Impact on right ventricular performance in patients undergoing permanent pacemaker implantation: Left bundle branch pacing versus right ventricular septum pacing

Xinyi Huang MD1 | Manxin Lin MD2 | Shufen Huang MD2 | Jincun Guo MD2 | Linlin Li MD2 | Simei Chen MD3 | Kunhui Huang MD1 | Jian Wu MD1 | Maolong Su MD1 | Binni Cai MD2

1Department of Ultrasound Medicine, Xiamen Cardiovascular Hospital of Xiamen University, School of Medicine, Xiamen University, Xiamen, China
2Department of Cardiology, Xiamen Cardiovascular Hospital of Xiamen University, School of Medicine, Xiamen University, Xiamen, China
3Department of Cardiac Function, Xiamen Cardiovascular Hospital of Xiamen University, School of Medicine, Xiamen University, Xiamen, China

Correspondence
Binni Cai and Maolong Su, Xiamen Cardiovascular Hospital of Xiamen University, No.2999 Jinshan Rd, Huli District, Xiamen 361009 China.
Email: 1140853669@qq.com and sumaolong@xmu.edu.cn

Disclosures: None.

Funding information
Science and Technology Planning Project of Xiamen; Xiamen's Key Project of Medical and Health Sciences

Abstract

Background: The novel method of left bundle branch pacing (LBBP) has been reported to achieve better electrical and mechanical synchrony in the left ventricle than conventional right ventricular pacing (RVP). However, its effects on right ventricle (RV) performance are still unknown.

Methods: Consecutive patients undergoing dual‐chamber pacemaker (PM) implantation for sick sinus syndrome (SSS) with normal cardiac function and a narrow QRS complex were recruited for the study. The pacing characteristics and echocardiogram parameters were measured to evaluate RV function, interventricular and RV synchrony, and were compared between ventricular pacing‐on and native‐conduction modes.

Results: A total of 84 patients diagnosed with SSS and an indication for pacing therapy were enrolled. Forty‐two patients (50%; mean age 65.50 ± 9.30 years; 35% male) underwent successful LBBP and 42 patients (50%; mean age 69.26 ± 10.08 years; 33% male) RVSP, respectively. Baseline characteristics were similar between the two groups. We found no significant differences in RV function [RV‐FAC (Fractional Area Change)%, 47.13 ± 5.69 versus 48.60 ± 5.83, \(p = .069\); Endo‐GLS (Global Longitudinal Strain)%, −28.88 ± 4.94 versus −29.82 ± 5.35, \(p = .114\); Myo‐GLS%, −25.72 ± 4.75 versus −25.72 ± 5.21, \(p = .559\); Free Wall St%, 27.40 ± 8.03 versus −28.71 ± 7.34, \(p = .304\)] between the native‐conduction and LBBP capture modes, while the RVSP capture mode was associated with a significant reduction in the above parameters compared with the native‐conduction mode (\(p < .0001\)). The interventricular synchrony in the LBBP group was also superior to the RVSP group significantly.

Conclusion: LBBP is a pacing technique that seems to associate with a positive and protective impact on RV performance.

J Cardiovasc Electrophysiol. 2022;33:2614–2624.

This is an open access article under the terms of the Creative Commons Attribution‐NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2022 The Authors. Journal of Cardiovascular Electrophysiology published by Wiley Periodicals LLC.
1 | INTRODUCTION

Conventional right ventricular pacing (RVP) is deemed as a well-established treatment for symptomatic bradycardia. However, prolonged RVP induces interventricular and left ventricular dysynchrony with subsequent risk of impaired left ventricular function. Some have reported that altered right ventricle (RV) activation may also lead to impaired RV performance.1 Left bundle branch pacing (LBBP) has recently emerged as one of the major physiological conduction system pacing strategies which has been demonstrated to achieve narrower QRS duration and better mechanical synchrony than RVP.2 Yet, the paced QRS morphology by LBBP demonstrated right bundle branch block (RBBB) pattern in lead V1, which means it gives priority to left ventricular activation. The impact of LBBP on RV performance has not yet been investigated. The purpose of this study is to evaluate the impact of LBBP versus RVP on RV performance.

2 | METHODS

2.1 | Patients and ethical considerations

This is a prospective observational study. Patients diagnosed with sick sinus syndrome (SSS) and normal cardiac function with a narrow QRS complex (QRSd < 120 ms) that received dual-chamber pacemaker implantation at Xiamen Cardiovascular Hospital between February 2018 and May 2019 were recruited consecutively in this study. The exclusion criteria include atroventricular block, left or right bundle branch block, cardiomyopathy, previous myocardial infarction, congenital heart disease, valvular heart disease, and in sufficient image quality. The study protocol was approved by the Research Ethics Committee of Xiamen Cardiovascular Hospital, Xiamen University. Our study was carried out in accordance with the Declaration of Helsinki and approval guidelines from the ethics committee. Informed consent was obtained from each patient before participation.

