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Twelve-Month Electrical Lead Performance of His Bundle Pacing Versus Left Bundle Branch Pacing in Older Patients With Bradyarrhythmias: A Retrospective Cohort Study

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Abstract

Background

Conduction system pacing is increasingly used to preserve physiological ventricular activation in patients requiring permanent pacing. His bundle pacing provides direct recruitment of the native His–Purkinje system but may be limited by higher or unstable capture thresholds, whereas left bundle branch pacing may offer more favorable electrical parameters. Evidence comparing these strategies in older patients, particularly with systematic frailty assessment and 12-month lead follow-up, remains limited. This study compared procedural characteristics, longitudinal electrical lead performance, and clinical outcomes between His bundle pacing and left bundle branch pacing in older patients with symptomatic bradyarrhythmias.

Methods

We conducted a retrospective cohort study of 167 older patients with symptomatic bradyarrhythmias who underwent conduction system pacing, including 75 treated with His bundle pacing and 92 treated with left bundle branch pacing. Device parameters were assessed at implantation, 6 months, and 12 months. Geriatric-relevant variables, including polypharmacy, multimorbidity, and Clinical Frailty Scale score, were recorded. The primary endpoint was high capture threshold, defined as capture threshold > 1.0 V at 0.4 ms at 12 months. Logistic regression was used to evaluate the association between pacing modality and high capture threshold.

Results

Procedural success was similar between the His bundle pacing and left bundle branch pacing groups [70/75 (93.3%) vs. 85/92 (92.4%); p = 0.815]. Frailty burden was comparable, with a median Clinical Frailty Scale score of 4 (3–5) in both groups. Left bundle branch pacing was associated with a lower implant capture threshold [0.6 (0.45–0.8) vs. 0.8 (0.7–1.0) V; p < 0.001] and higher R-wave amplitude [8.5 (7–11) vs. 5.4 (4–8) mV; p < 0.001], but longer procedure and fluoroscopy times. Capture thresholds remained consistently lower with left bundle branch pacing at 6 months [0.6 (0.5–0.8) vs. 0.9 (0.8–1.2) V; p < 0.001] and 12 months [0.6 (0.5–0.8) vs. 1.0 (0.8–1.3) V; p < 0.001]. High capture threshold at 12 months occurred in 23/72 patients (31.9%) in the His bundle pacing group and 4/88 patients (4.5%) in the left bundle branch pacing group. This association remained significant after adjustment for age, sex, pacing indication, baseline rhythm, lead type, and Clinical Frailty Scale score. Clinical outcomes and overall complications were similar between groups.

Conclusions

In older patients with symptomatic bradyarrhythmias undergoing conduction system pacing, left bundle branch pacing achieved procedural success comparable to His bundle pacing but demonstrated more favorable and stable 12-month electrical lead performance without an increase in overall clinical or device-related complications. These findings support left bundle branch pacing as a practical conduction

system pacing strategy in older patients, although longer follow-up is needed to determine whether improved threshold stability translates into better device longevity or clinical outcomes.

Trial registration

Not applicable.

BACKGROUND

Permanent pacing remains the cornerstone treatment for symptomatic bradyarrhythmias, including advanced atrioventricular block and sick sinus syndrome. Conventional right ventricular pacing is effective for bradycardia correction but may produce non-physiological ventricular activation, electrical dyssynchrony, and, in selected patients, pacing-induced cardiomyopathy. Cardiac physiologic pacing, including cardiac resynchronization therapy and conduction system pacing, has therefore gained increasing attention as a strategy to preserve or restore physiological ventricular activation [1].

Conduction system pacing directly engages the native His–Purkinje system and includes His bundle pacing (HBP) and left bundle branch pacing (LBBP). Contemporary guidelines and consensus documents recognize conduction system pacing as an evolving physiologic pacing strategy for patients requiring ventricular pacing, particularly when avoidance of pacing-induced ventricular dysfunction is clinically relevant [1, 2]. HBP represents the most anatomically physiological form of pacing, as it recruits the His bundle proximal to the bifurcation of the conduction system. Observational studies have suggested that HBP may be associated with improved clinical outcomes compared with conventional right ventricular pacing [3]. However, broader adoption of HBP has been limited by technical challenges, lower sensed R-wave amplitudes, higher capture thresholds, and concerns regarding threshold instability during follow-up [4, 5].

LBBP has emerged as an alternative conduction system pacing strategy. By targeting the left bundle branch region within the interventricular septum, LBBP offers a larger target area than HBP and may provide lower capture thresholds, higher R-wave amplitudes, and stable lead performance during follow-up [2, 6]. Previous comparative studies and meta-analyses have suggested that LBBP or left bundle branch area pacing may provide more favorable pacing parameters than HBP while maintaining physiological ventricular activation [7–10]. Nevertheless, data comparing HBP and LBBP in older patients with bradyarrhythmias remain limited, especially with systematic assessment of electrical lead performance through 12 months.

Older patients represent a clinically important population for permanent pacing. They often have a higher burden of comorbidities, advanced conduction disease, frailty-related vulnerability, medication complexity, and greater dependence on stable long-term device performance. Frailty, in particular, reflects biological vulnerability beyond chronological age and may influence procedural risk, recovery, and clinical outcomes in older adults [13]. In this context, lead performance is not merely a technical

endpoint but may have practical implications for device programming, battery longevity, follow-up burden, and the risk of reintervention.

Therefore, comparative data on conduction system pacing strategies in older patients should ideally incorporate geriatric-relevant variables, including frailty and multimorbidity, in addition to conventional electrophysiological endpoints. This study aimed to compare procedural characteristics, longitudinal electrical lead performance, and clinical outcomes between HBP and LBBP in older patients with symptomatic bradyarrhythmias. We hypothesized that LBBP would be associated with more favorable 12-month lead performance compared with HBP, particularly with respect to capture threshold stability.

METHODS

Study design and population

This was a retrospective cohort study including older patients with symptomatic bradyarrhythmias who underwent conduction system pacing with either HBP or LBBP. A total of 167 patients were included, comprising 75 patients in the HBP group and 92 patients in the LBBP group.

Patients were eligible if they were older individuals undergoing permanent pacemaker implantation for symptomatic bradyarrhythmias and if conduction system pacing was attempted using either HBP or LBBP. Pacing indications included atrioventricular block, sick sinus syndrome, or combined atrioventricular block and sick sinus syndrome. Patients were assigned to HBP or LBBP according to operator decision, anatomical feasibility, and procedural strategy at the time of implantation.

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Medicine and Pharmacy at Ho Chi Minh City (Approval No. 3732/DHYD-HDDD, September 17, 2025). The requirement for written informed consent was waived because of the retrospective nature of the study and the use of anonymized data.

This manuscript was prepared in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for observational cohort studies.

Data collection and definitions

Baseline demographic, clinical, echocardiographic, electrocardiographic, procedural, and device-related data were collected from medical records and device interrogation reports. Baseline symptoms and geriatric-relevant clinical variables, including syncope or presyncope, polypharmacy, multimorbidity, and frailty, were recorded.

