Revised: 11 March 2019

DEVICES

PACE wiley

Atrioventricular conduction in patients undergoing pacemaker implant following self-expandable transcatheter aortic valve replacement

Michael Ghannam MD¹ P Ryan Cunnane MD¹ Daniel Menees MD¹ Michael P. Grossman MD¹ Stanley Chetcuti MD¹ Himanshu Patel MD² Michael Deeb MD² Krit Jongnarangsin MD¹ Frank Pelosi Jr. MD¹ Hakan Oral MD¹ Rakesh Latchamsetty MD¹

¹Division of Cardiovascular Medicine, Department of Medicine, University of Michigan, Ann Arbor, Michigan

²Department of Cardiac Surgery, University of Michigan, Ann Arbor, Michigan

Correspondence

Michael Ghannam, MD, Cardiovascular Center, SPC 5853, 1500 East Medical Center Drive, Ann Arbor, MI 48109-5853. Email: mousajab@med.umich.edu

Subject Terms: Pacemaker, electrophysiology, quality and outcomes.

Funding/Disclosures: There were no external funding sources for this study. The authors have no relevant disclosures or conflicts of interests.

Abstract

Background: Heart block requiring a pacemaker is common after self-expandable transcatheter aortic valve replacement (SE-TAVR); however, conduction abnormalities may improve over time. Optimal device management in these patients is unknown.

Objective: To evaluate the long-term, natural history of conduction disturbances in patients undergoing pacemaker implantation following SE-TAVR.

Methods: All patients who underwent new cardiac implantable electronic device (CIED) implantation at Michigan Medicine following SE-TAVR placement between January 1, 2012 and September 25, 2017 were identified. Electrocardiogram and device interrogation data were examined during follow-up to identify patients with recovery of conduction. Logistic regression analysis was used to compare clinical and procedural variables to predict conduction recovery.

Results: Following SE-TAVR, 17.5% of patients underwent device placement for new atrioventricular (AV) block. Among 40 patients with an average follow-up time of 17.1 ± 8.1 months, 20 (50%) patients had durable recovery of AV conduction. Among 20 patients without long-term recovery, four (20%) had transient recovery. The time to transient conduction recovery was 2.2 ± 0.2 months with repeat loss of conduction at 8.2 ± 0.9 months. On multivariate analysis, larger aortic annular size (odds ratio: 0.53 [0.28–0.86]/mm, P = 0.02) predicted lack of conduction recovery.

Conclusions: Half of the patients undergoing CIED placement for heart block following SE-TAVR recovered AV conduction within several months and maintained this over an extended follow-up period. Some patients demonstrated transient recovery of conduction before recurrence of conduction loss. Larger aortic annulus diameter was negatively associated with conduction recovery.

KEYWORDS

atrioventricular block, conduction recovery, device therapy, pacemaker, transcutaneous aortic valve replacement

1 | INTRODUCTION

The advent of transcatheter aortic valve replacement (TAVR) has led to a new paradigm for the treatment of severe aortic stenosis.¹ While overall safety outcomes are attractive, a common complication of TAVR is the development of high-grade or complete atrioventricular (AV) conduction block which can occur in 8–40% of patients.^{2,3} Many patients who require a permanent pacemaker post-TAVR eventually recover AV conduction and do not remain pacemaker dependent.^{4,5} The significance of this recovery and the optimal device-management strategy in these patients are unknown. Delaying implantation immediately post-TAVR may identify those patients whose conduction block is

a transient phenomenon. However, the majority of devices post-TAVR are placed within 48 hours.^{6,7} This is done both to facilitate patient recovery and discharge, as well as for patient safety given the lack of predictors on recurrence of heart block and the highly variable time to conduction recovery.

Pacemaker implantation is higher with the use of self-expandable valves.^{8,9} These prostheses exert a continual outward force postdeployment which could impact long-term recovery of conduction. In this study, we sought to evaluate the long-term, natural history of conduction disturbances in patients receiving cardiac implantable electronic devices (CIEDs) following TAVR using self-expandable valves and to determine long-term pacing requirements.

2 | METHODS

2.1 | Study subjects

The subjects of this study were patients who underwent pacemaker or implantable cardiac defibrillator placement due to conduction disturbances in the periprocedural period (within 2 weeks) after TAVR using self-expandable valves. All patients at Michigan Medicine who underwent TAVR between January 1, 2012 and September 25, 2017 were identified through the Society for Thoracic Surgeons and the American College of Cardiology Transcatheter Valve Therapy (STS/ACC TVT) registry. Patients who had balloon-expandable valves, those with existing CIEDs, and those who had CIEDs placed for reasons other than new AV block were excluded. AV block was defined as continuous or intermittent third-degree heart block, second-degree type II heart block, or symptomatic second-degree type I AV block. Patients who did not have a minimum of 12 months of follow-up (due to either death, loss of CIED-related follow-up, or less than 12 months of CIED follow-up at the time of the study) were excluded. The University of Michigan Institutional Review Board approved the study protocol prior to data collection.

