Received: 12 May 2021 | Revised: 25 August 2021 | Accepted: 13 September 2021

DOI: 10.1002/joa3.12638

Journal of Arrhythmia Open Access WILEY

RAPID COMMUNICATION

Left bundle branch pacing: An evolving site for physiological pacing

Eka P. B. Mulia MD | Muhammad R. Amadis MD | Rerdin Julario MD | Budi B. Dharmadjati MD

Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Airlangga - Dr. Soetomo General Hospital, Surabaya, Indonesia

Correspondence
Eka P. B. Mulia, MD, Departement of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Airlangga-Dr. Soetomo General Hospital, Surabaya, Jalan Mayjen Prof. Dr. Moestopo No.6-8, Surabaya 60286, Indonesia.
Email: eka.prasetya.budi-2017@fk.unair.ac.id

Funding information
The authors received no financial support for the research, authorship, and/or publication of this article.

Abstract

For patients with symptomatic bradyarrhythmia, cardiac pacing is the only appropriate treatment option. Electrical and mechanical dyssynchrony caused by traditional right ventricular apical pacing leads to left ventricular dysfunction and atrial arrhythmias. Physiological pacing stimulates natural cardiac conduction, resulting in synchronized ventricular contraction. Even if His bundle pacing (HBP) is an ideal physiological pacing modality, it is technically not always feasible because of high capture thresholds, disease in the distal His bundle, and follow-up troubleshooting issues. Left bundle branch pacing (LBBP) has been proposed as a viable alternative to HBP since it provides lead stability, a low and stable pacing threshold, and correction of distal conduction system disease.

KEYWORDS

bradycardia, His bundle pacing, left bundle branch pacing, physiological pacing

1 | BACKGROUND

Atrial arrhythmias, heart failure, and pacing-induced cardiomyopathy have all been linked to chronic right ventricular (RV) pacing.[1-3] Alternative pacing sites, such as the septum and RV outflow tract, have not produced consistent outcomes. His bundle pacing (HBP) has evolved as an ideal physiological pacing form because it stimulates the natural cardiac conduction system, resulting in synchronized ventricle contraction and preventing complications of RV pacing.[4] Permanent HBP implantation was first reported with traditional RV leads.[5] Since dedicated sheath and lead are now available, HBP is becoming more common.[4,6]

While HBP is the ideal site of physiological pacing, it does have some drawbacks. In patients with dilated heart, the implant procedure necessitates more experience in targeting a narrow zone, resulting in a lengthy procedure and fluoroscopic times.[5,7,8] HBP lead usually has a low R-wave amplitude, which may cause oversensing of atrial or His signals and undersensing of ventricular signals. High capture thresholds at implantation and/or late follow-up can lead to premature battery depletion and replacement of generator, as well as the risks that come with them.[9,10] High rates of lead revision caused by unpredictability and delayed increase in HBP capture thresholds are also a significant concern. During follow-up, a small percentage of patients can lose His capture, resulting in RV septal pacing.[7,11,12]

Abbreviations: AF, atrial fibrillation; AV, atrioventricular; CRT, cardiac resynchronization therapy; HBP, His bundle pacing; LBB, left bundle branch; LBBP, left bundle branch pacing; LV, left ventricle; LVAT, left ventricular activation time; RBB, right bundle branch; RV, right ventricle; RWPT, R wave peak time.

The search for an optimal site led to a new physiological pacing method, introduced by Huang et al. Pacing lead was inserted deep into RV basal septum to capture the region of the left bundle branch (LBB).[13] Ever since left bundle branch pacing (LBBP) has emerged as the alternative way of delivering physiological pacing as it overcomes many limitations of the HBP.

2 | DEFINITION OF LEFT BUNDLE BRANCH PACING (LBBP)

LBBP is characterized as direct capture of the main left bundle or each of fascicle branches, along with left ventricle (LV) septal myocardium, at the low output (<1 V at 0.5 ms pulse width).[14] Aside from demonstrating a paced QRS pattern for the right bundle branch conductivity delay, one or more conditions should be demonstrated to ensure that the left bundle or its branches are captured: (1) Left bundle (LB) potential demonstration with the 20-35 ms LB-local ventricular electrogram interval, (2) Evidence of transition from non-selective to selective left bundle capture or LV septal capture with decrementing output, (3) Peak left ventricular activation time (LVAT) as measured in lead V5,6 less than 80ms, (4) Programmed deep septal stimulation to demonstrate LB refractory period.[4]

