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Clinical outcomes of His bundle pacing vs. right ventricular pacing in patients with conduction disturbances following transcatheter aortic valve replacement

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Abstract

Objective To assess and compare the clinical outcomes of His bundle pacing (HBP) versus right ventricular pacing (RVP) in patients who develop conduction disturbances following transcatheter aortic valve replacement (TAVR).

Methods In this retrospective study, 120 patients who developed CD following TAVR were enrolled, and were implanted with HBP or RVP between January 2015 and December 2024. To adjust for variations in initial risk factors and baseline characteristics between patients who underwent HBP or RVP, we employed the propensity score matching. Each patient was matched in a 1:1 ratio with replacement. Patients who either received HBP or RVP, but could not be adequately matched, were excluded from the study population. Procedural and clinical outcomes were compared among different modalities at pacing implantation and12-month follow-up.

Results Paced QRS duration, R-wave amplitude at implantation and at follow-up, impedance at follow-up were lower in HBP group compared to RVP group. At12-month follow-up, the decrease in pacing burden was significantly greater in the HBP group than in the RVP group. Pacing threshold at implantation and at follow-up and capture threshold at implantation and at follow-up were higher in HBP group compared to RVP group. During follow-up, the left ventricular ejection fraction (LVEF) and tricuspid regurgitation (TR) area in the HBP group showed a significant improvement compared to preoperative values, while no significant increase in LVEF was observed in the RVP group, with a clear statistical difference between the two groups. At 12-month follow-up, NT-proBNP levels in the HBP group were significantly lower than those in the RVP group. The rates of NYHA functional class II were higher, while the rates of NYHA functional class III and MACE were lower in the HBP group compared to the RVP group during follow-up.

Conclusions HBP was feasible and safe in patients after TAVR, demonstrating a reduction in the composite outcome of MACE and better cardiac function compared to RVP.

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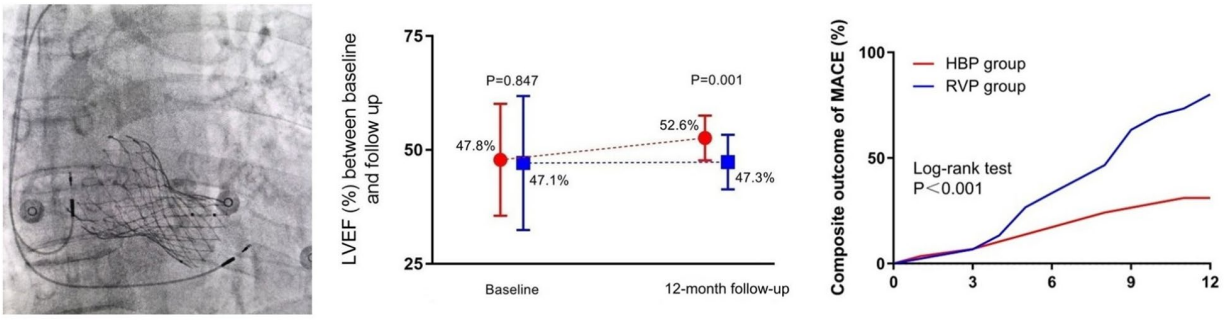
Graphical Abstract



The improvement was observed not only in cardiac function but also in the significant reduction of MACE in patients undergoing His bundle pacing

Keywords Cardiac function, His bundle pacing, Right ventricular pacing, Conduction disturbances, Transcatheter aortic valve replacement

Introduction

Transcatheter aortic valve replacement (TAVR) is a minimally invasive procedure used to treat severe aortic stenosis in patients who are not suitable candidates for traditional open-heart surgery. It involves the implantation of a prosthetic valve via a catheter, typically inserted through the femoral artery, to restore normal blood flow through the aortic valve. The clinical presentation of patients undergoing TAVR varies depending on the urgency of the procedure. Urgent TAVR is typically performed in patients with acute heart failure or advanced aortic stenosis, with acceptable in-hospital and one-year mortality rates. In emergent situations, such as severe acute dyspnea or cardiogenic shock, patients experience high procedural and 30-day mortality, but TAVR is preferred over surgical aortic valve replacement (SAVR) due to its less invasive nature. Management often involves hemodynamic stabilization and symptom control [1]. The diagnosis of aortic stenosis primarily relies on echocardiography, which plays a key role in assessing the severity of the condition. A standardized, stepwise approach to echocardiographic evaluation ensures a comprehensive assessment, including detailed analysis of left ventricular function and aortic valve anatomy. Early diagnosis is crucial for improving patient outcomes, and recent advancements in echocardiographic techniques, along with the integration of artificial intelligence, have further enhanced diagnostic accuracy [2].

