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Left ventricular ejection fraction is a determinant of cardiac performance after long-term conduction system pacing in patients with left bundle branch block?

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Abstract

Objective This study aims to explore the feasibility, safety, and clinical performance of conduction system pacing (CSP) in patients with left bundle branch block (LBBB) and varying left ventricular ejection fraction (LVEF) values.

Methods We consecutively enrolled all patients with LVEF ≤ 35% and LBBB who met the criteria for cardiac resynchronization therapy (CRT) and underwent CSP from January 2018 to December 2021. We compared the differences in improvements in cardiac performance after CSP between patients with LVEF < 25% and those with LVEF between 25 to 35%.

Results CSP was successfully deployed in 74 out of 80 patients (92.50%), including 32 patients with LVEF < 25% and 42 patients with LVEF 25%-35%. The CSP response rates were similar between the two groups (71.90% vs. 90.50%, $P=0.076$), as were the super-response rates (62.50% vs. 78.60%, $P=0.129$) and the rates of left ventricular complete reverse remodeling (21.90% vs. 42.90%, $P=0.059$) after a follow-up period of 40.81 ± 11.93 months. Significant improvements were observed in LVEF (20.50 ± 2.75% vs. 37.78 ± 13.04%, $P<0.001$), left ventricular end-diastolic dimension (LVEDD) (69.56 ± 6.77 mm vs. 59.41 ± 11.00 mm, $P<0.001$), left ventricular end-systolic volume (LVESV) (224.81 ± 50.65 ml vs. 134.00 ± 83.35 ml, $P<0.001$), NYHA class (3.59 ± 0.48 vs. 1.78 ± 0.66, $P<0.001$), and QRS duration (168.75 ± 21.52 ms vs. 117.81 ± 17.09 ms, $P<0.001$) in patients with LVEF < 25%. Despite these improvements, the final LVEF (37.78 ± 13.04 vs. 46.19 ± 9.47, $P=0.003$) and final LVESV (134.00 ± 83.35 vs. 70.89 ± 38.89, $P=0.001$) after CSP were inferior in patients with LVEF < 25%, and the rate of rehospitalization for heart failure was higher in this group (46.90% vs. 21.40%, $P=0.021$) compared to those with LVEF between 25 to 35%.

Conclusions CSP is feasible and safe for improving clinical outcomes in patients with LVEF < 25%. Timely CSP intervention in patients with LBBB and HF may be beneficial for cardiac performance.

Keywords Conduction system pacing, Left bundle branch block, Heart failure, Left ventricular ejection fraction, Long term follow-up

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Introduction

Patients with heart failure (HF) and significantly reduced left ventricular ejection fraction (LVEF) have become more prevalent [1]. Many of these patients experience higher rates of rehospitalization and mortality associated with end-stage HF. Biventricular pacing (BiVP) has been shown to reduce mortality and improve cardiac performance in patients with HF and left bundle branch block (LBBB) [2, 3]. However, individual outcomes vary substantially, with more than one-third of patients not responding to BiVP [4]. It had been reported that BiVP was beneficial for patients with LBBB and severely reduced LVEF, but challenges such as prolonged procedure duration, acute perioperative heart failure, and complications were particularly significant for those with severe heart failure. Although many CRT-BVP studies included patients with LVEF of 20–25%, data focusing on the feasibility, safety, and clinical outcomes of BiVP in patients with LVEF < 25% and LBBB were very limited [5–7].

Conduction system pacing (CSP), which includes His bundle pacing (HBP) and left bundle branch pacing (LBBP), had been proven to be a feasible alternative to BiVP [8–12]. CSP represented a promising pacing modality for patients with HF and LBBB due to its favorable response rates and procedural tolerance [11, 13, 14]. However, the long-term benefits of CSP in patients with severe cardiac dysfunction remained unknown [15]. This study aims to explore the feasibility, safety, and clinical outcomes of conduction system pacing (CSP) in patients with left bundle branch block (LBBB) and varying LVEF values.

