Evaluation of the shortening of the stimulus-to-peak left ventricular activation time at continuous low output to confirm left bundle branch capture

Jinyan Zhong, MD,[1] Nan Zheng, MD,[1] Longfu Jiang, MD

From the Department of Cardiology, Hwa Mei Hospital, University of Chinese Academy of Sciences, Ningbo, China.

BACKGROUND Left bundle branch area pacing (LBBAP) is a physiological pacing method for treatment of atrioventricular block. However, there is a need for a new convenient and safe method for performing left bundle branch pacing (LBBP) and to confirm left conduction system capture.

OBJECTIVE This study aimed to explore a new convenient and safe method for performing selective LBBP.

METHODS A total of 28 patients who had indications for pacing therapy and received LBBAP were recruited retrospectively. Demographic and baseline patient characteristics, electrocardiograms, pacing parameters, and intracardiac electrogram pattern were evaluated. Continuous unipolar pacing at low output (2 V / 0.5 ms) was performed during the whole period of LBBP lead implantation. Successful left bundle branch (LBB) capture was defined as the abrupt change of the pacing stimulus to the peak of R wave in lead V_5 during continuous pacing at low output (2 V / 0.5 ms).

RESULTS The parameters of the 2 shortenings (stimulus-to-peak left ventricular activation time [S-peak LVAT] before shortening, S-peak LVAT after shortening, and the duration of shortening) all showed a significant positive correlation (Pearson product-moment correlation coefficient [PCC] = 0.915, $P < .001$; PCC = 0.897, $P < 0.001$; PCCs = 0.765, $P < 0.001$). Shortening of the S-peak LVAT with continuous low output had a 100% sensitivity and 33.3% specificity for predicting stimulus-ventricular potential interval (S-V interval).

CONCLUSION Abrupt shortening of the S-peak LVAT at continuous low output was associated with abrupt shortening of the S-peak LVAT at low and high output. High rate of selective LBB capture can be achieved with the method of continuous low output, shortening the S-peak LVAT.

KEYWORDS Left bundle branch area pacing; Abrupt shortening of the S-peak LVAT; Left bundle branch capture; John Jiang's connecting cable; Pacemaker

(Heart Rhythm O2 2022;3:351–357)

Introduction

Cardiac pacing is often the only effective treatment for nonreversible bradyarrhythmias in the elderly population. Right ventricular pacing is the traditional implantation procedure, which presents many problems, including ventricular systolic and diastolic dysfunction, mitral regurgitation, and increased left atrial diameter during long-term follow-up.[1] Left bundle branch pacing (LBBP) has emerged as an alternative therapy for delivering physiological pacing to avoid electrical nonsynchronous activation of the left ventricle (LV),[2] especially in patients with left bundle branch block (LBBB).

LBBP was defined as capture of proximal left bundle branch (LBB) area for rapid and physiological LV activation with a low pacing threshold.[3] Huang and colleagues[4] described a transseptal approach for placement of the pacing lead in the LBB region. During LBB area pacing, 3 main types of capture (nonselective LBB capture, selective LBB capture, and LV septal myocardial capture) can be observed on endocardial electrocardiograph (ECG).[5] During the procedure, the operator usually stops advancing at a point and tests the lead to confirm LBB capture based on the change of endocardial ECG, impedance, and paced morphology. The shortening of the S-peak left ventricular activation time (LVAT) with increasing output merely demonstrates that the tip electrode of the LBBP lead is adjacent to the LBB. The final appropriate position of the tip electrode cannot be confirmed during advancement of the lead. Acute perforation of the LV septum is a frequent complication during implantation of the LBBP lead.