Polypharmacy was defined as the use of five or more medications. Multimorbidity was defined as the presence of three or more comorbid conditions.

Frailty was assessed using the Clinical Frailty Scale (CFS), originally developed by Rockwood and colleagues [13]. The CFS is a judgment-based frailty measure ranging from very fit to severely frail and has been widely used to summarize baseline fitness and frailty in older adults. In this study, frailty was defined as CFS ≥ 5. For descriptive purposes, CFS scores were categorized as CFS 1–3, very fit to managing well; CFS 4, vulnerable; and CFS 5–8, mildly to severely frail.

Baseline and follow-up N-terminal pro–B-type natriuretic peptide (NT-proBNP) levels and New York Heart Association (NYHA) functional class were collected when available. NT-proBNP and NYHA class were analyzed as exploratory longitudinal clinical and biomarker variables.

Implantation procedure

Conduction system pacing implantation was performed according to standard institutional practice. HBP was performed by positioning the pacing lead at the His bundle region with confirmation of His bundle capture using electrocardiographic and pacing criteria. HBP capture was categorized as selective or non-selective according to established criteria when available [4].

LBBP was performed by advancing the pacing lead deep into the interventricular septum to capture the left bundle branch region. LBBP was confirmed based on paced QRS morphology, left ventricular activation time, pacing parameters, and electrocardiographic criteria consistent with left bundle branch capture, in line with contemporary consensus recommendations [2]. Left ventricular activation time was reported descriptively in the LBBP group.

Procedural variables included procedural success, failed attempt or conversion, procedure time, fluoroscopy time, pacemaker pocket location, venous access route, conduction system pacing lead type, recorded His or left bundle branch potential, lead penetration depth, and acute pacing parameters. Lead penetration depth was reported descriptively and was not statistically compared between HBP and LBBP because the two approaches require anatomically distinct implantation strategies.

Procedural success was defined as successful implantation of a conduction system pacing lead with acceptable acute electrical parameters and stable lead position. Failed attempt or conversion was defined as inability to achieve the intended conduction system pacing strategy or need to convert to an alternative pacing approach.

Follow-up and device interrogation

Device interrogation was performed at implantation, 6 months, and 12 months. Electrical parameters included capture threshold at 0.4 ms, R-wave amplitude, lead impedance, and paced QRS duration. High capture threshold was defined as capture threshold > 1.0 V at 0.4 ms. Threshold rise requiring management, loss of capture, and lead revision were recorded during follow-up.

Clinical follow-up was complete for all patients. Deaths before scheduled device visits were recorded as clinical outcomes rather than missing device data. Device parameters at 6 and 12 months were analyzed among patients with available device interrogation data. Twelve-month device interrogation was assessed among patients who survived to the 12-month visit.

Missing data and follow-up handling

Deaths before scheduled device visits were treated as clinical outcomes rather than missing device data. Device interrogation analyses at 6 and 12 months were performed among patients with available device data at each time point. For the primary endpoint, the analysis population comprised patients who survived to the 12-month device visit and had available interrogation data. No imputation was performed for device parameters.

Outcomes

The primary endpoint was high capture threshold > 1.0 V at 0.4 ms at 12 months.

Secondary endpoints included procedural success, failed attempt or conversion, selective and non-selective capture, procedure time, fluoroscopy time, capture threshold at implantation and 6 months, R-wave amplitude, lead impedance, paced QRS duration, all-cause death before 12 months, heart failure hospitalization, overall complications, lead dislodgement, septal perforation, threshold rise requiring management, loss of capture, and lead revision.

Exploratory outcomes included longitudinal changes in NYHA functional class and NT-proBNP levels.

Statistical analysis

Continuous variables are presented as median and interquartile range or mean ± standard deviation, as appropriate. Categorical variables are presented as number and percentage. Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and the chi-square test, Fisher’s exact test, or Fisher–Freeman–Halton test for categorical variables, as appropriate. For categorical variables with more than two categories, p-values represent overall comparisons of category distributions between groups.

Logistic regression was used to evaluate the association between pacing modality and high capture threshold > 1.0 V at 12 months. The exposure of interest was LBBP versus HBP. Model 1 was adjusted for age and sex. Model 2 was adjusted for age, sex, and pacing indication. Model 3 was additionally adjusted for baseline rhythm, given the significant imbalance in baseline rhythm distribution between groups. Because conduction system pacing lead type differed between groups and may influence electrical parameters, an exploratory sensitivity model additionally adjusted for lead type was performed. Because frailty is clinically relevant in older patients, a further sensitivity model additionally adjusted for Clinical Frailty Scale score was conducted. Results are presented as odds ratios with 95% confidence

intervals. An odds ratio below 1.0 favored LBBP. A two-sided p-value < 0.05 was considered statistically significant.

RESULTS

Baseline characteristics

Baseline characteristics and follow-up completeness are summarized in Table 1. The median age was similar between the HBP and LBBP groups [78 (65–86) vs. 77 (66–85) years; p = 0.650], and the proportion of female patients was also comparable [39/75 (52.0%) vs. 50/92 (54.3%); p = 0.780]. Body mass index did not differ significantly between groups [21.56 (19.62–23.76) vs. 22.22 (20.20–24.49) kg/m²; p = 0.182].

Table 1
Baseline characteristics and follow-up completeness

Variable	HBP, n = 75	LBBP, n = 92	p-value
Demographic characteristics			
Age, years	78 (65–86)	77 (66–85)	0.650
Female sex	39 (52.0%)	50 (54.3%)	0.780
BMI, kg/m²	21.56 (19.62–23.76)	22.22 (20.20–24.49)	0.182
Comorbidities and geriatric-relevant variables			
Hypertension	63 (84.0%)	80 (87.0%)	0.610
Diabetes mellitus	42 (56.0%)	51 (55.4%)	0.930
Dyslipidemia	30 (40.0%)	41 (44.6%)	0.553
Coronary artery disease	28 (37.3%)	33 (35.9%)	0.850
Chronic kidney disease	28 (37.3%)	40 (43.5%)	0.422
eGFR, mL/min/1.73 m²	66.12 (48.81–88.70)	63.77 (47.08–85.55)	0.651
Atrial fibrillation history	2 (2.7%)	9 (9.8%)	0.084
Heart failure history	5 (6.7%)	7 (7.6%)	0.825
Syncope or presyncope	36 (48.0%)	52 (56.5%)	0.281
NT-proBNP at implantation, pg/mL	109.3 (66.4–388.4)	122.4 (64.4–435.0)	0.542
Polypharmacy, ≥ 5 medications	12 (16.0%)	26 (28.3%)	0.066
Multimorbidity, ≥ 3 comorbidities	28 (37.3%)	44 (47.8%)	0.209
Clinical Frailty Scale score	4 (3–5)	4 (3–5)	0.892
Frailty, CFS ≥ 5	28 (37.3%)	33 (35.9%)	0.845
Clinical Frailty Scale category			0.941
CFS 1–3, very fit to managing well	18 (24.0%)	24 (26.1%)	
CFS 4, vulnerable	29 (38.7%)	35 (38.0%)	
CFS 5–8, mildly to severely frail	28 (37.3%)	33 (35.9%)	
Baseline cardiac and ECG characteristics			
Baseline LVEF, %	60 (52–67)	63 (55–70)	0.074
Baseline QRS duration, ms	96 (90–122)	100 (90–132)	0.360