Methods

Study population

Patients with LBBB and left ventricular ejection fraction (LVEF) ≤ 35% who underwent CSP from January 2018 to December 2021 were consecutively enrolled at our center. LBBP was considered an alternative therapy when His bundle pacing (HBP) failed. In cases where CSP was unsuccessful, the left ventricular (LV) lead was implanted using a consecutive coronary venous approach. The hospital's ethics committee approved the study. Clinical outcomes were compared between patients with LVEF < 25% and those with LVEF between 25 and 35%. All patients received guideline-directed optimized medical therapy for at least three months prior to the procedure.

Implant procedure

The procedure utilized the Select Secure lead (3830–69 cm, Medtronic, Minneapolis, Minnesota, USA) [16, 17]. The unipolar-paced QRS configuration and pacing impedance were continuously monitored. His bundle electrograms and left bundle branch electrograms were recorded in a unipolar configuration using the Prucka Cardiolab system (GE Healthcare, Waukesha, WI, USA). Additionally, the unipolar configuration and pacing impedance were monitored alongside the left ventricular activation time (LVAT).

Patients follow-up

All patients were followed up regularly after the procedure at one month, three months, and every six months thereafter. Data collected included 12-lead electrocardiograms (ECG), six-minute walk distance (6MWD), echocardiography (assessing LVEF, left ventricular end-diastolic diameter (LVEDD), and left ventricular end-systolic volume (LVESV)), and pacemaker parameters. Adverse events such as thromboembolism, infection, stroke, rehospitalization due to HF, or death were recorded. Furthermore, pacemaker-related complications were documented, including a significant increase in capture threshold (defined as an increase of more than 2 V/0.4 ms after implantation or more than 5 V/0.4 ms at any visit), lead dislodgement, and cardiac perforation.

Criteria and definition

LBBB was defined according to the Strauss criteria [18]. Response to CSP was characterized by a decrease in LVESV of ≥ 15% or an increase in LVEF ≥ 5% with an increase in 6-MWD of ≥ 25% or an improvement in NYHA class ≥ 1 or NHYA class I at last follow-up. Super-response to CSP was defined as a reduction in LVESV of ≥ 30% or a ≥ 15% improvement in the LVEF accompanied by clinical improvements after six months of follow-up [19–21]. An LVEF greater than 50% and an LVEDD less than 50 mm were considered as complete reverse remodeling of the left ventricle [16]. HBP was deemed acceptable when the correcting threshold was lower than 3.0 V/0.4 ms in patients exhibiting acceptable His–ventricular conduction. LBBP was defined as pacing with a stim-left ventricular active time (S-LVAT) of less than 85 ms in lead V_5, a sudden drop in LVAT greater than 10 ms, and the presence of Qr, qR, or rSR' morphologies in lead V_1.

Statistical analysis

Data analysis was conducted using SPSS 26.0 (SPSS Inc., Chicago, USA). Continuous variables with a normal distribution were expressed as the mean ± standard deviation, and *t*-tests were performed. Continuous variables without a normal distribution were represented by the median (P_{25}, P_{75}), and nonparametric tests were employed. Categorical data were expressed as n (%), and the chi-square test was utilized. Independent predictors of complete reverse remodeling of the left ventricle after

CSP were identified through univariate and multivariate logistic regression analysis. A two-tailed P value of ≤ 0.05 was considered statistically significant.

Results

Baseline characteristics of the study population

Eighty patients were enrolled in this study, with CSP successfully deployed in 74 (92.50%) patients, comprising 60 patients with HBP and 14 patients with LBBP. Among these, thirty-two patients (mean age 67.59 ± 9.05 years, 56.3% male) had LVEF < 25%, including 25 patients with HBP and 7 patients with LBBP (Fig. 1). The average follow-up duration was 40.81 ± 11.93 months. No complications such as thrombosis, infection, lead dislodgement, perforation, or stroke were detected during the follow-up period.