However, TAVR procedures pose a risk of developing high-degree bundle branch block or atrioventricular block, which often necessitates the implantation of a permanent pacemaker [3]. Addressing and managing these conduction disturbances (CD) continues to be a significant clinical challenge in modern medical practice. Previous research reports right ventricular pacing (RVP) may elevate the risk of heart failure and is linked to negative clinical outcomes [4]. His-bundle pacing (HBP) offers several advantages over traditional RVP [5], which aims to improve cardiac function by preserving more physiological pacing pathways, thereby potentially reducing the risk of heart failure progression and improving long-term outcomes [6]. HBP, for instance, allows for more synchronized and efficient ventricular activation compared to conventional pacing methods, leading to better hemodynamic performance and potentially lower rates of adverse cardiac events [7]. By leveraging the native conduction system, these advanced pacing strategies represent a promising approach in modern cardiac electrophysiology for optimizing patient outcomes and quality of life [8].

Based on the aforementioned reasons, HBP seems to not only appears to address the complications of high-degree conduction block following TAVR but also potentially contributes positively to maintaining cardiac function in post-TAVR patients.

Methods

Study population

The screening process involved 411 consecutive patients admitted for aortic valve disease, who underwent TAVR at the First Affiliated Hospital of Harbin Medical University, Heilongjiang Provincial Hospital, the Second Affiliated Hospital of Harbin Medical University, Suzhou Kowloon Hospital, Shanghai Jiao Tong University School of Medicine, Forth Affiliated Hospital of Harbin Medical University, and the First Hospital of Jilin University between January 2015 and December 2024. Patients were divided into two groups: HBP group and RVP group. To account for differences in initial risk factors and baseline characteristics between these groups, we employed propensity score matching. Each patient was matched in

a 1:1 ratio with replacement. Patients who could not be adequately matched, regardless of their pacing participation status, were excluded from the study population. After matching, the final study cohort consisted of 60 patients in each group (Fig. 1).

Patients received TAVR complicated with CD requiring permanent pacemaker implantation, including high-degree or complete atrioventricular block (AVB), new-onset al.ternating bundle branch block (ABBB), and new LBBB with QRS > 150 ms or PR > 240 ms [9]. Patients aged > 18 years, non-pregnant, with life expectancy > 1