Variable	HBP, n = 75	LBBP, n = 92	p-value
Demographic characteristics			
Baseline rhythm			0.002
Sinus bradycardia	50 (66.7%)	48 (52.2%)	
Atrial fibrillation	2 (2.7%)	9 (9.8%)	
Junctional rhythm	18 (24.0%)	13 (14.1%)	
Ventricular escape rhythm	5 (6.7%)	22 (23.9%)	
Baseline QRS morphology			0.412
Narrow QRS	58 (77.3%)	61 (66.3%)	
LBBB	2 (2.7%)	5 (5.4%)	
RBBB	11 (14.7%)	21 (22.8%)	
IVCD	4 (5.3%)	5 (5.4%)	
Pacing indication			0.360
AV block only	54 (72.0%)	74 (80.4%)	
Sick sinus syndrome only	18 (24.0%)	14 (15.2%)	
Combined AV block and sick sinus syndrome	3 (4.0%)	4 (4.3%)	
Follow-up completeness			
Follow-up duration, months	12.1 (11.8–12.6)	12.0 (11.7–12.5)	0.450
Death before 12 months	3 (4.0%)	4 (4.3%)	> 0.999
Completed 12-month clinical follow-up	75 (100%)	92 (100%)	—
12-month device interrogation among survivors	72/72 (100%)	88/88 (100%)	—
12-month device interrogation in total cohort	72/75 (96.0%)	88/92 (95.7%)	> 0.999

Variable	HBP, n = 75	LBBP, n = 92	p-value
Demographic characteristics			

Table note:

Values are presented as median (interquartile range) for continuous variables and n (%) for categorical variables. Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and the chi-square test, Fisher's exact test, or Fisher–Freeman–Halton test for categorical variables, as appropriate. For categorical variables with more than two categories, including Clinical Frailty Scale categories, baseline rhythm, baseline QRS morphology, and pacing indication, p-values represent overall comparisons of category distributions between the HBP and LBBP groups. Follow-up duration was calculated from pacemaker implantation to the last available clinical follow-up, device interrogation, or death, whichever occurred first. Twelve-month device interrogation was assessed among patients who survived to 12 months. HBP, His bundle pacing; LBBP, left bundle branch pacing; BMI, body mass index; CFS, Clinical Frailty Scale; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; ECG, electrocardiographic; LBBB, left bundle branch block; RBBB, right bundle branch block; IVCD, intraventricular conduction delay; AV, atrioventricular.

Cardiovascular comorbidities were frequent in both groups and were generally well balanced. Hypertension was present in 63 patients (84.0%) in the HBP group and 80 patients (87.0%) in the LBBP group (p = 0.610), while diabetes mellitus was present in 42 patients (56.0%) and 51 patients (55.4%), respectively (p = 0.930). Dyslipidemia [30/75 (40.0%) vs. 41/92 (44.6%); p = 0.553], coronary artery disease [28/75 (37.3%) vs. 33/92 (35.9%); p = 0.850], and chronic kidney disease [28/75 (37.3%) vs. 40/92 (43.5%); p = 0.422] were similarly distributed between groups. Baseline renal function was also comparable, with a median estimated glomerular filtration rate of 66.12 (48.81–88.70) mL/min/1.73 m² in the HBP group and 63.77 (47.08–85.55) mL/min/1.73 m² in the LBBP group (p = 0.651).

Atrial fibrillation history was numerically more frequent in the LBBP group than in the HBP group [9/92 (9.8%) vs. 2/75 (2.7%)], although this difference did not reach statistical significance (p = 0.084). Heart failure history was uncommon and comparable between groups [5/75 (6.7%) vs. 7/92 (7.6%); p = 0.825].

Symptoms and geriatric-relevant clinical characteristics were also assessed. Syncope or presyncope was present in 36 patients (48.0%) in the HBP group and 52 patients (56.5%) in the LBBP group (p = 0.281). Baseline NT-proBNP levels were comparable between groups [109.3 (66.4–388.4) vs. 122.4 (64.4–435.0) pg/mL; p = 0.542]. Polypharmacy was observed in 12 patients (16.0%) undergoing HBP and 26 patients (28.3%) undergoing LBBP (p = 0.066). Multimorbidity was present in 28 patients (37.3%) in the HBP group and 44 patients (47.8%) in the LBBP group (p = 0.209).

Frailty burden was comparable between groups. The median CFS score was 4 (3–5) in both the HBP and LBBP groups (p = 0.892). Frailty, defined as CFS ≥ 5, was present in 28 patients (37.3%) in the HBP group and 33 patients (35.9%) in the LBBP group (p = 0.845). The distribution of CFS categories was also similar between groups (overall p = 0.941): CFS 1–3 in 18 patients (24.0%) versus 24 patients (26.1%), CFS 4 in 29 patients (38.7%) versus 35 patients (38.0%), and CFS 5–8 in 28 patients (37.3%) versus 33 patients (35.9%) in the HBP and LBBP groups, respectively.

Baseline left ventricular systolic function was preserved in both groups. The median baseline left ventricular ejection fraction was 60% (52–67) in the HBP group and 63% (55–70) in the LBBP group (p = 0.074). Baseline QRS duration was similar between groups [96 (90–122) vs. 100 (90–132) ms; p = 0.360]. The distribution of baseline QRS morphology did not differ significantly between the HBP and LBBP groups (overall p = 0.412). Narrow QRS was the most common baseline QRS pattern in both groups, observed in 58 patients (77.3%) undergoing HBP and 61 patients (66.3%) undergoing LBBP.

In contrast, baseline rhythm distribution differed significantly between groups (overall p = 0.002). Sinus bradycardia was the most common baseline rhythm in both groups but was more frequent in the HBP group than in the LBBP group [50/75 (66.7%) vs. 48/92 (52.2%)]. Ventricular escape rhythm was more frequent in the LBBP group than in the HBP group [22/92 (23.9%) vs. 5/75 (6.7%)].

The distribution of pacing indications was similar between groups (overall p = 0.360). Atrioventricular block alone was the most common indication, occurring in 54 patients (72.0%) in the HBP group and 74 patients (80.4%) in the LBBP group. Sick sinus syndrome alone was present in 18 patients (24.0%) and 14 patients (15.2%), respectively, whereas combined atrioventricular block and sick sinus syndrome was observed in 3 patients (4.0%) and 4 patients (4.3%), respectively.

Follow-up completeness was high in both groups. The median follow-up duration was 12.1 (11.8–12.6) months in the HBP group and 12.0 (11.7–12.5) months in the LBBP group (p = 0.450). Clinical follow-up was complete for all patients. Three patients (4.0%) in the HBP group and four patients (4.3%) in the LBBP group died before completion of the 12-month device visit. Among patients who survived to 12 months, device interrogation was available in all cases, including 72 of 72 patients in the HBP group and 88 of 88 patients in the LBBP group.