During the follow-up period, a total of 24 patients (24/74, 32.40%) were re-hospitalized. The rate of re-hospitalization for HF among patients with a LVEF of less than 25% was significantly higher than that of patients with an LVEF between 25 and 35% (46.90% vs. 21.40%, $P=0.021$). Notably, no patients in the study died. There were no significant differences observed in terms of sex, age, comorbidities, duration of HF, or QRS duration among all patients (all $P>0.05$). Baseline measurements revealed statistically significant differences between the two groups in terms of B-type natriuretic peptide (BNP) levels ($P<0.001$), LVEF ($P<0.001$), (LVEDD ($P<0.001$), LVESV ($P<0.001$) and digoxin usage ($P=0.006$), as detailed in Table 1.

Lead outcomes following conduction system pacing

The threshold for correcting LBBB was measured at 1.55 ± 0.90 V@0.4 ms during the procedure, with no significant increase observed during the follow-up period (1.55 ± 0.90 V@0.4 ms vs. 1.60 ± 0.89 V@0.4 ms, $P=0.544$) (Supplementary Fig. 1A). Both the initial correcting threshold ($P=0.003$) and the final correcting threshold ($P=0.013$) were significantly lower in the LBBP group compared to the HBP group. Impedance measurements showed no significant difference one-month post-operation compared to the last follow-up (415.64 ± 105.95 Ω vs. 412.76 ± 109.48 Ω, $P=0.648$) (Supplementary Fig. 1B). An increase in the correcting threshold greater than 1 V @ 0.4 ms was observed in 3 (including 2 in HBP and 1 in LBBP) out of 74 patients (4.05%,), and lead resets were performed in two of these cases due to correcting thresholds exceeding 5 V@0.4 ms. No instances of lead dislodgment, breakage, or infection were reported during the follow-up period. Detailed lead outcomes are presented in Supplementary Table 1.

Cardiac performance after CSP

Significant improvements were observed in LVEF (25.15 ± 5.26% vs. 42.55 ± 11.84%, $P<0.001$), LVEDD (65.81 ± 8.04 mm vs. 56.26 ± 9.63 mm, $P<0.001$), LVESV (196.87 ± 58.03 ml vs. 103.02 ± 72.22 ml, $P<0.001$), and QRS duration (165.78 ± 19.73 ms vs. 113.16 ± 18.64 ms, $P<0.001$) (as shown in Table 2) after CSP. Additionally, NYHA class (3.50 ± 0.52 vs. 1.55 ± 0.62, $P<0.001$) and 6-MWD (140.41 ± 18.09 m vs. 373.51 ± 119.22 m,