2.2 | Pacemaker and lead implantation

The patients were assigned to LBBP and RVSP therapy nonrandomly and were rendered the LBBP group and RVSP group respectively according to the pacing site. In the LBBP group, LBBP was achieved by a transventricular-septal method described elsewhere.3 The pacing leads (models 3830, Medtronic Inc, Minneapolis, MN) were positioned in the left ventricular (LV) septal subendocardium of the LBB region. According to the electrical features described by Huang et al.,4,5 a successful LBBP in our study was defined as paced QRS of an RBBB pattern and either of the followings: (a) confirmation of selective LBBP; (b) the stimulus to left ventricular activation time (Stim-LVAT) shortening abruptly with increasing output or remaining shortest and constant at the final depth. The LBB capture threshold less than 1.5 V/0.5 ms is recognized as acceptable. In the RVSP group, the pacing leads (models 5076, Medtronic Inc, Minneapolis, MN) were positioned in the right ventricular septum. Dual-chamber pacemakers (Medtronic Inc) were implanted with the active fixation leads (models 5076, Medtronic Inc) implanted in the right auricle in all patients.

2.3 | Electrocardiogram parameters measurement

Twelve-lead surface electrocardiography (ECG) was recorded by the GE CardioLab Electrophysiology recording system (GE Healthcare Inc.) at 100 mm/s. Three parameters, the intrinsic QRSd, paced QRSd, and Stim-LVAT were measured in sequence. The QRSd was measured from the first to last sharp vector of QRS complex crossing the isoelectric line on the 12 leads under the intrinsic rhythm and the ventricular pacing rhythm respectively for comparison. The paced QRSd was measured from the stimulus to the end of the last deflection of the QRS complex on 12 leads under unipolar pacing with an output of 3.5 V/0.4 ms. And the Stim-LVAT was measured from the pacing stimulus to the peak of R-wave in lead V5. Three continuous QRS complexes were measured and the averaged values were reported.

2.4 | Echocardiographic measurement

Transthoracic echocardiographic examinations were performed3 days after implantation using color Doppler ultrasonic diagnostic apparatus (EPIQ 7 C, Philips Medical Systems) equipped with an X5-1 transducer. Data were collected under two pacing modes in sequence: the AAI mode, which was defined as “native-conduction mode”; and the DDD mode with short AV delay to ensure complete capture of RVSP or LBBP and avoid fusion with native-conduction, which was defined as “ventricular pacing-on mode (LBBP capture or RVSP capture)”. The ventricular pacing parameters were programmed to unipolar pacing with an output of 3.5 V/0.4 ms. Pacing rate was set 5-10 bpm faster than intrinsic atrial rate to ensure total atrial capture. Surface ECGs were recorded simultaneously to measure the AP-R interval in AAI mode and help to set Pace AV interval (PAV) in DDD mode. An appropriate PAV was set up by gradually shortening from the AP-R interval until the ventricle is completely captured.

KEYWORDS

cardiac mechanical synchrony, echocardiography, left bundle branch pacing, physiological pacing, right ventricular function, right ventricular septum pacing, sick sinus syndrome
(i.e., without fusion). Several parameters including Doppler variables, two-dimensional echocardiographic (2DE) measurement data and the severity of tricuspid regurgitation (TR) were evaluated in both modes according to the latest American Society of Echocardiography guidelines. For tissue Doppler image (TDI) acquisition, the frame rate and speed range were optimized. The RV and LV free wall, as well as the interventricular septum (IVS), were separately imaged from an apical four-chamber view for five consecutive cardiac cycles and the sample was placed in a mid-myocardial position with a fixed width of 5 mm. For each wall, myocardial deformation as strain and strain rate was examined at basal and middle segments. The anatomical localizations of the electrodes were documented and the distance from the electrode fixation site to the tricuspid annulus (E-T distance) was measured in standard apical 4- or 5-chamber views.

2.5 RV and interventricular mechanical synchrony assessment

Patient data were deidentified and anonymized before analysis. The TDI data and other echocardiographic parameters were analyzed offline respectively on independent workstations (QLAB version 10.8, Philips Medical Systems, and TTA 2.3, TOMTEC-ARENA, TOMTEC Imaging Systems GmbH) by two board-certified echocardiographers.