Procedural characteristics, implant approach, and acute electrical parameters

Procedural characteristics, implant approach, and acute electrical parameters are shown in Table 2. Procedural success was similar between groups, occurring in 70 of 75 patients (93.3%) in the HBP group and 85 of 92 patients (92.4%) in the LBBP group (p = 0.815). Failed attempt or conversion occurred in 5 patients (6.7%) undergoing HBP and 7 patients (7.6%) undergoing LBBP (p = 0.815).

Table 2
Procedural characteristics, implant approach, and acute electrical parameters

Parameter	HBP, n = 75	LBBP, n = 92	p-value
Procedural success	70 (93.3%)	85 (92.4%)	0.815
Failed attempt/conversion	5 (6.7%)	7 (7.6%)	0.815
Selective capture among successful cases	25/70 (35.7%)	13/85 (15.3%)	0.005
Non-selective capture among successful cases	45/70 (64.3%)	72/85 (84.7%)	0.005
Procedure time, min	105 (80–120)	120 (90–122.5)	0.024
Fluoroscopy time, s	540 (330–900)	786 (408–1220)	0.030
Implant capture threshold, V at 0.4 ms	0.8 (0.7–1.0)	0.6 (0.45–0.8)	< 0.001
Implant R-wave amplitude, mV	5.4 (4–8)	8.5 (7–11)	< 0.001
Implant lead impedance, Ω	571 (480–650)	631.5 (550.5–752.5)	< 0.001
Post-implant paced QRS duration, ms	100 (90–110)	109.2 (100–120)	< 0.001
LVAT in LBBP group, ms	Not applicable	70 (70–77.5)	—
Pacemaker pocket location			0.465
Left subcutaneous	73 (97.3%)	86 (93.5%)	
Left submuscular/subpectoral	2 (2.7%)	3 (3.3%)	
Right subcutaneous	0 (0%)	2 (2.2%)	
Right submuscular/subpectoral	0 (0%)	1 (1.1%)	
Venous access route			0.327

Table note:

Values are presented as median (interquartile range) for continuous variables and n (%) for categorical variables. P-values were calculated using the Mann–Whitney U test for continuous variables and the chi-square test, Fisher's exact test, or Fisher–Freeman–Halton test for categorical variables, as appropriate. For categorical variables with more than two categories, p-values represent overall comparisons of category distributions between groups. Selective and non-selective capture were analyzed among patients with successful conduction system pacing implantation. LVAT was reported descriptively only in the LBBP group and was not used as a comparative endpoint between HBP and LBBP. Lead penetration depth was reported descriptively and was not statistically compared because HBP and LBBP involve anatomically distinct implantation strategies. HBP, His bundle pacing; LBBP, left bundle branch pacing; CSP, conduction system pacing; LVAT, left ventricular activation time; LBB, left bundle branch.

Parameter	HBP, n = 75	LBBP, n = 92	p-value
Axillary vein	72 (96.0%)	91 (98.9%)	
Subclavian vein	3 (4.0%)	1 (1.1%)	
CSP lead type			0.003
Lumenless lead	51 (68.0%)	41 (44.6%)	
Stylet-driven lead	24 (32.0%)	51 (55.4%)	
Recorded His/LBB potential	32 (42.7%)	46 (50.0%)	0.355
Lead penetration depth, mm	5 (4–6)	12.4 (10.2–15.0)	Not compared
Table note:			
Values are presented as median (interquartile range) for continuous variables and n (%) for categorical variables. P-values were calculated using the Mann–Whitney U test for continuous variables and the chi-square test, Fisher's exact test, or Fisher–Freeman–Halton test for categorical variables, as appropriate. For categorical variables with more than two categories, p-values represent overall comparisons of category distributions between groups. Selective and non-selective capture were analyzed among patients with successful conduction system pacing implantation. LVAT was reported descriptively only in the LBBP group and was not used as a comparative endpoint between HBP and LBBP. Lead penetration depth was reported descriptively and was not statistically compared because HBP and LBBP involve anatomically distinct implantation strategies. HBP, His bundle pacing; LBBP, left bundle branch pacing; CSP, conduction system pacing; LVAT, left ventricular activation time; LBB, left bundle branch.			

Among patients with successful conduction system pacing implantation, selective capture was more frequent in the HBP group than in the LBBP group [25/70 (35.7%) vs. 13/85 (15.3%); p = 0.005], whereas non-selective capture was more frequent in the LBBP group [72/85 (84.7%) vs. 45/70 (64.3%); p = 0.005].

Procedure time was longer in the LBBP group than in the HBP group [120 (90–122.5) vs. 105 (80–120) minutes; p = 0.024]. Fluoroscopy time was also longer in the LBBP group [786 (408–1220) vs. 540 (330–900) seconds; p = 0.030].

Implant approach characteristics were compared between groups. Most devices were implanted in a left subcutaneous pocket in both groups [73/75 (97.3%) in the HBP group and 86/92 (93.5%) in the LBBP group], with no significant difference in pacemaker pocket location distribution (overall p = 0.465). Axillary venous access was the predominant access route in both groups [72/75 (96.0%) vs. 91/92 (98.9%); overall p = 0.327].

Conduction system pacing lead type differed significantly between groups. Lumenless leads were used more frequently in the HBP group [51/75 (68.0%) vs. 41/92 (44.6%)], whereas stylet-driven leads were used more frequently in the LBBP group [24/75 (32.0%) vs. 51/92 (55.4%); overall p = 0.003]. His or left bundle branch potentials were recorded in 32 patients (42.7%) in the HBP group and 46 patients (50.0%) in the LBBP group (p = 0.355). Lead penetration depth was 5 (4–6) mm in the HBP group and 12.4 (10.2–

15.0) mm in the LBBP group; this parameter was reported descriptively and not statistically compared because the two pacing strategies require anatomically distinct implantation approaches.

Despite longer procedural and fluoroscopy times, LBBP was associated with more favorable acute electrical parameters. Implant capture threshold was lower in the LBBP group than in the HBP group [0.6 (0.45–0.8) vs. 0.8 (0.7–1.0) V at 0.4 ms; $p < 0.001$]. Implant R-wave amplitude was higher in the LBBP group [8.5 (7–11) vs. 5.4 (4–8) mV; $p < 0.001$], and implant lead impedance was also higher [631.5 (550.5–752.5) vs. 571 (480–650) Ω; $p < 0.001$]. Post-implant paced QRS duration was longer in the LBBP group than in the HBP group [109.2 (100–120) vs. 100 (90–110) ms; $p < 0.001$]. The median left ventricular activation time in the LBBP group was 70 (70–77.5) ms.

Longitudinal lead performance

Longitudinal lead performance from implantation to 12 months is summarized in Table 3 and Fig. 2. Device interrogation data were available in 73 patients in the HBP group and 90 patients in the LBBP group at 6 months, and in 72 and 88 patients, respectively, at 12 months.