An implantation procedure with continuous monitoring of endocardial ECG and testing has not been previously described. To date, there is no standardized method to obtain

[1]The first 2 authors contributed equally to the work. **Address reprint requests and correspondence:** Longfu Jiang, Department of Cardiology, Hwa Mei Hospital, University of Chinese Academy of Sciences, 41 North West St, Ningbo, Zhejiang, China. E-mail address: longfujianghwamei@163.com.

 https://doi.org/10.1016/j.hroo.2022.04.006

KEY FINDINGS

- Abrupt shortening of the stimulus-to-peak left ventricular activation time (S-peak LVAT) at continuous low output can become a symbol of the capture of the left bundle branch (LBB).
- A high rate of selective LBB capture can be achieved with the method of continuous low-output shortening of the S-peak LVAT.
- Abrupt shortening of the S-peak LVAT at continuous low output was associated with abrupt shortening of the S-peak LVAT at low and high output.

selective LBB capture. We intended to develop a new convenient and safe method for performing LBBP to confirm left conduction system capture.

Methods

Patient selection

This was a retrospective study conducted at the Second Hospital of Ningbo, China, from March 2021 to July 2021. All enrolled patients with indications received permanent pacemaker implantation according to the current guidelines.[6] An LBBP procedure was attempted as the preferred pacing method during the study period. Patients with indications for cardiac resynchronization therapy or implantable cardioverter-defibrillator implantation were excluded. After application of the inclusion and exclusion criteria, a total of 28 patients provided informed written consent for this research protocol. The study conformed to the ethical principles of the Helsinki Declaration and was approved by the institutional review board of the Second Hospital of Ningbo (SL-KYSB-NBEY-2021-079-01).

Criteria for LBBP

Previous studies have demonstrated the following criteria for LBBP[7]: (1) LBB potentials should always be recorded except for patients with LBBB; (2) change in the paced QRS morphology from LBBB to right bundle branch block (RBBB) pattern on 12-lead ECG; (3) abrupt shortening of stimulus-to-peak left ventricular activation time (S-peak LVAT) at different outputs in lead 5/6. S-LVAT as the duration between the pacing stimulus and the peak of the R wave is often used to reflect the LV myocardial depolarization time in lead V_5.

Procedure for lead implantation

The 3830 lead, C315 HIS sheath (Medtronic Inc, Minneapolis, MN) and John Jiang's connecting cable (Supplemental Figure 1) were used to perform LBBP. During the procedure, ECGs and pacing parameters were recorded by the tip electrode of the lead. The radiographic reference image of the tricuspid valve radiography in the right anterior oblique 30° projection was routinely set as an anatomical marker. The initial site for LBBP is approximately at the 1–3 o'clock region of the tricuspid annulus (Figure 1).

In the right anterior oblique 30° view, the lead with sheath was advanced from the right side of the septum to the left side. John Jiang's connecting cable was connected with the lead for pace mapping at low output (2 V / 0.5 ms). When the tip of the pacing lead was fixed at the septum, the paced QRS morphology usually demonstrated a "W" shape with a mid notch in lead V_1. With advancement of the helix into the interventricular septum, the mid notch shifted toward the end of the QRS wave in lead V_1. The impedance of the tip electrode of the LBBP lead was monitored discontinuously at high output (5 V / 0.5 ms). With the abrupt shortening between the stimulation signal and peak LV activation (S-peak LVAT) in lead V5, LBBP lead continued to be screwed slightly (Figure 2). The duration of the pacing S-peak LVAT in lead V_5 was measured with LBBP lead pacing. Continuous unipolar pacing at low output (2 V / 0.5 ms) was performed during the subsequent period of LBBP lead implantation. When the first abrupt shortening by adjacent paced beats with the low output (2 V / 0.5 ms) was longer than 10 ms, the operator stopped screwing the tip of the LBBP lead (Figure 3). At the same time, the output was rapidly reduced, and the intracardiac paced QRS morphology was recorded by the LBBP lead. The depth of the lead position inside the LV septum was estimated by radiography with contrast injection in the left anterior oblique 45° projection.

Data collection

Data pertaining to baseline patient characteristics, laboratory parameters, and indications for pacing were collected. Pacing parameters (unipolar pacing thresholds, R-wave amplitudes, and impedances), ECG and intracardiac electrogram (EGM) pattern, intracardiac isoelectric stimulus-ventricular potential interval (S-V interval), amplitude of the LBB potential, and imaging data were recorded during lead implantation. The characteristics of the changes in ECG and EGM morphology at the threshold test and stimulus to the R-wave peak time at different outputs (threshold: 2 V, 5 V) were also recorded in lead V_5 (measured in the electrophysiology recording system at a speed of 200 mm/s; gain setting: 0.5 mV/cm). Procedure-related complications (lead dislodgement, acute perforation of the LV septum, loss of capture) were recorded.

