






ORIGINAL RESEARCH

Temporal Incidence and Predictors of High-Grade Atrioventricular Block After Transcatheter Aortic Valve Replacement

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BACKGROUND: The temporal incidence of high-grade atrioventricular block (HAVB) after transcatheter aortic valve replacement (TAVR) is uncertain. As a result, periprocedural monitoring and pacing strategies remain controversial. This study aimed to describe the temporal incidence of initial episode of HAVB stratified by pre- and post-TAVR conduction and identify predictors of delayed events.

METHODS AND RESULTS: Consecutive patients undergoing TAVR at a single center between February 2012 and June 2019 were retrospectively assessed for HAVB within 30 days. Patients with prior aortic valve replacement, permanent pacemaker (PPM), or conversion to surgical replacement were excluded. Multivariable logistic regression was performed to assess predictors of delayed HAVB (initial event >24 hours post-TAVR). A total of 953 patients were included in this study. HAVB occurred in 153 (16.1%). After exclusion of those with prophylactic PPM placed post-TAVR, the incidence of delayed HAVB was 33/882 (3.7%). Variables independently associated with delayed HAVB included baseline first-degree atrioventricular block or right bundle-branch block, self-expanding valve, and new left bundle-branch block. Forty patients had intraprocedural transient HAVB, including 16 who developed HAVB recurrence and 6 who had PPM implantation without recurrence. PPM was placed for HAVB in 130 (13.6%) (self-expanding valve, 23.7% versus balloon-expandable valve, 11.9%; $P < 0.001$). Eight (0.8%) patients died by 30 days, including 1 unexplained without PPM present.

CONCLUSIONS: Delayed HAVB occurs with higher frequency in patients with baseline first-degree atrioventricular block or right bundle-branch block, new left bundle-branch block, and self-expanding valve. These findings provide insight into optimal monitoring and pacing strategies based on periprocedural ECG findings.

Key Words: bradycardia ■ bundle-branch block ■ pacemaker ■ sudden cardiac death ■ transcatheter aortic valve implantation

Despite innovative advances in transcatheter heart valve design and procedural technique over the past decade, conduction disturbances after transcatheter aortic valve replacement (TAVR), including high-grade atrioventricular block (HAVB), remain the most common complication.¹ Although predictors of permanent pacemaker (PPM) implantation after TAVR, including male sex, type of prosthesis, baseline conduction abnormalities, and development

of intraprocedural block have been identified,² the temporal risk of HAVB related to these risk factors is unknown. As a result, conduction management strategies in the periprocedural period continue to vary among centers, particularly for patients at elevated risk for delayed HAVB.^{3–5} This study aimed to describe the temporal incidence of HAVB stratified by pre- and post-TAVR conduction findings and identify predictors of delayed events.

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CLINICAL PERSPECTIVE

What Is New?

- Delayed high-grade atrioventricular block (HAVB) is closely associated with both baseline and post-transcatheter aortic valve replacement conduction abnormalities, including pre-transcatheter aortic valve replacement right bundle-branch block or first-degree atrioventricular block and new left bundle-branch block.
- Patients with no conduction abnormalities on pre- or immediate post-transcatheter aortic valve replacement had a very low rate of HAVB after 24 hours.
- Specific conduction abnormalities associated with high incidence of delayed HAVB included baseline right bundle-branch block with first-degree atrioventricular block or bifascicular block, new left bundle-branch block with PR interval >240 ms, new left bundle-branch block with QRS >150 ms combined with first-degree atrioventricular block or incalculable PR, and transient intraprocedural HAVB.

What Are the Clinical Implications?

- Close monitoring for conduction abnormalities in the periprocedural period is an effective strategy to identify patients at increased risk of delayed HAVB.
- An early dismissal strategy without need for prolonged monitoring can be considered as a potentially safe management strategy in patients without pre- or immediate post-transcatheter aortic valve replacement conduction abnormalities.
- In contrast, the groups identified to be at the highest risk for delayed HAVB may benefit from early permanent pacemaker implantation or prolonged inpatient monitoring to avoid morbidity associated with HAVB in the unmonitored setting, including risk of rehospitalization or sudden cardiac death.

Nonstandard Abbreviations and Acronyms

AEM	ambulatory ECG monitor
AVB	atrioventricular block
HAVB	high-grade atrioventricular block
PPM	permanent pacemaker
SEV	self-expanding valve
TAVR	transcatheter aortic valve replacement

METHODS

This study was approved by the Mayo Clinic Institutional Review Board and no informed consent was required. The authors have full access to all the data in the study and take responsibility for its integrity and the data analysis. The data that support the findings are available from the corresponding author upon reasonable request. Consecutive patients who underwent TAVR at Mayo Clinic, Rochester, Minnesota between February 2012 and June 2019 were retrospectively reviewed. Patients with prior aortic valve replacement, PPM or implantable cardioverter-defibrillator, intraprocedural death, or conversion to surgical replacement were excluded. Before TAVR, all patients were evaluated by the heart team with baseline ECG and echocardiogram. TAVR procedures were performed as previously described.^{6,7} The majority of patients had temporary balloon-tipped right ventricular pacemaker placed for rapid ventricular pacing that was removed before patients left the catheterization laboratory/hybrid operating room. Selected patients presumed to be at high risk for atrioventricular block (AVB) in the postprocedural period may have undergone active fixation temporary (screw-in) pacemaker placement that was typically left in place for 24 to 48 hours at the discretion of the operator. Continuous telemetry monitoring was performed intraprocedurally and continued for at least 24 hours in all patients. In addition, 12-lead ECG was performed immediately post-TAVR and daily thereafter until hospital discharge.

In the absence of national guidelines, an institutional clinical practice protocol to guide the decision of PPM was developed through multidisciplinary collaboration, which has evolved throughout the institutional experience. Potential indications for PPM included the following: (1) HAVB; (2) Mobitz type II second-degree AVB; (3) sinus node dysfunction (sinus bradycardia <40/min or sinus pause >3 seconds while awake); or (4) prophylactic placement for new left bundle-branch block (LBBB) or select patients with baseline right bundle-branch block (RBBB) (recommended in 2015–2017). Select patients who did not have PPM placed before hospital discharge received a remote 30-day continuous ambulatory ECG monitoring (AEM) system (BodyGuardian; Preventice Technologies, Inc; Eagan, MN) to assess for late HAVB.⁴ Since 2017, 30-day AEM has been recommended for all patients with baseline RBBB or new LBBB post-TAVR who were dismissed without PPM. All patients were encouraged to undergo in-person follow-up at 30 days.

Study End Points and Definitions

The primary outcome was the development of any HAVB or delayed HAVB (initial episode >24 hours

post-TAVR) within 30 days. Electrocardiographic diagnosis of HAVB was determined by the presence of a minimum of 2 consecutive nonconducted P waves for patients in sinus rhythm, or bradycardia <50 beats per minute with fixed rate for patients with atrial fibrillation/flutter (AF). Temporal incidence was described using the initial episode of HAVB for each patient and stratified by valve type and conduction on pre-TAVR and immediate post-TAVR 12-lead ECG. Subgroup analysis of patients with baseline RBBB and new LBBB was performed by stratifying the temporal incidence of HAVB based on the presence of baseline first-degree AVB, bifascicular block (defined as RBBB combined with left anterior or left posterior fascicular block), or bifascicular block with first-degree AVB for patients with RBBB and PR interval <200 ms, 200 to 239 ms, \geq 240 ms, or AF as determined on immediate post-TAVR ECG for patients with new LBBB. Additionally, the impact of QRS duration among patients with baseline RBBB or new LBBB was assessed by comparing those with QRS \geq 150 ms to those with QRS <150 ms.