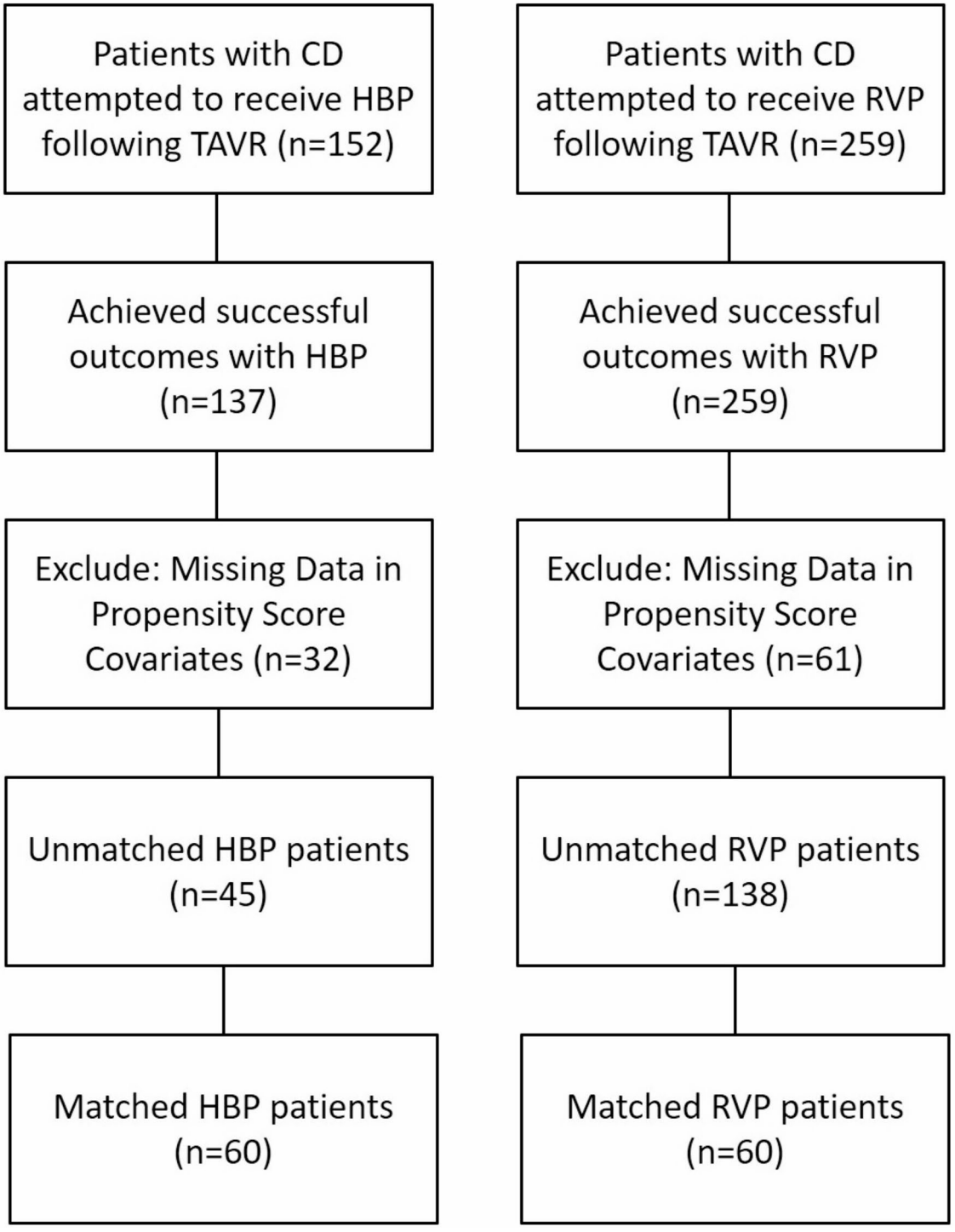


Fig. 1 Study flowchart

year, and anticipated ventricular pacing > 40% will be included. Exclusion criteria: (1) previous permanent pacemaker implantation for permanent atrial fibrillation (PAF) or sick sinus syndrome (SSS) related bradycardia; (2) lack of standard 12-lead ECG, echocardiography and pacemaker programming records; (3) inability to complete 12-month follow-up with severe data missing. The primary endpoint of the study is the occurrence of major adverse cardiovascular events (MACE), which includes all-cause mortality, cardiovascular mortality, heart failure hospitalization, upgrade to biventricular pacing, atrial fibrillation (AF), and pacemaker lead displacement. The secondary endpoint is the change in left ventricular ejection fraction (LVEF) from baseline to the12-month follow-up.

Covariate characteristics included

To ensure the integrity of the data, any covariates included in this study were required to have no more than 25% missing values in the original dataset. The study covered a range of patient demographic characteristics, including age, sex, body mass index (BMI) and medical history risk factors, such as hypertension, diabetes, and coronary artery disease (CAD). The medical history considered in the analysis included conditions such as coronary artery disease, and smoking. Absolute standardized differences (ASD) were employed to facilitate a comparative analysis of the various characteristics between on HBP group and RVP group [10]. This approach was selected due to the considerable sample size, with an absolute standard deviation (SD) exceeding 10% representing a practical significant difference in variables between the two groups.

Match processing

To adjust for variations in initial risk factors and baseline characteristics between patients undergoing HBP and RVP, we applied propensity score matching. The propensity score was calculated using a broad, non-interactive multivariable logistic regression model to estimate each patient's probability of pacing therapy, based on the selected covariates. Patients who received HBP were subsequently matched 1:1 with RVP, using a logit-transformed propensity score with a caliper limit of 0.03, allowing for replacement. Patients who could not be adequately matched were excluded from the study population.

Implantation procedure

The RVP implantation was carried out using the standard transvenous approach, with the ventricular lead positioned in the right ventricle. The implantation procedures for HBP and LBBP were conducted either using the traditional method or with the assistance of a visualization technique previously described [11, 12]. All CSP implantations utilized the fixed-curve C315 HIS sheath (Medtronic Inc, Minneapolis, MN) along with the Select Secure 3830 pacing lead (Medtronic Inc, Minneapolis, MN).

Target his bundle region

The His bundle (HB) region was defined as the area where the HB potential could be detected or where the HB could be captured through unipolar pacing. The HB region could also be identified using a visualization technique. This technique involved injecting 10–20 mL of contrast medium through the C315 HIS sheath below the root of the tricuspid septal leaflet to display the location of the tricuspid valve annulus (TVA). The fluoroscopic image of the TVA location was saved as an anatomical reference, which was then used to locate the HB region based on its positional relationship with the TVA, as previously described [11].

Data collection and Follow-Up

Baseline characteristics and indications for pacemaker implantation were recorded at the time of enrollment. Follow-up assessments were conducted 12 months after the implantation. Echocardiographic measurements of left ventricular ejection fraction (LVEF) were taken at baseline and again at the12-month follow-up. All transthoracic echocardiographic examinations were performed using a CX50 ultrasound (Philips Healthcare, Best, The Netherlands) equipped with 5 – 1 MHz transducer. The exams were performed by a team of two experienced cardiologists who were blinded to the patient group allocation and study hypothesis.

Pacing parameters, such as capture threshold, R-wave amplitude, and impedance, were documented during the procedure and at the12-month follow-up. MACE including all-cause mortality, cardiovascular mortality, heart failure hospitalization, need for rhythm-related treatment, and pacemaker lead displacement were also evaluated during 12-month follow-up.

