluations. Most patients with new-onset LBBB may experience little or no damage to the right bundle branch, such as local edema caused by mechanical compression with the THV. In our study, 3 patients with prior RBBB had new-onset LBBB; however, PPI was not required in these patients. This may be because their prior ECG showed incomplete RBBB, and new-onset LBBB was transient.

Time Course of Conduction Disturbances and Delayed Conduction Disturbances

In this study, 3 patients without prior BBB had both new-onset LBBB and RBBB. Although 1 patient with new-onset RBBB immediately after TAVR had transient delayed new-onset LBBB, delayed CAVB was not observed thereafter, suggesting that damage to the bundle branch may be insufficient to induce the development of CAVB. In contrast, the remaining 2 patients with new-onset LBBB immediately after TAVR had complications with alternative BBB or CAVB due to delayed new-onset RBBB, resulting in the need for PPI. Because the left bundle branch is anatomically vulnerable to damage by the implantation of a THV,⁹ damage to the conduction system may extend from the left bundle branch to the right bundle branch, resulting in the development of CAVB. Delayed conduction disturbances suggest that damage to the conduction system after TAVR may have been ongoing at that time. In this study, all patients with delayed new-onset RBBB (n=3) required PPI for delayed or recurrent CAVB. Furthermore, the rate of delayed or recurrent CAVB was 8.6%; among these, 65.7% required PPI. Muntané-Carol et al also demonstrated that 4.6% had postdischarge CAVB, and this population had a high rate of PPI (81.0%).²⁰ Therefore, delayed conduction disturbances should be carefully considered because the necessity of PPI is high.

Risk Factors of CAVB and PPI After TAVR and Management

Pre- and post-TAVR predictions of CAVB requiring PPI are important for appropriate decision-making in

patients undergoing TAVR. Patients who require PPI after TAVR have a higher risk of rehospitalization for heart failure and all-cause mortality than those who do not.^{32,33} Therefore, decision-making before TAVR based on predictors of PPI after TAVR, such as the selection of THV valves and procedural strategies, should be performed to avoid PPI. Furthermore, prediction of delayed and recurrent CAVB after TAVR plays an important role in determining whether early discharge is safe. Although early discharge after TAVR should be considered to improve patient quality of life,³⁴ our results suggest that patients with new-onset RBBB should be carefully managed for CAVB after TAVR.

As shown in previous studies, consistent with ours, prior RBBB and use of a self-expanding valve are important risk factors of PPI after TAVR.^{10,28,29} Left ventricular outflow tract calcification, aortic valve calcification, and membranous septum (MS) length are factors assessed using preprocedural CT. MS length had an inverse relationship with PPI after TAVR.^{35,36} Several studies showed that left ventricular outflow tract calcification and aortic valve calcification (eg, calcium score and volume) were associated with PPI after TAVR^{37–39}; however, other studies have not replicated these findings.^{40–43} As factors associated with the TAVR procedure, pre- and post-balloon dilatation have been reported as predictors of PPI.⁴⁴ The cusp overlap technique for TAVR with self-expanding valves is effective as a procedural technique to reduce the rate of PPI through deployment with optimal implantation depth compared with the standard technique using a coplanar view^{45,46}; however, the rate of cusp overlap technique was low in our study population. Moreover, implantation depth is associated with new conduction disturbances after TAVR.^{47–49} In particular, the interaction of MS length with implantation depth (Δ MSID [MS length – implantation depth]) may be an important factor of PPI. Low Δ MSID has been reported to be associated with higher risk of conduction abnormalities and PPI.⁵⁰ Therefore, we should measure MS length and establish an optimal implantation depth value before TAVR, ensuring THV deployment with optimal implantation depth during the TAVR procedure to reduce PPI.

Limitations

The present study had several limitations. First, it was a retrospective observational study with a small number of patients. Second, we could not evaluate several factors, specifically the aortic calcium score, MS length, and implantation depth, which have been reported to be associated with PPI after TAVR. This was because preprocedural computed tomography was not performed under the conditions necessary to calculate the aortic calcium score, and postprocedural computed tomography was also not performed in this study.

Third, the indication for delayed or recurrent PPI was difficult, especially when it was intermittent. However, in our study, ECG monitoring during hospitalization was performed, and the mean time from TAVR procedure to PPI was \approx 1 week or more. Consequently, the rate of PPI in our study was relatively low. Fourth, documenting all new-onset BBB cases was difficult, particularly transient RBBB, using ECG monitoring alone. Finally, temporary right ventricular pacing placement for rapid pacing during THV deployment may be associated with new-onset RBBB, because 3% of the patients who underwent right heart catheterization have been reported to develop new-onset RBBB.⁵¹

CONCLUSIONS

In the present study, the post-TAVR evaluation of patients without persistent intraprocedural CAVB demonstrated that new-onset RBBB was associated with the need for PPI. New-onset RBBB is a rare conduction disturbance after TAVR but has a high risk of delayed or recurrent CAVB requiring PPI.

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Supplemental Material

Tables S1–S4

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