A beginner’s guide to permanent left bundle branch pacing

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Introduction
Studies have demonstrated the feasibility and clinical benefits of permanent His-bundle pacing (HBP).1 However, concerns regarding higher pacing thresholds, lower R-wave amplitudes, and the potential to develop distal conduction block have limited the clinical application of HBP in certain subgroups.1,2

Thus, left bundle branch pacing (LBBP) has emerged as an alternative method for delivering physiological pacing to achieve electrical synchrony of the left ventricle (LV).3–7 especially in patients with infranodal atrioventricular block and left bundle branch block (LBBB). The proximal left bundle branches run through the LV septum and fan out to form a wider target for pacing compared to the His bundle.8 Recently, we reported that HBP can correct classic LBBB in 97% of patients,2 and Upadhyay et al9 demonstrated that the site of block usually is located within the His or proximal left bundle. We developed a technique for LBBP using a transseptal approach.3 LBBP has been reported to offer low pacing thresholds and large R waves, and because the distal conduction system is targeted, has a lower theoretical risk for development of distal conduction block.3

However, the definitions and implantation procedure have not been previously well described. Here we describe our method for performing LBBP to confirm intraseptal left conduction system capture and discuss programming options in order to standardize this approach.

Definitions and characteristics of LBBP
LBBP is defined as capture of the LBB (left bundle trunk or its proximal fascicles), usually with septal myocardium capture at low output (<1.0 V/0.4 ms). We have developed an innovative technique for intraseptal left conduction system pacing.3 The common features of this implantation technique are shown in Figure 1 and summarized as follows: (1) transvenous access; (2) transseptal placement of the pacing lead into the LV septal subendocardium in the LBB region; and (3) confirmation of capture of the LBB. Criteria for LBB capture confirmed by electrical characteristics are described in the following sections.

1. Paced morphology of right bundle branch block pattern
When the lead is placed transeptally from the right ventricular (RV) septum to LV septal subendocardium in the LBB region, the paced QRS morphology changes from an LBBB to a right bundle branch block (RBBB) pattern (Figures 2C and 2D), as the LV is activated earlier than the RV.1 However, the paced morphology could be influenced by the pacing site of the LBB, existing bundle disease, or selective or nonselective LBB capture (Figures 2D and 3B).6

2. Identification of the LBB potential
In patients with non-LBBB during intrinsic rhythm, LBB potentials should always be recorded from the LBB lead, with the potential to ventricle interval of 20–30 ms (Supplementary Figures 1A and 1C), to help confirm lead position and the level of conduction block (Supplementary Figure 2A).4 However, in patients with LBBB, LBB potentials can only be recorded during restoration of left bundle conduction by means of HBP® (Figure 3B) or under other conditions (Supplementary Figure 1B).
3. Pacing stimulus to LV activation time

Pacing stimulus to left ventricular activation time (Stim-LVAT) is defined as the interval from the pacing stimulus to the peak of the R wave and is often used to reflect the lateral precordial myocardium depolarization time in leads V4–V6 (Supplementary Figure 3). Stim-LVAT that shortens abruptly with increasing output or remains shortest and constant both at low and high outputs suggests LBB capture,4,6 which is also shorter than that in HBP (Figures 2D and 3B).
4. Determination of selective and nonselective LBBP

Selective LBBP, capturing only the LBB as a direct LBB capture sign, can be demonstrated with a discrete local component separate from the stimulus artifact on the unipolar electrogram (EGM) from the LBBP lead (Figure 3B and Supplementary Figure 4E). Capturing both the LBB and the adjacent local septal myocardium results in nonselective LBBP with no discrete local EGM and electrocardiogram morphology slightly different from that of selective LBBP (Figure 3B and Supplementary Figure 4E).

5. Evidence for direct LBB capture

The interval between the pacing stimulus and the retrograde His potential or anterograde distal LBB potential recorded with an additional lead/catheter during LBBP can be used to locate the site for left bundle branch pacing (LBBP) and electrogram characteristics. A: His potential and no clear left bundle branch (LBB) potential in left bundle branch block (LBBB). B: Location of the His-bundle pacing (HBP) lead and LBBP lead in the right anterior oblique 30° view. C: Paced morphology of “w” pattern with a notch at the nadir of the QRS in lead V1 and impedance of 300 Ω by unipolar tip pacing before fixation. D: Screwing the lead approximately 6–8 mm deep, the notch in lead V1 moved up and toward the end of the QRS with impedance of 650 Ω. With increased output from 6.0 V/0.5 ms (left) to 8.0 V/0.5 ms (middle), the paced morphology changed to right bundle branch block and the stimulus to left ventricular activation time shortened from 107 to 72 ms. The LBB potential could not be noted during LBBB correction by selective HBP.
to confirm LBB capture (Figure 4), but it need not be routinely used in clinical practice.