3 | DIFFERENCES BETWEEN HBP AND LBBP

HBP can be used as an alternative to conventional RV or biventricular pacing in the following circumstances: (1) atrioventricular (AV) node ablation due to refractory atrial fibrillation (AF), (2) high-degree AV block with expected ventricular pacing >20% of the time, (3) 1st degree AV block with long PQ (alone or in combination with intermittent 2nd to 3rd degree AV block or sick sinus syndrome), and (4) upgrade in pacing-induced cardiomyopathy.[15,16] Furthermore, HBP can be beneficial in cardiac resynchronization therapy (CRT) context. A limitation of HBP is the LBBB below the level of His, which recently can be corrected by implementing LBBP.[16]

Both HBP and LBBP are capable of capturing the conduction system. HBP is anatomically difficult because of a small target region, yet it is the most physiological type of pacing because the entire conduction system is recruited.[4] However, in 5%–10% of patients, high pacing thresholds of HBP at implantation or during follow-up can lead to early battery depletion and generator replacement.[9,10,17] In patients with infra-Hisian block and/or LBBB, the success rate for correcting distal conduction system disease is lower.[18,19] LBBP, on the other hand, aims for a wider target area of LBB fibers on the left sub-endocardium. In addition, histological issue (His embedded in fibrous, electrically nonconducting tissue while LBB located in the myocardium) also makes LBBP preferred.[7]

With no major sensing problems, LBBP offers a low and stable threshold. LBBP appears to be the most effective method of physiological pacing since it avoids many of the disadvantages associated with HBP.[4,7]

4 | IMPLANTATION OF LBBP

A SelectSecure 3830 pacing lead (Medtronic, Minneapolis, MN) is used for LBBP, which can be delivered through the fixed-curve C315-HIS sheath or deflectable SelectSite C304-HIS sheath (Medtronic).[7] Another implantation system used is stylet-driven leads with an extendable helix design (Solia S60, Biotronik, SE & CO) delivered through a new delivery sheath (Selectra 3D, Biotronik).[20] Unlike HBP, which has a narrow target, LBBP has a larger target area, however, it is located on the left side of the septum. Because the procedures are performed on the right side of the septum, there are no definite potentials to target at first. Before inserting the LBBP lead, it is critical to understand distal extent of His signals.[4] In the right anterior oblique (RAO) 30° view, the ideal target site is around 1-1.5 cm underneath the His bundle in an imaginary line traced from distal His signals to RV apex. The paced QRS morphology at this site usually, but not in all cases, shows a “w” pattern in lead V1 with the notch at the nadir of the QS complex, tall R in lead II, and RS in lead III before fixation (Figure 1).[4,14,21] Rapid rotations of the lead, 3-4 turns, are suggested to achieve penetration of the lead body behind the screw into the septum.[14]

A recent study evaluated several methods for monitoring lead depth, including sheath angiography, fulcrum sign, impedance monitoring, pacing from ring electrode, QRS notch changes in lead V1, and observation of fixation beat. Fixation beat, presented in 96% of the cases, is a novel marker to reach the LBB area, namely an ectopic beat with qR/rsR' morphology in lead V1.[22] In a study of 124 patients, Jastrzębski et al validated the time measured from QRS onset to the peak of the R wave in lead V6 (R wave peak time [RWPT]) during LBB capture similar to that of normal sinus rhythm, with high sensitivity and specificity. Moreover, they also reported an RWPT cutoff of 74 ms, which is 100% specific for LBB capture.[23]

5 | COMPLICATIONS OF LBBP

There are several potential complications of LBBP. During implantation, C315 sheath or the pacing lead open helix has the potential to cause right bundle branch (RBB) injury. As a result, patients with LBBB may need a temporary pacing lead implanted to provide backup pacing.[4] Li et al reported that 12.6% of their patients developed RBB block (RBBB) during the implantation procedure, which all resolved before hospital discharge.[21] However, Su et al reported that permanent right bundle branch injury occurred in 55 (8.9%) patients.[24]

Acute lead perforation into LV cavity and lead dislodgement can be one of the complications. Vijayaraman et al also reported acute lead dislodgement after implantation in 3 of 97 patients (3.1%) who underwent LBBP,[25] while Su et al reported that 2 of 618 patients