Numerous methods have been proposed for the evaluation of RV synchrony and interventricular mechanical synchrony. We measured the interventricular mechanical delay (IVMD) as the difference between left and right ventricular pre-ejection intervals on pulsed waved Doppler. A cutoff of ≥40 ms was used to definedysynchrony. For the TDI method, the time interval between the onset of the QRS complex and peak systolic (S') velocities were measured in the basal portion of the right ventricular (RV) free wall and LV lateral wall. Interventricular systolic asynchrony (IVSA) was defined as the time difference from the onset of the QRS complex to the peak systolic velocities between LV and RV. RV synchrony was calculated as the standard deviation (SD) of the times to peak-systolic strain for the four mid-basal RV segments corrected to the R-R interval between two QRS complexes, and called RV-SD. For the TDI method, RV systolic synchrony index (RV Ts-6) was defined as SD of the time from QRS onset to peak systolic velocity in six RV lateral wall and IVS segments.

2.6 RV function assessment

Parameters of RV function and dimension were collected (Figure 1), including EDA (right ventricular End Diastolic Area), ESA (right ventricular End Systolic Area), EDL (right ventricular End Diastolic Length), ESL(right ventricular End Systolic Length), EDDbas (right ventricular End Diastolic Diameter-basal), ESDbas (right ventricular End Systolic Diameter-basal), EDDmid (right ventricular End Diastolic Diameter-mid), ESDmid (right ventricular End Systolic Diameter-mid) and RV-FAC (Fractional Area Change, cutoff ≥ 35%). In addition to the conventional echocardiographic measurements, myocardial deformation derived from speckle-tracking echocardiographic (STE) analyses were performed according to the recommendations of the American Society of Echocardiography and European Association of Cardiovascular Imaging. Parameters derived from STE include EndoGLS (Endocardial Global Longitudinal Strain), MyoGLS (myocardial Global Longitudinal Strain), and FreeWallSt (which excluded the septal component).

2.7 Statistical analyses

The Shapiro–Wilk normal test was performed first. Continuous variables were expressed as mean ± standard deviation or median and interquantile range (IQR). Categorical variables were expressed as percentages. Differences in mean values between two groups or two modes (native-conduction mode and ventricular pacing-on mode) were compared by Student t test or Mann–Whitney U test for continuous variables. The χ^2 test was used for categorical data. Software SPSS 22.0 (SPSS Inc.) was used to statistically analyze the data for detection and observation. And a two-sided p value less than .05 was considered statistically significant.

3 RESULTS

3.1 Participants

Throughout the study period, LBBP was attempted in 52 patients and successful in 47 patients, with a success rate of 90.4%. Those that failed LBBP, received RVSP instead. The remaining patients underwent RVSP as planned. Finally, 84 patients were enrolled in this study after excluding patients who had an intrinsic QRS of more than 120 ms, or were accordant with other exclusive criteria, or refused to participate in the study. Forty-two patients (50%; mean age 65.50 ± 9.30 years; 33% male) underwent successful LBBP and 42 patients (50%; mean age 69.26 ± 10.08 years; 35% male) RVSP, respectively. Baseline demographics, clinical features and pacing characteristics of the overall population are reported in Table 1. There was no statistically significant difference in the two pacing groups in terms of baseline clinical characteristics, medications, and ECG features.

3.2 RV and interventricular synchrony

In the RVSP group, the paced QRSd was prominently wider and IVMD was significantly larger in the RVSP capture mode than those in the native-conduction mode (p < .0001), which represented a poor electrical and mechanical synchrony resulting from RVSP. While in the LBBP group, the paced QRSd in LBBP capture was only slightly
wider than that in the native-conduction mode (100.80 ± 8.11 ms vs. 91.09 ± 13.68 ms, \( p < .005 \)), and no significant differences were detected in the IVSA of the LBBP capture and native-conduction modes (\( p \geq .05 \)). However, there were no significant differences in RV mechanical synchrony parameters in both groups (Figure 2). The QRS\(_d\), RV, and interventricular mechanical synchronization parameters in LBBP and RVSP groups are summarized in Table 2.

### 3.3 RV function assessment

Echocardiographic parameters are reported in Table 3. We found no significant differences in RV-FAC\% [47.13 ± 5.69 versus 48.60 ± 5.83, \( p = .069 \)], EndoGLS\% [−28.88 ± 4.94 versus −29.82 ± 5.35, \( p = .114 \)], MyoGLS\% [−25.72 ± 4.75 versus −25.72 ± 5.21, \( p = .559 \)], and FreeWallSt\% [27.40 ± 8.03 versus −28.71 ± 7.34, \( p = .304 \)] between the native-conduction and LBBP capture modes, while the RVSP capture mode was associated with a significant reduction in the above parameters.