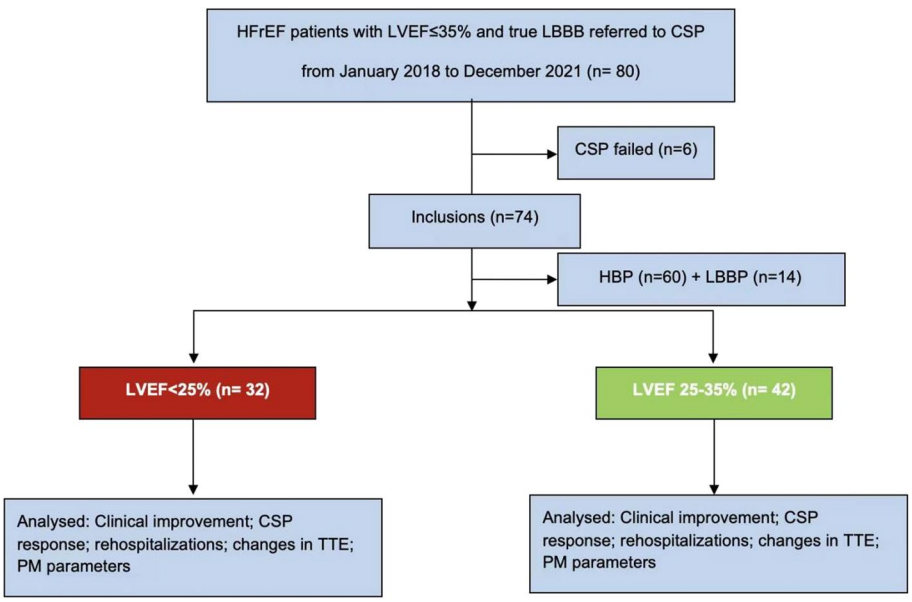

Fig. 1 Flow chart of patients' screen for inclusion

Table 1 Baseline characteristics in patients with different LVEF

	Total ($n=74$)	LVEF < 25%($n=32$)	LVEF25-35%($n=42$)	*P*
Age (years)	68.88 ± 8.60	67.59 ± 9.05	69.86 ± 8.22	0.265
Male, *n* (%)	37 (50.00%)	18 (56.30%)	19 (45.20%)	0.348
NYHA Class	3.50 ± 0.52	3.59 ± 0.48	3.43 ± 0.55	0.180
6-MWD (m)	140.41 ± 18.09	137.81 ± 15.40	142.38 ± 19.85	0.269
BNP (pg/mL)	731.61[333.99,1819.76]	1663.33[798.05,2715.18]	428.76[198.64, 711.41]	< 0.001
HF duration (months)	43 [14, 91]	67 [18, 112]	31 [13, 79]	0.200
QRS duration (ms)	165.78 ± 19.73	168.75 ± 21.52	163.52 ± 18.19	0.262
LVEF (%)	25.15 ± 5.26	20.50 ± 2.75	28.69 ± 3.73	< 0.001
LVEDD (mm)	65.81 ± 8.04	69.56 ± 6.77	62.95 ± 7.82	< 0.001
LVESV (mL)	196.87 ± 58.03	224.81 ± 50.65	170.93 ± 52.77	< 0.001
NVM, *n* (%)	3 (4.10%)	2 (6.30%)	1 (2.40%)	0.809
HCM, *n* (%)	1 (1.40%)	1 (3.10%)	0 (0.00%)	0.432
ICM, *n* (%)	18 (24.30%)	9 (28.10%)	9 (21.40%)	0.506
Hypertension, *n* (%)	11 (14.90%)	3 (9.40%)	8(19.00%)	0.407
DM, *n* (%)	23 (31.10%)	10(31.30%)	13 (31.00%)	0.978
DCM, *n* (%)	31 (41.90%)	13 (40.60%)	18 (42.90%)	0.847
CKD, *n* (%)	5 (6.80%)	4 (12.50%)	1 (2.40%)	0.211
ARNI/ACEI/ARB, n (%)	72 (97.30%)	32 (100.00%)	40 (95.20%)	0.502
β-blockers, n (%)	72 (97.30%)	32 (100.00%)	40 (95.20%)	0.502
Spirolactone, n (%)	73 (98.60%)	32 (100.00%)	41 (97.60%)	1.000
SGLT-2i, n (%)	12 (16.20%)	7 (21.90%)	5 (11.90%)	0.249
Diuretics, n (%)	72 (97.30%)	32 (100.00%)	40 (95.20%)	0.502
Antiplatelet drug, n (%)	28 (37.80%)	12 (37.50%)	16 (38.10%)	0.958
Nitrates, n (%)	34 (45.90%)	13 (40.60%)	21 (50.00%)	0.423
Statins, n (%)	39 (52.70%)	15 (46.90%)	24 (57.10%)	0.381
Digoxin, n (%)	47 (63.50%)	26 (81.30%)	21 (50.00%)	0.006

NVM Noncompaction of ventricular myocardium, *HCM* Hypertrophic cardiomyopathy, *ICM* Ischemic cardiomyopathy, *DM* Diabetes mellitus, *DCM* Dilated cardiomyopathy, *CKD* Chronic kidney disease, *NYHA* New York Heart Association, *6-MWD* 6-min walk distance, *BNP* Brain natriuretic peptide, *LVEF* Left ventricular ejection fraction, *LVEDD* Left ventricular end-diastolic diameter, *LVESV* Left ventricular end-systolic volume, *ARNI* Angiotensin receptor-neprilysin inhibitors, *ACEI* Angiotensin-converting enzyme inhibitors, *ARB* Angiotensin receptor blockers, *SGLT-2i* Sodium-dependent glucose transporters-2 inhibitors

$P<0.001$) also demonstrated significant improvement. All details are presented in Table 2.