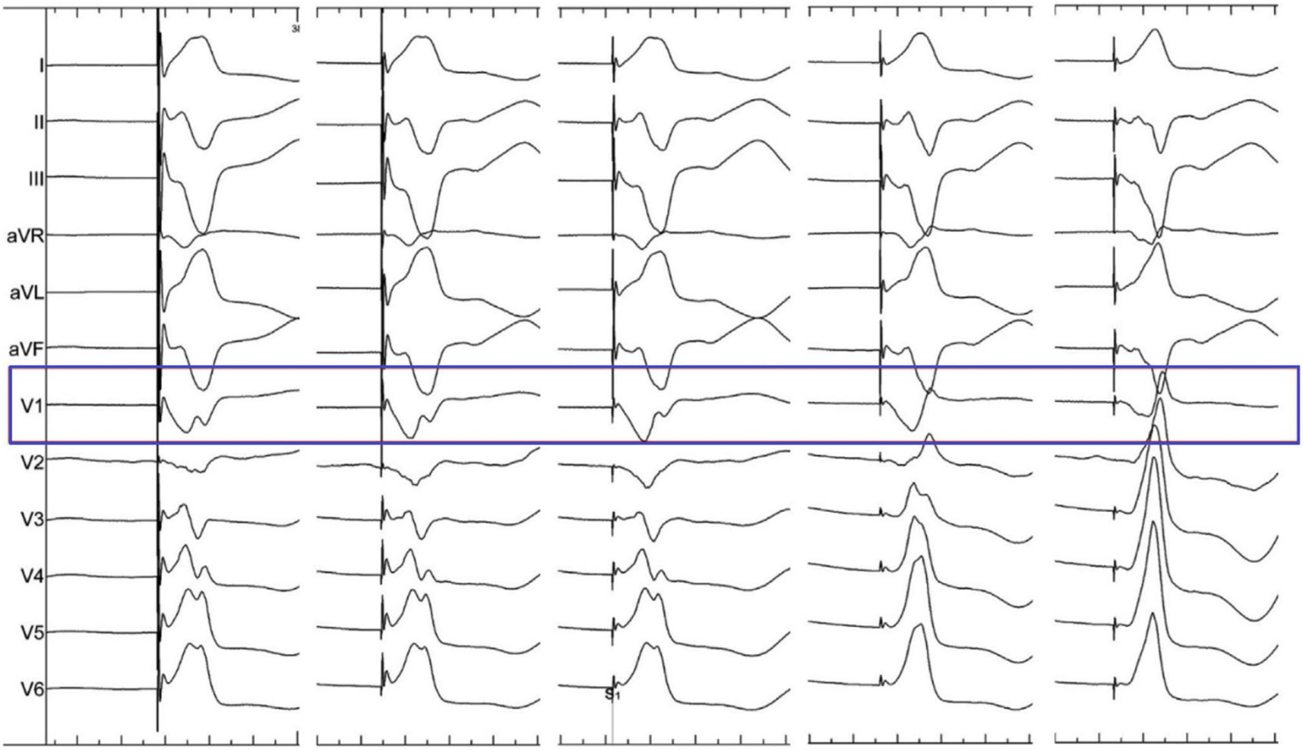

FIGURE 1 ECG showing the change in the notch morphology in lead V1 during rotating the lead from the right side (left part of ECG) to the left side (right part of ECG) of the septum as the lead goes deep into the septum. The notch in the nadir of the QS in V1 gradually ascended up to form the R wave (from "w-shape" to "fusion" and then to "incomplete RBBB" pattern). ECG, Electrocardiogram; RBBB, right bundle branch block