Secondary analysis was performed to identify the temporal incidence of HAVB recurrence in patients with transient intraprocedural HAVB. This was defined as HAVB that developed shortly after valve deployment with recovery of native atrioventricular conduction before transfer to the monitored bed. Other indications for PPM within 30 days and unexplained death were reported separately.

Statistical Analysis

Categorical variables were expressed as n (%) and continuous variables as mean \pm SD. Incidence of early (<24 hours) or any HAVB was calculated using the entire sample size of the cohort represented in the denominator. Incidence of delayed HAVB and temporal incidence after 24 hours was calculated excluding patients who underwent prophylactic PPM implantation after TAVR from the denominator, since delayed HAVB may not have been clinically noted in these patients. Univariable and multivariable analysis were done to determine characteristics associated with the development of any or delayed HAVB as compared with those without HAVB. Comparisons of continuous variables were performed using 2-sided Student *t* test and categorical variables using χ^2 test. Multivariable logistic regression was performed for all variables with $P<0.10$ in the univariable analysis since sample size and number of events precluded extensive multivariable adjustment. Clinical variables analyzed included age, sex, prior chest radiation, prior AF, aortic valve calcium score, baseline conduction abnormalities (first-degree AVB, RBBB, or LBBB), TAVR access site, type of valve implanted, postdilation

valvuloplasty, need for a second valve, and new post-TAVR first-degree AVB or LBBB. Results were considered significant at $P<0.05$. Statistical analyses were performed using JMP software (JMP version 14, SAS Institute, Cary, NC).

RESULTS

A total of 953 patients were included in this study. Patient and procedural characteristics are described in Tables 1 and 2, respectively. An active fixation temporary pacemaker was placed in 160 (16.8%) patients. Pericardial effusion requiring intervention occurred in 5/160 (3.1%) of those who had active fixation temporary pacemaker placed as compared with 13/793 (1.6%) without ($P=0.21$). Immediately post-TAVR, new first-degree AVB was observed in 78 (8.2%) and new LBBB in 184 (19.3%). Mean hospital length of stay was 3.8 \pm 3.9 days. Two hundred twenty-three (23.4%) patients were discharged with continuous 30-day AEM.

Temporal Incidence of HAVB

HAVB occurred in 153/953 (16.1%) patients, including 120 (12.6%) within 24 hours. After exclusion of patients who underwent prophylactic PPM implantation (n=71 including new LBBB, n=62; baseline RBBB, n=6; baseline RBBB that transitioned to LBBB post-TAVR, n=2; baseline severe PR prolongation, n=1), the incidence of delayed HAVB was 33/882 (3.7%). A flow chart demonstrating the timing of initial episode of HAVB within 30 days is shown in Figure 1. The temporal incidence of HAVB stratified by valve type and pre- or post-TAVR conduction is shown in Figure 2. Of the 9 patients with an initial episode of HAVB after 1 week, 2 patients had self-expanding valve (SEV) and the majority had baseline RBBB (n=2) or new LBBB after TAVR (n=4). A total of 13 occurred in the posthospital setting with 12 requiring readmission. The patient who was not readmitted was dismissed following evaluation by an outside emergency room after presenting for brief transient asymptomatic HAVB observed on AEM with recommendation to stop diltiazem and continue ambulatory monitoring without future recurrence noted. HAVB was captured on 30-day AEM in 12 and was symptomatic in seven. Six of the 7 patients who were symptomatic had HAVB captured on AEM and 1 patient without AEM had HAVB observed in the emergency department after presenting for presyncope.

A total of 130/953 (13.6%) had PPM placed within 30 days for indication of HAVB (SEV, 23.7% versus balloon-expandable valve, 11.9%; $P<0.001$). An additional 15/953 (1.6%) had PPM for sinus node

Table 1. Baseline Characteristics

Characteristic	Value
Age, y	81.1±7.8
Women	418 (43.9)
BMI, kg/m ²	30.1±8.0
Hypertension	862 (90.5)
Type 2 DM	355 (37.3)
Current dialysis	22 (2.3)
Chronic lung disease	
Mild	240 (25.2)
Moderate	194 (20.4)
Severe	111 (11.6)
Prior stroke or TIA	160 (16.8)
History of atrial fibrillation/flutter	357 (37.5)
Prior chest radiation	54 (5.7)
Prior MI	220 (23.1)
Prior PCI	414 (43.4)
Prior CABG	215 (22.5)
Coronary artery disease	
1 vessel	205 (21.5)
2 vessel	154 (16.2)
3 vessel	307 (32.2)
Left main	126 (13.2)
STS risk score, %	7.1±5.0
Porcelain aorta	52 (5.5)
AV calcium score	2525±1344
Bicuspid valve	4 (0.4)
AV area, cm	0.82±0.20
AV mean gradient, mm Hg	45.7±12.1
LVEF, %	58.5±12.0
RVSP, mm Hg	41.4±13.9
NYHA Class	
I-II	234 (24.6)
III-IV	719 (75.4)
Baseline ECG	
First-degree AVB	213 (22.4)
RBBB	119 (12.5)
LBBB	73 (7.7)
PR interval, ms	185±40
QRS interval, ms	106±25

Values are n (%) or mean±SD. AV indicates aortic valve; AVB, atrioventricular block; BMI, body mass index; CABG, coronary artery bypass surgery; DM, diabetes mellitus; LBBB, left bundle-branch block; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; RBBB, right bundle-branch block; RVSP, right ventricular systolic pressure; STS, Society of Thoracic Surgery; and TIA, transient ischemic attack.

dysfunction, 11/953 (1.2%) for Mobitz II AVB, 1/953 (0.1%) for spontaneous preprocedural HAVB, and 71/953 (7.5%) for prophylaxis per early institutional protocol. PPM was implanted at a median of 3 days (interquartile range, 1–5 days) post-TAVR.

Baseline RBBB

On subgroup analysis of patients with baseline RBBB (n=119), 55 had isolated RBBB, 14 had RBBB+first-degree AVB, 35 had bifascicular block, and 15 had bifascicular+first-degree AVB. Incidence of any HAVB was similar in these groups (isolated RBBB, 27/55 [49.1%]; RBBB+first-degree AVB, 10/14 [71.4%]; bifascicular block, 23/35 [65.7%]; bifascicular+first-degree AVB, 8/15 [53.3%]; *P*=0.29). Delayed HAVB incidence was greater in patients with concomitant first-degree AVB or bifascicular block, but this difference did not meet statistical significance (isolated RBBB, 1/53 [1.9%]; RBBB+first-degree AVB, 2/14 [14.3%]; bifascicular block, 3/31 [9.7%]; bifascicular+first-degree AVB, 3/13 [23.1%]; *P*=0.06). Temporal incidence of HAVB in these subgroups is shown in Figure 3A and patient characteristics and post-TAVR conduction management are shown in Table S1. Baseline QRS duration ≥150 ms was not associated with increased any or delayed HAVB when compared with those with QRS <150 ms (*P*=0.59 and *P*=0.11, respectively).