Statistical analysis

All statistical analyses were performed using SPSS version 26.0 (SPSS, Somers, NY). Continuous variables were presented as mean ± standard deviation and between-group differences assessed using the Student t test. Categorical variables were presented as frequency (percentage) and between-group differences assessed using χ^2 test. Two-sided P values $< .05$ were considered indicative of statistical significance.

Results

Baseline characteristics

Twenty-eight patients (14 men, 14 women; mean age: 73.76 ± 10.06 years) underwent an attempt at LBBAP

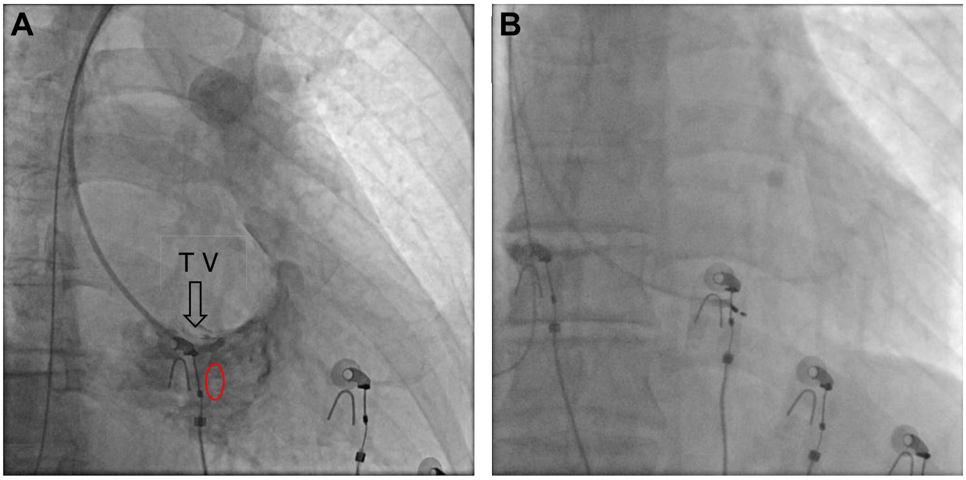

Figure 1 **A:** X-ray image of the tricuspid valve on the right anterior oblique 30° projection. The circle area is region of the initial site. **B:** The initial site for left bundle branch pacing. TV = tricuspid valve.

during the study reference period. The baseline characteristics of the study population are summarized in Table 1. The prevalence of coronary artery disease in our cohort was 7.14%. Mean LV ejection fraction was 66.6% ± 5.2%; underlying LV dysfunction was present in 10.71% of patients. Indications for pacing were atrioventricular block in 60.71%, sinus node dysfunction in 28.57%, and sinus node dysfunction plus atrioventricular block in 10.71%. At baseline, the mean QRS duration was 103.11 ± 28.19 ms with underlying RBBB in 35.71%, LBBB in 3.57%, and intraventricular conduction defect in 3.57% of patients.

Procedural parameters and characteristics

The procedural parameters and characteristics of the study population are shown in Table 2. Twenty-seven of the 28 (96.43%) patients received LBBAP successfully. LBBAP was unsuccessful in 1 patient with a large atrium. All patients presented RBBB morphology during pacing. Abrupt change was observed 2 times in S-peak LVAT (at 5 V / 0.5 ms and 2 V / 0.5 ms pacing; 2 V / 0.5 ms continuous pacing) was observed in 96.43% of patients; S-V interval appeared after the abrupt change at low output (2 V / 0.5 ms continuous pacing) in 89.29% by rapidly reducing the output. However, none of the patients showed S-V interval after abrupt change at high and low outputs (5 V / 0.5 ms and 2 V / 0.5 ms pacing). Patients who exhibited abrupt change was observed 2 times in S-LVAT had higher myocardium threshold (mean: 1.19 ± 0.46 V) than the LBB threshold (mean: 0.68 ± 0.37 V). LBB potential (0.22 ± 0.12 mV) was observed in 27 (96.43%) patients. At the completion of the procedure, the mean unipolar LBBP threshold and sensing of the R