In clinical practice, patients who meet criteria 1, 2, and at least 1 of latter 3 criteria can be confirmed to have LBB capture.

**Procedure description (Figure 1 and Supplementary Video 1)**

**Preprocedure evaluation and implantation tools**

The thickness of the basal interventricular septum and the presence of septal scar are assessed preprocedure. Ventricular backup pacing is recommended before LBBP lead implantation in patients with LBBB because complete AV block may occur due to RBBB injury during the procedure.

The 3830 lead and the C315His sheath (Medtronic Inc, Minneapolis, MN) are used as the pacing lead and the delivery catheter. During the procedure, the pacing threshold and impedance are measured in unipolar configuration, whereas final R-wave amplitude is measured in bipolar configuration.

**How to determine the initial site for LBBP**

HBP is achieved as previously reported.\(^2,10\) The X-ray reference image of distal HBP location is routinely set as a marker for LBBP lead implantation. The initial site for LBBP is approximately 1–1.5 cm distal to the HBP lead position in the RV septum along the line between the HBP site and RV apex in the right anterior oblique (\(30^\circ\)) fluoroscopic view (Figure 2B).\(^3\) At this site, the paced QRS morphology before fixation usually demonstrates a “w” pattern with a notch at the nadir of the QRS in lead V\(_1\) (Figure 2C). We can use the “dual lead technique”\(^10\) to help improve the success rate of LBBP lead implantation in challenging implants or to confirm direct evidence of LBB capture shown in Figure 4.

**Deep fixation of the lead into the septum**

The sheath is rotated counterclockwise to maintain the orientation of the lead tip perpendicular to the septal surface and provide adequate support to screw the lead into the septum. Rapid rotations of the lead, 3–4 turns at a time by one or both hands, is suggested to achieve penetration of the lead body behind the screw, into the septum. Then, the lead is released and the rapid rotations are repeated. The myocardial current of injury (COI) would often be recorded in the EGM (Supplementary Figure 2B). With advancement of the screw in the interventricular septum, one would expect the following: (1) the notch on the paced QRS in lead V\(_1\) will move from the nadir to the end of the QRS (resultant RBBB pattern) (Figures 2B and 2C); (2) increase in unipolar pacing impedance; and (3) change in the lead’s position along with the fulcrum sign (Figure 3A) on fluoroscopy, which demonstrates the hinge point at which the lead body meets the RV septum. If perforation into the LV occurs, simply withdrawing the lead is not adequate. The lead must be repositioned at a different location.

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**Figure 4** Demonstration of direct left bundle branch (LBB) capture using retrograde His potential and anterograde distal left conduction system potential. A: Narrow QRS complex case. Deep septal pacing (first 2 beats) with a smaller \(P_{\text{O,LBB}}\), longer stimulus to left ventricular activation time (LVAT) of 90 ms, and no \(P_{\text{O,ReHis}}\). Selective left bundle branch pacing (LBBP) and nonselective LBBP at a deeper site (last 3 beats), larger \(P_{\text{O,LBB}}\), shortest and constant stimulus to LVAT of 74 ms, and \(P_{\text{O,ReHis}}\) with stimulus to \(P_{\text{O,ReHis}}\) interval of 28 ms at low and high outputs. B: In left bundle branch block, \(P_{\text{O,LBB}}\) recorded after the ventricular electrogram (EGM) from the multipolar catheter (MPC) placed distal to the LBBP lead (first beat). During septal pacing, \(P_{\text{O,LBB}}\) remained after the ventricular EGM with stimulus to LVAT of 121 ms (second beat). With selective LBBP was achieved at a deeper site, \(P_{\text{O,LBB}}\) recorded ahead of the ventricular EGM and stimulus to LVAT of 90 ms (third beat). \(P_{\text{O,LBB}}\) = distal left bundle branch potential; \(P_{\text{O,His}}\) = His potential; \(P_{\text{O,LBB}}\) = left bundle branch potential; \(P_{\text{O,ReHis}}\) = retrograde His potential.
Additional considerations

Monitoring and testing
When the tip of the lead is inside the septum to a depth of approximately 6–8 mm (confirmed by lead location on fluoroscopy by fulcrum sign or during contrast injection and/or the paced morphology of RBBB pattern and/or occurrence of RBBB morphology premature ventricular beat), low- and high-output pacing is performed to confirm whether high output can shorten the paced QRS duration and the LVAT, which indicates the nearby presence of the left conduction system (Figure 2D).