Table 2. Procedural Characteristics

Characteristic	Value
Anesthesia	
General	500 (52.5)
Moderate sedation	453 (47.5)
Access site	
Femoral	783 (82.2)
Transapical	142 (14.9)
Other	28 (2.9)
Valve type	
Balloon-expandable	814 (85.4)
Sapien	107 (11.2)
Sapien XT	56 (5.9)
Sapien S3	580 (60.9)
Sapien S3 ultra	71 (7.5)
Self-expanding	139 (14.6)
Corevalve	57 (6.0)
Evolut R	63 (6.6)
Evolut Pro	19 (2.0)
Valve size, mm	
20	16 (1.7)
23	249 (26.1)
26	408 (42.8)
29	223 (23.4)
31–34	57 (6.0)
Postdilation valvuloplasty	115 (12.1)
Need for second valve	20 (2.1)

Values are n (%).

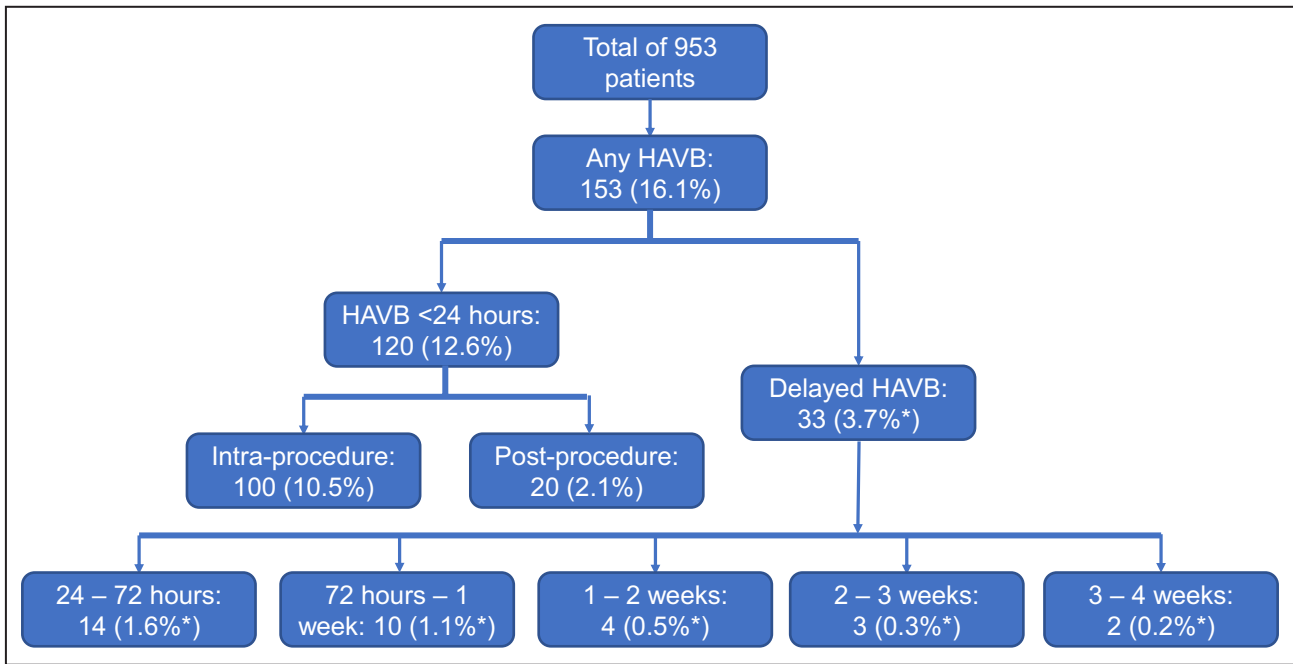


Figure 1. Flow chart showing the temporal incidence of initial episode of HAVB after TAVR.
 *Incidence of delayed HAVB determined after exclusion of 71 patients who had prophylactic permanent pacemaker placement without early HAVB. HAVB indicates high-grade atrioventricular block; and TAVR, transcatheter aortic valve replacement.

New LBBB

On subgroup analysis of patients with new LBBB (n=184) on immediate post-TAVR ECG stratified by PR interval, 84 had PR interval <200 ms, 42 had PR between 200 and 239 ms, 18 had PR ≥240 ms, and 37 had AF. Three patients with new LBBB had a junctional escape rhythm. Incidence of any HAVB was greater in patients with PR prolongation or incalculable PR because of AF (PR interval <200 ms, 4/84 [4.8%]; PR between 200 and 239 ms, 9/42 [21.4%]; PR ≥240 ms, 6/18 [33.3%]; AF, 7/37 [18.9%]; P=0.003). PR prolongation or incalculable PR was also associated with increased incidence of delayed HAVB (PR <200 ms, 1/63 [1.6%]; PR 200 and 239 ms, 4/33 [12.1%]; PR ≥240 ms, 3/10 [30.0%]; AF, 4/29 [13.8%]; P=0.01). Patient characteristics and post-TAVR conduction management of these subgroups are shown in Table S2.

Comparison of new patients with LBBB stratified by QRS length showed a non-statistically significant increase in incidence of any HAVB (14/66 [21.2%] versus 13/118 [11.0%], P=0.06) and significant increase in delayed HAVB (8/48 [16.7%] versus 4/89 [4.5%], P=0.02) in patients with QRS ≥150. The temporal incidence of HAVB stratified by PR interval and QRS duration is shown in Figure 3B and Figure S1, respectively.

LBBB resolved in 23/184 (12.5%) by time of hospital discharge with none developing delayed HAVB. New LBBB developed at time of hospital dismissal in 32/953 (3.4%) who did not have LBBB on immediate post-TAVR ECG, including 1 patient who developed delayed HAVB.

Isolated First-Degree AVB

Isolated baseline first-degree AVB was present in 120 patients without periprocedural bundle-branch block. Of these, 28/120 (23.3%) had post-TAVR PR ≥240 ms. Incidence of any HAVB was 9/120 (7.5%). After exclusion of those with prophylactic PPM (new LBBB developing after post-TAVR ECG, 3; severe PR prolongation, 1), incidence of delayed HAVB was 5/116 (4.3%). Temporal incidence is shown in Figure 2. Three of the 5 patients with delayed HAVB had post-TAVR PR ≥240 ms. New isolated first-degree AVB on post-TAVR ECG was noted in 42 patients, with none progressing to HAVB.

Normal Pre- and Post-TAVR ECG

A total of 388/953 (40.7%) patients were in sinus rhythm (n=273) or AF (n=115) on periprocedural ECG without evidence of any AV conduction abnormality. Incidence of any HAVB was 15/388 (3.9%) and was greater in the subset of patients with AF (7/273 [2.6%] in sinus versus 8/115 [7.0%] in AF; P=0.04). After exclusion of those with prophylactic PPM (n=10, all because of new LBBB developing after post-TAVR ECG), delayed HAVB incidence was 4/378 (1.1%). This was similar among those in AF or sinus rhythm periprocedurally (P=0.38). Temporal incidence is shown in Figure 2.