Table 3
Longitudinal lead performance from implantation to 12 months

Parameter	Time point	HBP	LBBP	p-value
Capture threshold, V at 0.4 ms	Implant	0.8 (0.7–1.0), n = 75	0.6 (0.45–0.8), n = 92	< 0.001
	6 months	0.9 (0.8–1.2), n = 73	0.6 (0.5–0.8), n = 90	< 0.001
	12 months	1.0 (0.8–1.3), n = 72	0.6 (0.5–0.8), n = 88	< 0.001
High capture threshold > 1.0 V	Implant	15/75 (20.0%)	4/92 (4.3%)	< 0.001
	6 months	20/73 (27.4%)	4/90 (4.4%)	< 0.001
	12 months	23/72 (31.9%)	4/88 (4.5%)	< 0.001
R-wave amplitude, mV	Implant	5.4 (4–8), n = 75	8.5 (7–11), n = 92	< 0.001
	6 months	5.2 (4–7.5), n = 73	9.0 (7.5–12), n = 90	< 0.001
	12 months	5.0 (3.8–7.5), n = 72	9.2 (7.5–12), n = 88	< 0.001
Lead impedance, Ω	Implant	571 (480–650), n = 75	631.5 (550.5–752.5), n = 92	< 0.001
	6 months	480 (400–550), n = 73	510 (450–600), n = 90	0.120
	12 months	450 (380–520), n = 72	490 (430–580), n = 88	0.080
Paced QRS duration, ms	Implant	100 (90–110), n = 75	109.2 (100–120), n = 92	< 0.001
	6 months	101 (90–111), n = 73	109.5 (101–120), n = 90	< 0.001
	12 months	102 (91–112), n = 72	110 (101–120), n = 88	< 0.001

Table note:

Values are presented as median (interquartile range) for continuous variables and n (%) for categorical variables. P-values represent between-group comparisons at the corresponding time point using the Mann–Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. High capture threshold was defined as capture threshold > 1.0 V at 0.4 ms. Device interrogation data were available in 75, 73, and 72 patients in the HBP group and in 92, 90, and 88 patients in the LBBP group at implantation, 6 months, and 12 months, respectively. HBP, His bundle pacing; LBBP, left bundle branch pacing.

Compared with HBP, LBBP demonstrated consistently lower capture thresholds at implantation, 6 months, and 12 months. At implantation, the median capture threshold was 0.8 (0.7–1.0) V in the HBP group and 0.6 (0.45–0.8) V in the LBBP group ($p < 0.001$). This difference persisted at 6 months [0.9 (0.8–1.2) vs. 0.6 (0.5–0.8) V; $p < 0.001$] and at 12 months [1.0 (0.8–1.3) vs. 0.6 (0.5–0.8) V; $p < 0.001$].

The proportion of patients with high capture threshold > 1.0 V at 0.4 ms was also significantly lower in the LBBP group throughout follow-up. At implantation, high capture threshold occurred in 15 of 75 patients (20.0%) in the HBP group and 4 of 92 patients (4.3%) in the LBBP group ($p < 0.001$). At 6 months, the corresponding rates were 20 of 73 patients (27.4%) and 4 of 90 patients (4.4%), respectively ($p < 0.001$). At 12 months, high capture threshold was observed in 23 of 72 patients (31.9%) in the HBP group compared with 4 of 88 patients (4.5%) in the LBBP group ($p < 0.001$).

R-wave amplitude remained higher in the LBBP group throughout follow-up. At implantation, R-wave amplitude was 5.4 (4–8) mV in the HBP group and 8.5 (7–11) mV in the LBBP group ($p < 0.001$). At 6 months, R-wave amplitude was 5.2 (4–7.5) mV versus 9.0 (7.5–12) mV ($p < 0.001$), and at 12 months it was 5.0 (3.8–7.5) mV versus 9.2 (7.5–12) mV ($p < 0.001$), respectively.

Lead impedance decreased over time in both groups. Implant lead impedance was higher in the LBBP group than in the HBP group [631.5 (550.5–752.5) vs. 571 (480–650) Ω; $p < 0.001$]. At 6 months and 12 months, lead impedance did not differ significantly between groups [510 (450–600) vs. 480 (400–550) Ω; $p = 0.120$, and 490 (430–580) vs. 450 (380–520) Ω; $p = 0.080$, respectively].

Paced QRS duration remained longer in the LBBP group than in the HBP group at all time points. At implantation, paced QRS duration was 109.2 (100–120) ms in the LBBP group and 100 (90–110) ms in the HBP group ($p < 0.001$). Similar between-group differences were observed at 6 months [109.5 (101–120) vs. 101 (90–111) ms; $p < 0.001$] and 12 months [110 (101–120) vs. 102 (91–112) ms; $p < 0.001$].

Clinical and device-related outcomes

Clinical and device-related outcomes through 12 months are shown in Table 4. Hospital stay was similar between the HBP and LBBP groups [5 (4–7) vs. 5 (4–8) days; $p = 0.815$]. All-cause death before 12 months occurred in 3 patients (4.0%) in the HBP group and 4 patients (4.3%) in the LBBP group ($p > 0.999$). Heart failure hospitalization was infrequent and did not differ significantly between groups [4/75 (5.3%) vs. 3/92 (3.3%); $p = 0.702$].

Table 4
Clinical and device-related outcomes through 12 months

Outcome	HBP, n = 75	LBBP, n = 92	p-value
Hospital stay, days	5 (4–7)	5 (4–8)	0.815
All-cause death before 12 months	3 (4.0%)	4 (4.3%)	> 0.999
Heart failure hospitalization	4 (5.3%)	3 (3.3%)	0.702
Overall complications	7 (9.3%)	9 (9.8%)	0.922
Lead dislodgement	4 (5.3%)	3 (3.3%)	0.702
Septal perforation	0 (0%)	4 (4.3%)	0.128
Pocket infection/hematoma	0 (0%)	0 (0%)	—
Threshold rise requiring management	3 (4.0%)	2 (2.2%)	0.658
Loss of capture	2 (2.7%)	0 (0%)	0.198
Lead revision	5 (6.7%)	3 (3.3%)	0.325
Procedure-related death	0 (0%)	0 (0%)	—
Clinically significant pericardial effusion	0 (0%)	0 (0%)	—

Table note:

Values are presented as median (interquartile range) for hospital stay and n (%) for categorical outcomes. P-values were calculated using the Mann–Whitney U test for hospital stay and the chi-square test or Fisher's exact test for categorical outcomes, as appropriate. Outcomes were assessed in the total cohort from implantation through 12 months. All-cause deaths occurring before the 12-month device visit were recorded as clinical outcomes. HBP, His bundle pacing; LBBP, left bundle branch pacing.

Overall complications were similar between the HBP and LBBP groups [7/75 (9.3%) vs. 9/92 (9.8%); p = 0.922]. Lead dislodgement occurred in 4 patients (5.3%) in the HBP group and 3 patients (3.3%) in the LBBP group (p = 0.702). Septal perforation was observed in 4 patients (4.3%) in the LBBP group and in no patients in the HBP group, although this difference did not reach statistical significance (p = 0.128). No pocket infection or hematoma, procedure-related death, or clinically significant pericardial effusion occurred in either group.