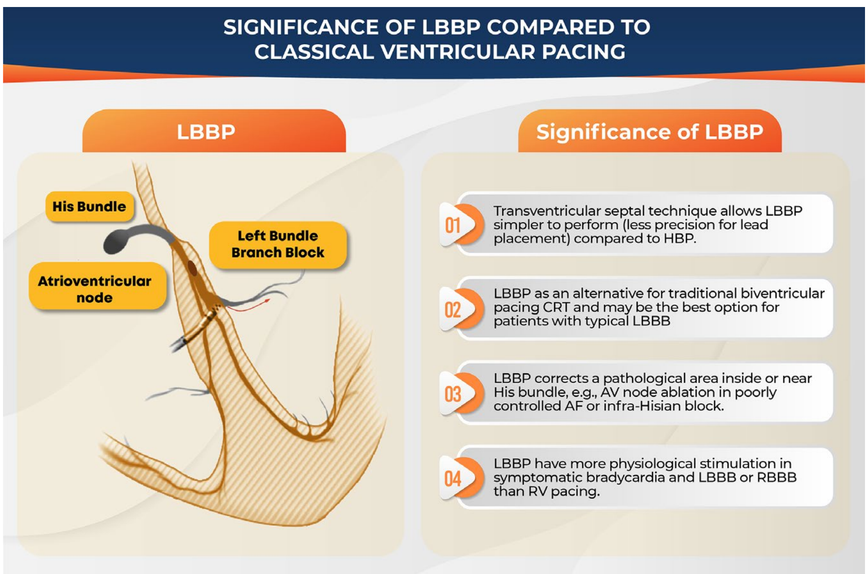

FIGURE 2 Clinical significance of left bundle branch pacing. AF, atrial fibrillation; CRT, cardiac resynchronization therapy; HBP, His bundle pacing; LBBB, left bundle branch block; RBBB, right bundle branch block; RV, right ventricle

required lead revision because of lead dislodgement to the RV the day after implantation.[24] Ravi et al reported a case of LBBP complicated by a late sudden increase in threshold secondary to interventricular septal perforation.[26] In addition, Ponnusamy et al also reported late lead dislodgement and successful extraction after 2 years of implantation.[27] Possibility of acute dislodgement and late lead dislodgement into LV cavity means that patients should be closely monitored during follow-up.

Injury of the septal branch of left anterior descending artery can occur during LBBP. A case of aborted ST-elevation myocardial infarction during LBBP lead implantation because of coronary artery injury has been reported.[28] Lastly, patients should have a post-procedure echocardiogram to evaluate the lead's depth and search for exposed helix in LV cavity because of a potential possibility of thromboembolism, although it has not been reported.

TABLE 1 Several published studies on left bundle branch pacing

No	Study	Design	Sample (n)	Success rate (%)	Paced QRS (ms)	Threshold at implant (V@ 0.5 ms)	R wave at implant (mV)	Follow up (mo)	Lead revision (%)
1	Chen et al (2019)[30]	Prospective, LBBP vs RVP	20	NR	111.8 ± 10.7	0.73 ± 0.2	NR	3	0
2	Zhang et al (2019)[32]	Prospective, LBBP vs RVP	23	87	112.6 ± 12.14	0.68 ± 0.2	9.28 ± 5.00	NR	0
3	Hou et al (2019)[33]	Prospective, HBP vs LBBP vs RVP	56	NR	117.8 ± 11.0	0.5 ± 0.1	17 ± 6.7	4.5	0
4	Li et al (2019)[34]	Retrospective, LBBP in AV block	33	90.9%	112.8 ± 10.9	0.76 ± 0.26	14.4	3	3.03
5	Li et al (2019)[21]	Prospective, pacing for bradycardia indications	87	80.5%	113.2 ± 9.9	0.76 ± 0.22	11.99 ± 5.36	3	0
6	Vijayaraman et al (2019)[25]	Prospective, pacing for bradycardia or HF indications	100	93%	136 ± 17	0.6 ± 0.4	10 ± 6 mV	3	3
7	Zhang et al (2019)[31]	Prospective, LBBP in patients with HF, reduced LVEF and LBBB	11	NR	129.09 ± 15.9	0.83 ± 0.16	9.1 ± 3.4	6.7	0
8	Hasumi et al (2019)[35]	Retrospective, LBBP in failed HBP for AV block	21	81%	116 ± 8.3	0.77 ± 0.07	9.1 ± 1.4	6	0
9	Cai et al (2020)[36]	Prospective, Observational LBBAP vs RVP	40	90%	101 ± 8.7	0.49 ± 0.22	11.7 ± 5.3	NR	0
10	Jiang et al (2020)[37]	Retrospective, whether typical use of strict criteria to define BBB predicts LBBP success	73 (63 + 10)	Atypical BBB – 30% (3) Typical BBB – 82.5% (52) Overall 75.3%	133 ± 14 118 ± 14	0.6 ± 0.2	13.6 ± 7.6	NR	0
11	Wang et al (2020)[38]	Prospective Randomized, LBBP vs RVP	66	94%	121.4 ± 9.8	0.94 ± 0.21	12.1 ± 3.6	6	4.5%
12	Vijayaraman et al (2020)[39]	Retrospective, feasibility of HPCSP after TAVR (LBBP and HBP)	28	93%	125 ± 15	0.64 ± 0.3	14 ± 8	12	0

(Continues)

TABLE 1 (Continued)