Predictors of HAVB

Univariable and multivariable analysis of characteristics associated with any HAVB and delayed HAVB are

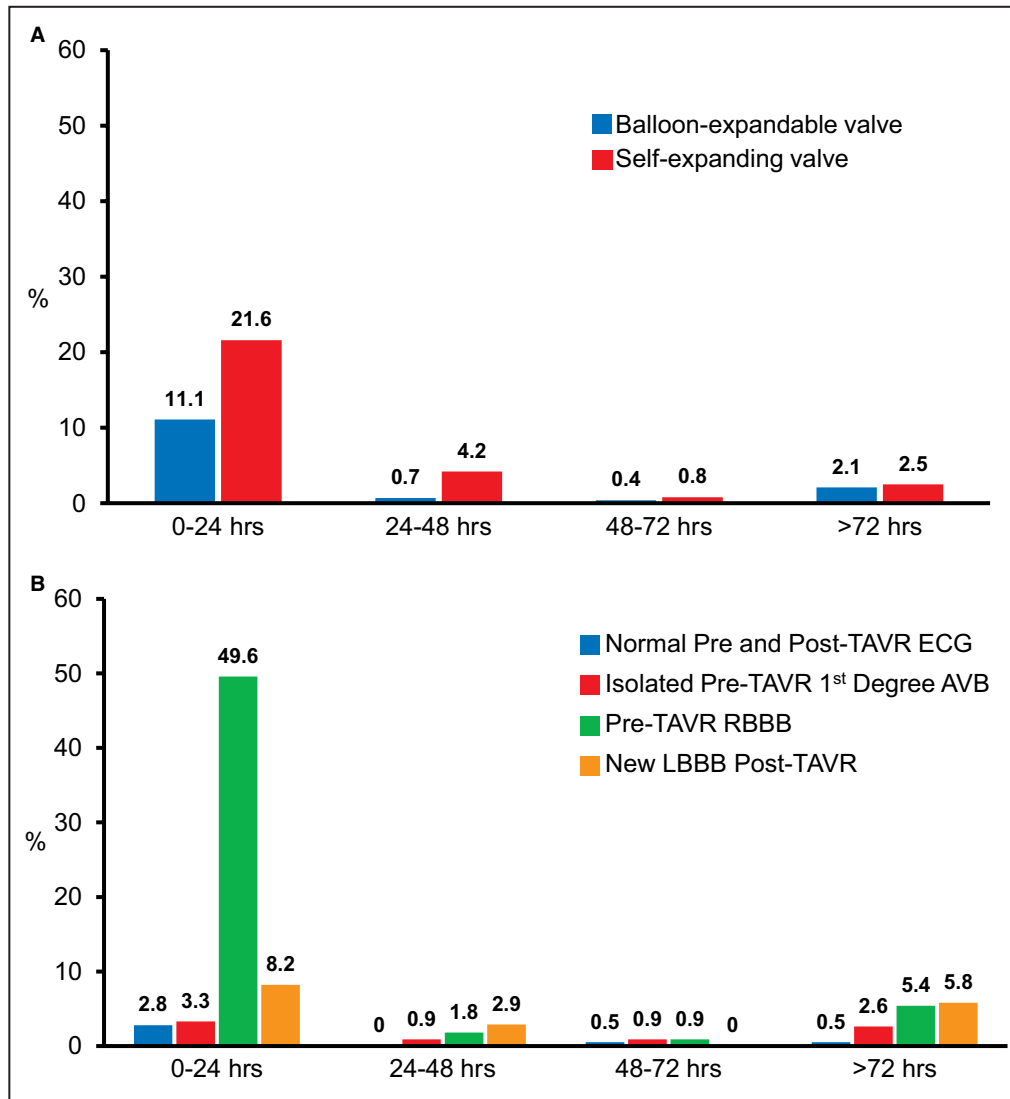


Figure 2. Temporal incidence of high-grade atrioventricular block after TAVR.
A, Temporal incidence stratified by type of valve. **B,** Temporal incidence stratified by presence of pre-TAVR RBBB, post-TAVR new LBBB, isolated pre-TAVR first-degree AVB, and normal pre- and post-TAVR ECG. AVB indicates atrioventricular block; LBBB, left bundle-branch block; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

shown in Table 3. Male sex, prior AF, baseline RBBB, SEV, and aortic valve calcium score were significantly associated with any HAVB on univariable analysis. On multivariable analysis, only pre-TAVR RBBB and SEV remained statistically significant. Variables associated with delayed HAVB on univariable and multivariable analysis included baseline first-degree AVB or RBBB, SEV, and new LBBB.

Intraprocedural Transient HAVB

Of the 100 patients with intraprocedural HAVB, 40 were transient. Six of these patients had PPM placed prophylactically because of concern about HAVB recurrence (4 with baseline RBBB, 2 with new LBBB). Of

the remaining patients, 16/34 (47.1%) had HAVB recurrence within 30 days. This included 9/34 (26.5%) with recurrent HAVB within 24 hours post-TAVR, 2/34 (5.9%) in 24 to 48 hours, and 5/34 (14.7%) after 72 hours. Two cases occurred after hospital discharge and led to re-admission. Characteristics of patients with transient intraprocedural HAVB with and without recurrence are shown in Table S3.

Survival/Follow-Up

Eight (0.8%) patients died at 30 days, including 3 unexplained. Of those with unexplained deaths, 2 had PPM placed before discharge and one 88-year-old patient with pre-existing bifascicular block and no device