In patients with LVEF < 25%, significant improvements were noted in LVEF (20.50 ± 2.75% vs. 37.78 ± 13.04%, $P<0.001$), LVEDD (69.56 ± 6.77 mm vs. 59.41 ± 11.00 mm, $P<0.001$), LVESV (224.81 ± 50.65 ml vs. 134.00 ± 83.35 ml, $P<0.001$), and QRS duration (168.75 ± 21.52 ms vs. 117.81 ± 17.09 ms, $P<0.001$) (as illustrated in Fig. 2). Furthermore, NYHA class (3.59 ± 0.48 vs. 1.78 ± 0.66, $P<0.001$) and 6-MWD (137.81 ± 15.40 m vs. 324.06 ± 128.34 m, $P<0.001$) also showed significant improvement.

Clinical outcomes between patients with different LVEF

The super-response ratio (62.50% vs. 78.60%, $P=0.129$), response ratio (71.90% vs. 90.50%, $P=0.076$), and the rate of LV complete reverse remodeling (21.90% vs. 42.90%, $P=0.059$) were similar in patients with LVEF < 25% and those with LVEF 25–35%. A total of 25 patients (33.80%) achieved the criteria of LV complete reverse remodeling, including 7 patients (21.90%) with LVEF < 25% and 18 patients (42.90%) with LVEF 25–35%, with no significant difference detected between the two groups ($P=0.059$). Although the improvements magnitude in LVEF (17.28 ± 13.26% vs. 17.50 ± 9.20%, P = 0.937), LVEDD (10.16 ± 9.46 mm vs. 9.10 ± 6.41 mm, $P=0.587$), LVESV (94.38 ± 62.19 ml vs. 97.74 ± 46.54 ml, $P=0.825$), and QRS duration (50.94 ± 26.91 ms vs. 53.90 ± 19.86 ms, $P=0.587$) were not significantly different between the two groups, the final 6-MWD (324.06 ± 128.34 m vs. 411.19 ± 97.41 m, $P=0.002$), NYHA class (1.78 ± 0.66 vs. 1.38 ± 0.54, $P=0.005$), LVEF (37.78 ± 13.04% vs. 46.19 ± 9.47%, $P=0.003$), LVESV (134.00 ± 83.35 ml vs. 70.89 ± 38.89 ml, $P=0.001$), and LVEDD (59.41 ± 11.00 mm vs. 53.86 ± 7.75 mm, $P=0.019$), and the re-hospitalization (46.90% vs. 21.40%, $P=0.021$) in patients with LVEF < 25% were inferior to those in patients with LVEF 25–35% after follow-up (Table 2). The super-response ratio (71.40%