---

**TABLE 1** Patient baseline characteristics

| Parameters     | LBBP (n = 42) | RVSP (n = 42) | \( p \) |
|----------------|--------------|--------------|------|
| Age, year      | 65.50 ± 9.30 | 69.26 ± 10.08 | .079 |
| Male, n (%)    | 15 (35%)     | 14 (33%)     | .818 |
| BSA, m\(^2\)   | 1.64 ± 0.15  | 1.61 ± 0.26  | .664 |
| Baseline QRS\(_d\), ms | 91.09 ± 13.68 | 92.50 ± 10.77 | .600 |
| Hypertension, n (%) | 16 (38%) | 24 (57%) | .081 |
| DM, n (%)      | 4 (10%)      | 9 (21%)      | .131 |
| CAD, n (%)     | 5 (12%)      | 12 (29%)     | .057 |
| LVEDD, mm      | 48.78 ± 5.07 | 47.05 ± 4.87 | .116 |
| LVESD, mm      | 30.56 ± 4.18 | 28.74 ± 4.71 | .066 |
| LVEF (M-mode, %) | 66.13 ± 6.51 | 69.16 ± 7.85 | .059 |

Abbreviations: BSA, body surface area; CAD, coronary artery disease; DM, diabetes mellitus; EF, ejection fraction; LBBP, left bundle branch pacing; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; QRS\(_d\), QRS duration; RVSP, right ventricular septum pacing.
FIGURE 2  Comparison of RV and interventricular mechanical synchrony between LBBP and RVSP groups. Smaller means of IVMD during LBBP indicates mechanical contraction of LV earlier than RV (A). LBBP maintained a similar IVSA to native conduction, and was significantly better than that of RVSP (B). There were no significant differences on RV Ts-6 (C), or RV-SD4 (D) between pacing mode or native conduction mode in both groups. RV Ts-6, the standard deviation of the time from QRS onset to peak systolic velocity in six right ventricular lateral wall and interventricular septal segments. IVMD, interventricular mechanical delay; IVSA, the time difference from the onset of the QRS complex to the peak systolic velocities between left ventricle and right ventricle; LBBP, left bundle branch pacing; NCM, native conduction mode; PCM, paced capture mode; RVSP, right ventricular septum pacing; RV-SD4, the standard deviation of the times to peak-systolic strain for the four mid-basal right ventricular segments corrected to the R-R interval between two QRS complexes.

TABLE 2  Electrocardiographic and echocardiographic parameters for RV and interventricular synchronization in LBBP and RVSP groups

| Parameters                             | LBBP (n = 42) | RVSP (n = 42) |
|----------------------------------------|---------------|---------------|
|                                        | Native-conduction | LBBP capture | Native-conduction | RVSP capture |
| Heart rate, bpm                        | 66.90 ± 6.62   | 66.90 ± 6.62  | 63.17 ± 5.33      | 63.17 ± 5.33 |
| P< .001: LBBP capture versus RVSP capture |
| AP-R/AP-VP interval, msa               | 183.10 ± 5.05  | 128.33 ± 4.99 | 176.07 ± 6.08     | 132.00 ± 5.17 |
| P< .001: LBBP capture versus RVSP capture |
| QRSd, msa                             | 91.09 ± 13.68  | 100.81 ± 8.11 | 92.51 ± 10.77     | 140.32 ± 11.22 |
| P< .001: LBBP capture versus RVSP capture |
| Paced QRSd, msb                       | NA            | 120.82 ± 8.13* | NA            | 150.50 ± 12.55* |

Abbreviations: HR, heart rate; IVMD, interventricular mechanical delay; IVSA, interventricular systolic asynchrony; LBBP, left bundle branch pacing; LV, left ventricle; QRSd, QRS duration; RVSP, right ventricular septum pacing; RV-SD4, the standard deviation of the times to peak-systolic strain for the four mid-basal RV segments corrected to the R-R interval between two QRS complexes; RV Ts-6, the standard deviation of the time from QRS onset to peak systolic velocity in six RV lateral wall and IVS segments.

aAP-R interval was measured from atrial stimulus to QRS onset on native-conduction mode; AP-VP was interval from atrial stimulus to ventricular stimulus on ventricular capture mode.
bQRSd was measured from the first to last sharp vector of QRS complex crossing the isoelectric line of the 12-lead electrocardiogram.
cPaced QRSd was measured from stimulus to the end of the last QRS complex deflection in the 12-lead electrocardiogram.