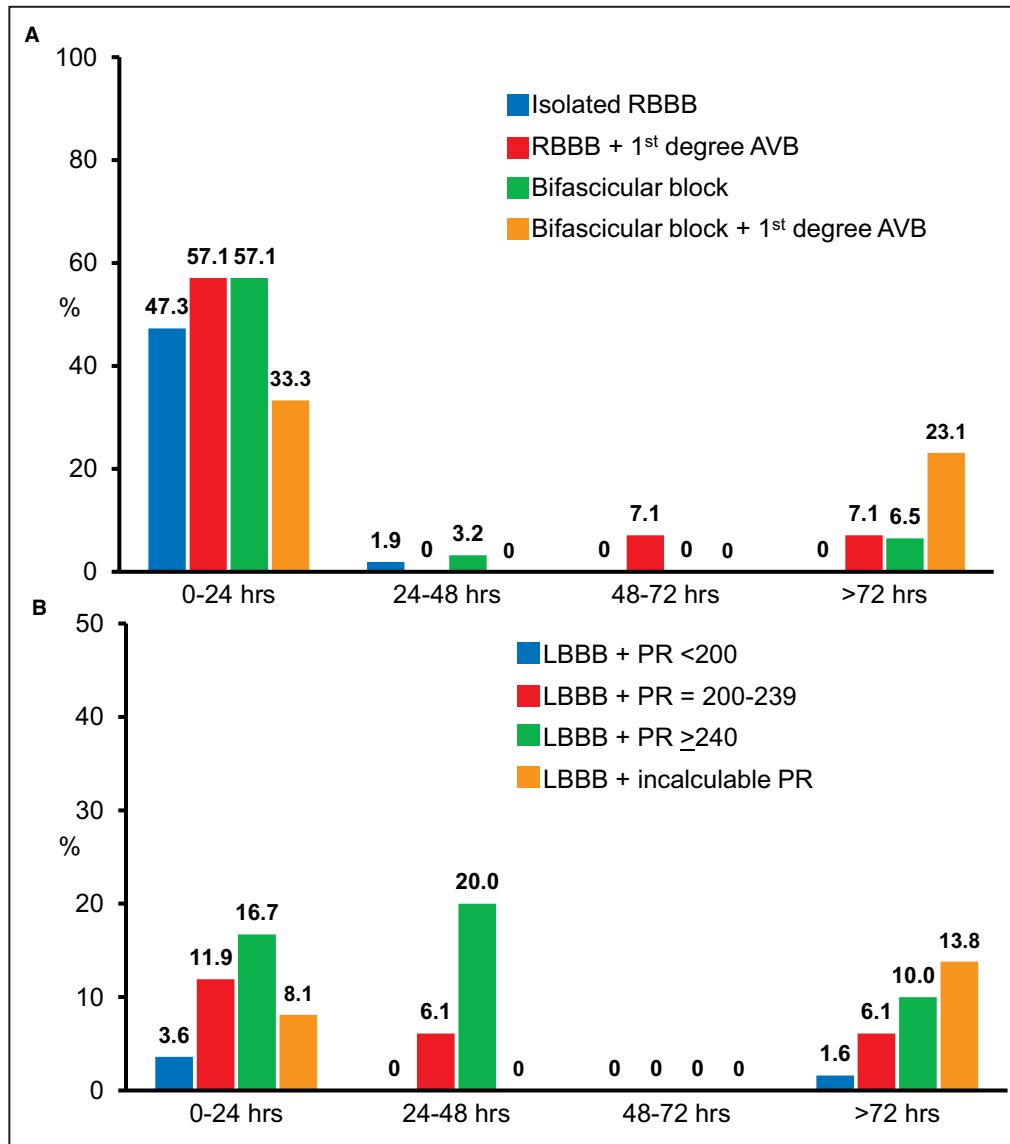


Figure 3. Temporal incidence of high-grade atrioventricular block after TAVR in patients with baseline RBBB or new LBBB stratified by presence of concomitant conduction abnormalities.

A, Temporal incidence stratified into groups including isolated RBBB (n=55), RBBB+first-degree AVB (n=14), bifascicular block (n=35), or bifascicular block+first-degree AVB (n=15). **B**, Temporal incidence stratified into groups including new LBBB on post-TAVR ECG with PR <200 ms (n=84), PR=200 to 239 ms (n=42), PR ≥240 ms (n=18), or incalculable PR because of AF (n=37). AF indicates atrial fibrillation; AVB, atrioventricular block; LBBB, left bundle-branch block; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

present died on day 23. A total of 932 (97.8%) patients had clinical 30-day follow-up.

DISCUSSION

In this large single-center analysis of the temporal occurrence of HAVB following TAVR, several practice-guiding observations were made: (1) the majority of HAVB occurs within 24 hours of TAVR and immediately after transcatheter valve implantation; (2) risk of

delayed HAVB is closely associated with periprocedural conduction abnormalities; (3) patients with no conduction abnormalities on pre- and post-TAVR ECG had a very low rate of HAVB after 24 hours (1%); and (4) specific conduction abnormalities including baseline RBBB with first-degree AVB, bifascicular block, new LBBB with PR interval ≥240 ms, new LBBB with QRS ≥150 ms combined with first-degree AVB or incalculable PR, and transient intraprocedural HAVB are associated with high rates of HAVB after 72 hours.

Table 3. Univariable and Multivariable Analysis of Characteristics Associated With Any HAVB and Delayed HAVB

Characteristic	Univariable			Multivariable		
	OR	95% CI	P Value	OR	95% CI	P Value
Any HAVB						
Age	1.00	0.98–1.02	0.95			
Male sex	1.53	1.07–2.19	0.02	1.19	0.78–1.84	0.42
History of chest radiation	1.05	0.50–2.19	0.90			
Atrial fibrillation/flutter	1.51	1.06–2.14	0.02	1.48	0.99–2.20	0.06
AV calcium score*	1.01	1.00–1.03	0.04	1.00	0.98–1.02	0.65
Pre-TAVR ECG						
First-degree AVB	1.34	0.90–1.99	0.15			
RBBB	11.75	7.67–18.00	<0.001	13.16	8.32–20.83	<0.001
LBBB	1.03	0.54–1.96	0.93			
Access						
Transfemoral	1.35	0.83–2.20	0.22			
Transapical	0.58	0.33–1.01	0.053	0.59	0.30–1.14	0.12
Other	1.78	0.74–4.26	0.19			
Self-expanding valve	2.39	1.57–3.64	<0.001	2.96	1.82–4.79	<0.001
Postdilation valvuloplasty	0.90	0.52–1.55	0.69			
Need for second valve	0.27	0.03–2.04	0.17			
Post-TAVR ECG						
New First-degree AVB	0.78	0.39–1.55	0.47			
New LBBB	0.88	0.56–1.38	0.57			
Delayed HAVB						
Age	1.00	0.96–1.05	0.85			
Male sex	1.69	0.81–3.54	0.16			
History of chest radiation	0.50	0.07–3.74	0.49			
Atrial fibrillation/flutter	1.51	0.75–3.05	0.25			
AV calcium score*	1.02	0.99–1.04	0.07	1.01	0.99–1.04	0.32
Pre-TAVR ECG						
First-degree AV block	3.63	1.79–7.36	<0.001	2.98	1.39–6.38	0.01
RBBB	5.98	2.62–13.66	<0.001	10.74	4.04–28.60	<0.001
LBBB	0.72	0.17–3.08	0.66			
Access						
Transfemoral	1.72	0.60–4.98	0.31			
Transapical	0.69	0.24–2.01	0.50			
Other†			
Self-expanding valve	3.04	1.37–6.77	0.004	3.29	1.35–7.98	0.01
Postdilation	0.74	0.22–2.47	0.62			
Need for second valve	1.23	0.16–9.54	0.84			
Post-TAVR ECG						
New first-degree AVB	1.10	0.32–3.69	0.88			
New LBBB	3.22	1.54–6.72	0.001	5.59	2.36–13.23	<0.001

AV indicates aortic valve; AVB, atrioventricular block; HAVB, high-grade atrioventricular block; LBBB, left bundle-branch block; OR, odds ratio; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

*Odds ratio calculated per 100 units.

†Odds ratio not reported because no delayed HAVB occurred.

Any HAVB After TAVR

The incidence of HAVB in this study (16.1%, 13.6% leading to new PPM) was similar to post-TAVR PPM rates previously reported from registry studies and meta-analyses (6%–34%).^{2,8–10} Concordant with prior investigations, baseline RBBB was the strongest risk factor for the development of HAVB with an odds ratio of 13 after multivariable adjustment.^{2–4,9} Furthermore, SEV was associated with a higher risk of HAVB compared with balloon-expandable valve (28% versus 14%) and was an independent predictor of HAVB on multivariable analysis.^{2,8,10} Factors related to implantation technique and imaging characteristics that were not assessed in the current study but have been previously identified to be associated with need for PPM include the ratio of prosthesis size to annular diameter,^{9,11} depth of prosthesis implantation,¹² left ventricular end-diastolic diameter,⁹ and membranous septum length.¹²

Delayed HAVB

With accumulating reports of post-TAVR HAVB presenting in the posthospital setting, there has been an increased focus recently on studying the incidence of delayed events with 30-day AEM. One study reported an incidence of 8% with late HAVB (>2 days post-TAVR) in 150 patients.³ A recent study from our institution involving 127 patients who were included in the current study showed an incidence of 7.1% with grade II/III degree AVB after hospital discharge.⁴ In the present study, incidence of delayed HAVB (defined as >24 hours) was 3.7%, with the majority occurring in the first week after TAVR. The lower incidence of delayed HAVB in this study may be related to fewer patients (23%) with AEM and differences in methodology, including the practice of early prophylactic PPM implantation in high-risk patients per early institutional protocol and exclusion of recurrent HAVB from the delayed incidence calculation in patients who developed early transient HAVB. Recurrent HAVB for patients with intraprocedural transient HAVB was reported separately because this represents a higher-risk patient population that warrants different postprocedural management as compared with those who maintained native conduction early,^{2,13} with nearly 50% developing recurrence within 30 days in our study (15% after 72 hours).