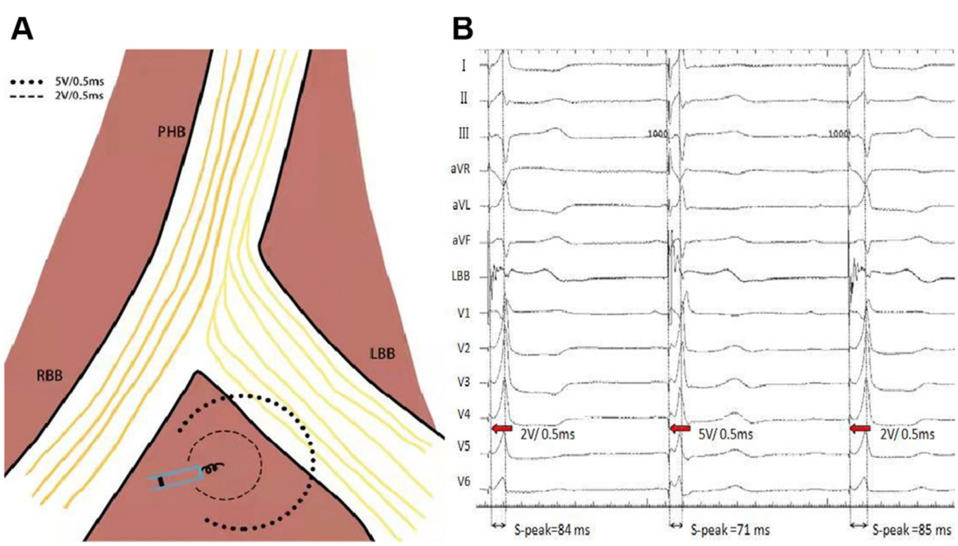

Figure 2 **A:** Schematic diagram of pacing at different outputs (5 V / 0.5 ms; 2 V / 0.5 ms). **B:** The duration of the stimulus-to-peak left ventricular activation time before and after shortening at different outputs (5 V / 0.5 ms; 2 V / 0.5 ms). LBB = left bundle branch; PHB = penetrating his bundle; RBB = right bundle branch.

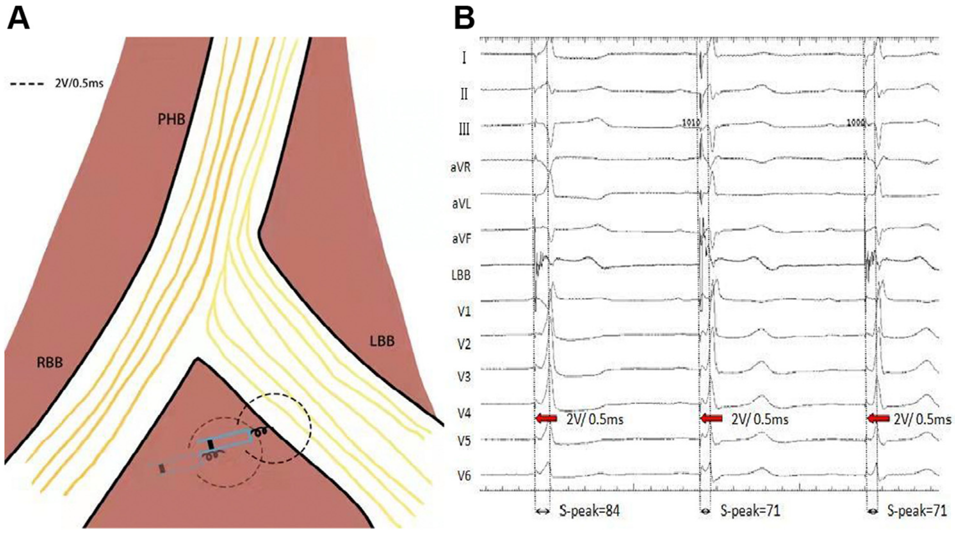

Figure 3 **A:** Schematic diagram of continuous pacing at low output (2 V / 0.5 ms). **B:** Duration of the stimulus-to-peak left ventricular activation time before and after shortening at low output (2 V / 0.5 ms). Abbreviations as in Figure 2.