*p < .0001: LBBP capture versus RVSP capture.
compared with the native-conduction mode ($p < .0001$), representing a deterioration in RV systolic function. Regarding the degree of TR, there were no differences between the native-conduction or LBBP capture modes. However, worse TR ($VCW, 0.33 \pm 0.28 \text{ vs. } 0.36 \pm 0.30, p = .008; \text{jet area}/LAA, 12.27 \pm 14.66 \text{ vs. } 15.00 \pm 16.93, p = .016$) were observed in the RVSP capture mode. LBBP capture mode had no significant changes in morphological parameters of RV, whereas ESA, EDL, and ESDmid in the RVSP group increased ($p < .05$), which indicated worsened RV performance (Figure 3).

Among 42 patients who underwent LBBP, 19 leads were fixed into anterior interventricular septum (AIVS) and 23 leads into posterior interventricular septum (PIVS). E-T distance $>20$ mm were found in 29 patients while the other 13 with an E-T distance of $\leq 20$ mm. RV function and TR were compared between subgroups of different pacing sites and different E-T distances. No significant difference were found between the subgroups (Figure 4; Table 4).

### DISCUSSION

The present study evaluates the acute effects of LBBP and RVSP on echocardiographic measures of RV function, right ventricular synchrony, interventricular synchrony and TR. The main findings of our study were as follows: (1) LBBP could preserve satisfactory RV morphological parameters better than RVSP. (2) RVSP worsened RV performance while no significant differences in RV performance were found between LBBP group and native conduction. (3) RVSP...
increased the degrees of TR compared with native conduction, while no similar changes were observed in the LBBP group. (4) LBBP maintained a good interventricular mechanical synchrony, while RVSP impaired interventricular mechanical synchrony. There has been increasing attention to the effect of pacing on RV function. RV is a geometrically complex cardiac cavity traditionally considered as a conduit ventricle, which has recently been brought to our attention that its premise measurement provides the best insight into cardiac outcomes. Yet, neither RVP nor LBBP, little is known about the influence of pacing on RV function itself. LBBP has recently emerged as one of the major physiological pacing strategies and its effect on LV contractility and synchrony have been well demonstrated. However, this kind of “physiologic” pacing gives priority to left ventricular function. The impact of LBBP on RV performance has not yet been investigated. To our knowledge, this is the first study focusing on the evaluation of functional and anatomic characteristics of RV following LBBP.

4.1 Interventricular mechanical synchrony

In this study, we found that LBBP preserved good interventricular mechanical synchrony, while RVSP had impaired interventricular mechanical synchrony, which was consistent with recent research. Chen’s study showed LBBP initiated earlier LV activation than RV with negative values of IVMD (−19.25 ± 18.43 ms), significantly different from RVSP (22.85 ± 22.05 ms). In the present study, smaller means of IVMD during LBBP indicate mechanical contraction of LV earlier than RV.

We noticed that although IVMD is a recognized indicator, its relatively large dispersion becomes unnegligible. To enhance the credibility of the results, IVSA was measured by TDI analysis, which is a feasible method with high time resolution for evaluating interventricular mechanical dyssynchrony and a valuable index relevant to RV afterload. Our study demonstrated that LBBP maintained a similar IVSA to native conduction, and was significantly better than that of RVSP. The result hinted that LBBP is superior in maintaining interventricular synchrony, which may be due to its favorable electrical synchrony. In RVP, electrical activity spreads throughout the myocardium predominantly from myocyte to myocyte and the propagation velocity is relatively slow. The heterogeneous electrical activation results in a significant widening of QRS duration, leading to interventricular dyssynchrony. While in LBBP, electrical activity spreads quickly throughout the left conduction system and the impulse may retrogradely recruit RBB to excite the RV in a way similar to normal His-Purkinje conduction and improve the delayed activation of RV. This was confirmed by electrocardiogram performance of LBBP which exhibited an incomplete right bundle branch block pattern with the duration of paced QRS usually less than 120 ms.

4.2 RV mechanical synchrony

At present, there are no official indicators of RV mechanical synchrony due to the complicated anatomic structure of RV and software limits. Previous studies have quantified RV mechanical synchrony...
synchrony using TDI-derived RV velocities or strain. RV Ts-6 and RV-SD4 mentioned in this study strongly correlate with markers of right ventricular size, and Eccentricity Index was chosen in most studies referring to pulmonary hypertension and RV dysfunction.\textsuperscript{8,9,20} In our study, there were no significant differences on RV Ts-6 or RV-SD4 between pacing mode or native conduction mode in both groups, hinted that neither LBBP nor RVP had deteriorative effects on RV mechanical synchrony. However, the sample size of this study is relatively small with a limited follow-up time, and the indicators for RV synchronization are still controversial, so we must be cautious in interpreting these findings. Powered studies with larger sample sizes and more accurate methods are needed to verify the results in the future.