No	Study	Design	Sample (n)	Success rate (%)	Paced QRS (ms)	Threshold at implant (V@ 0.5 ms)	R wave at implant (mV)	Follow up (mo)	Lead revision (%)
13	Huang et al (2020)[40]	Prospective, feasibility and efficacy of LBBP in LBBB with NICM	63	97%	118 ± 12	0.5 ± 0.15	11.1 ± 4.9	12	0
14	Ponnusamy et al (2021)[41]	Prospective, efficacy and mid-term outcomes of LBBP in Indian population	99	94%	110.8 ± 12.4	0.59 ± 0.22	14.1 ± 7.1	4.8	0
15	Wu et al (2021)[42]	Prospective, CRT efficacy of LBBP, HBP and BiV pacing.	32	100%	110.8 ± 11.1	0.49 ± 0.13	11.2 ± 5.1	12	0
16	Vijayaraman et al (2021)[43]	Retrospective, feasibility and outcomes of LBBP in CRT eligible patients	325	85%	137 ± 22	0.6 ± 0.3	10.6 ± 6	6	2.5%

Abbreviations: BBB, bundle branch block; BiV, biventricular; CRT, cardiac resynchronization therapy;HBP, His bundle pacing; HF, heart failure; HPCSP, His-Purkinje conduction system *pacing*; LBBB, left bundle branch pacing; LBBP, left bundle branch pacing; LVEF, left ventricular ejection fraction; NICM, non-ischemic cardiomyopathy; RVP, right ventricular pacing.

6 | PROMISING CLINICAL IMPLICATIONS OF LBBP

The obvious benefit of LBBP is that the pacing site can be distal to the pathological or vulnerable conduction system area.[29] Furthermore, compared to HBP implantation, the transventricular septal technique mentioned earlier allows LBBP simpler to perform, requiring less precision for lead placement.[21,30] In patients with ventricular dyssynchrony and heart failure, LBBP may provide an alternative to traditional biventricular pacing CRT, and may be the best option for patients with typical LBBB.[29] Zhang et al recently published a report in 11 consecutive CRT-indicated patients that showed LBBB correction, and electric and mechanical ventricular resynchronization, as well as a substantial increase in outcomes.[31] LBBP corrects a pathological area inside or near His bundle, such as AV node ablation in poorly controlled AF or infra-Hisian block. Similarly, LBBP will have more physiological stimulation than RV pacing in patients with symptomatic bradycardia and LBBB or RBBB. As a result, in these patients, LBBP may be a preferred pacing alternative.[29]

LBBP is increasingly becoming a viable alternative to CRT. LBBP can provide correction of distal conduction disease and better lead stability compared to HBP.[4] Because of septal tissue as pacing site, LBBP has a lower and more reliable capture threshold than HBP, increasing system durability and eliminating the need for a backup pacing lead. Finally, in patients who have had their HBP implantation fails, LBBP is a viable option.[29] Clinical significance of LBBP was presented in Figure 2, and the available studies on left bundle pacing are summarized in Table 1.

7 | FUTURE DIRECTION

LBBP emerges as a safe and reliable method of physiological pacing, however, there are some issues to be addressed. In improving overall success rates, more refinements in the LBBP technique and equipment are required. The parameters for capturing LBB need to be fine-tuned and validated. The lead behind the helix is buried within the septum, and myocardial contractility's long-term effect on lead insulation is unknown. One of the most anticipated complications is late lead migration into the LV cavity.

The potential for thrombus occurs if the pacing lead tip of LBBP remains in the LV chamber. Methods to avoid this complication and estimate the true risk need to be further determined. It is necessary to assess the long-term lead integrity, safety profile, and deep septal LBBP lead extraction risk. The effectiveness and role of LBBP, including in patients requiring CRT, must be explored in prospective randomized clinical trials.

A study by Lin et al[44] modified the LBBP technique in which the distal electrode of the bipolar pacing lead was placed and paced in the left bundle branch area via a transventricular septal approach (as was done in LBBP), while a ring electrode was used to pace the right bundle branch area. Bilateral bundle branch area pacing (BBBP) was achieved by stimulating the cathode and anode in various pacing configurations. This study showed that BBBP can reduce delayed right ventricular activation, resulting in more physiological ventricular activation. However, full implementation of such a pacing strategy clinically would require further advances in pacing technology.

8 | CONCLUSION

LBBP, as a newer pacing therapy, has the advantage of being a physiological pacing therapy that eliminates many of the disadvantages of RV pacing or HBP. Although several studies have demonstrated its feasibility and efficacy, more studies are needed to better understand this technique and identify the patient population that would benefit the most.