wave were 0.42 ± 0.14 V and 13.61 ± 4.67 mV, respectively. This method was found to reduce the risk of acute ventricular septal perforation (incidence: 1/28, 3.57%) and lead dislocation (incidence 0%) during the procedure.

As shown in Table 3, the parameters of the 2 shortenings (the S-peak LVAT before shortening, the S-peak LVAT after shortening) all showed significant positive correlation (Pearson product-moment correlation coefficient [PCC] = 0.915, $P < .001$; PCC = 0.897, $P < .001$) between abrupt shortening of the S-peak LVAT at high and low outputs (5 V / 0.5 ms and 2 V / 0.5 ms pacing) and at low output (2 V / 0.5 ms continuous pacing). Moreover, the duration of shortening showed significant positive correlation (PCC = 0.765, $P < .001$) in patients with abrupt change was observed 2 times shortening during lead implantation. Using this method, the abrupt change in the S-peak LVAT at low output (2 V / 0.5 ms continuous pacing) had a sensitivity of 100% and specificity of 33.3% for predicting S-V interval (Table 4).

Discussion

LBBP lead implantation is the primary procedure for LBB pacemakers. During this procedure, selecting the final implantation location for the tip of the LBBP lead is a key challenge. Previous studies recommended that the LBBP lead

Table 1 Baseline characteristics of the study population

Total number of patients	28
Age (years)	73.76 ± 10.06
Men	14 (50.00%)
Coronary heart disease	2 (7.14%)
Atrial fibrillation	9 (32.14%)
Hypertension	14 (50.00%)
Heart failure	2 (7.14%)
LVEF	66.6% ± 5.2%
Cardiomyopathy	3 (10.71%)
Indication for pacing	
Sinus node dysfunction	8 (28.57%)
AV block	17 (60.71%)
Sinus node dysfunction and AV block	3 (10.71%)
Baseline ECG characteristics	
QRS duration (ms)	103.11±28.19
Normal	16 (57.14%)
RBBB	10 (35.71%)
LBBB	1 (3.57%)
IVCD	1 (3.57%)

AV = atrioventricular; ECG = electrocardiogram; IVCD = intraventricular conduction defect; LBBB = left bundle branch block; LVEF = left ventricular ejection fraction; RBBB = right bundle branch block.

Data presented as frequency (percentage) or mean ± standard deviation.

Table 2 Procedural parameters and characteristics

Paced RBBB morphology	28 (100%)
Threshold of myocardium (V) (n = 25)	1.19 ± 0.46
Threshold of LBB (V) (n = 25)	0.68 ± 0.37
Abrupt shortening of S-peak LVAT (5 V / 0.5 ms and 2 V / 0.5 ms pacing)	27 (96.43%)
S-V interval after abrupt shortening (5 V / 0.5 ms and 2 V / 0.5 ms pacing)	0 (0%)
Abrupt shortening of S-peak LVAT (2 V / 0.5 ms continuous pacing)	27 (96.43%)
S-V interval after abrupt shortening (2 V / 0.5 ms continuous pacing)	25 (89.29%)
LBB potential	27 (96.43%)
Amplitude of LBB potential (mV)	0.22 ± 0.12
Times of screwing	2.54 ± 1.69
Acute perforation of the LV septum	1 (3.57%)
Dislocation	0 (0%)
Successful LBBAP	27 (96.43%)
Threshold (V)	0.42 ± 0.14
Sensation (mV)	13.61 ± 4.67
Impedance (Ω)	719.19 ± 97.62
Depth of LBB electrode (mm)	13.24 ± 1.88

LBB = left bundle branch; LBBAP = left bundle branch area pacing; LV = left ventricle; S-peak LVAT = stimulus-to-peak left ventricular activation time; RBBB = right bundle branch block; S-V interval = stimulus-ventricular potential interval.