Statistical analysis

Quantitative variables were expressed as mean value ± standard deviation, and qualitative variables were expressed as total number and percentage. Comparisons between groups were conducted using an independent two-sample *t*-test. Categorical variables, including the changes in NYHA functional class, were compared using chi-square or Fisher's exact test, as appropriate. To estimate survival status, the Kaplan-Meier (KM) technique was utilized, and the log-rank test was used to compare survival distributions. The univariate and multivariate logistic regression analyses were used to identify predictors of MACE. Statistical significance was indicated when

Table 1 Characteristics of the patients at baseline

	HBP (*n* = 60)	RVP (*n* = 60)	*P*-value
Age, years	74.3 ± 3.8	73.8 ± 3.0	0.568
Male sex, n (%)	22 (36.7)	21 (35.0)	1.000
BMI, kg/m^2	24.7 ± 3.7	25 ± 3.9	0.730
Active Smoking, n (%)	24 (40.0)	19 (31.7)	0.116
Medical history risk factors, n (%)			
Hypertension	39 (65.0)	43 (71.7)	0.556
diabetes	17 (28.3)	15 (25.0)	0.837
History of CAD	16 (26.7)	14 (23.3)	0.833
Indications for pacing, n (%)			
High-degree AVB	14 (23.3)	15 (25.0)	1.000
Complete AVB	26 (43.3)	28 (46.7)	0.855
ABBB	4 (6.7)	6 (10.0)	0.743
LBBB	16 (26.7)	11 (18.3)	0.382
LVEF, %	47.8 (12.4)	47.1 (14.7)	0.847
LVEF ≥ 50%, n (%) (%)	20 (33.3)	18 (30.0)	0.845
LVEF < 50%, n (%)	40 (66.7)	42 (70.0)	0.845
NYHA functional class, n (%)			
I	4 (6.7)	6 (10.0)	0.743
II	16 (26.7)	14 (23.3)	0.833
III	36 (60.0)	35 (58.3)	1.000
IV	4 (6.7)	5 (8.3)	1.000
Medications, n (%)			
Beta-blockers	28 (46.7)	27 (45.0)	1.000
Diuretics	52 (86.7)	50 (83.3)	0.799
ACEI/ARB	14 (23.3)	11 (18.3)	0.654
Aldosterone antagonist	22 (36.7)	21 (35.0)	1.000
Anticoagulants	20 (33.3)	17 (28.3)	0.693
Antiplatelets	40 (66.7)	42 (70.0)	0.845
Vasodilators	24 (40.0)	19 (31.7)	0.447

Values are mean ± standard deviation, or number (%). HBP, conduction system pacing; RVP, right ventricle pacing; BMI, body mass index; AVB, atrioventricular block; ABBB, alternating bundle branch block; LBBB, left bundle branch block; NYHA, New York Heart Association; LVEF, left ventricular ejection fraction; ACEI/ARB, angiotensin-converting enzyme inhibitors or receptor blocker; CAD, coronary artery disease

a two-sided p-value was < 0.05. All data cleaning and preprocessing were conducted using the R software, version 4.3.2. All statistical analyses were performed using SPSS version 22.0 (SPSS Inc., Chicago, IL).

Results

Baseline characteristics

The screening process involved 411 patients, of whom 152 were allocated to the HBP group and 259 to the RVP group. In the HBP group, 137 patients successfully underwent HBP treatment, yielding a success rate of 90.1%. All 259 patients in the RVP group successfully completed RVP treatment, resulting in a 100.0% success rate. Propensity score matching was employed to balance baseline characteristics between the groups, after which 120 patients were ultimately enrolled in the study for final analysis. The ASD between the matched groups were found to be < 10% for all covariates. There is no significant difference between HBP and RVP groups at baseline (Table 1).

Table 2 Procedural pacing and clinical outcomes among groups

	HBP (*n* = 60)	RVP (*n* = 60)	*P*-value
Baseline QRS duration (ms)	132.83 ± 14.33	135.62 ± 33.76	0.370
Paced QRS duration (ms)	121.72 ± 8.70	153.86 ± 7.84	< 0.001
Pacing burden (%)	82 ± 11	86 ± 11	0.120
Pacing parameters at implantation			
Pacing threshold (V)	2.25 ± 0.70	1.40 ± 0.20	< 0.001
Capture threshold (V)	1.25 ± 0.46	0.80 ± 0.11	< 0.001
R-wave amplitude (mV)	5.9 ± 2.7	12.8 ± 3.8	< 0.001
Impedance (Ω)	607.8 ± 144.1	671.8 ± 180.7	0.146
Parameters at one year follow-up			
Pacing threshold (V)	1.80 ± 0.60	1.30 ± 0.25	< 0.001
Capture threshold (V)	1.05 ± 0.38	0.77 ± 0.15	0.002
R-wave amplitude (mV)	4.7 ± 2.6	12.6 ± 3.4	< 0.001
Impedance (Ω)	404.2 ± 76.3	537.9 ± 113.9	< 0.001
Decrease in pacing burden (%)	20.4 ± 5.8	5.5 ± 1.1	< 0.001
LVEF at one year follow up	52.6 ± 5.2	47.3 ± 6.0	0.001

Values are mean ± standard deviation, or number (%). HBP, His bundle pacing; RVP, right ventricle pacing; LVEF, left ventricular ejection fraction