2.2 | Data collection

Baseline demographic, clinical, and procedural data were obtained from the STS/ACC TVT registry or through review of medical records where appropriate. Aortic annulus perimeter was derived from computed tomography (CT) planimetry performed for preprocedural planning. Imaging and measurements were performed in accordance with the SCCT Expert Consensus document.¹⁰ Calculated area oversizing was derived from the following formula: oversizing (%) = (TAVR perimeter/annulus perimeter – 1) × 100.^{11,12}

At each follow-up device interrogation, native conduction was assessed by temporarily programming the CIED to VVI 30. Patients were routinely evaluated at 1 week and 2 months postimplantation; follow-up then occurred every 6 months unless clinicians felt more frequent in-office evaluation was warranted. Device intracardiac electrograms and electrocardiograms (EKGs) were reviewed when available to characterize AV node conduction into normal (1:1 AV conduction with a PR interval <200 ms), first-degree AV block, second-degree type I AV block, or third-degree AV block. For patients in atrial fibrillation, complete heart block was defined as a regular junctional rhythm at less than 50 beats/min. Patients were deemed to have no recovery of AV nodal conduction if they had complete heart block, highgrade AV block, or a native ventricular rate of less than 50 beats/min in the absence of normal AV nodal conduction. Pacemaker programming mode, percentage of atrial and ventricular pacing, and sensed/paced AV intervals were also collected.

2.3 | Statistical analysis

Patients were classified into two groups based upon whether or not they had sustained recovery of AV nodal conduction at the end of their follow-up period. Those who had only transient recovery of AV nodal conduction were included in the no-recovery group. Patient and procedural characteristics were compared to identify factors associated with recovery of conduction. Data were compared using the Fisher's exact *t*-test or chi-square test for categorical variables and the Student's *t*-test or Mann-Whitney test for continuous variables where appropriate. Data are expressed as means \pm standard deviations or medians [interquartile range] where appropriate. Kaplan-Meyer curves were created to track recovery of AV node conduction over time. Univariate logistic regression analysis was performed. Variables with a univariate P-value of < 0.10 were then incorporated into a multivariate analysis. All statistical testing was performed on R version 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria).

3 | RESULTS

3.1 General population

A total of 701 patients underwent TAVR over the study period including 524 (75%) with a self-expandable valve. Among the total population, 128 patients (18%) had preexisting pacemakers (n = 85) or implantable cardioverter defibrillator (ICD) (n = 43). Among the remaining 573 patients who underwent TAVR (n = 422 selfexpandable valve, n = 151 balloon expandable valve) and did not have a preexisting CIED, 14% (n = 82) underwent device placement for new AV block (Figure 1). New CIED utilization rates among patients receiving self-expandable valves were 17.5% (74/422) and for patients receiving balloon-expandable valves was 5% (8/151). Age, preexisting conduction block, the use of self-expandable valves, and diabetes were associated with an increased risk of requiring a CIED post-TAVR implantation (Table 1).

3.2 | CIED population

We evaluated 40 patients who received a CIED for AV conduction abnormality following self-expandable TAVR. The mean patient age was 78.2 \pm 9.9 years, 53% of the population were male (n = 21), and the mean ejection fraction was 57 \pm 14% (Table 2). Patients with less than 1-year follow-up, patients who died within 1 year of followup, and patients with a CIED placed for reasons other than AV block



FIGURE 1 Study population selection. Included were 40 patients who underwent CIED placement for AV conduction abnormalities following self-expandable TAVR with a follow-up period at the time of this study of at least 1 year. TAVR = transcutaneous aortic valve replacement; ICD = implantable cardiac defibrillator; CIED = cardiac implantable electronic device; AV = atrioventricular

were excluded. Thirteen patients were excluded due to death which occurred during the index hospitalization for TAVR placement (n = 3), or within 12 months due to cardiovascular (n = 4), or noncardiovascular causes (n = 5). Cardiovascular causes of death included progression of systolic congestive heart failure in three patients, and diastolic heart failure in one patient. Deaths during the index hospitalization for TAVR included sepsis in two patients and complications from COPD in one patient. There were no deaths related to CIED placement.

