Permanent pacemaker reduction using temporary-permanent pacemaker as a 1-month bridge after transcatheter aortic valve replacement: a prospective, multicentre, single-arm, observational study

Sanshuai Chang,[a,q] Zhengming Jiang,[a,q] Xinmin Liu,[a] Yida Tang,[b] Ming Bai,[c] Jizhe Xu,[c] Haiping Wang,[d] Yuguo Chen,[e] Chuanbao Li,[e] Yundai Chen,[f] Changfu Liu,[f] Jianzeng Dong,[g] Jianfang Luo,[h] Jie Li,[h] Guosheng Fu,[i] Sheng Wang,[j] Hui Huang,[k] Yuewu Zhao,[l] Xijin Zhuang,[m] Hasan Jilaihawi,[n] Nicolo Piazza,[o] Feicheng Yu,[i,**] Thomas Modine,[p] and Guangyuan Song[a,*]

[a]Interventional Center of Valvular Heart Disease, Beijing AnZhen Hospital, Capital Medical University, National Clinical Research Centre for Cardiovascular Diseases, Beijing, China
[b]Department of Cardiology and Institute of Vascular Medicine, Peking University Third Hospital, Beijing, China
[c]Department of Cardiology, The First Hospital of Lanzhou University, Lanzhou, China
[d]Department of Cardiology, Qingdao Fuwai Cardiovascular Hospital, Qingdao, China
[e]Department of Emergency Medicine and Chest Pain Center, Qilu Hospital of Shandong University, Cheeloo College of Medicine Shandong University, Jinan, China
[f]Senior Department of Cardiology, The Sixth Medical Center of PLA General Hospital, Beijing, China
[g]Department of Cardiology, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China
[h]Guangdong Provincial People's Hospital, Guangdong Academy of Medical Sciences, Guangdong Cardiovascular Institute, Guangzhou, China
[i]Department of Cardiology, Sir Run Shaw Hospital, Zhejiang University of Medicine, Hangzhou, China
[j]Department of Cardiology, Fuwai Central China Cardiovascular Hospital, Zhengzhou, China
[k]Department of Cardiology, General Hospital of Ningxia Medical University, Yinchuan, China
[l]Department of Cardiology, Xuzhou Municipal Hospital Affiliated to Xuzhou Medical University, Xuzhou, China
[m]Department of Cardiology, Dalian Municipal Central Hospital, Dalian, China
[n]NYU Langone Health, New York, USA
[o]Division of Cardiology, Department of Medicine, McGill University Health Centre, Montreal, Quebec, Canada
[p]UMCV, Hôpital Haut Leveque, Centre Hospitalier Universitaire (CHU) de Bordeaux, France

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Summary

Background The permanent pacemaker (PPM) implantation and pacemaker dependency rates after transcatheter aortic valve replacement (TAVR) are highly variable as some of the conduction disturbances are reversible. It remains poorly investigated how to optimise temporary pacing in these patients. This study aimed to explore the potential reduction in the PPM implantation rate using temporary-permanent pacemaker (TPPM) as a 1-month bridge.

Methods This is a prospective, multicentre, single-arm, observational study. Consecutive patients undergoing TAVR from March 1, 2022 to March 1, 2023 in 13 tertiary hospitals in China were screened. Patients who developed high-degree atrioventricular block, complete heart block, or first-degree atrioventricular block plus new onset left bundle branch block during the TAVR procedure or within 1 month after TAVR were included to receive TPPM. Patients with pre-existing PPM implantation or indications for PPM implantation before the TAVR procedure were excluded. Patients with TPPM were monitored to determine whether the conduction disturbances persisted or recovered. The primary endpoint was the rate of freedom from indications for PPM implantation 1 month after TAVR. This study is registered with ChiCTR, ChiCTR2200057931.

Findings Of 688 patients who have undergone TAVR, 71 developed conduction disturbance and met the inclusion criteria, 1 patient withdrew due to noncompliance, 70 patients received TPPM and completed follow-up. There were 41 (58.6%) men and 29 (41.4%) women in the study, with a mean age of 74.3 ± 7.3 years. At 1 month follow-up, 75.7% (53/70) of the patients with TPPM did not require PPM implantation. For 688 patients who have undergone TAVR, the rate of PPM implantation at 1 month was 2.47% (17/688, 95% CI 1.55%–3.92%), representing a significant reduction in self-comparison with the rate at 48 h after TPPM (2.47% vs. 8.28% [95% CI 6.45%–10.58%],

*Corresponding author.
**Corresponding author.
E-mail addresses: songgy_fuwai@163.com (G. Song), yufeicheng@zju.edu.cn (F. Yu).
[q]Contributed equally to this paper.

P < 0.0001). Similar results were obtained in the subgroup analysis of patients with HAVB/CHB. Multivariate analysis revealed the baseline PR interval, difference between the membranous septum length and implantation depth, and timing of postprocedural conduction disturbance occurrence were independent predictors of freedom from indications for PPM implantation at 1 month after TAVR.

Interpretation Using TPPM as a 1-month bridge allows for a buffer period to distinguish whether conduction disturbances are reversible or persistent, resulting in a significant reduction in the PPM implantation rate after TAVR when compared with the current strategy. However, this is an observational study, the results need to be confirmed in a randomized trial.

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Keywords: Transcatheter aortic valve replacement; High-degree atrioventricular block; Permanent pacemaker; Pacemaker dependency; Temporary-permanent pacemaker

Research in context

Evidence before this study

We searched PubMed for studies published until March 24, 2024, using search terms transcatheter aortic valve replacement (TAVR), high degree atrioventricular block, permanent pacemaker (PPM), temporary pacemaker with search terms found in abstract, title or MESH headings. We also searched references listed in the identified papers. Previous studies have indicated PPM implantation is one of the most common complications after TAVR. However, conduction disturbances after TAVR are often transient and pacemaker dependency rates in patients who received PPM implantation after TAVR are highly variable. Prolonged ECG monitoring and temporary pacing after TAVR may help reduce PPM implantation but temporary pacing methods currently used are not suitable for prolonged waiting period. Notably, the temporary-permanent pacemaker (TPPM) involving active fixation pacing lead and an external pulse generator secured to the skin surface may have advantages, whether using TPPM as a 1-month bridge after TAVR can reduce PPM implantation is unknown.

Added value of this study

This study adds important insights into the use of TPPM by providing prospective data in a multicentre setting. TPPM allows for a valuable buffer period to distinguish between patients who really require PPM implantation and those who will recover naturally, and significantly reduces the rate of PPM implantation after TAVR when compared to current strategies.