Table 3 Comparison of parameters and characteristics between 2 modes of abrupt shortenings of stimulus-to-peak left ventricular activation time (n = 25)

	Abrupt shortening of S-peak LVAT (5 V / 0.5 ms and 2 V / 0.5 ms pacing)	Abrupt shortening of S-peak LVAT (2 V / 0.5 ms continuous pacing)	PCC	*P* value
S-peak LVAT before shortening (ms)	83.68 ± 7.43	82.82 ± 8.27	0.915	<.001
S-peak LVAT after shortening (ms)	65.00 (64.92, 67.00)	68.11 ± 6.32	0.897	<.001
Duration of shortening (ms)	15.86 ± 5.64	14.86 ± 5.95	0.765	<.001

PCC = Pearson product-moment correlation coefficient; S-peak LVAT = stimulus-to-peak left ventricular activation time.

should be rotated slowly with careful monitoring of the paced QRS morphology and the impedance to avoid perforation.[8] Rotations should be stopped when the mid notch of the QRS complex moves up and toward the end in lead V_1.[7] The paced ECG QRS morphology frequently presents as RBBB morphology with a low threshold and the impedance of the tip electrode >500 Ω. In the study by Li and colleagues,[7] 80.5% (70/87) of patients received LBBP successfully. John Jiang's connecting cable consists of a rotatable port and a connection wire. Previous alligator clips are replaced by the ports, which can rotate with the 3830 lead and provide continuous monitoring and testing during the procedure. In our study, once there was change of the stimulus to the peak of R wave in lead V5 during continuous pacing at low output (2 V / 0.5 ms), we stopped screwing the lead. This electrode implantation method can reduce acute ventricular septal perforation (1/28, 3.57%) and achieve a higher success rate of LBBP (27/28, 96.43%) during the procedure.

Huang and associates[5] monitored the paced QRS duration and the LVAT at low and high output pacing to confirm whether the final implantation site of the LBBP was adjacent to the left conduction system. ECG morphology usually shows that the tip electrode of the lead captures both the LBB and the adjacent LV septal myocardium at high output pacing. Different outputs or implantation positions in the LV subendocardium may show different intracardiac ECG changes. Three main types of capture (nonselective LBB capture, selective LBB capture, and LV septal myocardial capture) constitute the morphology of LBB area pacing.[5]

Selective LBB capture is defined as a discrete local component separate from the stimulus artifact in the intracardiac EGM from the LBBP lead.[9] The S-V interval as a primary criterion of selective LBB capture means that the LBB can be selectively captured at low output.[10] The duration of the S-peak LVAT in nonselective LBBP may be prolonged with the decrease in the output. We speculate that a temporary increase in myocardial threshold occurs owing to myocardial injury during the procedure of electrode implantation. With the decrease in output, the S-V interval was observed and the intracardiac EGM changed from nonselective LBB capture to selective LBB capture after the shortening of the S-peak LVAT at continuous low output (Figure 4).

Table 4 Predictive ability of abrupt change of the stimulus-to-peak left ventricular activation time at low output for the stimulus-ventricular potential interval

	AUC	Sensitivity	Specificity
Abrupt change of the S-peak LVAT at low output (2 V / 0.5 ms continuous pacing)	0.667	1.000	0.333

AUC = area under the curve; S-peak LVAT = stimulus-to-peak left ventricular activation time.