Of the CIEDs implanted, 34 (85%) were dual-chamber pacemakers, four (10%) were cardiac resynchronization therapy-defibrillators (CRT-D), one (2%) was a CRT-pacemaker, and one (2%) was a dual-chamber ICD. The average time between TAVR placement to CIED implantation was 2.4 ± 2.4 days with 17/40 devices placed at the time of TAVR implantation. The indication for CIED implantation included complete heart block (n = 33), Mobitz type II heart block (n = 2), and high-grade AV block (n = 5). There were no intraprocedural complications during CIED placement.

3.3 Follow-up and recovery of conduction

Average time of follow-up was 17.1 ± 8.1 months, during which 50% of the patients (20/40) had durable recovery of AV node conduction.

There was one patient with a device-related complication over the follow-up period. This patient had a right ventricular lead fracture that was replaced without further sequela.

The recovery of AV node conduction over the follow-up period is displayed in Figure 2. About half of the patients who recovered AV conduction did so within 1 month (11/20 patients), with an average recovery time of 2.8 ± 4.0 months. The longest time to recovery of conduction was 15 months.

Patients who underwent CIED placement at the time of TAVR and those who underwent CIED placement later in their hospitalization had similar rates of long-term conduction recovery (47% vs 52%, P = 0.75). Time between TAVR and CIED placement had no effect on long-term recovery rates (P > 0.05). There were no demographic differences between patients who underwent CIED placement at the time of TAVR (n = 17) and those who underwent placement later in their hospitalization (n = 23) including age, sex, Society of Thoracic Surgeons risk score, ejection fraction, preexisting conduction abnormalities, or history of atrial fibrillation/flutter (P > 0.05 for all).

Patient characteristics for those with and without recovery of AV node conduction are displayed in Table 2. Univariate predictors for lack of AV node recovery that were then included in the multivariate analysis included a history of prior cardiac surgery (odds ratio [OR]: 0.12 [0.0.01–0.83]), left ventricular intraventricular dimension diastole (0.37 [0.13–0.91]/mm), aortic valve annular size (OR: 0.50 [0.29-0.75]/mm), and atrial fibrillation or flutter (0.27 [0.06–1.0]) (Table 3). On multivariate analysis, only aortic annular size (0.53 [0.28–0.86]/mm) significantly predicted a lack of conduction recovery (P = 0.02).

3.4 | Recovery and later loss of conduction

Among the 20 patients who remained pacemaker dependent, four patients (20%) had intermittent recovery of AV conduction but were pacemaker dependent by the end of the follow-up period (Table 4). The average time to recovery of conduction was 2.2 ± 0.2 months with recurrent loss of conduction diagnosed at 8.2 ± 0.9 months and the latest recurrent loss of conduction occurring at 14 months. There were no significant procedural or demographic differences between this group and the group which recovered conduction permanently (P > 0.05 for all). Three patients displayed bundle branch blocks after initial recovery of conduction; these abnormalities were already present in two patients post-TAVR; one patient had progression from intraventricular conduction delay (IVCD) to a left bundle branch block (LBBB) and took the longest to eventually lose conduction (14 months). All four patients had return to their pre-TAVR AV conduction after initial recovery of conduction (2/4 with return to first-degree AV block, 1/4 with persistent atrial fibrillation and normal ventricular rates, and 1/4 with sinus rhythm and normal AV conduction that developed atrial fibrillation with normal ventricular rates).

3.5 | Device settings and follow-up EKG

Device settings and EKG characteristics at the time of last follow-up among patients who had recovery of conduction are shown in Table 5.

TABLE 1	Comparison of demographic and clinical data among patients with and without cardiac implantable electronic devices for AV block
after TAVR	placement

	No post-TAVR CIED (n = 491)	Post-TAVR CIED (n = 82)	OR	Р
Age	78.75 ± 12.17	80.9 ± 8.6	1.03 [1.01–1.05]/year	0.02
Male sex (%)	57% (283)	62% (51)		0.44
White race (%)	93% (459)	94% (77)		0.88
Preexisting conduction abnormality	42% (205)	62% (51)	2.3 [1.4-3.7]	< 0.001
LVEF	57.9 ± 15.4	56.4 ± 14.6		0.39
STS risk score	6.27 ± 5.07	6.61 ± 4.14		0.57
CoreValve	71% (348)	90% (74)	3.81 [1.89-8.73]	< 0.001
Stroke	10% (51)	11% (9)		0.83
Smoker	46% (226)	45% (37)		0.88
HTN	70% (398)	80% (65)		0.7
DM	35% (176)	50% (41)	1.79 [1.11-2.87]	0.02
Prior MI	20% (96)	20% (16)		0.79
Prior CABG	22% (107)	22% (18)		0.97
Prior PCI	34% (169)	31% (26)		0.68
PAD	46% (226)	45% (37)		0.88
AF/flutter	34% (167)	40% (33)		0.26

Note: AF = atrial fibrillation; AV = atrioventricular; CABG = coronary artery bypass graft; CI = confidence interval; CIED = cardiac implantable electronic device; DM = diabetes mellitus; HTN = hypertension; LVEF = left ventricular ejection fraction; MI = myocardial infarction; OR = odds ratio; PAD = peripheral artery disease; PCI = percutaneous coronary intervention; STS = Society of Thoracic Surgeons; TAVR = transcutaneous aortic valve replacement.