ACKNOWLEDGMENTS

Not applicable.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

EPBM and MRA contributed to the concept and design of article, acquisition data, and drafting the article. RJ and BBD were involved in revising the article critically for important intellectual content. All authors read and approved the final manuscript.

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

ORCID

Eka P. B. Mulia https://orcid.org/0000-0002-2681-7743
Rerdin Julario https://orcid.org/0000-0002-7201-2460

REFERENCES

1. Pastore G, Zanon F, Baracca E, Aggio S, Corbucci G, Boaretto G, et al. The risk of atrial fibrillation during right ventricular pacing. Europace. 2016;18:353–8. https://doi.org/10.1093/europace/euv268
2. Merchant FM, Hoskins MH, Musat DL, Prillinger JB, Roberts GJ, Nabutovsky Y, et al. Incidence and time course for developing heart failure with high-burden right ventricular pacing. Circ Cardiovasc Qual Outcomes. 2017;10. https://doi.org/10.1161/CIRCOUTCOMES.117.003564
3. Bansal R, Parakh N, Gupta A, Juneja R, Naik N, Yadav R, et al. Incidence and predictors of pacemaker-induced cardiomyopathy with comparison between apical and non-apical right ventricular pacing sites. J Interv Card Electrophysiol. 2019;56:63–70. https://doi.org/10.1007/s10840-019-00602-2
4. Ponnusamy SS, Arora V, Namboodiri N, Kumar V, Kapoor A, Vijayaraman P. Left bundle branch pacing: a comprehensive review. J Cardiovasc Electrophysiol. 2020;31:2462–73. https://doi.org/10.1111/jce.14681
5. Deshmukh P, Casavant DA, Romanyshyn M, Anderson K. Permanent, direct His-bundle pacing: a novel approach to cardiac pacing in patients with normal His-Purkinje activation. Circulation. 2000;101:869–77. https://doi.org/10.1161/01.CIR.101.8.869
6. Subzposh FA, Vijayaraman P. Long-term results of His bundle pacing. Card Electrophysiol Clin. 2018;10:537–42. https://doi.org/10.1016/j.ccep.2018.05.011
7. Padala SK, Ellenbogen KA. Left bundle branch pacing is the best approach to physiological pacing. Hear Rhythm O2. 2020;1(1):59–67. https://doi.org/10.1016/j.hroo.2020.03.002
8. Nagarajan VD, Ho SY, Ernst S. Anatomical considerations for His bundle pacing. Circ Arrhythmia Electrophysiol. 2019;12. https://doi.org/10.1161/CIRCEP.118.006897
9. Lustgarten DL, Sharma PS, Vijayaraman P. Troubleshooting and programming considerations for His bundle pacing. Hear Rhythm. 2019;16:654–62. https://doi.org/10.1016/j.hrthm.2019.02.031
10. Vijayaraman P, Naperkowski A, Subzposh FA, Abdelrahman M, Sharma PS, Oren JW, et al. Permanent His-bundle pacing: long-term lead performance and clinical outcomes. Hear Rhythm. 2018;15:696–702. https://doi.org/10.1016/j.hrthm.2017.12.022
11. Bhatt AG, Musat DL, Milstein N, Pimienta J, Flynn L, Sichrovsky T, et al. The efficacy of His bundle pacing: lessons learned from implementation for the first time at an experienced electrophysiology center. JACC Clin Electrophysiol. 2018;4:1397–406. https://doi.org/10.1016/j.jacep.2018.07.013
12. Zanon F, Abdelrahman M, Marcantoni L, Naperkowski A, Subzposh FA, Pastore G, et al. Long term performance and safety of His bundle pacing: a multicenter experience. J Cardiovasc Electrophysiol. 2019;30:1594–601. https://doi.org/10.1111/jce.14063
13. Huang W, Su L, Wu S, Xu L, Xiao F, Zhou X, 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. https://doi.org/10.1016/j.cjca.2017.09.013
14. Huang W, Chen X, Su L, Wu S, Xia X, Vijayaraman P. A beginner's guide to permanent left bundle branch pacing. Hear Rhythm. 2019;16:1791–6. https://doi.org/10.1016/j.hrthm.2019.06.016
15. Sharma PS, Dandamudi G, Herweg B, Wilson D, Singh R, Naperkowski A, et al. Permanent His-bundle pacing as an alternative to biventricular pacing for cardiac resynchronization therapy: a multicenter experience. Hear Rhythm. 2018;15:413–20. https://doi.org/10.1016/j.hrthm.2017.10.014
16. Israel CW, Tribunyan S, Richter S. Indications for His bundle and left bundle branch pacing. Herzschrittmachertherapie Und Elektrophysiologie. 2020;31:135–43. https://doi.org/10.1007/s00399-020-00689-5
17. Abdelrahman M, Subzposh FA, Beer D, Durr B, Naperkowski A, Sun H, et al. Clinical outcomes of His bundle pacing compared to right ventricular pacing. J Am Coll Cardiol. 2018;71:2319–30. https://doi.org/10.1016/j.jacc.2018.02.048
18. Upadhyay GA, Cherian T, Shatz DY, Beaser AD, Aziz Z, Ozcan C, et al. Intracardiac delineation of septal conduction in left bundle-branch block patterns: mechanistic evidence of left intrahisian block circumvented by His bundle pacing. Circulation. 2019;139:1876–88. https://doi.org/10.1161/CIRCULATIONAHA.118.038648
19. Vijayaraman P, Naperkowski A, Ellenbogen KA, Dandamudi G. electrophysiologic insights into site of atrioventricular block lessons