Implications of all the available evidence

This study is hypothesis generating, and the results need to be confirmed in a randomized trial. Furthermore, the need for an innovative pacing device for a prolonged bridge window after TAVR is warranted based on safety and necessity considerations.

Introduction

Transcatheter aortic valve replacement (TAVR) is a therapeutic approach for patients with severe aortic stenosis.[1] With the expanding indications for TAVR, the focus has shifted toward minimising procedure-related complications. New-onset conduction disturbances that require permanent pacemaker (PPM) implantation are common complications and cause major concerns.[2]

Conduction disturbances may occur due to TAVR-related injury. However, the damage is often reversible as it is partly caused by edema and inflammation, which can resolve over time.[3] Consequently, the rates of post-procedural conduction disturbances and PPM implantation are highly variable in different trials. However, the rates of 30-day PPM dependency after TAVR range from 35% to 44%.[4–6]

Despite the rapid adoption of TAVR, there is a lack of prospective trials investigating the optimal management of patients with conduction disturbances after TAVR. The guidelines for cardiac pacing recommend different time thresholds for PPM implantation, ranging from 48 h to 7 days after TAVR.[7,8] The current clinical pathway on the management of conduction disturbances after TAVR primarily relies on expert opinion.[9] Accordingly, the lack of clinical evidence and effective strategies has resulted in extensive variations in PPM implantation patterns, potentially leading to over-early or unnecessary PPM implantation.

Notably, the temporary-permanent pacemaker (TPPM) involving active fixation pacing lead and an external pulse generator secured to the skin surface has been used to provide a longer bridging period in patients

with infected cardiac implantable electronic devices undergoing lead extraction.[10] Previous studies also reported using TPPM may offer advantages in reducing rates of PPM implantation in patients after TAVR. However, the available data are still limited to case series or retrospective study.[11,12] Therefore, this multi-centre study aimed to explore the efficacy of the use of a TPPM in reducing the rate of PPM implantation in a large patient population. We investigated the occurrence and recovery time of conduction disturbances for up to 30 days after TAVR. Additionally, we conducted a self-comparison of the rates of indications for PPM implantation at different time points and evaluated the predictors of conduction disturbance recovery in these patients.

Methods

Study design and patients

This prospective multi-centre single-arm study was conducted in 13 tertiary hospitals in China (ChiCTR2200057931). Patients who underwent TAVR between March 1, 2022 and March 1, 2023 were evaluated using 24-h continuous electrocardiography (ECG) monitoring and post-procedural 12-lead ECG. The decision to use TPPM was based on the following selection criteria. Patients who developed high-degree atrioventricular block (HAVB) or complete heart block (CHB) (a minimum of 30 min duration of the HAVB/CHB episode) during the TAVR procedure or within 1 month after TAVR were included. HAVB was defined as any of the following: second-degree atrioventricular block (AVB) type 2 (Mobitz II); 2:1 AVB in the presence of a QRS duration of ≥120 ms; or two or more consecutive P-waves at a constant physiologic rate that do not conduct to the ventricles. CHB was defined as P-waves at a constant rate with a dissociated ventricular rhythm (no association between P- and R-waves) or fixed slow ventricular rhythm in the presence of atrial fibrillation. Patients with first-degree AVB (PR interval ≥240 ms and ≥20 ms larger than baseline) plus new onset left bundle branch block (LBBB) (QRS duration ≥150 ms) were also included in this study since these patients were generally considered to be at a higher risk of delayed HAVB/CHB and PPM was always implanted before discharge. We excluded patients with pre-existing PPM implantation or indications for PPM implantation before the TAVR procedure. The study was approved by the medical ethics committees in each participating hospital, and the patients provided written informed consent for participation. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines.

Procedure

In this study, a balloon-expandable trans-catheter heart valves (THV) SAPIEN 3 (Edwards Lifesciences) and four self-expandable THVs including Evolut PRO (Medtronic), VenusA-Plus (Venus Medtech), TaurusElite (Peijia Medical) and VitaFlow (CardioFlow Medtech) has been used in this study. After TAVR, patients eligible for enrollment received TPPM procedure. An active-fixation pacing lead (St. Jude Medical, 2088 TC, US) permitting bipolar stimulation was inserted through a 7- or 8-F peel-away introducer sheath, and the electrode was positioned in the right ventricular septum. The proximal end of the lead was fixed to the skin surface using a suture sleeve and connected to a pulse generator (Biotronik, Medtronic, or St. Jude Medical). The pulse generator was secured on the skin surface next to the lead implantation site and fixed using an adhesive dressing (Fig. 1). The pacing threshold was acceptable when acute measurements demonstrated a stable ventricular capture of <1 V/0.48 ms and sensing values of >5 mV. The pacemaker was initially set as a VVI model with a lower rate limit of 60 beats per min (bpm), the output was set to 3.5 times the pacing threshold, and the sensitivity value was set at half the sensing threshold. For all patients received a TPPM, beta-blockers and all other drugs that can decrease heart rate were discontinued.

Outcomes

Follow-up visits were scheduled at 48 h, 1 week, 2 weeks, 3 weeks, 1 month, and 6 months after TPPM implantation. Pacemaker interrogation, including the assessment of threshold, sensing, impedance, and ventricular pacing rate (VPR), was performed during the first five visits. For patients who recovered from HAVB and had a VPR of <10%, the rate limit of the pacemaker was reduced by 10 bpm weekly to prevent unnecessary pacing during nocturnal sinus bradycardia. Standard aseptic disinfection procedures and weekly wound dressing changes were performed to minimise the risk of infection. Additionally, the data of 12-lead ECG, pacemaker interrogation, and 24-h HOLTER monitoring were collected at 1 month to evaluate the indications for PPM implantation; 12-lead ECG reading and 24-h HOLTER monitoring were repeated at 6 months to confirm if the indications for PPM implantation recurred. For patients who underwent PPM implantation, ECG and pacemaker interrogation were performed at 6 months to evaluate PPM dependency.

The primary endpoint was the rate of freedom from indications for PPM implantation at 1 month after TPPM use. Freedom from indications for PPM implantation was defined as the absence of pacing signals in the 12-lead ECG and 24-h HOLTER records at 1 month, meanwhile the pacemaker interrogation of the previous week revealed a VPR of 0%. Otherwise, the PPM should be implanted according to the latest guidelines. The secondary endpoint was the rate of freedom from indications for PPM implantation at 6 months after TPPM use.