Most patients had near normalization of their EKGs compared to their pre-TAVR assessment. All patients with return of conduction had normal AV conduction (n = 7) or first-degree AV block (n = 13). In 19/20 patients, the mean PR prolongation between pre-TAVR implant and follow-up was 32.2 ± 45.5 ms; one patient had second-degree AV type I block pre-TAVR and had no AV block at follow-up. Most patients (n = 15) (75%) had abnormal QRS morphologies (LBBB, n = 6; right bundle branch block, n = 6; IVCD, n = 3) at follow-up, 73% (n = 11) patients had preexisting abnormal QRS morphologies, and 27% (n = 4) patients developed new abnormal QRS morphologies. The mean QRS prolongation at the time of follow-up was 13.8 ± 22.8 ms.

The median ventricular pacing burden in patients who had recovered AV nodal conduction was 0 [0-1.5]%; there was a minority of patients (n = 3) who had first-degree AV block and pacing burdens >50%. This may have been minimized by programming changes to minimize ventricular pacing.

4 DISCUSSION

In this study, we reported on the natural history of conduction abnormalities in patients who received CIED implant for conduction abnormalities following self-expandable TAVR. We demonstrated that 50% of patients who received a CIED for new AV block had recovery of conduction on long-term follow-up. Those who underwent CIED placement at the time of TAVR had a similar rate of conduction recovery as those who had them placed later in the hospitalization stay. While the majority of patients who recovered conduction did so within several months, some patients will continue to display recovery up to 15 months after their procedure. Clinical factors associated with long-term conduction status included aortic annulus diameter.

Our baseline TAVR population and incidence of CIED placement reflect real-world practices.¹³ Our mean time-to-CIED-implant (2.4 days) was similar to previously reported large cohort studies.⁶ Similar to prior studies, older age and preexisting conduction abnormalities were associated with the need for CIED placement post-TAVR.^{14,15} In addition, in our study population a history of diabetes was also found to be associated with CIED placement following TAVR.

4.1 | Incidence and timing of conduction recovery

We reported on detailed conduction and device data over an extended follow-up period and found that 20/40 (50%) of patients recovered AV nodal conduction. Furthermore, these patients experienced only mild PR prolongation and QRS changes compared to pre-TAVR assessment. The majority of patients that recovered conduction did so within several months and maintained conduction over a follow-up period over 1 year.

Acute conduction abnormalities post-TAVR are caused by mechanical compression of adjacent structures by the prosthesis leading to ischemic and inflammatory changes in the perinodal tissue.¹⁶ Sinhal et al reported on an autopsy performed in a patient with new AV block after TAVR who died on postoperative day 10 of an unrelated cause.¹⁷ Pathology showed necrosis and ischemic injury of the perinodal tissue, with sparing of the AV node and subendocardial septal issue. Intramyocardial hemorrhage and hematoma formation have also been described¹⁸ which can exert further local compressive forces. Resolution of these changes over time leads to recovery of conduction. The self-expanding valve exerts a persistent radial force and extends