Baseline RBBB and Risk of Delayed HAVB

In agreement with smaller single-center studies, baseline RBBB was a strong independent predictor of delayed events.^{3,4,14} A recent multicenter analysis of 3527 patients found that not only was baseline RBBB associated with increased PPM (40% versus 14%), but also cardiovascular mortality and that the risk of mortality and sudden cardiac death was greatest in patients who were discharged without PPM.¹⁵ These

cumulative findings demonstrate a need to better risk stratify patients with RBBB early on to identify who may benefit from more aggressive monitoring and pacing strategies. In the present study, by stratifying patients with baseline RBBB by the presence of concomitant conduction abnormalities, we found that the incidence of delayed HAVB was particularly high (\approx 10% or greater) in patients with first-degree AVB and/or bifascicular block with the majority of cases occurring in >72 hours. In comparison, risk of delayed HAVB with isolated RBBB was low (2%), with no cases after 48 hours. Given the high rate of early and late HAVB in these groups, at our institution we favor PPM implantation in patients with RBBB with first-degree AVB or bifascicular block immediately following TAVR.

New LBBB and Risk of Delayed HAVB

Patients with new LBBB post-TAVR have been identified as another group at elevated risk of developing late HAVB.^{4,16} A recent study demonstrated that 15% of 103 patients progressed to HAVB during a 12-month follow-up using an implantable loop recorder and that half of these cases occurred within the first 4 weeks.¹⁶ New LBBB, as determined on immediate post-TAVR ECG, was an independent predictor of delayed HAVB in our study, with 8.7% of patients discharged without PPM developing delayed HAVB within 30 days. The determination of which patients with persistent LBBB are at greatest risk of progression to HAVB remains challenging. A recent scientific statement proposed risk stratification of patients with new LBBB using QRS length \geq 150 ms or PR \geq 240 ms to identify those who may be at highest risk of progression to HAVB; however, data validating this approach are lacking.⁵ In our analysis, assessment of the PR interval on immediate post-TAVR ECG was a useful method of determining risk of progression to HAVB within 30 days. After stratification into groups with PR <200 ms, 200 to 239 ms, PR \geq 240, or incalculable PR because of AF, PR \geq 240 ms was associated with the greatest risk of delayed HAVB (30%). Patients with PR <200 ms post-TAVR had a very low risk of progression to HAVB. Additionally, QRS duration \geq 150 ms was associated with delayed HAVB, with the greatest risk observed in those with concomitant PR prolongation or AF. These data suggest the feasibility of this early risk stratification approach in patients with new LBBB after TAVR.

First-Degree AVB and Risk of Delayed HAVB

Although prior studies have not consistently found first-degree AVB to be a predictor of any HAVB,^{2,9} PR prolongation has been associated with late HAVB or PPM requirement using different time points of ECG assessment (immediate post-TAVR¹⁷ or 48 hours post-TAVR¹⁴).

In our study, pre-existing first-degree AVB was an independent predictor of delayed HAVB; however, new first-degree AVB on post-TAVR ECG was not. This may be because of a longer PR interval post-TAVR in the pre-existing first-degree AVB group compared with the new first-degree AVB group (242 ± 46 versus 220 ± 38 ms). On subgroup analysis of patients with isolated baseline first-degree AVB and no concomitant periprocedural bundle-branch block, the majority of patients with delayed HAVB had PR ≥ 240 ms on post-TAVR ECG, suggesting that these patients may benefit from longer monitoring.

Normal Pre- and Post-TAVR ECG and Risk of Delayed HAVB

Patients with normal pre- and post-TAVR ECG had a low risk of HAVB (1%) after 24 hours. This is consistent with a smaller single-center study that reported no cases of late HAVB in 70 patients with PR < 200 ms and QRS < 120 ms on immediate post-TAVR ECG,¹⁷ suggesting the safety of early dismissal.

Clinical Implications for Early Risk Stratification Post-TAVR

Recently, a consensus decision pathway for the management of conduction disturbances in patients undergoing TAVR was published.¹⁸ In this document, internal jugular venous access with a secure pacing lead was considered reasonable for patients who develop intraprocedural conduction disturbance (eg, LBBB, PR/QRS prolongation ≥ 20 ms, or complete transient heart block) with inpatient monitoring for at least 48 hours and discharge with AEM ≥ 14 days. Maintaining transvenous pacing ability for at least 24 hours without recommendation for prolonged monitoring was suggested for patients with baseline RBBB with stable conduction post-TAVR. Importantly, it was noted that although studies are forthcoming, PPM indications for high-risk conduction features specific to the TAVR population are not supported by the available evidence. Disadvantages to the above-proposed strategy include prolonged patient hospitalization, inability of the temporary pacemaker to address HAVB occurring after 24 to 48 hours, and potential morbidity related to prolonged indwelling temporary pacemaker.

In the current study, we were able to further risk stratify groups known to be at elevated risk of delayed HAVB by using the presence of concomitant conduction abnormalities, including PR and QRS length for new LBBB and PR length or concomitant fascicular block for baseline RBBB. Transient intraprocedural HAVB was associated with a high rate of delayed HAVB regardless of baseline conduction. We postulate that performing PPM implantation the same day in

groups at the highest risk of delayed HAVB, including new LBBB with PR ≥ 240 ms, new LBBB with QRS ≥ 150 ms combined with first-degree AVB or incalculable PR, baseline RBBB with first-degree AVB or bifascicular block, or transient intraprocedural HAVB, may allow for definitive treatment to avoid prolonged hospital stay, reduce risk of hospital readmission, and avoid potential risk associated with use of active fixation temporary pacemaker. Alternatively, in groups at intermediate risk of delayed HAVB, including patients with new LBBB and PR < 240 ms and QRS < 150 ms, isolated RBBB, or isolated PR ≥ 240 ms, longer inpatient monitoring for 48 hours with use of AEM may be warranted. In patients with no transient HAVB or conduction abnormalities post-TAVR, the rate of HAVB is very low, supporting hospital dismissal within 24 hours without outpatient rhythm monitoring. A proposed algorithm based on these principles is shown in Figure 4. Prospective study of these strategies, particularly early prophylactic PPM implantation in the highest-risk subgroups, is needed to determine whether this leads to improved short- and long-term outcomes after TAVR.