from permanent His bundle pacing. JACC Clin Electrophysiol. 2015;1:571–81. https://doi.org/10.1016/j.jacep.2015.09.012
20. De Pooter J, Calle S, Timmermans F, Van Heuverswyn F. Left bundle branch area pacing using stylet-driven pacing leads with a new delivery sheath: a comparison with lumen-less leads. J Cardiovasc Electrophysiol. 2021;32:439–48. https://doi.org/10.1111/jce.14851
21. Li Y, Chen K, Dai Y, Li C, Sun QI, Chen R, et al. Left bundle branch pacing for symptomatic bradycardia: implant success rate, safety, and pacing characteristics. Hear Rhythm. 2019;16:1758–65. https://doi.org/10.1016/j.hrthm.2019.05.014
22. Jastrzębski M, Kiełbasa G, Moskal P, Bednarek A, Kusiak A, Sondej T, et al. Fixation beats: a novel marker for reaching the left bundle branch area during deep septal lead implantation. Hear Rhythm. 2021;18:562–9. https://doi.org/10.1016/j.hrthm.2020.12.019
23. Jastrzębski M, Kiełbasa G, Curila K, Moskal P, Bednarek A, Rajzer M, et al. Physiology-based electrocardiographic criteria for left bundle branch capture. Hear Rhythm. 2021;18:935–43. https://doi.org/10.1016/j.hrthm.2021.02.021
24. Su L, Wang S, Wu S, Xu L, Huang Z, Chen X, et al. Long-term safety and feasibility of left bundle branch pacing in a large single-center study. Circ Arrhythmia Electrophysiol. 2021;14:9261. https://doi.org/10.1161/CIRCEP.120.009261
25. Vijayaraman P, Subzposh FA, Naperkowski A, Panikkath R, John K, Mascarenhas V, et al. Prospective evaluation of feasibility and electrophysiologic and echocardiographic characteristics of left bundle branch area pacing. Hear Rhythm. 2019;16:1774–82. https://doi.org/10.1016/j.hrthm.2019.05.011
26. Ravi V, Larsen T, Ooms S, Trohman R, Sharma PS. Late-onset interventricular septal perforation from left bundle branch pacing. Hear Case Reports. 2020;6:627–31. https://doi.org/10.1016/j.hrcr.2020.06.008
27. Ponnusamy SS, Vijayaraman P. Late dislodgement of left bundle branch pacing lead and successful extraction. J Cardiovasc Electrophysiol. 2021;32:2346–9. https://doi.org/10.1111/jce.15155
28. Ponnusamy SS, Vijayaraman P. Aborted ST-elevation myocardial infarction—An unusual complication of left bundle branch pacing. Hear Case Reports. 2020;6:520–2. https://doi.org/10.1016/j.hrcr.2020.05.010
29. Zhang S, Zhou X, Gold MR. Left bundle branch pacing: JACC review topic of the week. J Am Coll Cardiol. 2019;74:3039–49. https://doi.org/10.1016/j.jacc.2019.10.039
30. Chen K, Li Y, Dai Y, Sun QI, Luo B, Li C, et al. Comparison of electrocardiogram characteristics and pacing parameters between left bundle branch pacing and right ventricular pacing in patients receiving pacemaker therapy. Europace. 2019;21:673–80. https://doi.org/10.1093/europace/euy252
31. Zhang W, Huang J, Qi Y, Wang F, Guo L, Shi X, et al. Cardiac resynchronization therapy by left bundle branch area pacing in patients with heart failure and left bundle branch block. Hear Rhythm. 2019;16:1783–90. https://doi.org/10.1016/j.hrthm.2019.09.006
32. Zhang JM, Wang Z, Cheng L, Zu L, Liang Z, Hang F, et al. Immediate clinical outcomes of left bundle branch area pacing vs conventional right ventricular pacing. Clin Cardiol. 2019;42:768–73. https://doi.org/10.1002/clc.23215