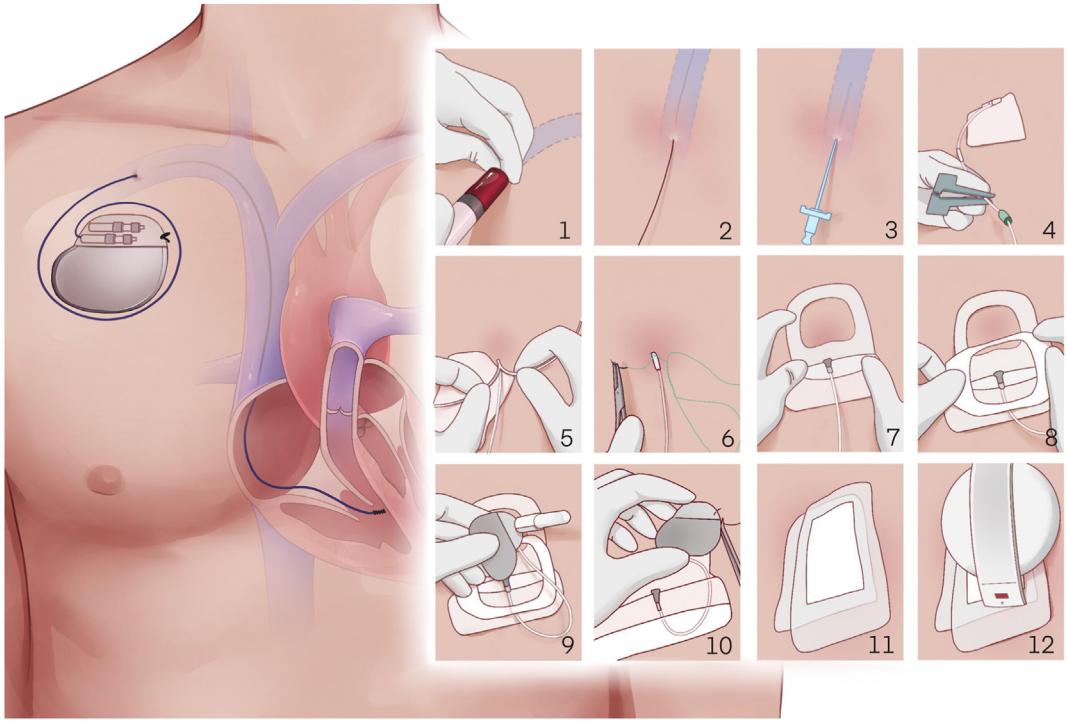

Fig. 1: **Schematic illustration for TPPM procedure step by step**. An active fixation, single-chamber pacemaker lead is fixated to the right ventricular septum, the lead's suture sleeve was sutured to the skin, and a pulse generator was connected to the lead and placed over the patient's skin using an adhesive dressing.

Safety endpoints were defined as composite endpoints, including all-cause mortality, cardiovascular mortality, and TPPM procedure-related adverse events, such as infection, vascular access complications, cardiac perforation, lead dislodgement, and thromboembolism.

Statistical analyses

Statistical analyses were performed using SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, New York). Continuous variables were expressed as means ± standard deviations. Categorical data are represented as frequencies and percentages, and comparisons were made across groups using the t-test or chi-square test, as appropriate. Willson method was adopted to calculate the 95% confidence intervals (CI) of the proportion. McNemar's test was used in the self-comparison of the rate of indications for PPM implantation at different time points. Logistic regression was used to estimate the independent effects of multiple variables on 30-day freedom from indications for PPM implantation. The results of the analysis are presented as odds ratios and 95% CI. Statistical significance was set at $P < 0.05$.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. All authors had access to dataset and had final responsibility for the decision to submit for publication.

Results

Of the 688 patients who underwent TAVR between March 2022 and March 2023, those (N = 18) with a previous PPM implantation or indications for PPM implantation were excluded, and 71 met the inclusion criteria. One patient dropped out due to noncompliance. Finally, 70 patients received a TPPM and were enrolled in this study (Fig. 2); 54 had CHB, 6 had HAVB, and 10 had first-degree AVB (PR interval ≥240 ms and ≥20 ms larger than baseline) plus new onset LBBB (QRS duration ≥150 ms).

The mean age was 74.3 ± 7.3 years, 41.4% of participants were female individuals, and the mean Society of Thoracic Surgeons risk score was 4.0%. The baseline clinical and ECG characteristics of the patients according to PPM implantation at 1 month are shown in Table 1. Compared with patients who underwent PPM implantation, those free from PPM implantation showed less frequent baseline first-degree AVB (9.4% vs. 29.4%; P = 0.041) and tended to have a shorter PR interval (169.3 ms vs. 187.4 ms; P = 0.031).

All patients underwent preprocedural contrast-enhanced cardiac computed tomography, and two

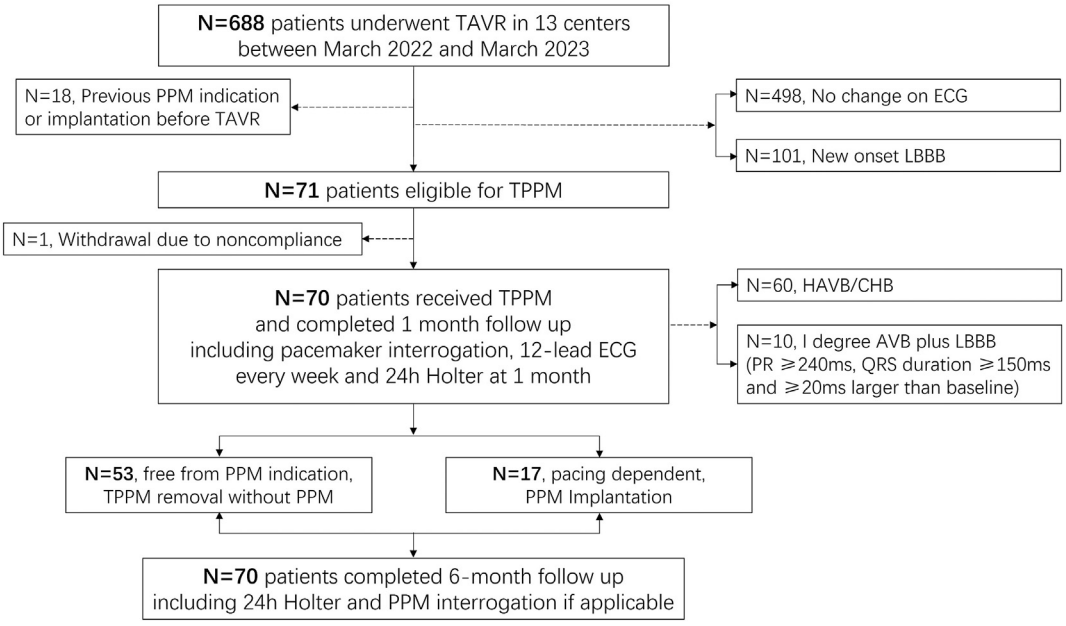

***Fig. 2:* Patients flowchart**. Abbreviations: TAVR, transcatheter aortic valve replacement; ECG, electrocardiography; PPM, permanent pacemaker; TPPM, temporary-permanent pacemaker; LBBB, left bundle-branch block; HAVB, high degree atrioventricular block; AVB, atrioventricular block; CHB, complete heart block.

experienced structural interventional cardiologists performed all measurements. No difference was observed in imaging characteristics between the groups.