Table 2 Clinical outcomes in patients with different LVEF value

	Total ($n=74$)	LVEF < 25% ($n=32$)	LVEF25-35% ($n=42$)	*P*
Initial QRSd (ms)	165.78 ± 19.73	168.75 ± 21.52	163.52 ± 18.19	0.262
Final QRSd (ms)	113.16 ± 18.64	117.81 ± 17.09	109.62 ± 19.19	0.061
Initial NYHA Class	3.50 ± 0.52	3.59 ± 0.48	3.43 ± 0.55	0.180
Final NYHA Class	1.55 ± 0.62	1.78 ± 0.66	1.38 ± 0.54	0.005
Initial 6-MWD (m)	140.41 ± 18.09	137.81 ± 15.40	142.38 ± 19.85	0.269
Final 6-MWD (m)	373.51 ± 119.22	324.06 ± 128.34	411.19 ± 97.41	0.002
Initial LVEF (%)	25.15 ± 5.26	20.50 ± 2.75	28.69 ± 3.73	< 0.001
Final LVEF (%)	42.55 ± 11.84	37.78 ± 13.04	46.19 ± 9.47	0.003
Initial LVEDD (mm)	65.81 ± 8.04	69.56 ± 6.77	62.95 ± 7.82	< 0.001
Final LVEDD (mm)	56.26 ± 9.63	59.41 ± 11.00	53.86 ± 7.75	0.019
Initial LVESV (mL)	196.87 ± 58.03	224.81 ± 50.65	170.93 ± 52.77	< 0.001
Final LVESV (mL)	103.02 ± 72.22	134.00 ± 83.35	70.89 ± 38.89	0.001
Response ratio, *n* (%)	61 (82.40%)	23 (71.90%)	38 (90.50%)	0.076
Super-response ratio, *n* (%)	53 (71.60%)	20 (62.50%)	33 (78.60%)	0.129
LV complete reverse remodeling, *n* (%)	25 (33.80%)	7 (21.90%)	18(42.90%)	0.059
Re-hospitalization, *n* (%)	24(32.40%)	15(46.90%)	9(21.40%)	0.021

NYHA New York Heart Association, *6-MWD* 6-min walk distance, *LVEF* Left ventricular ejection fraction, *LVEDD* Left ventricular end-diastolic diameter, *LVESV* Left ventricular end-systolic volume

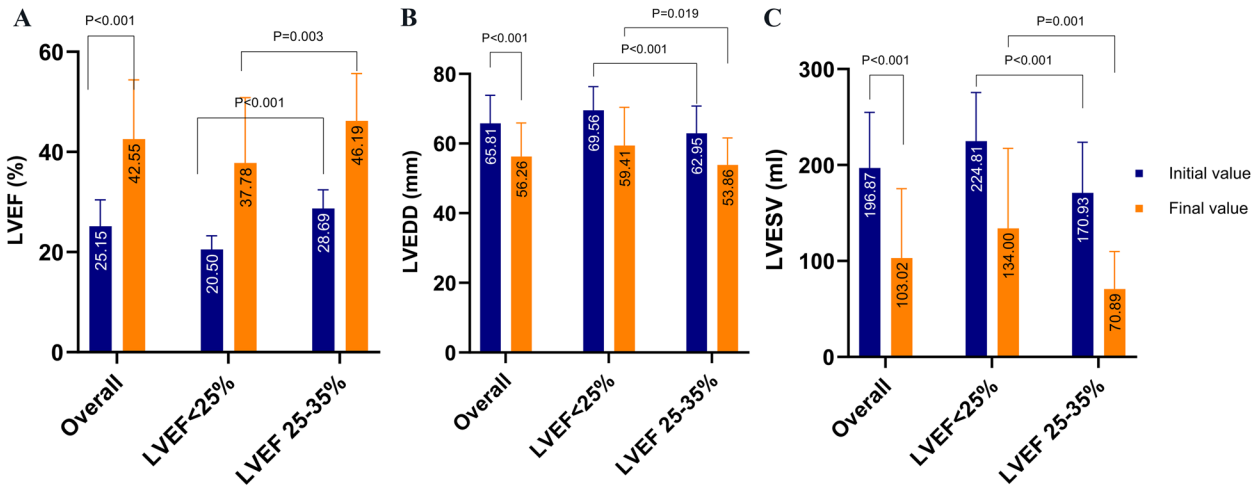

Fig. 2 Improvement of cardiac performance after CSP

vs. 71.70%, $P=1.000$), response ratio (85.70% vs. 81.70%, $P=1.000$), and the LV complete reverse remodeling ratio (21.40% vs. 36.70%, $P=0.440$) were similar in LBBP and HBP.