Threshold rise requiring management occurred in 3 patients (4.0%) in the HBP group and 2 patients (2.2%) in the LBBP group (p = 0.658). Loss of capture occurred in 2 patients (2.7%) in the HBP group and in no patients in the LBBP group (p = 0.198). Lead revision was required in 5 patients (6.7%) in the HBP group and 3 patients (3.3%) in the LBBP group (p = 0.325).

Logistic regression and sensitivity analyses

Logistic regression analyses for high capture threshold > 1.0 V at 12 months are shown in Table 5. In the unadjusted analysis, LBBP was associated with substantially lower odds of high capture threshold compared with HBP (OR 0.10; 95% CI, 0.03–0.31; p < 0.001).

Table 5
Logistic regression and sensitivity analyses for high capture threshold > 1.0 V at 12 months

Analysis	OR	95% CI	p-value
Unadjusted LBBP vs. HBP	0.10	0.03–0.31	< 0.001
Model 1: adjusted for age and sex	0.11	0.04–0.34	< 0.001
Model 2: adjusted for age, sex, pacing indication	0.10	0.03–0.33	< 0.001
Model 3: additionally adjusted for baseline rhythm	0.12	0.04–0.38	< 0.001
Model 4: additionally adjusted for CSP lead type	0.14	0.05–0.45	< 0.001
Model 5: additionally adjusted for CFS score	0.15	0.05–0.48	< 0.001

Table note:

The dependent variable was high capture threshold > 1.0 V at 0.4 ms at 12 months. Analyses were performed among patients who survived to the 12-month device visit and had available device interrogation data. Model 1 was adjusted for age and sex. Model 2 was adjusted for age, sex, and pacing indication. Model 3 was additionally adjusted for baseline rhythm. Model 4 was additionally adjusted for CSP lead type. Model 5 was additionally adjusted for Clinical Frailty Scale score. OR < 1 favors LBBP. CFS, Clinical Frailty Scale; CSP, conduction system pacing; HBP, His bundle pacing; LBBP, left bundle branch pacing; OR, odds ratio; CI, confidence interval.

This association remained robust across sequentially adjusted models. After adjustment for age and sex, the association remained significant (OR 0.11; 95% CI, 0.04–0.34; p < 0.001). Additional adjustment for pacing indication yielded similar results (OR 0.10; 95% CI, 0.03–0.33; p < 0.001). After further adjustment for baseline rhythm, the association remained significant (OR 0.12; 95% CI, 0.04–0.38; p < 0.001).

In sensitivity models, LBBP remained associated with lower odds of high capture threshold after additional adjustment for conduction system pacing lead type (OR 0.14; 95% CI, 0.05–0.45; p < 0.001) and after further adjustment for CFS score (OR 0.15; 95% CI, 0.05–0.48; p < 0.001).

Exploratory longitudinal clinical and biomarker changes

Exploratory longitudinal changes in NYHA functional class and NT-proBNP levels are shown in Supplementary Table 1. Baseline NYHA functional class was similar between groups. At 6 and 12 months, NYHA functional class was numerically lower in the LBBP group than in the HBP group. Baseline NT-proBNP levels were comparable between groups, and NT-proBNP levels decreased during follow-up in both groups. At 12 months, NT-proBNP was lower in the LBBP group than in the HBP group. These exploratory findings should be interpreted cautiously because functional status and natriuretic peptide levels may be influenced by comorbidities, medical therapy, pacing burden, and survival status.

DISCUSSION

Principal findings

In this retrospective cohort study of older patients with symptomatic bradyarrhythmias undergoing conduction system pacing, LBBP was associated with more favorable and stable electrical lead performance through 12 months compared with HBP. Procedural success was similar between groups, whereas LBBP demonstrated lower capture thresholds, higher R-wave amplitudes, and a markedly lower proportion of patients with high capture threshold at 12 months. Importantly, the association between LBBP and lower odds of high capture threshold persisted after adjustment for age, sex, pacing indication, baseline rhythm, conduction system pacing lead type, and CFS score.

Clinical outcomes and overall complications were similar between groups. However, the present study was not powered to detect differences in mortality, heart failure hospitalization, or rare device-related complications. Therefore, the findings should primarily be interpreted as evidence of more favorable electrical lead performance with LBBP in older patients, rather than as definitive evidence of superiority for clinical outcomes.

Comparison with previous studies

The findings of this study are consistent with previous reports suggesting that LBBP or left bundle branch area pacing may provide more favorable pacing parameters than HBP. Prior studies have shown that HBP can achieve physiological ventricular activation but may be limited by higher capture thresholds, lower R-wave amplitudes, and threshold instability during follow-up [4, 5]. These limitations may affect programming flexibility, battery longevity, and the need for closer device surveillance.

In contrast, LBBP targets the left bundle branch region within the interventricular septum and provides a broader anatomical target than HBP. This may explain the lower and more stable capture thresholds and higher R-wave amplitudes observed in this and previous studies [6–10]. In the present cohort, median capture threshold in the LBBP group remained stable at 0.6 V from implantation to 12 months, whereas the HBP group showed a gradual increase from 0.8 V at implantation to 1.0 V at 12 months. The proportion of patients with high capture threshold > 1.0 V at 12 months was also substantially lower with LBBP.

However, LBBP was associated with longer procedure and fluoroscopy times in this cohort. This likely reflects the technical requirements of deep septal lead deployment, confirmation of left bundle branch capture, and operator decision-making during the learning curve. Although septal perforation occurred only in the LBBP group, the difference was not statistically significant, and no clinically significant pericardial effusion or procedure-related death was observed. These findings highlight the need to balance electrical advantages with procedural complexity when selecting a conduction system pacing strategy.

Clinical relevance in older patients

The clinical relevance of stable lead performance may be particularly important in older patients. Older adults requiring permanent pacing frequently have multimorbidity, polypharmacy, frailty, limited physiological reserve, and a higher burden of follow-up care. In such patients, a pacing strategy associated with low and stable capture thresholds may allow greater programming flexibility and may reduce concerns regarding premature battery depletion, frequent reprogramming, or reintervention.

This geriatric context is important because chronological age alone may not adequately capture clinical vulnerability. Frailty reflects reduced physiological reserve and may influence procedural tolerance, recovery, and outcomes in older adults [13]. In the present study, frailty burden was well balanced between groups, with similar median CFS scores and similar distributions of CFS categories. More than one-third of patients in both groups met the definition of frailty using CFS ≥ 5, underscoring the clinical vulnerability of this population.

Importantly, the association between LBBP and lower odds of high capture threshold remained robust after adjustment for CFS score. This suggests that the observed difference in electrical lead performance was unlikely to be explained by baseline frailty imbalance. From a practical standpoint, these findings support LBBP as an electrically stable conduction system pacing strategy in older patients, including those with measurable frailty burden.