High output shortens the S-peak LVAT, which indicates that the tip electrode of the LBBP lead is adjacent to the left conduction system. Continuous low-output pacing is performed to confirm whether the consecutive low output can shorten the S-peak LVAT, which indicates the capture of the left conduction system. More importantly, the parameters of the 2 shortenings (the S-peak LVAT before shortening, the S-peak LVAT after shortening, and the duration of shortening) all showed significant positive correlation (PCC = 0.915, $P < .001$; PCC = 0.897, $P < .001$; PCC = 0.765, $P < .001$). In this study, none of the patients presented the S-V interval by reducing the output after the shortening of the S-peak LVAT at low and high output. However, in the majority of patients (25/28, 89.29%), the S-V interval was observed after the shortening of the S-peak LVAT at continuous low output. Low-output shortening of the S-peak LVAT predicted the S-V interval with 100% sensitivity and 33.3% specificity. This method obtained a high rate of S-V interval and LBBP owing to the simultaneous use of John Jiang's connecting cable.

Limitations

Several limitations of this study should be mentioned. First, this was a single-center study with a small sample size. Second, use of John Jiang's connecting cable was necessary for continuous monitoring and testing. Finally, this study only evaluated and analyzed the parameters of LBBP during the lead implantation procedure without follow-up. Prospective studies with a large sample size are required to further corroborate our findings.

Conclusion

Abrupt shortening of the S-peak LVAT at continuous low output was associated with abrupt shortening of the S-peak LVAT at low and high output. Recording the S-V interval provided direct evidence of selective LBB capture in the present study. Continuous low output shortened the S-peak LVAT, which had a high sensitivity (100%) and 33.3% specificity for predicting the S-V interval. Moreover, this method could obtain a high rate of S-V interval and LBBP and a low rate of acute ventricular septal perforation.