Procedural pacing and clinical outcomes among groups

Paced QRS duration (121.72 ± 8.70 ms vs. 153.86 ± 7.84 ms, $P < 0.001$), R-wave amplitude at implantation (5.9 ± 2.7 mV vs. 12.8 ± 3.8 mV, $P < 0.001$) and at follow-up (4.7 ± 2.6 mV vs. 12.6 ± 3.4 mV, $P < 0.001$), impedance at follow-up (404.2 ± 76.3 Ω vs. 537.9 ± 113.9 Ω, $P < 0.001$) were lower in HBP group compared to RVP group (Table 2). At12-month follow-up, the decrease in pacing burden was significantly greater in the HBP group than in the RVP group (20.4 ± 5.8% vs. 5.5 ± 1.1, $P < 0.001$; Table 2). Pacing threshold at implantation (2.25 ± 0.70 V vs. 1.40 ± 0.20 V, $P < 0.001$) and at follow-up (1.80 ± 0.60 V vs. 1.30 ± 0.25 V, $P < 0.001$) and capture threshold at implantation (1.25 ± 0.46 V vs. 0.80 ± 0.11 V, $P < 0.001$) and at follow-up (1.05 ± 0.38 V vs. 0.77 ± 0.15 V, $P = 0.002$) were higher in HBP group compared to RVP group (Table 2). During follow-up, the left ventricular ejection fraction (LVEF) (52.6% vs. 47.3%, $P = 0.001$; Fig. 2) and tricuspid regurgitation (TR) area (2.7 ± 0.4 cm^2 vs. 3.7 ± 0.6 cm^2, $P = 0.014$; Fig. 2) in the HBP group showed a significant improvement compared to preoperative values, while no significant increase in LVEF was observed in the RVP group, with a clear statistical difference between the two groups. At the12-month follow-up, NT-proBNP levels in the HBP group were significantly lower than those in the RVP group (Fig. 3).

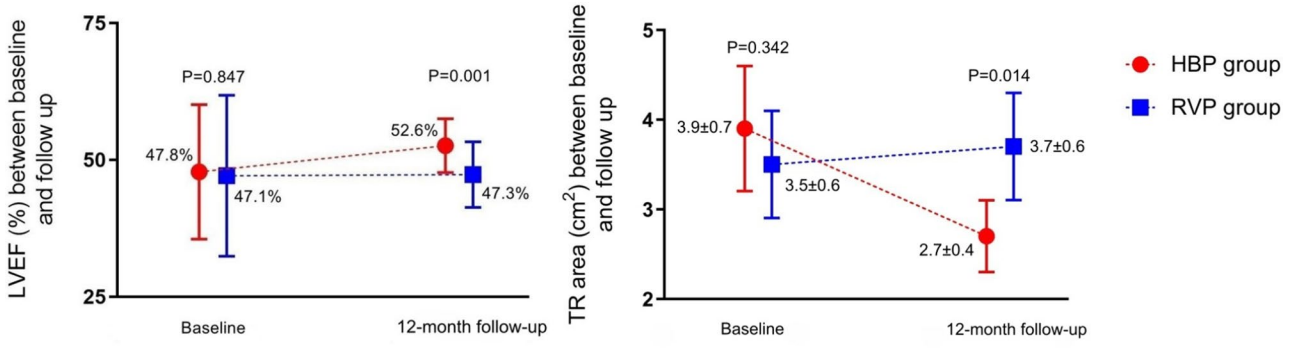


Fig. 2 Changes of LVEF and TR from baseline to follow-up. HBP, His bundle pacing; RVP, right ventricle pacing; LVEF, left ventricular ejection fraction; TR, tricuspid regurgitation

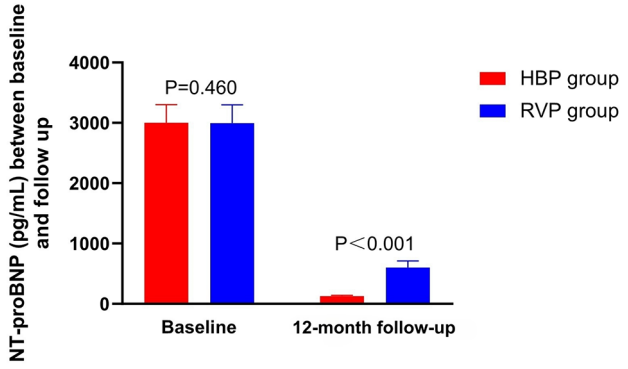


Fig. 3 Changes of NT-proBNP from baseline to follow-up. HBP, His bundle pacing; RVP, right ventricle pacing; NT-proBNP, N-terminal pro B-type natriuretic peptide

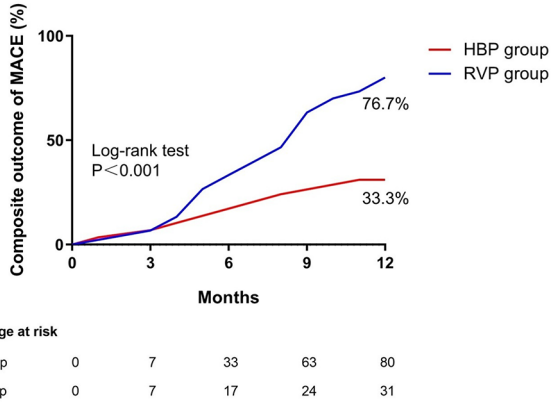


Fig. 4 Analysis of MACE in 12-month follow-up. HBP, His bundle pacing; RVP, right ventricle pacing; MACE, major adverse cardiovascular events