F I G U R E 4  Comparison of TR and RV function between LBBP subgroups of different pacing sites. AIVS, anterior interventricular septum; E-T distance, the distance from the electrode fixation site to the tricuspid annulus; EndoGLS, endocardial global longitudinal strain; NCM, native conduction mode; PIVS, posterior interventricular septum; PCM, paced capture mode; RAA, right atrial area; RV-FAC, fractional area change; TR, tricuspid regurgitation.
| Parameters          | AIVS (n = 19) |      |      |      | PIVS (n = 23) |      |      |      | E-T distance ≤ 20 mm (n = 13) |      |      |      | E-T distance > 20 mm (n = 29) |      |      |      |
|---------------------|---------------|------|------|------|---------------|------|------|------|-------------------------------|------|------|------|-------------------------------|------|------|------|
|                     | NCM           | PCM  | p    |      | NCM           | PCM  | p    |      | NCM                          | PCM  | p    |      | NCM                          | PCM  | p    |      |
| Stim-LVAT           | NA            | 60.15 ± 7.23 | / |      | NA            | 63.00 ± 6.22 | / |      | NA            | 63.87 ± 8.69 | / |      | NA            | 60.73 ± 5.50 | / |      |
| LVFT/RR interval (%)| 50.77 ± 5.86  | 49.56 ± 5.95 | .504 | 49.84 ± 46.41 | 46.41 ± 8.14 | .052 | 48.05 ± 5.60 | 44.97 ± 10.94 | .341 | 50.37 ± 5.34 | 47.79 ± 5.61 | .020 |      |
| TR VCW (cm)         | 0.44 ± 0.12\(a\) | 0.41 ± 0.12\(b\) | .560 | 0.51 ± 0.30\(a\) | 0.51 ± 0.29\(b\) | .980 | 0.41 ± 0.19\(c\) | 0.42 ± 0.17\(d\) | .435 | 0.54 ± 0.29\(c\) | 0.52 ± 0.30\(d\) | .287 |      |
| TR jet area/RAA (%)  | 13.77 ± 5.87  | 14.13 ± 6.60 | .891 | 18.30 ± 10.61 | 18.78 ± 12.32 | .734 | 18.25 ± 9.22 | 20.93 ± 13.60 | .290 | 18.79 ± 8.50 | 18.09 ± 6.86 | .677 |      |
| FAC (%)             | 44.87 ± 9.90  | 47.01 ± 9.74 | .080 | 47.10 ± 5.40 | 48.47 ± 5.29 | .258 | 46.24 ± 7.58 | 47.64 ± 8.00 | .406 | 46.09 ± 7.52 | 47.79 ± 7.50 | .064 |      |
| MyoGLS (%)          | -24.33 ± 6.10 | -23.68 ± 5.81 | .608 | -26.40 ± 3.50 | -26.42 ± 4.82 | .981 | -26.50 ± 3.85 | -25.93 ± 4.13 | .467 | -25.40 ± 5.11 | -25.15 ± 5.66 | .750 |      |
| EndoGLS (%)         | -27.75 ± 6.45 | -28.77 ± 7.37 | .454 | -29.79 ± 3.77 | -30.48 ± 3.56 | .223 | -28.59 ± 4.25 | -29.32 ± 3.94 | .325 | -29.00 ± 5.27 | -30.04 ± 5.89 | .195 |      |
| FreeWallSt (%)      | -24.75 ± 10.85 | -26.93 ± 9.87 | .452 | -29.08 ± 5.25 | -29.34 ± 4.99 | .815 | -29.00 ± 4.03 | -29.89 ± 4.72 | .560 | -26.75 ± 9.19 | -28.23 ± 8.21 | .385 |      |

Abbreviations: AIVS, anterior interventricular septum; EndoGLS, endocardial global longitudinal strain; E-T distance, the distance from the electrode fixation site to the tricuspid annulus; FreeWallSt, strain of right ventricular free wall; LVFT, left ventricular filling time; MyoGLS, myocardial global longitudinal strain; NCM, native conduction mode; PCM, paced capture mode; PIVS, posterior interventricular septum; RAA, right atrial area; RV-FAC, fractional area change; Stim-LVAT, the interval from the pacing stimulus to the peak of the R-wave; TR, tricuspid regurgitation; VCW, vena contracta width.

\(p = .571\): AIVS versus PIVS.

\(p = .424\): AIVS versus PIVS.

\(p = .571\): E-T distances20 mm versus E-T distance > 20 mm.