TAVR was performed through femoral access in all patients using the cusp-overlapping projection technique. Self-expandable valves were used in most patients, with no significant differences in valve oversizing of the annulus or left ventricular outflow tract (LVOT) between the groups. Compared with patients with PPM implantation, patients who achieved freedom from indications for PPM implantation showed higher implantation depth under non-coronary cusp (5.7 vs. 7.5; P = 0.022), smaller difference between the membranous septum length and implantation depth (ΔMSID) (2.9 vs. 4.7 mm; P = 0.040), and a lower percentage of ΔMSID ≥3 mm (43.2% vs. 85.7%; P = 0.0070) (Table 2).

HAVB/CHB occurred after the procedure in 41.4% of patients, with similar rates between the groups. However, patients who achieved freedom from indications for PPM implantation were more likely to experience a later occurrence of postprocedural HAVB/CHB (4.5 days vs. 1.4 days, P = 0.036). Regarding the reasons for TPPM use, CHB was more frequent in patients who underwent PPM implantation (100% vs. 69.8%, P = 0.010); first-degree AVB plus LBBB was more frequent in patients who achieved freedom from indications for PPM implantation (18.9% vs. 0%, P = 0.053). The TPPM procedure was easy to perform, with an average duration of 28.6 min and a radiation

	All patients (N = 70)	Free from PPM implantation (N = 53)	PPM implantation (N = 17)	p value
Demographics				
Age, years	74.3 ± 7.3	73.8 ± 7.4	76.1 ± 7.1	0.25
Female sex	29 (41.4%)	22 (41.5%)	7 (41.2%)	0.98
Male sex	41 (58.6%)	31 (58.5%)	10 (58.8%)	0.98
STS score, %	4.0 ± 1.4	3.9 ± 1.3	4.1 ± 1.8	0.77
Aortic valve regurgitation	22 (31.4%)	16 (30.2%)	6 (35.3%)	0.69
Hypertension	49 (70.0%)	35 (66.0%)	14 (82.4%)	0.20
Diabetes	16 (22.9%)	12 (22.6%)	4 (23.5%)	0.94
CAD	35 (50.0%)	27 (50.9%)	8 (47.1%)	0.78
CVD	11 (15.7%)	8 (15.1%)	3 (17.6%)	0.80
CKD	6 (8.6%)	3 (5.7%)	3 (17.6%)	0.12
PCI	13 (18.6%)	11 (20.8%)	2 (11.8%)	0.41
CABG	2 (2.9%)	0 (0%)	2 (11.8%)	0.090
Electrocardiogram				
First-degree AVB	10 (14.3%)	5 (9.4%)	5 (29.4%)	0.041
LBBB	6 (8.6%)	5 (9.4%)	1 (5.9%)	0.65
RBBB	14 (20.0%)	9 (17.0%)	5 (29.4%)	0.27
Atrial fibrillation	6 (8.6%)	5 (9.4%)	1 (5.9%)	0.65
Heart rate, bpm	72.7 ± 14.7	72.3 ± 15.4	73.8 ± 13.0	0.71
PR interval, ms	173.8 ± 29.3	169.3 ± 28.8	187.4 ± 27.4	0.03
QRS duration, ms	116.4 ± 26.9	115.7 ± 27.3	118.7 ± 26.4	0.70

Values are mean ± SD, n (%). RBBB, right bundle branch block; AS, aortic valve stenosis; AR, aortic valve regurgitation; CAD, coronary artery disease; CVD, Cerebrovascular disease; CKD, chronic kidney disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; AVB, atrioventricular block; LBBB, left bundle-branch block; RBBB, right bundle branch block; PPM, permanent pacemaker.

***Table 1:* Characteristics of the trial population at baseline.**

	All patients (N = 70)	Free from PPM implantation (N = 53)	PPM implantation (N = 17)	P value
Bicuspid aortic valve	27 (38.6%)	22 (41.5%)	5 (29.4%)	0.37
Bicommissural non-Raphe type	3 (4.3%)	3 (5.7%)	0 (0%)	0.32
Bicommissural Raphe type	11 (15.7%)	7 (13.2%)	4 (23.5%)	0.31
Tricommissural	13 (18.6%)	12 (22.6%)	1 (5.9%)	0.12
Left-right coronary cusp fusion	16 (22.9%)	12 (22.6%)	4 (23.5%)	0.94
Aortic annulus, mm	24.9 ± 2.6	24.8 ± 2.6	25.4 ± 2.4	0.41
LVOT, mm	24.8 ± 3.2	24.7 ± 3.4	25.2 ± 2.5	0.57
Aortic valve Calcium, mm^3				
Under the LCC	71.5 ± 104.4	70.9 ± 107.3	73.6 ± 98.1	0.93
Under the RCC	71.6 ± 131.5	70.8 ± 139.4	74.3 ± 107.1	0.92
Under the NCC	125.9 ± 187.5	122.1 ± 196.5	137.7 ± 160.1	0.77
Membrane septum length, mm	3.0 ± 2.1	2.9 ± 2.2	3.0 ± 1.6	0.90
Pre-dilatation (%)	47 (67.1%)	36 (67.9%)	11 (64.7%)	0.81
Post-dilatation (%)	27 (38.6%)	21 (39.6%)	6 (35.3%)	0.75
Self-expandable valve	68 (97.1%)	52 (98.1%)	16 (94.1%)	0.39
Oversizing of the aortic annulus (%)	10.9 ± 8.1	10.8 ± 7.9	11.0 ± 9.0	0.94
Oversizing of LVOT (%)	12.5 ± 9.7	12.6 ± 9.3	12.4 ± 11.1	0.95
Implantation depth under the NCC, mm	6.2 ± 2.8	5.7 ± 2.9	7.5 ± 2.0	0.022
ΔMSID, mm	3.4 ± 3.1	2.9 ± 3.2	4.7 ± 2.5	0.040
ΔMSID ≥3 mm	54.9%	43.2%	85.7%	0.0070

LVOT, left ventricular outflow tract; LCC, left coronary cusp; RCC, right coronary cusp; NCC, non-coronary cusp; ΔMSID, difference between implantation depth and membranous septum length.