A recent study has proposed the use of rapid atrial pacing immediately after TAVR to risk stratify patients for future HAVB.¹⁹ Although the end point was placement of PPM rather than incidence of HAVB, which may lead to confirmation bias, the lack of development of Wenckebach AVB during rapid atrial pacing had a high negative predictive value (98.7%) for requiring PPM, suggesting potential utility of this approach to risk stratify intermediate-risk patient subgroups.

Limitations

This study has several limitations, including its single-center and retrospective design with inherent biases. Temporal occurrence of HAVB may vary with differences in TAVR technique or type of prosthesis as well as postprocedural monitoring. Subclinical transient episodes of HAVB after dismissal in patients who did not receive 30-day AEM, which was often deferred in patients without high-risk conduction abnormalities, may be underestimated. Furthermore, HAVB is not limited to 30 days post-TAVR and these events were not captured in this study. Reporting of temporal incidence > 24 hours and delayed events was potentially impacted by bias because patients without early HAVB and who had prophylactic PPM implantation for presumed high risk were excluded from this incidence calculation. It is possible that the rate of delayed HAVB would be increased if these higher-risk patients did not receive prophylactic PPM. Analysis to evaluate risk factors for delayed HAVB was limited by low event rates, and subgroup analysis of patients with new LBBB or baseline RBBB was limited by sample sizes. Larger

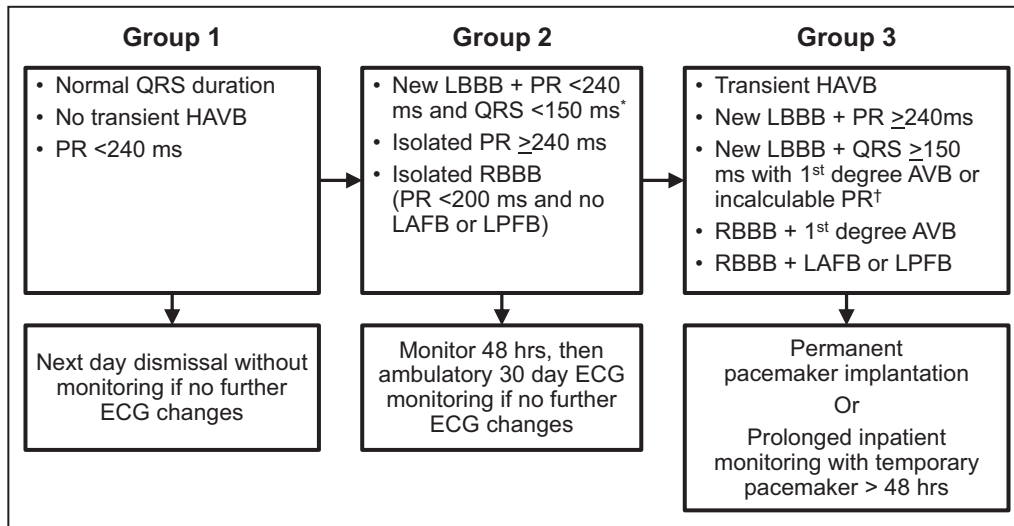


Figure 4. Proposed algorithm of pre- and post-TAVR conduction assessment and management. *New LBBB with QRS ≥ 150 ms but with PR interval < 200 ms are at similar risk of delayed HAVB to those with QRS < 150 ms and could be managed similarly. †Incalculable PR because of atrial fibrillation. AVB indicates atrioventricular block; HAVB, high-grade atrioventricular block; LAFB, left anterior fascicular block; LBBB, left bundle-branch block; LPFB, left posterior fascicular block; RBBB, right bundle-branch block; and TAVR, transcatheter aortic valve replacement.

studies are needed to confirm these findings before wide implementation of the proposed post-TAVR conduction management algorithm in clinical practice.

CONCLUSIONS

Delayed HAVB is closely associated with both baseline and post-TAVR conduction abnormalities, including pre-TAVR RBBB or first-degree AVB and new LBBB. Patients with no conduction abnormalities on pre- or immediate post-TAVR ECG had a low rate of HAVB after 24 hours, supporting early hospital dismissal in this group. Specific conduction abnormalities associated with high incidence of delayed HAVB included baseline RBBB with first-degree AVB or bifascicular block, new LBBB with PR interval ≥ 240 ms, new LBBB with QRS ≥ 150 ms combined with first-degree AVB or incalculable PR, and transient intraprocedural HAVB. Groups at the highest risk of HAVB may benefit from early PPM implantation or prolonged inpatient monitoring to avoid morbidity associated with HAVB in the unmonitored setting, including risk of rehospitalization or sudden cardiac death.

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None.

Supplementary Material

Tables S1–S3
Figure S1

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SUPPLEMENTARY MATERIAL

Table S1. Patient characteristics and post-TAVR management of patients with baseline RBBB stratified by presence of concomitant conduction abnormalities.

Characteristic	Isolated RBBB (n=55)	RBBB + 1st degree AVB (n=14)	Bifascicular block (n=35)	Bifascicular + 1st degree AVB (n=15)
Age, years	82.7±6.2	82.1±8.9	82.1±7.0	84.3±5.2
Female	18 (32.7)	4 (28.6)	12 (34.3)	3 (20.0)
History of AF	22 (40.0)	6 (42.9)	13 (37.1)	5 (33.3)
AV calcium score	2780±1318	2581±1195	2520±1249	2978±926
Baseline QRS ≥150 ms	17 (30.9)	8 (57.1)	15 (42.9)	10 (66.7)
Type of valve				
Balloon-expandable	49 (89.1)	11 (78.6)	31 (88.6)	13 (86.7)
Self-expanding	6 (10.9)	3 (21.4)	4 (11.4)	2 (13.3)
Hospital stay, days ^a	2 (2-4)	3.5 (2-5)	5 (3-6)	3 (2-6)
Discharged with 30-day AEM	7 (12.7)	4 (28.6)	4 (11.4)	3 (20.0)
Indications for new PPM				
HAVB	24 (43.6)	9 (64.3)	19 (54.3)	7 (46.7)

Mobitz Type II AVB	0 (0)	0 (0)	0 (0)	1 (6.7)
Sinus node dysfunction	1 (1.8)	0 (0)	0 (0)	1 (6.7)
Prophylaxis ^b	2 (3.6)	0 (0)	4 (11.4)	2 (13.3)

Values are n (%) or mean \pm SD

^aMedian (interquartile range) reported

^bProphylactic pacemaker per early institutional protocol for indication of baseline RBBB or new left bundle branch block after TAVR

AEM, ambulatory ECG monitoring; AF, atrial fibrillation/flutter; AV, aortic valve; AVB, atrioventricular block; HAVB, high-grade atrioventricular block; PPM, permanent pacemaker; RBBB, right bundle branch block; TAVR, transcatheter aortic valve replacement

Table S2. Patient characteristics and post-TAVR management of patients with new LBBB post-TAVR stratified by PR interval length or atrial fibrillation/flutter as determined on immediate post-TAVR ECG.