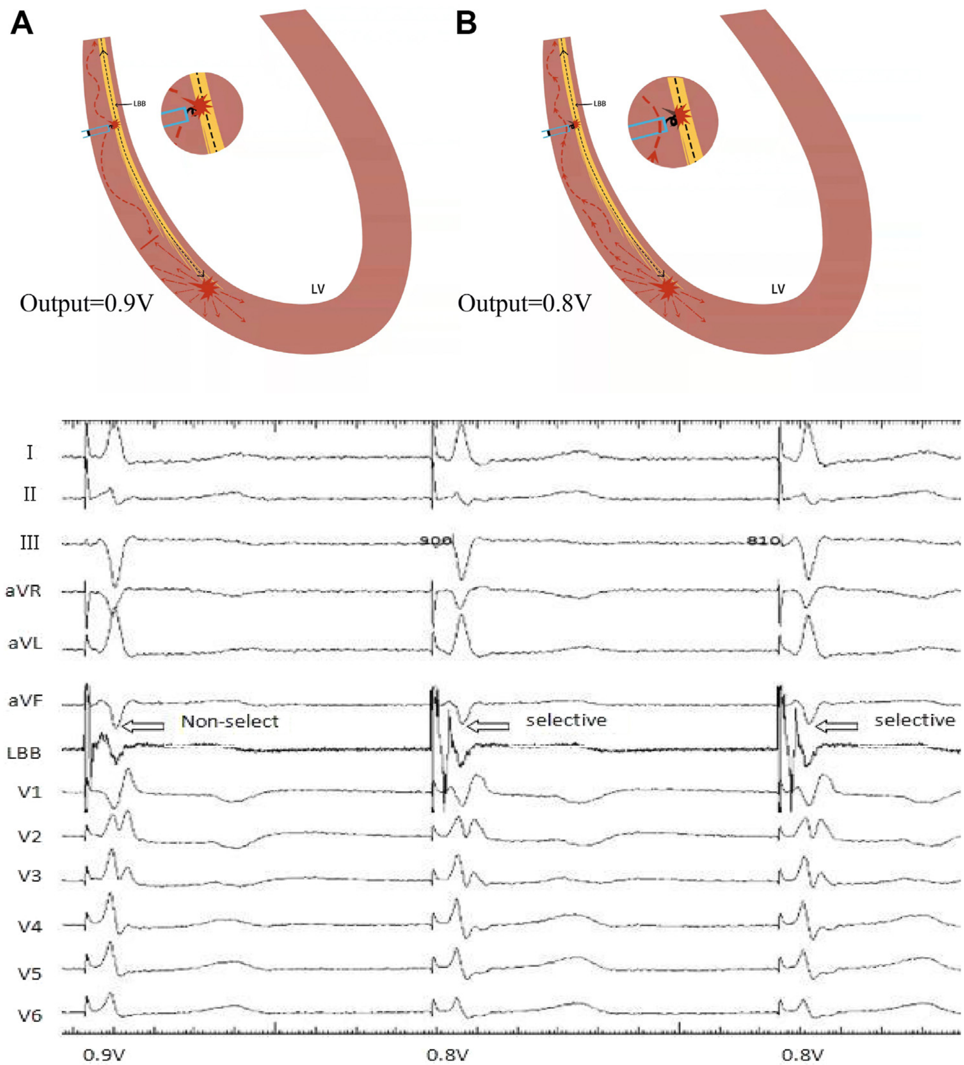

Figure 4 **A,B:** Schematic diagram of the change from nonselective left bundle branch (LBB) capture to selective LBB capture. **C:** With the decrease of output (0.9 V / 0.5 ms – 0.8 V / 0.5 ms), the intracardiac electrogram changed from nonselective LBB capture to selective LBB capture.

Funding Sources: This study was supported in part by grants from the Ningbo Health Branding Subject Fund (No. PPXK2018-01) and the Zhejiang Provincial Public Service and Application Research Foundation (No. LGF22H020009).

Disclosures: The authors have no conflicts to disclose.

Authorship: All authors attest they meet the current ICMJE criteria for authorship.

Patient Consent: Patients provided informed written consent for this research protocol.

Ethics Statement: The study conformed to the ethical principles of the Helsinki Declaration and was approved by the institutional review board of the Second Hospital of Ningbo (SL-KYSB-NBEY-2021-079-01).

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hroo.2022.04.006.

References

1. Wilkoff BL, Cook JR, Epstein AE, et al. Dual-chamber pacing or ventricular backup pacing in patients with an implantable defibrillator: the Dual Chamber and VVI Implantable Defibrillator (DAVID) Trial. JAMA 2002;288:3115–3123.
2. Vijayaraman P, Subzposh FA, Naperkowski A, et al. Prospective evaluation of feasibility and electrophysiologic and echocardiographic characteristics of left bundle branch area pacing. Heart Rhythm 2019;16:1774–1782.
3. Zhang S, Zhou X, Gold MR. Left bundle branch pacing: JACC review topic of the week. J Am Coll Cardiol 2019;74:3039–3049.
4. Huang W, Su L, Wu S, et al. A novel pacing strategy with low and stable output: pacing the left bundle branch immediately beyond the conduction block. Can J Cardiol 2017;33:1736.e1–1736.e3.
5. Huang W, Chen X, Su L, Wu S, Xia X, Vijayaraman P. A beginner's guide to permanent left bundle branch pacing. Heart Rhythm 2019;16:1791–1796.
6. Sandoe JAT, Barlow G, Chambers JB, et al. Guidelines for the diagnosis, prevention and management of implantable cardiac electronic device infection. Report of a joint Working Party project on behalf of the British Society for Antimicrobial Chemotherapy (BSAC, host organization), British Heart Rhythm Society (BHRS), British Cardiovascular Society (BCS), British Heart Valve Society (BHVS) and British Society for Echocardiography (BSE). The J Antimicrob Chemother 2015;70:325–359.

7. Li Y, Chen K, Dai Y, et al. Left bundle branch pacing for symptomatic bradycardia: implant success rate, safety, and pacing characteristics. Heart Rhythm 2019;16:1758–1765.
8. Sundaram S, Vijayaraman P. Left bundle branch pacing. Herzschrittmachertherther Elektrophysiol 2020;31:124–134.
9. Wu S, Su L, Wang S, Vijayaraman P, Ellenbogen KA, Huang W. Peri-left bundle branch pacing in a patient with right ventricular pacing-induced cardiomyopathy and atrioventricular infra-Hisian block. Europace 2019;21:1038.
10. Ponnusamy SS, Vijayaraman P. How to implant His bundle and left bundle pacing leads: tips and pearls. Card Fail Rev 2021;7:e13.