33. Hou X, Qian Z, Wang Y, Qiu Y, Chen X, Jiang H, et al. Feasibility and cardiac synchrony of permanent left bundle branch pacing through the interventricular septum. Europace. 2019;21:1694–702. https://doi.org/10.1093/europace/euz188
34. Li X, Li H, Ma W, Ning X, Liang E, Pang K, et al. Permanent left bundle branch area pacing for atrioventricular block: feasibility, safety, and acute effect. Hear Rhythm. 2019;16:1766–73. https://doi.org/10.1016/j.hrthm.2019.04.043
35. Hasumi E, Fujiu K, Nakanishi K, Komuro I. Impacts of left bundle/peri-left bundle pacing on left ventricular contraction. Circ J. 2019;83:1965–7. https://doi.org/10.1253/circj.CJ-19-0399
36. Cai B, Huang X, Li L, Guo J, Chen S, Meng F, et al. Evaluation of cardiac synchrony in left bundle branch pacing: Insights from echocardiographic research. J Cardiovasc Electrophysiol. 2020;31:560–9. https://doi.org/10.1111/jce.14342
37. Jiang Z, Chang Q, Wu Y, Ji L, Zhou X, Shan Q. Typical BBB morphology and implantation depth of 3830 electrode predict QRS correction by left bundle branch area pacing. PACE - Pacing Clin Electrophysiol. 2020;43:110–7. https://doi.org/10.1111/pace.13849
38. Wang J, Liang Y, Wang W, Chen X, Bai J, Chen H, et al. Left bundle branch area pacing is superior to right ventricular septum pacing concerning depolarization-repolarization reserve. J Cardiovasc Electrophysiol. 2020;31:313–22. https://doi.org/10.1111/jce.14295
39. Vijayaraman P, Cano Ó, Koruth JS, Subzposh FA, Nanda S, Pugliese J, et al. His-purkinje conduction system pacing following transcatheter aortic valve replacement: feasibility and safety. JACC Clin Electrophysiol. 2020;6:649–57. https://doi.org/10.1016/j.jacep.2020.02.010
40. Huang W, Wu S, Vijayaraman P, Su L, Chen X, Cai B, et al. Cardiac resynchronization therapy in patients with nonischemic cardiomyopathy using left bundle branch pacing. JACC Clin Electrophysiol. 2020;6:849–58. https://doi.org/10.1016/j.jacep.2020.04.011
41. Ponnusamy SS, Muthu G, Kumar M, Bopanna D, Anand V, Kumar S. Mid-term feasibility, safety and outcomes of left bundle branch pacing–single center experience. J Interv Card Electrophysiol. 2021;60:337–46. https://doi.org/10.1007/s10840-020-00807-w
42. Wu S, Su L, Vijayaraman P, Zheng R, Cai M, Xu L, et al. Left bundle branch pacing for cardiac resynchronization therapy: nonrandomized on-treatment comparison with His bundle pacing and biventricular pacing. Can J Cardiol. 2021;37:319–28. https://doi.org/10.1016/j.cjca.2020.04.037
43. Vijayaraman P, Ponnusamy SS, Cano Ó, Sharma PS, Naperkowski A, Subsposh FA, et al. Left bundle branch area pacing for cardiac resynchronization therapy: results from the international LBBAP collaborative study group. JACC Clin Electrophysiol. 2021;7:135–47. https://doi.org/10.1016/j.jacep.2020.08.015
44. Lin J, Chen K, Dai Y, Sun QI, Li Y, Jiang Y, et al. Bilateral bundle branch area pacing to achieve physiological conduction system activation. Circ Arrhythmia Electrophysiol. 2020;13: https://doi.org/10.1161/CIRCEP.119.008267

How to cite this article: Mulia EPB, Amadis MR, Julario R, Dharmadjati BB. Left bundle branch pacing: An evolving site for physiological pacing. J Arrhythmia. 2021;37:1578–1584. https://doi.org/10.1002/joa3.12638