Characteristic	LBBB + PR	LBBB + PR	LBBB + PR	LBBB + AF
	<200 ms (n=84)	200-239 ms (n=42)	>240 ms (n=18)	(n=37)
Age, years	78.2±9.0	82.5±7.4	82.3±5.9	82.6±6.7
Female	50 (59.5)	12 (28.6)	3 (16.7)	22 (59.5)
History of AF	18 (21.4)	12 (28.6)	9 (50.0)	34 (91.9)
AV calcium score	2191±1259	2873±1376	2653±1345	2764±1650
Type of valve				
Balloon-expandable	67 (79.8)	37 (88.1)	14 (77.8)	28 (75.7)
Self-expanding	17 (20.2)	5 (11.9)	4 (22.2)	9 (24.3)
Post-TAVR QRS ≥150 ms	21 (25.0)	19 (45.2)	12 (66.7)	14 (37.8)
Hospital stay, days ^a	3 (1-6)	2 (1-5)	3.5 (2-5)	3 (2-5.5)
Discharged with 30-day AEM	28 (33.3)	22 (52.4)	4 (22.2)	15 (40.5)
Indications for new PPM				

HAVB	3 (3.6)	7 (16.7)	6 (33.3)	7 (18.9)
Mobitz II AVB	2 (2.4)	1 (2.4)	0 (0)	0 (0)
Sinus node dysfunction	1 (1.2)	0 (0)	0 (0)	1 (2.7)
Prophylaxis ^b	21 (25.0)	9 (21.4)	8 (44.4)	8 (21.6)

Values are n (%) or mean \pm SD

^aMedian (interquartile range) reported

^bProphylactic pacemaker per early institutional protocol for indication of baseline right bundle branch block or new LBBB after TAVR

AEM, ambulatory ECG monitoring; AF, atrial fibrillation/flutter; AV, aortic valve; AVB, atrioventricular block; HAVB, high-grade atrioventricular block; LBBB, left bundle branch block; PPM, permanent pacemaker; TAVR, transcatheter aortic valve replacement

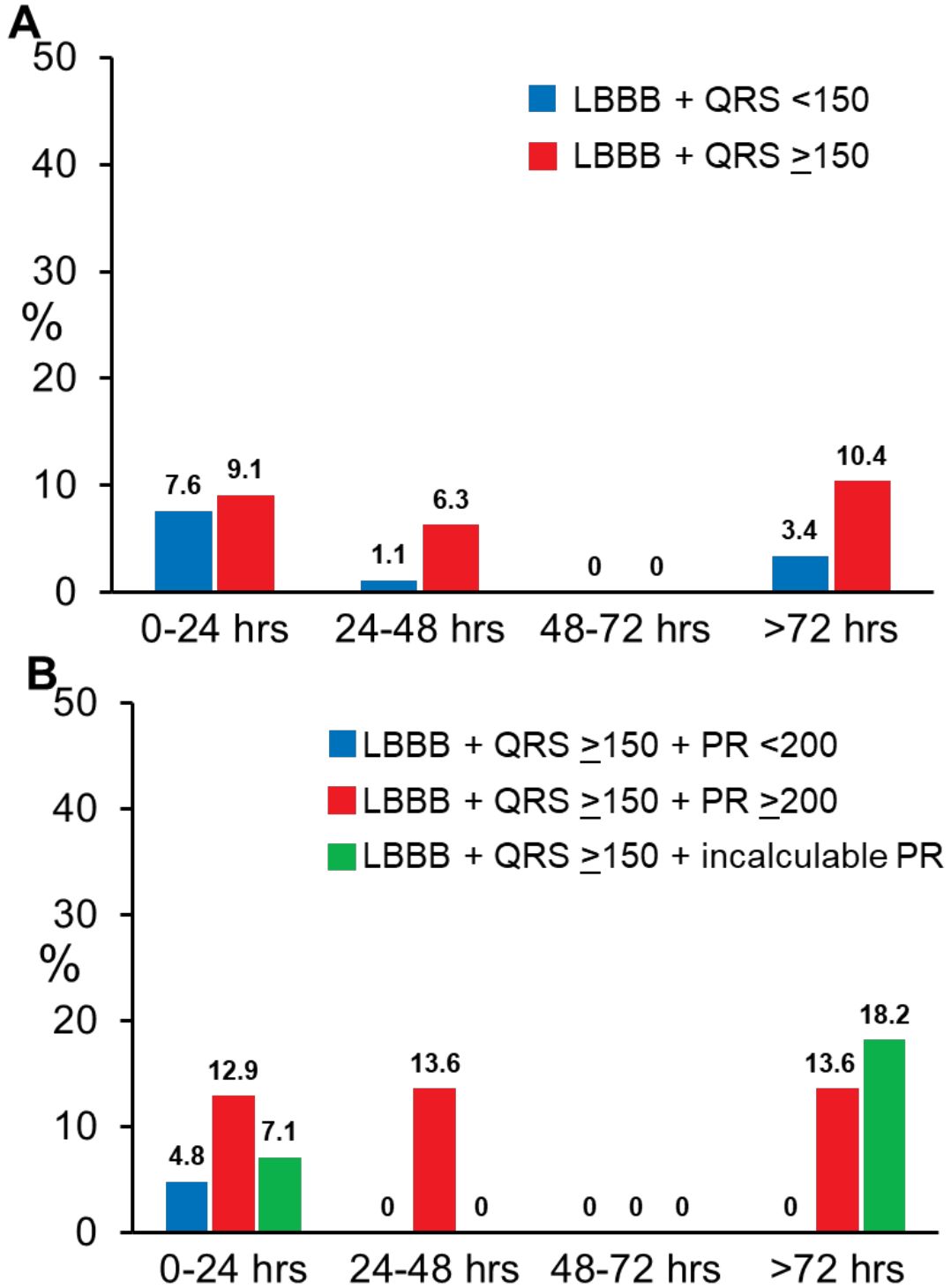
Table S3. Comparison of patient characteristics that had transient intra-procedural high-grade atrioventricular block with or without recurrence within 30 days.

Characteristic	HAVB Recurrence		
	Yes (n=16)	No (n=18)	P-value
Age	80.8±7.9	80.4±7.5	0.87
Female	6 (37.5)	11 (61.1)	0.17
Atrial fibrillation/flutter	7 (43.8)	9 (50.0)	0.53
AV calcium score	2822±298	1947±298	0.04
Pre-TAVR ECG			
1 st degree AVB	3 (18.8)	2 (11.1)	0.53
RBBB	11 (68.8)	6 (33.3)	0.04
LBBB	0 (0)	4 (22.2)	-
Type of valve			
Balloon-expandable	14 (87.5)	13 (72.2)	0.27
Self-expanding	2 (12.5)	5 (27.8)	
Post-TAVR ECG			
New 1 st degree AVB	2 (12.5)	2 (11.1)	0.90
New LBBB	3 (18.8)	3 (16.7)	0.87

Values are n (%) or mean±SD

AV, aortic valve; AVB, atrioventricular block; HAVB, high-grade AV block; LBBB, left bundle branch block; RBBB, right bundle branch block; TAVR, transcatheter aortic valve replacement

Figure S1. Temporal incidence of high-grade atrioventricular block in patients with new LBBB after TAVR.



A) Temporal incidence in patients with new LBBB and QRS duration ≥ 150 ms (n=66) or QRS < 150 ms (n=118). B) Temporal incidence in patients with new LBBB and QRS duration ≥ 150 ms stratified by PR < 200 ms (n=21), PR ≥ 200 ms (n=31), or incalculable PR (n=14).

LBBB, left bundle branch block; TAVR, transcatheter aortic valve replacement