In terms of predictors of LV complete reverse remodeling, univariate logistic regression analysis indicated that digoxin ($P=0.004$), LVESV ($P=0.001$), and LVEDD ($P=0.006$) prior to CSP were associated with LV complete reverse remodeling. Further multivariate logistic regression analysis revealed that LVESV prior to CSP (OR 0.977, 95% CI 0.961–0.994, $P=0.007$) was an independent predictor of LV complete reverse remodeling in patients with LBBB and HF, with a cutoff value of 106.5 mL and an area under the curve (AUC) of 0.858, demonstrating a sensitivity of 94.10% and specificity of 73.00%. The results are presented in Supplementary Table 2.

Discussion

This study is the first to demonstrate that improvements in LVEF, LVESV and NYHA class were comparable in patients with LBBB and severely reduced LVEF (< 25%)

when compared to those with LVEF between 25 and 35% after CSP. However, the final LVEF and LVESV were inferior in patients with LVEF < 25%.

Safety of CSP in patients with severe cardiac dysfunction

Patients with severely depressed LVEF presented significant challenges during BiVP due to severe symptoms, prolonged procedure duration, perioperative acute heart dysfunction, and complications related to the operation. Several prognostic models, incorporating multiple risk factors, have been developed to predict response to CRT [22]. The well-established EAARN (Ejection fraction, Age, Atrial fibrillation, Renal dysfunction, NYHA class IV) score indicates that an LVEF < 22% predicts mortality during BiVP [23]. Although Rickard et al. reported no procedure-related deaths in patients with very low LVEF (less than 15%) during the BiVP procedure, a machine learning-based score for predicting all-cause mortality in CRT patients identified LVEF as a significant predictor of all-cause death [22, 24].

CSP demonstrated a shorter procedure duration compared to BiVP, which is advantageous for improving operational tolerance and reducing the risk of complications [11, 25]. In this study, complications such as thrombosis, infection, lead dislodgement, and perforation were not observed in patients with LVEF < 25%. The pacing thresholds remained stable during follow-up, with only two patients requiring electrode replacement post-operation. The high success rate (92.50%) and low thresholds may be attributed to the distal HBP and proximal LBBP [26]. Thus, the safety of CSP has been established in patients with significantly reduced ejection fraction.

Feasibility of CSP in patients with severe cardiac dysfunction

Several studies have demonstrated that CSP serves as an effective alternative to BiVP. Additionally, numerous investigations have confirmed that HBP is superior to BiVP in enhancing ventricular electrical synchronization; however, the failure of the HBP procedure remains a significant concern [27, 28]. Abdelrahman et al. reported that only 4.2% of patients (14 out of 332) required lead replacement in BiVP [29]. In contrast, approximately 20% of patients with BiVP were found to have leads in suboptimal positions, which could potentially impair cardiac performance [30].

The LBBP-RESYNC trial indicated a more substantial improvement in LVEF with CSP compared to BiVP in patients with non-ischemic cardiomyopathy and LBBB, along with a significant reduction in LVESV [11]. Our previous study also reported a more pronounced enhancement in LVEF in CSP compared to BiVP in patients with HFrEF and permanent AF [25].

It is well established that the overall response rate to BiVP is only 70% [6, 7]. In our study, we observed a notable improvement in LVEF (from 20.50 ± 2.75% to 37.78 ± 13.04%) and LVEDD (from 69.56 ± 6.77 ml to 59.41 ± 11.00 ml), even among patients with LVEF < 25%. A higher response rate (74% vs. 60%) for CSP compared to BiVP was also identified in a multicenter retrospective study [14]. Similarly, our research revealed a response ratio of 71.90% and a super-response ratio of 62.50% after CSP in patients with LVEF < 25%. These findings suggest that patients may be tailored for CSP or BiVP therapy based on individual characteristics [31].