Interpretation of clinical and biomarker findings

Clinical outcomes, including all-cause death, heart failure hospitalization, and overall complications, were similar between groups through 12 months. These findings are reassuring but should be interpreted cautiously. The number of clinical events was small, and the study was not designed or powered to detect modest differences in clinical outcomes.

NYHA functional class and NT-proBNP were analyzed as exploratory longitudinal variables. Although the LBBP group showed numerically more favorable values at follow-up, these outcomes may be influenced by multiple factors, including comorbidities, medical therapy, pacing burden, baseline cardiac status, and survival. Therefore, no causal inference should be made regarding the effect of pacing modality on functional status or biomarker improvement. Larger prospective studies with standardized echocardiographic and clinical follow-up are needed to clarify whether the electrical advantages of LBBP translate into better patient-centered outcomes in older adults.

Strengths

The strengths of this study include its focus on an older bradyarrhythmia population, direct comparison of HBP and LBBP, systematic reporting of longitudinal device parameters at three clinically relevant time points, and complete clinical follow-up. The 12-month device interrogation rate among survivors was 100%, allowing robust assessment of lead performance in patients who remained alive to the 12-month visit.

In addition, the study incorporated frailty assessment using the Clinical Frailty Scale, allowing better characterization of the older population beyond chronological age alone. The analysis also accounted for baseline rhythm imbalance, conduction system pacing lead type, and CFS score in sensitivity models, supporting the robustness of the primary result.

Limitations

This study has several limitations. First, it was a retrospective observational study, and treatment allocation was not randomized. Therefore, selection bias and residual confounding remain possible despite adjustment. Second, the study was conducted at a single center, which may limit generalizability to other institutions with different operator experience or implantation protocols. Third, the sample size was modest, and the number of clinical events was limited; therefore, the study was not powered to detect differences in mortality, heart failure hospitalization, or rare complications.

Fourth, although baseline rhythm, conduction system pacing lead type, and CFS score were adjusted for in regression analyses, other potential confounders such as detailed anatomical factors, pacing burden, and operator learning curve may not have been fully captured. Fifth, frailty was assessed using the Clinical Frailty Scale and incorporated into a sensitivity model, but retrospective frailty assessment may be subject to misclassification. In addition, the study was not powered to evaluate whether frailty modified the association between pacing modality and clinical outcomes.

Sixth, echocardiographic follow-up was not systematically available, limiting assessment of ventricular remodeling or pacing-induced cardiomyopathy. Seventh, NYHA class and NT-proBNP were analyzed as exploratory longitudinal clinical and biomarker variables. Because these outcomes may be influenced by comorbidities, medical therapy, pacing burden, and survival status, no causal inference should be made regarding the effect of pacing modality on functional status or NT-proBNP levels. Finally, longer follow-up is needed to determine whether the observed differences in threshold stability translate into improved battery longevity, fewer reinterventions, or better clinical outcomes.

CONCLUSION

In older patients with symptomatic bradyarrhythmias undergoing conduction system pacing, LBBP achieved procedural success comparable to HBP but demonstrated more favorable and stable electrical lead performance through 12 months. LBBP was associated with lower capture thresholds, higher R-wave amplitudes, and substantially lower odds of high capture threshold at 12 months, even after adjustment for age, sex, pacing indication, baseline rhythm, lead type, and Clinical Frailty Scale score. Clinical outcomes and overall complications were similar between groups. These findings support LBBP as a practical and electrically stable conduction system pacing strategy in older patients, including those with frailty burden, while prospective multicenter studies with longer follow-up are needed to confirm its long-term clinical benefits.

Abbreviations

AV
atrioventricular
BMI
body mass index
CFS
Clinical Frailty Scale
CI
confidence interval
CSP
conduction system pacing
ECG
electrocardiographic
eGFR
estimated glomerular filtration rate
HBP
His bundle pacing
IVCD
intraventricular conduction delay
LBBB
left bundle branch block
LBBP
left bundle branch pacing
LVAT
left ventricular activation time
LVEF
left ventricular ejection fraction
NT-proBNP
N-terminal pro–B-type natriuretic peptide
NYHA
New York Heart Association
OR
odds ratio
RBBB
right bundle branch block

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Medicine and Pharmacy at Ho Chi Minh City (Approval No. 3732/DHYD-HDDD, September 17, 2025). The requirement for written informed consent was waived because of the retrospective nature of the study and the use of anonymized data.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are not publicly available due to institutional and patient privacy restrictions but are available from the corresponding author on reasonable request and with permission from the relevant institutional review board.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Minh Nguyen Quang: Conceptualization; writing – review and editing

Dung Kieu Ngoc: Supervision; visualization; writing – review and editing

Phuong Tran Le Uyen: Methodology; validation; writing – review and editing

Thuc Nguyen Tri: Data curation; investigation; writing – original draft

Tan Nguyen Van: Investigation; data curation; writing – review and editing

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Authors' information

Not applicable.

Use of generative artificial intelligence

During manuscript preparation, the authors used a generative artificial intelligence tool to assist with language editing and formatting. The authors reviewed, edited, and approved all content and take full responsibility for the integrity and accuracy of the manuscript.