Table 3 NYHA functional class and MACE in follow-up

	HBP ($n=60$)	RVP ($n=60$)	*P*-value
NYHA functional class, n (%)			
I	8 (13.3)	10 (16.7)	0.799
II	42 (70.0)	22 (36.7)	< 0.001
III	10 (16.7)	28 (46.7)	0.001
Accumulated MACE, n (%)	20 (33.3)	46 (76.7)	< 0.001
All-cause mortality	2 (3.3)	2 (3.3)	1.000
Cardiovascular mortality	2 (3.3)	2 (3.3)	1.000
Heart failure hospitalization	6 (10.0)	14 (23.3)	0.085
Upgrade to biventricular pacing	4 (6.7)	14 (23.3)	0.019
AF	2 (3.3)	10 (16.7)	0.029
Pacemaker lead displacement	4 (6.7)	4 (6.7)	1.000

Values are number (%). HBP, His bundle pacing; RVP, right ventricle pacing; NYHA, New York Heart Association; MACE, major cardiovascular adverse events; AF, atrial fibrillation

MACE in one year follow-up

The rates of NYHA functional class II (70.0% vs. 36.7%, $P<0.001$) were higher, while the rates of NYHA functional class III (16.7% vs. 46.7%, $P=0.001$), upgrade to biventricular pacing (6.7% vs. 23.3%, $P=0.019$), atrial fibrillation (3.3% vs. 16.7%, $P=0.029$), and accumulated MACE were lower in the HBP group compared to the RVP group during follow-up (33.3% vs. 76.7%, $P<0.001$; Table 3; Fig. 4). LVEF in 12-month follow-up (OR = 0.890, 95% CI = 0.800-0.992, $P=0.018$) were independently related with MACE (Table 4).

Discussion

High-grade atrioventricular (AV) block is a significant complication that can occur following TAVR. Studies show that the incidence of high-grade AV block post-TAVR ranges from 1 to 8%, with higher rates observed in patients with extensive calcification in the valve area [13]. The occurrence of high-grade AV block postoperatively is concerning due to its potential to lead to severe bradycardia, hemodynamic instability, heart failure, and an increased risk of sudden cardiac death [14]. Often, these patients require permanent pacemaker implantation, which carries long-term risks and can significantly impact the patient's quality of life. The development of CD may also indicate underlying damage to the conduction system, especially if the interventricular septum or adjacent conduction pathways are involved during the procedure [15, 16]. Therefore, careful monitoring of

Table 4 Univariate and multivariate regression analysis for MACE in follow-up

	Univariate			Multivariate		
	OR	**95% CI**	***P*-value**	**OR**	**95% CI**	***P*-value**
Age	1.167	1.022–1.331	0.214	-	-	-
Sex	0.932	0.842–1.032	0.161	-	-	-
Pacing threshold	0.910	0.810–0.922	0.008	0.905	0.810–9.920	0.072
Capture threshold	0.896	0.786–0.977	0.019	0.876	0.780–0.982	0.094
R-wave amplitude	1.112	1.020–1.213	0.026	1.115	1.025–1.214	0.084
Impedance	1.204	1.058–1.368	0.007	1.035	0.950–1.128	0.445
Decrease in pacing burden	0.812	0.715–0.922	0.013	0.809	0.800-0.991	0.071
NT-proBNP	1.234	1.056–1.442	0.015	1.057	0.965–1.158	0.235
LVEF	0.876	0.782–0.981	0.007	0.890	0.800-0.992	0.018

CI, confidence interval; OR, odds ratio; MACE, major adverse cardiovascular events; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal pro-brain natriuretic peptide

patients post-TAVR for signs of CD is essential, and early intervention should be considered when indicated [17].

In this study, we demonstrated that HBP is feasible and safe in patients who develop conduction disturbances following TAVR. Importantly, HBP was associated with a significant reduction in the composite outcome of MACE and improved cardiac function compared to RVP. These findings suggest that HBP may provide a favorable alternative to RVP, particularly in TAVR patients with aortic stenosis [18, 19]. HBP's physiological nature, which directly stimulates the His-Purkinje system, helps maintain better ventricular synchrony, potentially resulting in superior clinical outcomes in this cohort. It is important to note that TAVR is often performed in elderly patients with significant comorbidities, and the development of conduction disturbances such as high-grade AV block or left bundle branch block (LBBB) can complicate post-procedural management [20, 21]. Previous studies have highlighted the risks associated with RVP, including its potential contribution to heart failure and increased mortality [22]. These concerns are especially relevant in patients with other underlying cardiac conditions. However, our study focuses specifically on TAVR patients with aortic stenosis, where HBP may offer a more effective and physiologically beneficial approach.