Table 2: **Imaging and TAVR procedural characteristics.**

dose of 37.8 mGy, with no difference between the groups (Table 3).

Patients with TPPM were discharged 3 days (median) after the procedure, the conduction disturbance was still present in 71.4% (50/70) of the patients at discharge. TPPMs were used for 36 ± 13 days. At 1 month follow-up, 75.7% (53/70) of patients were free from indications for PPM implantation. The recovery of conduction disturbances did not occur overnight; 13 patients recovered within 48 h after TPPM, 18 recovered at 1-week visit, 10 recovered at 2-week visit, 8 recovered at 3-week visit, and 4 recovered at 1 month follow-up (Fig. 3).

	All patients (N = 70)	Free from PPM implantation (N = 53)	PPM implantation (N = 17)	P value
Occurrence of conduction disturbance				
Intraprocedural	41 (58.6%)	29 (54.7%)	12 (70.6%)	0.25
Postprocedural, days	3.9 ± 3.0 (N = 29)	4.5 ± 3.0 (N = 24)	1.4 ± 0.9 (N = 5)	0.036
Time from TAVR to TPPM, days	2.3 ± 3.2	2.5 ± 3.5	1.6 ± 2.2	0.31
Reason of TPPM				
CHB	54 (77.1%)	37 (69.8%)	17 (100%)	0.010
HAVB	6 (8.6%)	6 (11.3%)	0 (0%)	0.15
First-degree AVB + LBBB	10 (14.3%)	10 (18.9%)	0 (0%)	0.05
Threshold, v	0.75 ± 0.23	0.73 ± 0.23	0.79 ± 0.24	0.44
Time, min	28.6 ± 8.9	27.7 ± 9.1	31.4 ± 8.0	0.28
X ray, mGy	37.8 ± 46.3	36.8 ± 46.6	40.7 ± 48.1	0.83

TAVR, transcatheter aortic valve replacement; TPPM, temporary permanent pacemaker; other abbreviations as in Table 1.

Table 3: **TPPM procedural characteristics.**

A subgroup analysis of patients with HAVB/CHB was performed; 71.7% (43/60) of patients were free from indications for PPM implantation, and the number of recoveries at the scheduled follow-up visits was 13, 13, 7, 6, and 4, respectively (Fig. 3).

At the 6-month follow-up, no recurrence of HAVB/CHB was observed in patients who achieved freedom from indications for PPM implantation. Of the 17 patients who underwent PPM implantation, 15 were PPM-dependent with high VPRs (average, 63.3%), while the other two had intermittent HAVB with VPRs of <10%.

No adverse events occurred during the TPPM procedure, and no deaths were reported during the 6-month follow-up. However, two adverse events related to the TPPM procedure were observed during follow-up, including one case of lead-related pericardial effusion and one case of lead dislodgement: in the former case, the lead was repositioned, allowing the patient to complete the follow-up period without requiring PPM implantation. In the latter case, the patient pulled out the lead due to discomfort and underwent PPM implantation 5 days earlier than scheduled.

For the 688 patients who have undergone TAVR, the rate of indication for PPM implantation was 10.8% (77/688) at the time of enrollment to receive TPPM, as some of the conduction disturbances recovered, the rate of indication for PPM implantation reduced to 8.28% (95% confidence interval [CI] 6.45%–10.58%) at 48 h and further reduced to 2.47% (95% CI 1.55%–3.92%) at 1 month using TPPM for a prolonged bridge (McNemar's test $P < 0.0001$). Similar results were obtained in the subgroup analysis of patients with HAVB/CHB, the rate of indication for PPM implantation reduced from 8.72% to 6.83% (95% CI 5.17%–8.96%) and further to 2.47% (95% CI 1.55%–3.92%) (McNemar's test $P < 0.0001$) (Fig. 4).

For patients with TPPM, univariate analysis revealed that the baseline PR interval, a ΔMSID of ≥3 mm, and the timing of postprocedural conduction disturbance occurrence were associated with freedom from indications for PPM implantation at 1 month. Furthermore, a multivariate model revealed the baseline PR interval and a ΔMSID of ≥3 mm were negative independent predictors of the 1-month freedom from indications for PPM implantation after TAVR, and a delayed occurrence of postprocedural conduction disturbance was a positive independent predictor of the 1-month freedom from indications for PPM implantation after TAVR (Table 4).

Before TAVR, among 53 patients who achieved freedom from indications for PPM implantation, LBBB was present in 5 (9.4%), RBBB in 9 (17.0%), first-degree AVB in 5 (9.4%), and atrial fibrillation in 5 (9.4%); at the

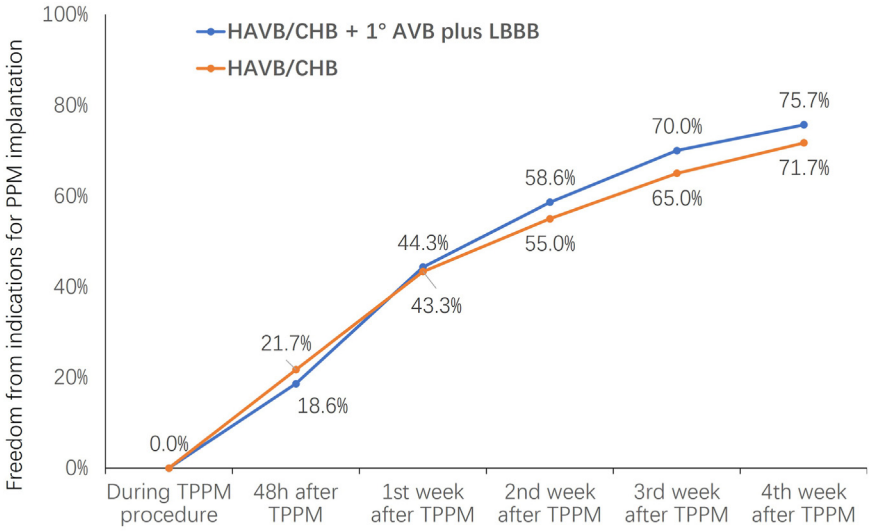

***Fig. 3:* Trends of freedom from indications for PPM implantation for patients who received TPPM during the bridge window.** Abbreviations: PPM, permanent pacemaker; TPPM, temporary-permanent pacemaker; LBBB, left bundle-branch block; HAVB, high degree atrioventricular block; AVB, atrioventricular block; CHB, complete heart block.