When to stop advancing the lead
As the lead is advanced into the septum, the notch on the nadir of the QRS in lead V1 moves up and toward the end of the QRS and becomes R’ (Figures 2D and 3B). Premature ventricular contractions of RBBB pattern are noted often during lead fixation (Supplementary Figure 1B). Caution should be taken at this point to avoid perforation into the LV cavity by slowly rotating the lead half to one turn at a time and carefully monitoring the paced QRS morphology and the impedance, which should be >500 Ω by unipolar pacing. When LBB capture is confirmed with a low threshold (usually <1.5 V/0.5 ms), additional rotations should be stopped.

Determination of the depth
The length between the hinge point and the helix of the lead can simply indicate the depth in the septum. The exact depth of the lead can be determined by contrast injection through the sheath in the left anterior oblique (35°) view during the procedure (Figure 3C). Other means of confirming the depth are echocardiogram during and computed tomographic imaging after the procedure (Supplementary Figures 5B and 5C).

How to manage difficulties in lead fixation
Common causes include tissue lodged in the lead helix, deformed sheath or lead helix, scar/fibrosis at the fixation site, and inadequate support by the sheath. Removing the tissue, replacing the sheath or lead, and repositioning the lead distally and inferiorly may be helpful in these situations.

Removing the sheath and confirming adequate fixation
Unlike HBP, we do not observe significant rebound or torque back after the lead is fixed to assess stability. The sheath is pulled back to the atrium while the lead is gently advanced to allow for slack. The pacing parameters are checked again to confirm stability. Adequate slack is needed to avoid perforation or lead dislodgement after sliding the sheath. The characteristics related to the implantation of LBBP and HBP are summarized and compared in Supplementary Table 1.

Potential complications

RBB injury during the procedure
Maintaining the lead inside the sheath and pulling back the sheath from the ventricle with slight counterclockwise rotation and fixing the lead at the inferior septum may decrease RBB injury. Furthermore, it is suggested to avoid lead fixation into the ventricular septum when a potential, which probably is the RBB potential, is seen.

Lead dislodgment and septal perforation
Evaluation of the septum preimplantation by echocardiogram or magnetic resonance imaging in special circumstances, such as noncompaction of the ventricular myocardium, thin septum, or scars in the septum, may help avoid lead placement at these areas. Importantly, monitoring the paced QRS morphology and impedance during each step may help prevent these problems during the procedure. Adequate slack should be provided to avoid either lead dislodgment (too little slack) or septal perforation (excessive slack) post-procedure.

Potential for coronary artery injury
To avoid injury to the coronary artery, especially the septal perforator branches, it is preferable that the lead be placed inferiorly and posteriorly because of the large septal branches in the anterior septum (Supplementary Figure 5A).

Programming considerations for LBBP
When the LBBP lead is used for cardiac resynchronization therapy (CRT) devices, the lead connection to the generator depends on the underlying rhythm (atrial fibrillation or sinus rhythm) and the choice of CRT-pacemaker or CRT-defibrillator device. For patients with chronic atrial fibrillation, the LBBP lead can be connected to the atrial port of the generator. In patients with sinus rhythm, the LBBP lead can be connected to the LV port if it completely corrects the LBBB and the AV delay adjusted to allow native conduction via the right bundle branch (Supplementary Figures 4B and 4C). In patients with Intraventricular conduction delay (IVCD) the LBBP lead can sometimes be used together with the LV lead to achieve better electrical synchrony of the LV.

Given that the pacing parameters typically are low and stable (short- and medium-term follow-up), it may not be necessary to change the sensitivity and pacing output during initial programming as with HBP. Different pacing outputs and configurations will lead to different paced QRS complex morphology. Due to anodal capture of RV septum by bipolar pacing at higher output, the paced QRS morphology may not resemble a typical RBBB; even a non-RBBB paced morphology may occur as RV delay is compensated by RV preexcitation (Supplementary Figure 4D). During threshold testing in the device clinic and follow-up, it is important to observe and document anodal capture threshold and nonselective to selective LBBP thresholds if applicable. Bipolar pacing at an acceptable pacing output (eg, 3.5 V/0.4 ms) is suggested to achieve anodal capture for partly compensating
the RV delay, but programming above anodal capture is not mandatory. Final programmed pacing output would depend on the clinical need to ensure anodal capture vs preventing excessive battery drain.

**Conclusion**
In our experience, LBBP is safe and feasible in routine clinical practice. Several concerns regarding long-term outcomes that need to be further evaluated are long-term lead performance due to excessive myocardial contractile strain on the deep-seated lead and the ability to safely extract these leads in the future. It is possible that with new deflectable sheaths and leads with a longer helix and/or stylet, LBBP could be performed more easily. Large prospective randomized studies are needed to further confirm the feasibility, long-term safety, and effectiveness of LBBP.

**Appendix**

**Supplementary data**
Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2019.06.016.

**References**