	Recovery (n = 20)	No Recovery (n = 20)	Р	OR [95% CI]
Demographics				
Age (years)	80.5 ± 10.0	75.9 ± 9.5	0.14	
Sex (male)	40% (8)	65% (13)	0.12	
Race (white)	90% (18)	100% (20)	0.15	
STS risk score	5.3 ± 2.6	6.1 ± 3.8	0.42	
Preexisting conduction abnormality	70% (14)	65% (13)	0.75	
Smoker	5% (1)	10% (2)	0.56	
HTN	70% (14)	70% (14)	1	
DM	40% (8)	45% (9)	0.75	
Prior MI	15% (3)	5% (1)	0.3	
Prior PCI	20% (4)	30% (6)	0.48	
PAD	40% (8)	35% (7)	0.75	
AF/flutter	25% (5)	55% (11)	0.05	0.27 [0.06-1.00]
CAD (# of diseased vessels)	0.85 ± 1.22	1.1 ± 1.25	0.53	
Prior CABG	5% (1)	15% (3)	0.3	
Prior cardiac surgery (yes)	5% (1)	30% (6)	0.06	0.12 [0.01-0.83]
Procedural characteristics				
Time to implant (days)	2.4 ± 2.1	2.4 ± 2.8	1	
Intraprocedural placement	40% (8)	45% (9)	0.54	
Implant depth (mm)	4.1 ± 1.2	4.1 ± 0.9	0.74	
TAVR size (mm)	29.6 ± 2.6	30.1 ± 2.0	0.49	
TAVR/LVOT	1.41 ± 0.12	1.35 ± 0.12	0.14	
TAVR to aortic annulus oversize (%)	16.85 ± 7.15	18.5 ± 9.86	0.65	
Pre-Lab				
Creatinine (mg/dL)	1.26 ± 0.48	1.54 ± 1.75	0.48	
Hemoglobin (g/dL)	12.06 ± 1.9	12.05 ± 2.1	0.98	
Albumin (g/dL)	3.89 ± 0.37	3.91 ± 0.32	0.85	
Platelet (103 / μ L)	251 ± 115	202 ± 57	0.09	
Echo/Imaging				
Left ventricular EF (%)	$59.0 \pm 11.6\%$	55.4 ± 16.2	0.42	
RV systolic pressure (mm Hg)	45.6 ± 13.5	50.5 ± 9.3	0.25	
LVIDd (cm)	4.58 ± 0.75	5.12 ± 0.75	0.04	0.37 [0.13-0.91]
LVIDs (cm)	3.12 ± 0.81	3.54 ± 1.02	0.27	
Septal wall thickness (cm)	1.2 ± 0.25	1.2 ± 0.22	0.63	
Aortic valve annulus (mm)	23.5 ± 1.5	25.9 ± 2.15	<0.01	0.50 [0.29-0.75]/mm
LVOT (mm)	21.1 ± 2.4	22.3 ± 2.3	0.12	
Aortic valve area (cm ²)	0.76 ± 0.19	0.73 ± 0.17	0.57	
Aortic valve peak velocity (m/s)	3.90 ± 0.91	3.94 ± 0.85	0.89	
Pre-EKG				
PR (ms)	187.6 ± 69.7	176.9 ± 31.4	0.63	
QRS (ms)	121.6 ± 23.1	116.5 ± 28.31	0.56	
QTc (ms)	467 ± 38.5	458.1 ± 34	0.44	
RBBB	35% (7)	30% (6)	0.74	
LBBB	5% (1)	5% (1)	1	

TABLE 2 Comparison of demographic, clinical, and procedural data among patients with and without recovery of AV nodal conduction following cardiac implantable electronic device placement

984

TABLE 2 Continued.

	Recovery (n = 20)	No Recovery $(n = 20)$	Р	OR [95% CI]
IVCD	15% (3)	10% (2)	0.64	
Fascicular block	10% (2)	15% (3)	0.64	

Note: AF = atrial fibrillation; AV = atrioventricular; CABG = coronary artery bypass grafting; CAD = coronary artery disease; CI = confidence interval; Cr = creatinine; DM = diabetes mellitus; EF = ejection fraction; EKG = electrocardiogram; Hgb = hemoglobin; HTN = hypertension; IVCD = intraventricular conduction delay; LBBB = left bundle branch block; LVEF = left ventricular ejection fraction; LVIDd = left ventricular intraventricular dimension diastole; LVIDs = left ventricular intraventricular dimension systole; LVOT = left ventricular outflow tract; MI = myocardial infarction; OR = odds ratio; PAD = peripheral arterial disease; PCI = percutaneous coronary intervention; RBBB = right bundle branch block; RV = right ventricle; STS = Society of Thoracic Surgeons; TAVR = transcatheter aortic valve replacement.



FIGURE 2 Recovery of AV node conduction was seen in 50% of patients following self-expandable transcutaneous aortic valve replacement. Among these patients, more than half recovered conduction within the first month. AV = atrioventricular; mo = months

TABLE 3
Multivariate analysis for predictors of conduction

recovery
Image: Second Se

	OR [95% CI]	Р
AF/flutter	0.15 [0.01-1.03]	0.07
Prior cardiac surgery	0.13 [0.04-1.52]	0.14
LVIDd	0.56 [0.13-2.15]/mm	0.39
Aortic annulus	0.53 [0.28-0.86]/mm	0.02

Note: AF = atrial fibrillation; CI = confidence interval; LVIDd = left ventricular intercavitary dimension diastole; OR = odds ratio.

deeper in the LVOT.^{16,19} These device-specific factors may help explain the delayed conduction recovery seen months later though the exact mechanisms are unknown. A comparison between self-expanding and balloon expandable valves should be the focus of future studies.