HBP has recently gained recognition as the most physiological pacing strategy. Clinical studies have demonstrated its effectiveness in correcting LBBB in patients with chronic heart failure, leading to significant improvements in their condition. Furthermore, HBP has been shown to produce comparable improvements in LVEF when compared to RVP [23]. Our findings align with this, as patients in the HBP group exhibited significantly higher LVEF at follow-up compared to those in the RVP group. This improvement highlights the physiological benefits of HBP, as it closely mimics the heart's natural conduction pathways, thereby enhancing synchrony and overall heart function. Additionally, the HBP group demonstrated lower rates of MACE and improved New York Heart Association (NYHA) functional class outcomes, further emphasizing the superiority of HBP in managing heart failure and improving patient prognosis post-TAVR. Our study also showed an increased incidence of atrial fibrillation (AF) and the need for upgrade to biventricular pacing (BiVP) in the RVP group. His-bundle pacing (HBP) more closely mimics the heart's natural conduction system, preserving synchronized ventricular activation and improving overall cardiac function [7]. This leads to better hemodynamic stability and reduces the likelihood of arrhythmias like AF. Additionally, the more physiological nature of HBP reduces pacing-induced dyssynchrony [8], which is a common cause of worsening heart failure and the need for BiVP in RVP patients. As demonstrated in our study, the HBP group showed a significant improvement in LVEF compared to the RVP group. This improvement may reduce the occurrence of complications such as AF, which is often linked to heart failure and ventricular dysfunction [24]. In contrast, the RVP group did not experience the same level of functional improvement, which could explain the higher incidence of AF and the need for BiVP upgrades.

In short, HBP offers several advantages, including more physiological cardiac activation, better ventricular synchrony, improved preservation of left ventricular function, and enhanced hemodynamics, making it particularly suitable for patients expected to be pacing-dependent long-term, those with impaired left ventricular function or at risk of heart failure, younger patients due to the long-term impact of pacing, and patients requiring high ventricular synchrony. Conversely, RVP may be more appropriate for patients in whom HBP is technically unfeasible or unsuccessful, those requiring lower and more stable pacing thresholds, patients with specific pathological conditions favoring RVP, or those treated in facilities with limited HBP experience or equipment. While these recommendations provide a framework for decision-making, the choice of pacing strategy should be individualized based on each patient's clinical profile, including comorbidities, anatomical considerations, and resource availability. Future research, particularly

large-scale randomized controlled trials, is needed to validate these findings, refine patient selection criteria, and establish evidence-based guidelines to optimize pacing strategies and improve outcomes in this patient population.

It has been reported that in many patients with cardiac implantable electronic devices (CIEDs), a causal relationship should be assumed when tricuspid regurgitation (TR) of any grade develops or when pre-existing TR worsens following the insertion of a RV lead [25]. Some studies have indicated that new-onset TR is rarely reported following HBP, whereas a reduction in TR has been more frequently observed [26, 27]. Our findings are consistent with the results of the aforementioned studies. In the HBP group, the TR area significantly decreased at the 12-month follow-up, whereas in the RVP group, the TR area significantly increased. This could be attributed to the lead placement in the atrial portion of the tricuspid annulus or at the antero-septal commissure. Additionally, HBP may help reduce TR by preventing dyssynchrony and minimizing mechanical stress, as it utilizes thinner and lighter pacing leads [28].

In our study, LVEF at follow-up was a strong predictor of the composite outcome of MACE, underscoring the important role of LVEF in evaluating cardiac function and predicting patient outcomes. Specifically, HBP preserves more physiological pacing by maintaining the heart's natural conduction pathways, enhancing synchronous cardiac contractions, and improving overall pumping efficiency. Consequently, patients in the HBP group showed better LVEF at follow-up, leading to a lower incidence of MACE and improved overall cardiac function. Our study is consistent with other research that highlights the advantages of HBP in improving heart function, underscoring its clinical importance [29, 30].

Both HBP and left bundle branch area pacing (LBBAP) aim to restore more physiological ventricular activation, but they achieve this through different mechanisms. HBP directly targets the His-Purkinje system, providing synchronized activation of the ventricles. This approach has been shown to reduce the risk of heart failure and improve long-term outcomes, particularly in patients with conduction disturbances following TAVR. By preserving normal ventricular activation, HBP potentially mitigates the adverse effects of RVP, such as the progression of heart failure. In contrast, LBBAP targets the left bundle branch area and has demonstrated promising results in improving resynchronization in patients with LBBB [31]. LBBAP may be especially beneficial in patients with heart failure, where improved left ventricular resynchronization is needed. However, the procedure for LBBAP is technically more challenging and may carry a higher risk of complications, such as lead dislodgement or injury to the left bundle branch [5]. Furthermore, although LBBAP is gaining attention as a viable pacing modality, there is currently less long-term data available compared to HBP. It is found that, although temporary LBBB occurs frequently after TAVR, it does not significantly impact survival or major clinical outcomes at 1-year follow-up. Moreover, the study highlighted that advanced valve disease, especially with lower LVEF, could predispose patients to temporary LBBB, emphasizing the importance of patient baseline characteristics in predicting these outcomes [32]. While our study focused on comparing HBP with RVP, LBBAP could be explored in future studies.