\(p = .424\): E-T distances20 mm versus E-T distance > 20 mm.
4.3 | RV function

Our study demonstrated that LBBP is similar to native conduction in all indexes relating to RV hemodynamic effects, on the contrary, RVSP manifested significant worsening in RV-GLS, RV-FAC compared with intrinsic conduction. Favorable RV hemodynamics were preserved in LBBP due to good interventricular and RV mechanical synchrony as well as preserved LV function.

Previous studies suggested that the deterioration in synchrony was associated with deterioration in RV systolic function.21 Earlier LV activation, favorable interventricular mechanical synchrony, and RV synchrony achieved by LBBP are important factors in protecting the RV function.15 Notably, one of the main characteristics of RV is its greater sensitivity to changes in afterload.22 The RV afterload is the sum of the resistance and stiffness of the pulmonary circulation, left atrium, mitral valve, LV, aortic valve, and systemic circulation. Having excluded cor pulmonale and valvular heart disease patients enrolled in this study were relatively healthy. Thereby, in this study, the damage to LV function will increase the afterloads, manifesting as reduced RV strain.

Positive interaction between RV and LV contractions can be explained by a mechanical entrainment effect. LV systole is essential to RV coronary perfusion. Additionally, both ventricles share the septum, and up to 40% of RV systolic function is dependent on septal contraction.23 According to our data mentioning LV function, LBBP kept a similar SV and EF to native-conduction, while RVSP reduced both SV and EF significantly. This finding was consistent with our previous studies, which have shown that LBBP can well preserve LV function.2 The favorable hemodynamics maintained in LV could contribute to RV systolic function.

Moreover, heart rate and AV delay may affect the filling of the heart and thus affect the parameters of cardiac function. In this study, the pacing rate of both modes was the same, while a shorter AV delay was set in ventricular capture mode. Even if this, the RV function parameters of LBBP capture mode remained similar to native conduction mode, which further supported the protection of LBBP on cardiac function.

4.4 | Tricuspid regurgitation

Our study demonstrated that no influences were observed on TR in LBBP group while significant worsening TR in RVSP group. A recent study by Xiaohei Li et al. suggested a similar TR worsening risk in both LBBP and RVSP after long-term follow-up (1-year outcome: 15.2% vs. 17.2%; 2-year outcome: 21.6% vs. 24.6%, p > .05 for all), furthermore, the lower risk of TR progression was reported to be related with an E-T distance of >19 mm.24 Different from their results, our study showed that the electrode fixation site did not affect TR and RV function in the LBBP group immediately postimplantation. Previous studies have shown that pacemaker-induced TR is related to various factors including ventricular synchrony, LV and RV function, the interference of the lead to the tricuspid valve apparatus, and so on.25 Favorable ventricular synchrony and cardiac function as well as thinner and softer lead may prevent the deterioration of TR in LBBP. Further research with large sample size and long follow-up period is needed to explore the long-term impact on TR of LBBP.

The importance of RV has been recognized, and its role in cardiac hemodynamics has been highlighted nowadays. However, it is easily disturbed by many factors along with its complex structure and contraction pattern, which poses additional challenges in evaluation. In this self-controlled study, all patients enrolled had a normal cardiac function and a narrow QRS duration. Thus, selection bias and interference with RV shall be minimized. We believed that the design applied in the research enhanced the credibility of our results.

5 | LIMITATIONS

This was a single-center observational study with relatively small sample size. In addition, these findings were short-term hemodynamic results, and the long-term impact on the right ventricular performance of LBBP remains uncertain. Moreover, we did not discriminate between nonselective-LBBP (NS-LBBP) and selective-LBBP (S-LBBP) capture in this study. Randomized multicenter studies with larger sample sizes and longer follow-up periods may be beneficial for evaluating the further potential impact on RV function in patients who underwent LBBP.

6 | CONCLUSION

This study provides a detailed analysis of the impact of RV performance and hemodynamic effects under native-conduction, RVSP, and LBBP modes in patients with SSS and normal cardiac function. LBBP is a novel pacing technique that seems to associate with a positive and protective impact on RV performance.

ACKNOWLEDGMENTS

This study was supported by the Xiamen’s Key Project of Medical and Health Sciences (3502Z20191103), the Science and Technology Planning Project of Xiamen (3502Z20214ZD2183).

DATA AVAILABILITY STATEMENT

The data underlying this article will be shared on reasonable request to the corresponding author.

INFORMED CONSENT

The patient involved signed informed consent including consent to publish the anonymized data.