4.2 | Factors associated with conduction recovery

Several clinical factors were associated with conduction recovery. Using a multivariate analysis, the only significant predictor was aortic annulus size where patients with a larger aortic annulus were less likely to recover conduction (OR: 0.53, 95% confidence interval [CI]: 0.28–0.86, P = 0.02). The cause of this association is not clear but may be related to abnormal aortic and left ventricular outflow tract (LVOT) geometry resulting in increased radial forces being delivered to conductive tissue by the valve prosthesis. This observation is supported

by procedural factors associated with new heart block, such as device implantation depth, angle of deployment, and prosthesis to LVOT diameter ratios.^{7,20}

Patients who received a CIED at the time of TAVR had similar rates of conduction recovery as those who had them placed later in the hospitalization. Presumably, a longer duration of heart block prior to CIED implant would be more specific in identifying those who will have longterm conduction abnormalities. Waiting periods are broadly recommended though the optimal timing of CIED implantation is unknown.²¹ Implant timing in our study was based on operator judgment. Prospective clinical trials are needed to better understand the effect of immediate versus delayed CIED implantation.

4.3 | Recovery and subsequent loss of conduction

In 16% of patients who recovered conduction early on, a subsequent loss of conduction was observed. Most patients' ultimate loss of conduction occurred within 8 months of TAVR, although one patient experienced a late loss of conduction at 14 months. No clinical factors were associated with later loss of AV conduction, though the patient who lost conduction at 14 months was notable for the development of a new LBBB after initial recovery of conduction. This ability for late recurrent loss of conduction can have important implications for device programming and management.

4.4 | Prior studies

These results contribute to a growing body of evidence that recovery of conduction is common in patients who undergo CIED implantation after TAVR. There is substantial heterogeneity in follow-up periods, methodology of conduction assessment (resting EKGs vs device interrogation), and definition of conduction recovery; however, reports show that most patients will experience partial, if not complete conduction recovery over long-term follow-up. $^{3,22-26}$ Reported rates of long-term recovery are approximately 50-60%, consistent with this study. Clinical factors associated with recovery are less reliably demonstrated. A recent study by Kaplan et al followed 67 patients with high-grade or complete AV block following balloon-expandable and SEV TAVR placement and reported that only 21.9% remained pacemaker dependent after 1 year.²⁵ The use of SEV as well as postballoon dilation was associated with higher rates of pacemaker dependency. In contrast, Raelson et al performed a similar analysis on patients undergoing both balloon-expandable and SEV

Patient (#)	Age	Sex	STS risk score	EF (%)	Atrial rhythm	PR duration (ms)	QRS width (ms)	QTc (ms)	QRS morphology	Time to recovery (mo)	Time to loss (mo)
1	83.0	Male	3.5	60	A flutter	NA	156	528	LBBB	2.0	3.9
2	69.8	Male	0.9	65	AF	NA	82	457	Normal	2.2	14.4
3	91.7	Female	6.8	60	NSR	214	126	460	RBBB, LAFB	2.3	9.7
4	72.0	Female	8.1	30	NSR	224	172	452	LBBB	2.3	4.6

TABLE 4 Characteristics of patients with transient recovery of conduction

Note: EKG data shown are from the last EKG prior to the development of heart block. AF = atrial fibrillation; EF = ejection fraction; EKG = electrocardiogram; IVCD = intraventricular conduction delay; LAFB = left anterior fascicular block; LBBB = left bundle branch block; m = months; m = milliseconds; NSR = normal sinus rhythm; RBBB = right bundle branch block; STS = Society of Thoracic Surgeons; TAVR = transcatheter aortic valve replacement.

TABLE 5 EKG and device characteristics at final follow-up in patients with recovery of conduction

Time to follow-up EKG (days)	Atrial rhythm	AV conduction	Native ventricular rate (beats/min)	PR (ms)	QRS (ms)	QTc (ms)	QRS (ms)	Fascicular block
414 ± 197	NSR: 12, SB:4, AP: 4	Normal: 7 1st°AV Block: 13	70.3 ± 13.5	225 ± 54	128 ± 25	456 ± 36	Normal: 5 LBBB:6 RBBB:6 IVCD: 3	LAFB: 4
Time to follow up Device Interrogation (days)	Device Mode	%A pace	%V pace	Pace AV	Sense AV	LR		
521 ± 226	$AAI(R) \rightarrow DDD:13$ DDD(R):7 DDI(R):1	25.6 ± 28.5	0[0-1.5]	220.0 ± 61.4	205.2 ± 61.4	59.3 ± 2.4		

Note: Values are mean \pm standard deviation or median [1st quartile-3rd quartile]. AP = atrial pacing; AV = atrioventricular; EKG = electrocardiogram; IVCD = intraventricular conduction delay; LAFB = left anterior fascicular block; LBBB = left bundle branch block; LR = lower rate; NSR = normal sinus rhythm; RBBB = right bundle branch block; SB = sinus bradycardia.

and were unable to find predictors of recovery.²³ Our study expands on these findings by detailing the patterns of conduction recovery in patients who underwent device implantation following balloonexpandable valves and highlights the risk of late loss of conduction and the subsequent implications for device management.