As highlighted in our study, HBP has demonstrated significant improvements in clinical outcomes, including reduced MACE rates and improved LVEF compared to RVP. In addition to these clinical benefits, it is also important to consider long-term lead performance and battery longevity, which are crucial factors in evaluating the viability and sustainability of pacing strategies [33]. While our study focused primarily on relative short-term outcomes, we acknowledge that long-term lead performance and battery longevity may differ between HBP and RVP. HBP, due to its more physiological pacing mechanism, may potentially lead to improved lead stability and a reduced risk of lead failure over time, as it requires less manipulation of the right ventricle. Conversely, RVP has been associated with a higher risk of lead fracture, displacement, and increased pacing demands, which may contribute to shorter battery life.

Recent studies have demonstrated that Acute Kidney Injury (AKI) remains a common complication following TAVR, primarily due to the substantial volume of contrast media administered during the procedure [34]. Furthermore, contrast-induced nephropathy after cardiac resynchronization therapy implantation may impair the recovery of ejection fraction in responders [35]. Our research findings indicate no significant differences in contrast volume or AKI incidence between HBP and RVP groups (Fig. 5). This suggests that the impact of contrast-induced renal dysfunction on cardiac function may be comparable between the two groups in our study. However, it is crucial to note that these phenomena should not be overlooked in future post-TAVR pacing therapies. The potential renal and cardiac implications of contrast use in TAVR procedures warrant continued vigilance and further investigation to optimize patient outcomes and minimize complications in this vulnerable population.

Limitations

First, the retrospective study design may introduce inherent biases and limit the ability to establish causality, despite rigorous statistical adjustments, the potential for unmeasured confounding remains, which may result in over-correction and unreliable estimates. Second, the

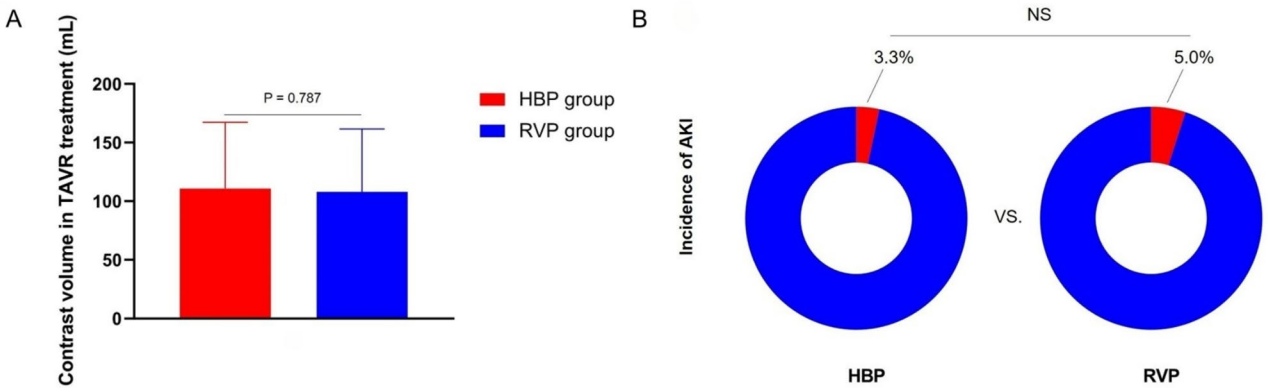


Fig. 5 Contrast volume and AKI between HBP and RVP groups. AKI, acute kidney injury; HBP, His bundle pacing; RVP, right ventricle pacing

relatively small sample size reduces the statistical power of the study and may affect the robustness of the conclusions. Third, the study was conducted in a limited number of centers, which may not fully represent the broader patient population and practice variations. Finally, the absence of randomization in the study design may introduce confounding variables that could influence the outcomes. In future research, we plan to conduct multicenter, large-sample, randomized controlled trials to address these limitations.

Conclusions

HBP was feasible and safe in patients after TAVR, demonstrating a reduction in the composite outcome of MACE and better cardiac function compared to RVP.

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Author contributions
Conception and design: Donghui Zhang and Ruoxi Zhang. Development of the methodology: Qi Zhao, Donghui Zhang, and Huimin Xian. Acquisition of data: Qi Zhao, Shenglong Hou, and Chao Qu. Analysis and interpretation of data: Yanhui Gao, Ou Yang, Qi Zhao, Donghui Zhang, Shenglong Hou, and Chao Qu. Writing, review, and/or revision of the manuscript: Ruoxi Zhang, and Huimin Xian.

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Data availability
People can get a copy of study data by emailing the corresponding author.

Declarations

Ethics statement
The studies involving human participants were reviewed and approved by Ethics Committee for the First Affiliated Hospital of Harbin Medical University, Heilongjiang Provincial Hospital, the Second Affiliated Hospital of Harbin Medical University, Suzhou Kowloon Hospital, Shanghai Jiao Tong University School of Medicine, Forth Affiliated Hospital of Harbin Medical University, and the First Hospital of Jilin University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Competing interests
The authors declare no competing interests.

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