ORCID

Xinyi Huang https://orcid.org/0000-0001-7655-6652
Manxin Lin https://orcid.org/0000-0002-5406-9711
11. Badano LP, Kolias TJ, Muraru D, et al. Standardization of left atrial, right atrial, and right atrial deformation imaging using two-dimensional speckle tracking echocardiography: a consensus document of the EACVI/ASE/Industry task force to standardize deformation imaging. *Eur Heart J Cardiovasc Imaging*. 2018;19(6):591-600. doi:10.1093/ehjci/jey042

12. Amsallem M, Mercier O, Kobayashi Y, Moneghetti K, Haddad F. Forgotten no more: a focused update on the right ventricle in cardiovascular disease. *JACC Heart Fail*. 2018;6(11):891-903. doi:10.1016/j.jchf.2018.05.022

13. Hou X, Qian Z, Wang Y, et al. Feasibility and cardiac synchrony of permanent left bundle branch pacing through the interventricular septum. *Europace*. 2019;21(11):1694-1702. doi:10.1093/europace/ezu188

14. Xie H, Chen X, Wang Y, et al. Comparison of the acute effects of different pacing sites on cardiac synchrony and contraction using speckle-tracking echocardiography. *Front Cardiovasc Med*. 2021;8:758500. doi:10.3389/fcm.2021.758500

15. Chen X, Zhou X, Wang Y, et al. Evaluation of electrophysiological characteristics and ventricular synchrony: an intrapatient-controlled study during His-Purkinje conduction system pacing versus right ventricular pacing. *Clin Cardio*. 2022;45(7):723-732. doi:10.1002/ccl.32387

16. Gorcsan J, Abraham T, Agler DA, et al. Echocardiography for cardiac resynchronization therapy: recommendations for performance and reporting—a report from the American society of echocardiography dysynchrony writing group endorsed by the Heart Rhythm Society. *J Am Soc Echocardiogr*. 2008;21(3):191-213. doi:10.1016/j.echo.2008.01.003

17. van Bommel RJ, Tanaka H, Delgado V, et al. Association of intraventricular mechanical dyssynchrony with response to cardiac resynchronization therapy in heart failure patients with a narrow QRS complex. *Eur Heart J*. 2010;31(24):3054-3062. doi:10.1093/eurheartj/ehq334

18. Zhang J, Wang Z, Zu L, et al. Simplifying physiological left bundle branch area pacing using a new nine-particle method. *Can J Cardiol*. 2021;37(2):329-338. doi:10.1016/j.cjca.2020.05.011

19. Zhu K, Sun Y, Cai B, et al. Left bundle branch pacing in patients with right bundle branch block. *Kardiol Pol*. 2021;79(10):1127-1129. doi:10.33963/KP.a2021.0091

20. Hui W, Slorach C, Bradley TJ, et al. Measurement of right ventricular mechanical synchrony in children using tissue Doppler velocity and two-dimensional strain imaging. *J Am Soc Echocardiogr*. 2020;23(12):1289-1296. doi:10.1016/j.echo.2020.09.009

21. Saito M, Iannaccone A, Kaye G, Negishi K, Kosmala W, Marwick TH. Effect of right ventricular pacing on right ventricular mechanics and tricuspid regurgitation in patients with high-grade atrioventricular block and sinus rhythm (from the protection of left ventricular function during right ventricular pacing study. *Am J Cardiol*. 2015;116(12):1875-1882. doi:10.1016/j.amjcard.2015.09.041

22. La Gerche A, Claessen G. Right ventricular function: the barometer of all that lies ahead. *JACC Cardiovascular Imaging*. 2019;12(12):2386-2388. doi:10.1016/j.jcmg.2018.12.018

23. LahmT DouglasIS, Archer SL, et al. Assessment of right ventricular function in the research setting: knowledge gaps and pathways forward. *Am J Respir Crit Care Med*. 2018;198(4):e15-e43. doi:10.1164/rccm.201806-1160ST

24. Li X, Zhu H, Fan X, et al. Tricuspid regurgitation outcomes in left bundle branch area pacing and comparison with right ventricular septal pacing. *Heart Rhythm*. 2022;19(7):1202-1203. doi:10.1016/j.hrthm.2022.03.005

25. Addetia K, Harb SC, Hahn RT, et al. Cardiac implantable electronic device lead-induced tricuspid regurgitation. *JACC Cardiovascular Imaging*. 2019;12(4):622-636. doi:10.1016/j.jcmg.2018.09.028

**How to cite this article:** Huang X, Lin M, Huang S, et al. Impact on right ventricular performance in patients undergoing permanent pacemaker implantation: left bundle branch pacing versus right ventricular septum pacing. *J Cardiovasc Electrophysiol*. 2022;33:2614-2624. doi:10.1111/jce.15675