1-month follow-up, 17 (32.1%) patients had LBBB, 16 (30.2%) had RBBB, 18 (34.0%) had first-degree AVB, and 6 (11.3%) had atrial fibrillation (Fig. 5).

Discussion

In a pilot study by our group, which included fewer cases, we showed that TPPM use is a reliable and safe method for patients with conduction disturbances after TAVR.[13] However, no study has evaluated the rates of PPM implantation using TPPM in different patient populations and no existing data has compared the rates of PPM implantation achieved with TPPM to those following current expert consensus. To the best of our knowledge, this is the first study to systematically evaluate the clinical outcomes of TPPM implantation in a multi-centre prospective population.

The main findings of this study can be summarized as follows: 75.7% of patients who developed HAVB/

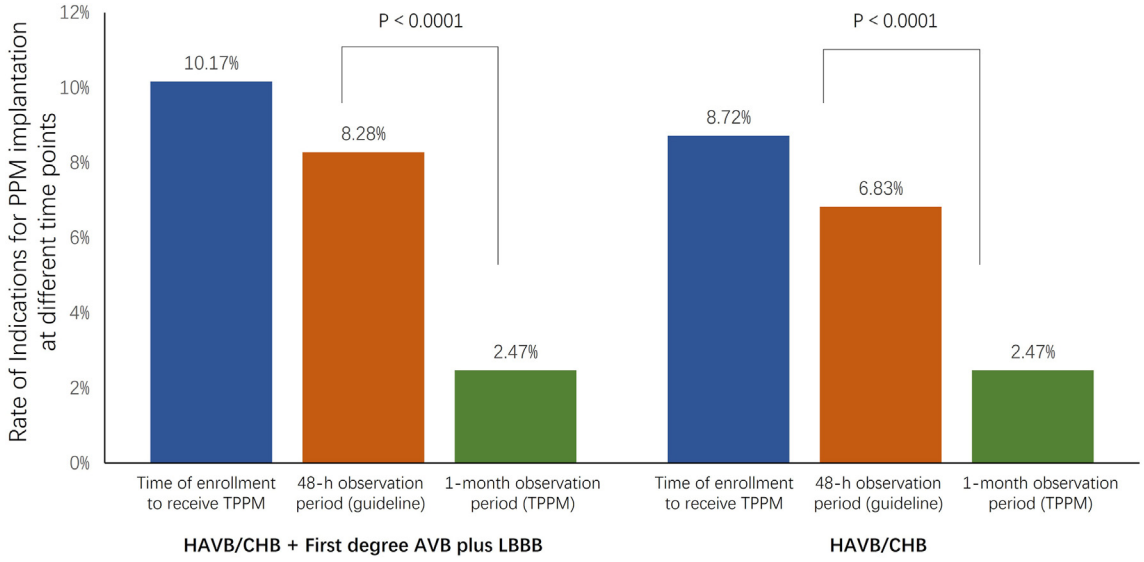

***Fig. 4:* Self-comparison of the rate of indications for PPM implantation for all patients who have undergone TAVR.** Abbreviations: PPM, permanent pacemaker; TPPM, temporary-permanent pacemaker; LBBB, left bundle-branch block; HAVB, high degree atrioventricular block; AVB, atrioventricular block; CHB, complete heart block.

	Univariate			Multivariate		
	OR	95% CI	P value	OR	95% CI	P value
Age (years)	0.956	0.887–1.031	0.25			
Female sex	1.004	0.336–3.001	0.99			
Baseline RBBB	0.491	0.138–1.741	0.27			
Baseline first-degree AVB	0.250	0.062–1.005	0.05			
PR interval, MS	0.977	0.956–0.999	0.04	0.947	0.907–0.989	0.013
Valve oversizing (%)	0.997	0.932–1.067	0.93			
Lvot oversizing (%)	1.002	0.946–1.060	0.95			
Implantation depth under the NCC	0.873	0.695–1.097	0.24			
ΔMSID	0.807	0.639–1.020	0.073			
ΔMSID ≥3 mm	0.127	0.025–0.649	0.013	0.047	0.005–0.416	0.0060
Postprocedural AVB, days	1.609	1.011–2.561	0.045	2.152	1.127–4.108	0.020

OR, odds ratio; CI, confidence interval; other abbreviations as Table 1.

Table 4: **Univariate analysis of predictors of freedom from PPM after TAVR and multivariate logistic regression model for patients who received TPPM.**

CHB after TAVR did not require PPM implantation after a 1-month bridge with a TPPM. The rate of PPM implantation was as low as 2.47%, indicating an obvious reduction when compared with that of the guideline recommended strategy (up to 48-h waiting period). Among patients who did not require PPM implantation, 18.6% recovered within 48-h bridge with a TPPM and 57.1% recovered after 48-h bridge; independent predictors of freedom from indications for PPM implantation at 1 month after TPPM included the baseline PR interval, a ΔMSID of ≥3 mm, and the timing of postprocedural conduction disturbance occurrence.

With the expanding indications for TAVR in younger patients with a lower surgical risk, complications that may affect long-term prognosis, such as conduction disturbances and PPM dependency, become increasingly clinically important. PPM implantation may adversely affect left ventricular function and increase the risk of heart failure or all-cause readmission.[14] Recent real-world registry data have shown a high rate of PPM implantation after TAVR, particularly with self-expanding valves, which have been linked to higher 1-year mortality.[15] Therefore, the decision to perform PPM implantation after TAVR must be carefully considered.[16]

Conduction disturbances after TAVR are due to mechanical injury caused by the transcatheter valve frame. However, this damage is often reversible, as it is partly associated with edema and inflammation, which can resolve over time.[3] Furthermore, a recent multidisciplinary expert consensus recommended a 48-h window after TAVR to confirm the indications for PPM implantation.[7] Although the timing of PPM implantation after TAVR varies between different centres, over 90% of PPM implantations were performed within 1 week after TAVR. However, conduction disorders may resolve several days after TAVR. In this study, 18.6% patients with HAVB/CHB recovered within 48-h bridge with a TPPM and 31.4% of patients recovered after 1-week bridge. Through self-comparison, it is shown that the strategy using a TPPM for 1-month bridge could reduce rates of PPM implantation compared to the guideline-recommended strategy using a temporary pacemaker for 48-h observation. Notably, the recovery rate remained stable at 6 months, consistent with the