Cardiac performance in different LVEF value after CSP

The relationship between improvements in cardiac performance and baseline LVEF values following CRT remains to be thoroughly elucidated. The REVERSE study compared the effects of BiVP in patients with LVEF greater than 30% to those with LVEF of at least 30%, revealing no significant benefits of CRT that varied with LVEF [32]. However, numerous studies have indicated that the severity of left ventricular (LV) dysfunction correlates inversely with the benefits derived from BiVP. Kutyifa et al. found that patients with a baseline LVEF of 25% or lower faced an increased risk of subsequent HF or death compared to those with LVEF between 26 and 30% or greater than 30% [33]. Notably, the clinical benefits of BiVP were evident regardless of baseline LVEF in the sub-study of MADIT-CRT [33]. Additionally, Rickard et al. reported that patients with severe cardiac dysfunction, defined as LVEF of 15% or lower, exhibited a diminished response ratio [24]. This study demonstrates that CSP can yield promising clinical outcomes in patients with severely reduced LVEF (LVEF < 25%) following long-term follow-up, with the correction of LBBB significantly enhancing cardiac function. There were no statistically significant differences in CSP response (71.90% vs. 90.50%, $P = 0.076$), or super response (62.50% vs. 78.60%, $P = 0.129$) among patients with varying LVEF values. These findings indicated that patients with severely reduced LVEF can also benefit from CSP. However, the rate of hospitalization for HF was higher than that in patients with LVEF 25–35%. And the ratio of complete LV reverse remodeling between patients with LVEF < 25% and LVEF 25–35% showed trends of significance (21.90% vs. 42.90%, $P = 0.059$). Furthermore, more favorable LVEF and LVESV levels, along with a lower rate of heart failure-related rehospitalization, were observed in patients with LVEF between 25 and 35% during follow-up. Collectively, these results suggested that timely CSP may enhance clinical prognosis for patients with LBBB and CRT indications.

Numerous studies have demonstrated that LBBB serves as a robust predictor of CRT response and super response in patients with heart failure. Specifically, correcting LBBB may resolve heart failure if the underlying cause is attributed to LBBB. However, the progression of heart failure is a critical factor influencing LV reverse remodeling [34, 35]. It is important to acknowledge that severe, irreversible cardiac remodeling, coupled with significantly reduced LVEF, can adversely affect cardiac outcomes following CRT, particularly if heart failure persists for an extended duration. While LVEF is not a definitive prognostic determinant for heart failure in patients with LBBB, it does play a vital role in determining ultimate cardiac performance.

Limitations

This study has several limitations, including a small sample size and its design as a single-center retrospective analysis. The findings necessitate validation through larger, multicenter studies with randomized controls. The medical therapy adjustments post CSP is important and could affect cardiac function. However, due to the inherent limitations of real-world retrospective studies, the dynamic and often short-term adjustments of patients' postoperative medications cannot entirely exclude the possibility that these medications may have contributed to the observed improvement in cardiac function. The large populations with non-ICM in this study may overestimated the benefit of CSP. Additionally, there are many different factors involved in patient demographics that could make conventional CRT may be a better choice for certain patient groups, Thus, the study did not fully address whether CSP is preferable to conventional CRT in all cases. A comparison with conventional CRT, which is the current evidence-based standard for this patient population, would provide more meaningful insights.

Conclusion

CSP has demonstrated feasibility and safety in enhancing clinical outcomes for patients with severely reduced LVEF. A smaller LVESV prior to CSP may predict LV complete reverse remodeling. Furthermore, the final LVEF and LVESV outcomes were more favorable in patients with LVEF between 25 and 35% compared to those with LVEF less than 25%. This suggests that timely initiation of CSP may be beneficial for patients with LBBB and HF.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-025-04660-5.

Supplementary Material 1.

Authors' contributions
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by ZM. The first draft of the manuscript was written by ZM and CM. ZM and CM have the same contributions to this manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
The data supporting the results of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All the procedures in studies involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Ethics Committee of the First Affiliated Hospital of Dalian Medical University approved this trial. All the participants agreed to participate, and written informed consent was obtained.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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