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Figures

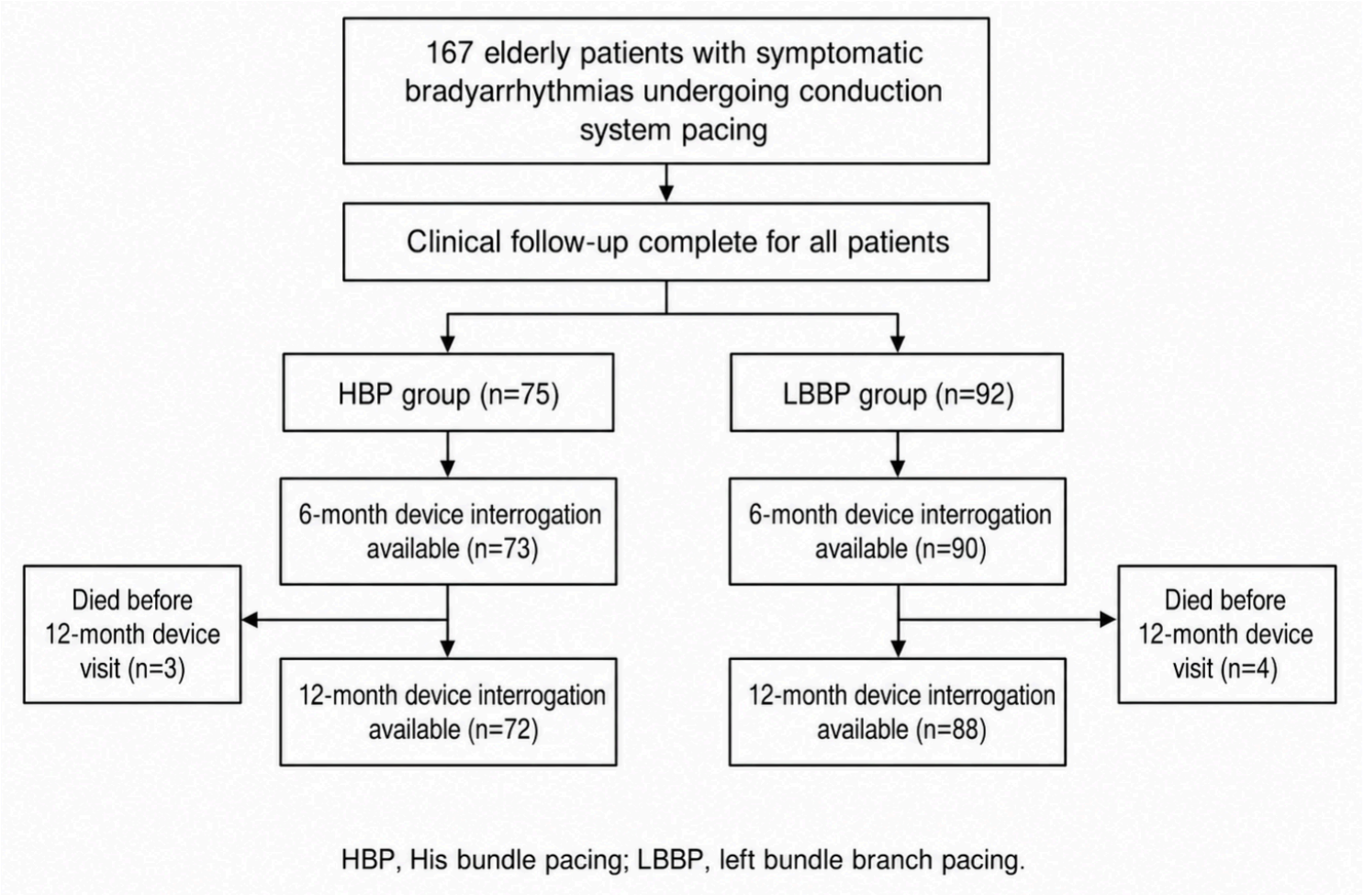


Figure 1

Study flow diagram

A total of 167 older patients with symptomatic bradyarrhythmias undergoing conduction system pacing were included, comprising 75 patients in the His bundle pacing group and 92 patients in the left bundle branch pacing group. Clinical follow-up was complete for all patients. Three patients in the His bundle pacing group and four patients in the left bundle branch pacing group died before the 12-month device visit. Device interrogation data were available in 73 and 90 patients at 6 months and in 72 and 88

patients at 12 months in the His bundle pacing and left bundle branch pacing groups, respectively. HBP, His bundle pacing; LBBP, left bundle branch pacing.

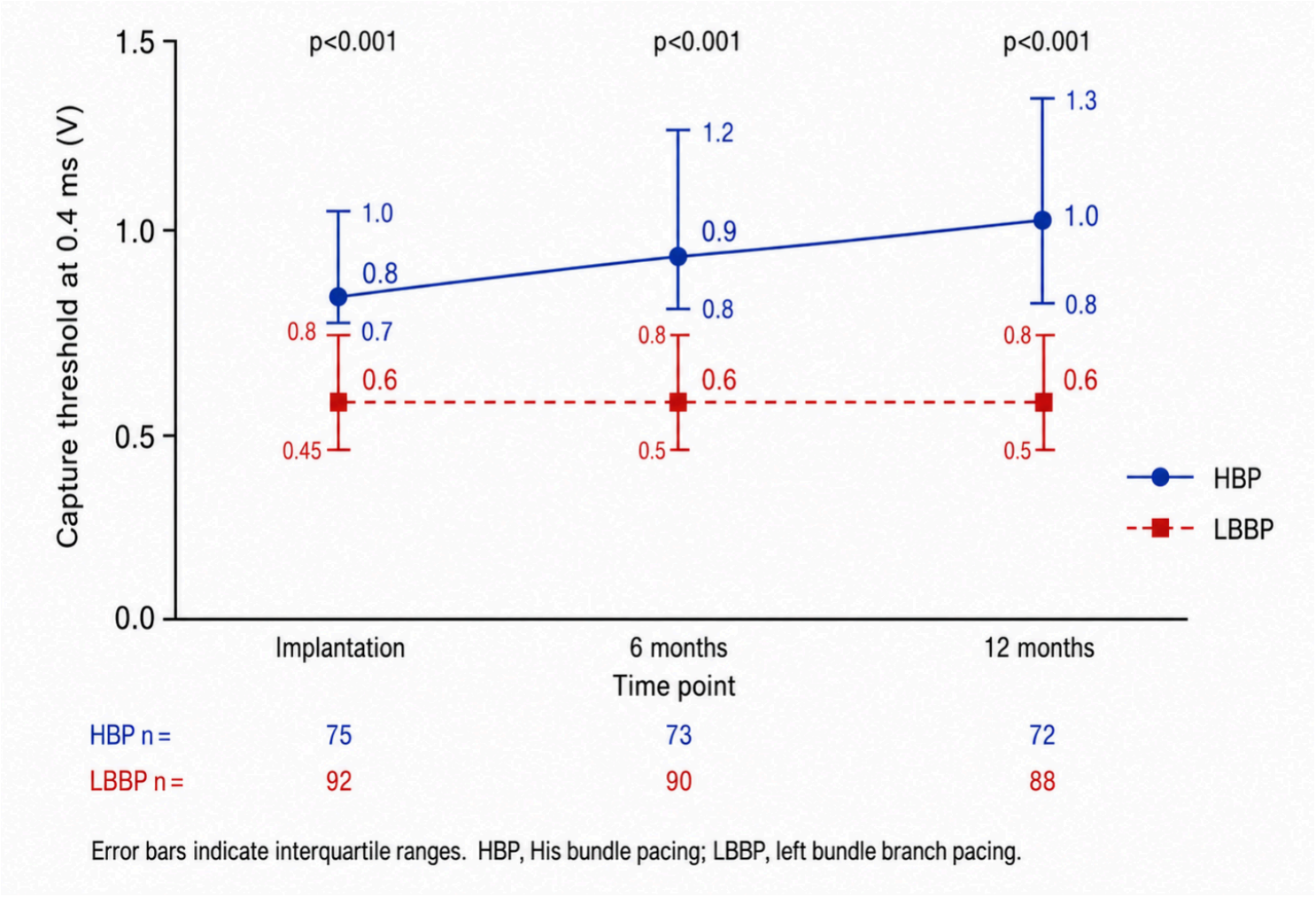


Figure 2

Longitudinal capture threshold

Median capture threshold at 0.4 ms was consistently lower in the left bundle branch pacing group than in the His bundle pacing group at implantation, 6 months, and 12 months. In the His bundle pacing group, median capture threshold increased from 0.8 (0.7–1.0) V at implantation to 0.9 (0.8–1.2) V at 6 months and 1.0 (0.8–1.3) V at 12 months. In contrast, median capture threshold in the left bundle branch pacing group remained stable at 0.6 V across all three time points. Error bars indicate interquartile ranges. Between-group comparisons at each time point were performed using the Mann–Whitney U test. HBP, His bundle pacing; LBBP, left bundle branch pacing.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

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