4.5 | Implications for patient management

We demonstrate that TAVR-induced heart block is transient in about half of the patients receiving a CIED following TAVR. Device programming in these patients should incorporate strategies to identify this recovery early and utilize device programming to limit unnecessary RV pacing.²⁷ The use of cardiac resynchronization therapy or His bundle pacing as opposed to traditional right ventricular pacing is influenced in part by the anticipated pacing burden and cardiac function.²⁸ In select patients, a trial of single-chamber pacing with later upgrade based on long-term pacing needs may be pursued; however, device therapy must ultimately be tailored to an individual patient's needs based on multiple factors.

The observation of durable as well as transient recovery of AV conduction in these patients may have implications for device explantation. Elective explantation in patients who experience recovery of conduction is not standard of care but could reduce exposure to the long-term risks of implantable devices. This issue has added relevance given the expanding indications for TAVR and the use of these valves in lower risk and younger patients.²⁹ Patients who undergo device extraction for traditional indications (infection, device malfunction, vascular stenosis, etc.) may likewise face an uncertain need for device reimplantation. Prior to explantation, one must keep in mind that despite apparent recovery in conduction, patients may still have intermittent AV conduction block requiring rare ventricular pacing. Device diagnostics (which are available through select CIED vendors) revealing if any ventricular paced beats were present over a period of time would have to be analyzed.

5 | LIMITATIONS

This was a single-center, retrospective study with limited patient numbers and the results of this study should be confirmed with larger, multicenter studies. We focused our analysis on self-expandable valves and future studies should compare these findings to balloonexpandable values. Our analysis was limited to patients who survived greater than 1-year post-TAVR and had adequate follow-up. This was done to focus the results on long-term conduction assessment which will provide clinically meaningful implications on device management. We reported on all available EKG and device interrogation reports over the follow-up period; however, these events occurred months apart and we cannot account for conduction patterns between device interrogations. Patients with recovery of AV conduction had minimal or unchanged EKGs and minimal or no ventricular pacing burden at follow-up but this does not preclude transient high-grade block, rate-dependent conduction abnormalities, or sinus node dysfunction. Future studies will incorporate standardized device programming and follow-up to better assess clinical pacing requirements.

6 | CONCLUSIONS

Factors associated with an increased risk of requiring a CIED in all patients undergoing TAVR were age, preexisting conduction block, the use of self-expandable valves, and diabetes. Despite a higher need for CIEDs in patients with heart block following self-expandable TAVR, half of these patients will recover conduction over long-term follow-up and this recovery can occur months after TAVR deployment. A larger aortic annulus was the lone clinical predictor showing less chance of conduction recovery. Highlighted in this study were a group of patients with transient recovery of conduction with subsequent return of heart block.

FUNDING SOURCES

None.

DISCLOSURES

None.

ORCID

Michael Ghannam MD (D https://orcid.org/0000-0001-6951-5238

REFERENCES

- Nishimura R, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 2014;63:e57-185.
- Piazza N, Onuma Y, Jesserun E, et al. Early and persistent intraventricular conduction abnormalities and requirements for pacemaking after percutaneous replacement of the aortic valve. JACC Cardiovasc Interv. 2008;1:310-316.
- Guetta V, Goldenberg G, Segev A, et al. Predictors and course of high-degree atrioventricular block after transcatheter aortic valve implantation using the CoreValve revalving system. Am J Cardiol. 2011;108:1600-1605.
- van der Boon RM, Van Mieghem NM, Theuns DA, et al. Pacemaker dependency after transcatheter aortic valve implantation with the self-expanding Medtronic CoreValve system. *Int J Cardiol.* 2013;168:1269-1273.
- Goldenberg G, Kusniec J, Kadmon E, et al. Pacemaker implantation after transcatheter aortic valve implantation. Am J Cardiol. 2013;112:1632-1634.
- Urena M, Webb JG, Tamburino C, et al. Permanent pacemaker implantation after transcatheter aortic valve implantation: Impact on late clinical outcomes and left ventricular function. *Circulation*. 2014;129:1233-1243.