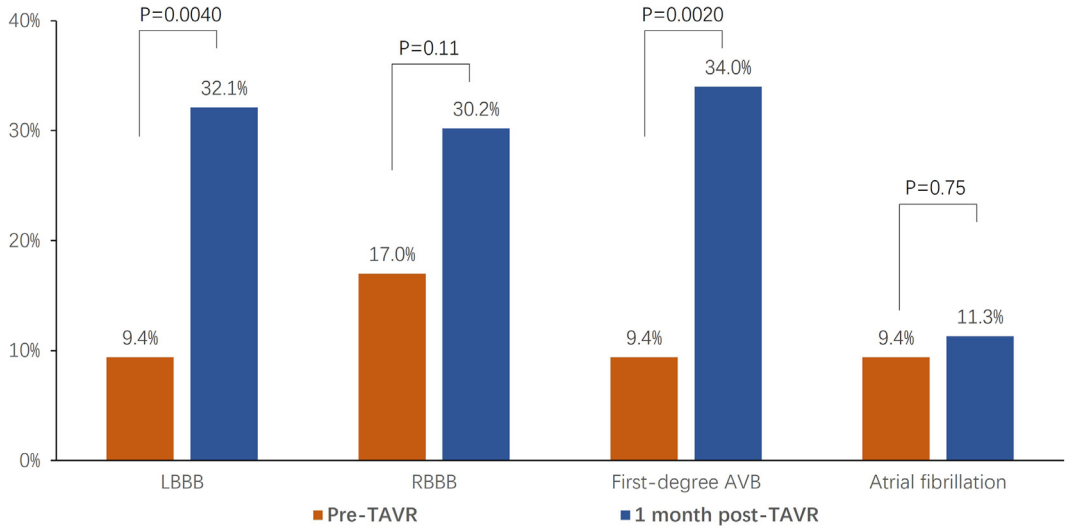

Fig. 5: **Prevalence of conduction disturbances among patients who received TPPM and free from PPM implantation before and at 1-month after TAVR.** Abbreviations: LBBB, left bundle-branch block; RBBB, right bundle-branch block; AVB, atrioventricular block; TAVR, transcatheter aortic valve replacement.

finding of a previous report.[6] Consequently, the rate of PPM implantation was reduced to 2.47% in the multicentre TAVR patient population, much lower than the reported rates ranging from 9% to 35% in previous literature.[2,3]

Prolonged ECG monitoring and temporary pacing after TAVR can help reduce PPM implantation. However, patients are increasingly being discharged within 24–48 h after TAVR, and some experts have even advocated same-day discharge in carefully selected patients.[17,18] Currently, the temporary pacing methods used during the perioperative period of TAVR are not suitable for discharged patients and are associated with a higher risk of infection, venous thrombosis, prolonged hospitalization, and delayed rehabilitation; patients should be bedridden until the pacing lead is removed to avoid dislodgement.[19] Accordingly, strategies that offer pacing protection, improve mobility, shorten hospital stay, and reduce the PPM implantation rate are vital to advancing TAVR and preventing cardiac arrest events in outpatients, which can result in sudden death.

The use of a TPPM has advantages in the management of conduction disturbances after TAVR. The active fixation lead offers a retractable helix with extraordinary flexibility and an extended scope for regular monitoring and pulse generator interrogation. Vascular access to the internal jugular or subclavian veins enables rapid ambulation after the procedure without increasing hospitalization length while ensuring greater patient comfort and mobility; patients undergoing TPPM implantation can be discharged early to resume normal daily activities.

Safety is crucial when considering TPPM use. A review of 24 studies involving 770 patients reported 2.3% cases of TPPM-related infections, with loss of capture documented in only 1%, and the duration of TPPM use varied from a few days to 336 days.[20] The consensus document of the European Heart Rhythm Association recommends the use of a TPPM with an ipsilateral active fixation strategy in patients requiring antibiotic treatment before re-implantation.[21] In our study, no infection was encountered due to standard aseptic disinfection procedures and weekly wound dressing changes. Two adverse events were managed appropriately, this highlights the importance of careful monitoring and management. In addition, cost-effectiveness is a crucial factor. Although the initial cost of active fixation leads is higher, the use of TPPM facilitates early discharge and potential cost savings beyond 24 h.[22]

Another interesting finding is that all patients with first-degree AVB plus LBBB ultimately do not require the implantation of a PPM, which is inconsistent with the previous position stating that these patients are at high risk of delayed HAVB/CHB and need PPM implantation before discharge9. If more clinical data confirms this finding, these patients would not need a PPM or a TPPM, and remote ECG monitoring may suffice. However, until then, we should proceed with caution to ensure safety.

While predictors of conduction disorders leading to PPM implantation after TAVR have been extensively investigated, and previous studies have identified several independent predictors of long-term pacemaker dependency, including pre-existing RBBB, first-degree AVB, and the ΔMSID,[4–6] our study confirmed that the baseline PR interval and a ΔMSID of ≥3 mm were independent predictors of PPM implantation; the timing of postprocedural conduction disturbance occurrence is an additional predictor of conduction disturbances recovery. These predictors provide valuable information for risk stratification and personalized decision-making regarding PPM implantation after TAVR.

At the anatomical level, the AV bundle penetrates the central fibrous body and continues through the membranous part of the interventricular septum, which is situated below the right and noncoronary aortic cusps. The valve stent frame may damage the branches through direct mechanical interactions or by inducing edema or inflammation. While a small (<1 mm) overlap between the valve frame and AV bundle might cause transient conduction abnormalities in the acute phase, a more pronounced direct mechanical interaction (≥3 mm) may be necessary to cause an irreversible AVB.

Notably, the timing of postprocedural conduction disturbances was associated with conduction recovery. This finding is consistent with that of a study by Costa, who reported that PPM implantation on day 1 was a predictor of PPM dependency. In contrast, PPM implantation on days 2 and days 3–30 was not associated with PPM dependency.[4] One possible explanation is that the later the postprocedural conduction disturbance occurs, the more likely it is to be secondary to edema or inflammation. Additionally, the continuous compression of the AV branch by self-expandable valves could contribute to the later occurrence of postprocedural conduction disorders. Notably, the likelihood of conduction disorder recovery increases as the interaction forces diminish.

This study has generated a hypothesis, and the results need to be confirmed in larger cohort. Randomised trials are also warranted to fully evaluate the use of TPPM against traditional temporary pacing, and recommendations for the timing of PPM implantation after TAVR should be proposed on a safe and necessary basis.