- Bates MG, Matthews IG, Fazal IA, Turley AJ. Postoperative permanent pacemaker implantation in patients undergoing trans-catheter aortic valve implantation: What is the incidence and are there any predicting factors? Interactive Cardiovasc Thoracic Surg. 2011;12:243-253.
- Abdel-Wahab M, Neumann FJ, Mehilli J, et al. 1-year outcomes after transcatheter aortic valve replacement with balloon-expandable versus self-expandable valves: Results from the CHOICE randomized clinical trial. J Am Coll Cardiol. 2015;66:791-800.
- Achenbach S, Delgado V, Hausleiter J, Schoenhagen P, Min JK, Leipsic JA. SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). J Cardiovasc Comput Tomogr. 2012;6:366-380.
- Dvir D, Webb JG, Piazza N, et al. Multicenter evaluation of transcatheter aortic valve replacement using either Sapien Xt or CoreValve: Degree of device oversizing by computed-tomography and clinical outcomes. *Catheter Cardiovasc Interv.* 2015;86:508-515.
- Maeno Y, Abramowitz Y, Yoon SH, et al. Transcatheter aortic valve replacement with different valve types in elliptic aortic annuli. *Circ* J. 2017;81:1036-1042.
- Holmes DR Jr, Nishimura RA, Grover FL, et al. Annual outcomes with transcatheter valve therapy: From the STS/ACC TVT Registry. J Am Coll Cardiol. 2015;66:2813-2823.
- Fadahunsi OO, Olowoyeye A, Ukaigwe A, et al. Incidence, predictors, and outcomes of permanent pacemaker implantation following transcatheter aortic valve replacement: Analysis from the U.S. Society of Thoracic Surgeons/American College of Cardiology TVT Registry. JACC Cardiovasc Interv. 2016;9:2189-2199.
- 15. Di Carlo D. A mechanical biomarker of cell state in medicine. J Lab Autom. 2012;17:32-42.
- Young Lee M, Chilakamarri Yeshwant S, Chava S, Lawrence Lustgarten D. Mechanisms of heart block after transcatheter aortic valve replacement - cardiac anatomy, clinical predictors and mechanical factors that contribute to permanent pacemaker implantation. Arrhythm Electrophysiol Rev. 2015;4:81-85.
- Sinhal A, Altwegg L, Pasupati S, et al. Atrioventricular block after transcatheter balloon expandable aortic valve implantation. JACC Cardiovasc Interv. 2008;1:305-309.
- Moreno R, Dobarro D, Lopez de Sa E, et al. Cause of complete atrioventricular block after percutaneous aortic valve implantation: Insights from a necropsy study. *Circulation*. 2009;120:e29-30.
- MacDonald I, Pasupati S. Transcatheter aortic valve implantation: Know the differences between the currently available technologies. *Eur Heart J.* 2010;31:1663-1665.
- Wilczek K, Regula R, Bujak K, Chodor P, Dlugaszek M, Gasior M. Conduction disturbances after transcatheter aortic valve implantation procedures - predictors and management. *Postepy Kardiol Interwencyjnej*. 2016;12:203-211.
- Brignole M, Auricchio A, Baron-Esquivias G, et al. 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.
- Roten L, Wenaweser P, Delacretaz E, et al. Incidence and predictors of atrioventricular conduction impairment after transcatheter aortic valve implantation. *Am J Cardiol.* 2010;106:1473-1480.

- 23. Raelson CA, Gabriels J, Ruan J, et al. Recovery of atrioventricular conduction in patients with heart block after transcatheter aortic valve replacement. *J Cardiovasc Electrophysiol*. 2017;28:1196-1202.
- Gaede L, Kim WK, Liebetrau C, et al. Pacemaker implantation after TAVI: Predictors of AV block persistence. *Clin Res Cardiol.* 2018;107:60-69.
- Kaplan RM, Yadlapati A, Cantey EP, et al. Conduction recovery following pacemaker implantation after transcatheter aortic valve replacement. *Pacing Clin Electrophysiol*. 2019;42:146-152.
- Baraki H, Al Ahmad A, Jeng-Singh S, et al. Pacemaker dependency after isolated aortic valve replacement: Do conductance disorders recover over time. *Interact Cardiovasc Thorac Surg.* 2013;16:476-481.
- Jankelson L, Bordachar P, Strik M, Ploux S, Chinitz L. Reducing right ventricular pacing burden: Algorithms, benefits, and risks. *Europace*. 2019;21:539-547.
- 28. Kusumoto FM, Schoenfeld MH, Barrett C, et al. ACC/AHA/HRS guideline on the evaluation and management of patients with

bradycardia and cardiac conduction delay. *Circulation*. 2018;2018: CIR000000000000628.

 Nishimura RA, Otto CM, Bonow RO, et al. AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease: A report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol. 2017;70:252-289.

How to cite this article: Ghannam M, Cunnane R, Menees D, et al. Atrioventricular conduction in patients undergoing pacemaker implant following self-expandable transcatheter aortic valve replacement. *Pacing Clin Electrophysiol*. 2019;42:980–988. https://doi.org/10.1111/pace.13694