This study had certain limitations due to its single-arm design, including selection and confounding biases. However, we attempted to mitigate these biases by performing self-comparison and subgroup analyses, which yielded consistent results. Given the limited follow-up period and advanced age of our study population, the potential impact of freedom from indications

for PPM implantation on long-term survival, particularly in younger patients undergoing TAVR, cannot be definitively inferred. Additionally, the patients included in this study primarily received self-expanding valves; therefore, caution should be exercised when extrapolating these results. Further, the high percentage of bicuspid aortic valves is another study limitation of the present study. Finally, patients who recovered from HAVB or experienced late-onset HAVB beyond 6 months after TAVR could not be identified and long-term drug therapy was not collected after 6 months. Notably, conduction abnormalities occurring beyond 30 days after TAVR are rare; and as time passes, directly attributing a TAVR procedure as the cause of PPM becomes more challenging.

In conclusion, using TPPM as a bridge pacing for a prolonged window significantly reduced the rates of PPM implantation after TAVR, which can be attributed to the high rates of recovery within 1 month in patients with conduction disturbances after TAVR.

Contributors

GS AND ZJ designed and coordinated the study, with input from FY. SC contributed in conducting the study, collecting and analyzing the data, accessing and verifying the data, reviewing published literature, and writing the first draft. XL contributed to data collection and interpretation of data. YT, MB, JX, HW, YC, CL, YC, CL, JD, JL, JL, GF, FY, SW, HH, YZ, and XZ contributed to data collection as the principal investigator of each participating centre. TM, NP, and HJ contributed to interpretation of data and revising of the manuscript. All authors edited and approved the final version. All authors had access to and verify the underlying study data, and take responsibility for data integrity, accuracy, and completeness and decision for submission and publication.

Data sharing statement

The raw data supporting the conclusions of this article will be available from the corresponding author upon request.

Declaration of interests

HJ received grants from Pi-Cardia for his institution, and received consulting fees from Edwards Lifesciences and Medtronic Inc. All other authors declare no competing interests.

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References

1 Otto CM, Nishimura RA, Bonow RO, et al. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *J Am Coll Cardiol*. 2021;77:450–500.
2 Sammour Y, Krishnaswamy A, Kumar A, et al. Incidence, predictors, and implications of permanent pacemaker requirement after transcatheter aortic valve replacement. *JACC Cardiovasc Interv*. 2021;14:115–134.
3 Auffret V, Puri R, Urena M, et al. Conduction disturbances after transcatheter aortic valve replacement: current status and future perspectives. *Circulation*. 2017;136:1049–1069.
4 Costa G, Zappulla P, Barbanti M, et al. Pacemaker dependency after transcatheter aortic valve implantation: incidence, predictors and long-term outcomes. *EuroIntervention*. 2019;15:875–883.
5 Meduri CU, Kereiakes DJ, Rajagopal V, et al. Pacemaker implantation and dependency after transcatheter aortic valve replacement in the REPRISE III trial. *J Am Heart Assoc*. 2019;8:e012594.
6 Nai FL, Cipriani A, Fabris T, et al. Anatomical predictors of pacemaker dependency after transcatheter aortic valve replacement. *Circ Arrhythm Electrophysiol*. 2021;14:e009028.
7 Brignole M, Auricchio A, Baron-Esquivias G, et al. 2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy: the Task Force on cardiac pacing and resynchronization therapy of the European Society of Cardiology (ESC). *Eur Heart J*. 2013;34:2281–2329.
8 Glikson M, Nielsen JC, Kronborg MB, et al. 2021 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy. *Eur Heart J*. 2021;42:3427–3520.
9 Rodés-Cabau J, Ellenbogen KA, Krahn AD, et al. Management of conduction disturbances associated with transcatheter aortic valve replacement: JACC Scientific Expert Panel. *J Am Coll Cardiol*. 2019;74(8):1086–1106.
10 Kawata H, Pretorius V, Phan H, et al. Utility and safety of temporary pacing using active fixation leads and externalized re-useable permanent pacemakers after lead extraction. *Europace*. 2013;15:1287–1291.
11 Goncalves CR, Bertog S, Tholakanahalli V, et al. Permanent pacemaker lead insertion connected to an external pacemaker generator for temporary pacing after transcatheter aortic valve implantation. *Cardiovasc Revasc Med*. 2020;21:726–729.
12 Leong D, Sovari AA, Ehdaie A, et al. Permanent-temporary pacemakers in the management of patients with conduction abnormalities after transcatheter aortic valve replacement. *J Intervent Card Electrophysiol*. 2018;52:111–116.
13 Chang S, Liu X, Lu ZN, et al. Feasibility study of temporary permanent pacemaker in patients with conduction block after TAVR. *Front Cardiovasc Med*. 2023;10:978394.
14 Gupta R, Mahajan S, Behnoush AH, et al. Short- and long-term clinical outcomes following permanent pacemaker insertion post-TAVR: a systematic review and meta-analysis. *JACC Cardiovasc Interv*. 2022;15:1690–1692.
15 Pagnesi M, Kim WK, Baggio S, et al. Incidence, predictors, and prognostic impact of new permanent pacemaker implantation after TAVR with self-expanding valves. *JACC Cardiovasc Interv*. 2023;16:2004–2017.
16 Franzone A, Windecker S. The conundrum of permanent pacemaker implantation after transcatheter aortic valve implantation. *Circ Cardiovasc Interv*. 2017;10:e005514.
17 Barker M, Sathananthan J, Perdoncin E, et al. Same-day discharge post-transcatheter aortic valve replacement during the COVID-19 pandemic: the multicenter PROTECT TAVR study. *JACC Cardiovasc Interv*. 2022;15:590–598.
18 Krishnaswamy A, Isogai T, Brilakis ES, et al. Same-day discharge after elective percutaneous transcatheter cardiovascular interventions. *JACC Cardiovasc Interv*. 2023;16:1561–1578.
19 Metkus TS, Schulman SP, Marine JE, et al. Complications and outcomes of temporary transvenous pacing: an analysis of >360,000 patients from the national inpatient sample. *Chest*. 2019;155:749–757.
20 Suarez K, Banchs JE. A review of temporary permanent pacemakers and a comparison with conventional temporary pacemakers. *J Innov Card Rhythm Manage*. 2019;10:3652–3661.
21 Blomström-Lundqvist C, Traykov V, Erba PA, et al. European Heart Rhythm Association (EHRA) international consensus document on how to prevent, diagnose, and treat cardiac implantable electronic device infections. *Europace*. 2020;22:515–549.
22 Chihrin SM, Mohammed U, Yee R, et al. Utility and cost effectiveness of temporary pacing using active fixation leads and an externally placed reusable permanent pacemaker. *Am J Cardiol*. 2006;98:1613–1615.