Complications, Troubleshooting and Follow-up for Left Bundle Branch Area Pacing

Sharma, Parikshit S; Vijayaraman, Pugazhendhi; Burri, Haran Kumar

How to cite

SHARMA, Parikshit S, VIJAYARAMAN, Pugazhendhi, BURRI, Haran Kumar. Complications, Troubleshooting and Follow-up for Left Bundle Branch Area Pacing. In: Arrhythmia & electrophysiology review, 2025, vol. 14, p. e20. doi: 10.15420/aer.2024.12

This publication URL: https://archive-ouverte.unige.ch/unige:189674

Publication DOI: 10.15420/aer.2024.12

Complications, Troubleshooting and Follow-up for Left Bundle Branch Area Pacing

Parikshit S Sharma ,[1] Pugazhendhi Vijayaraman [2] and Haran Burri [3]

1. Division of Cardiology, Rush University Medical Center, Chicago, IL, US; 2. Cardiology, Geisinger Heart Institute, Wilkes Barre, PA, US; 3. Cardiology Department, University Hospital of Geneva, Geneva, Switzerland

Abstract

Conduction system pacing, particularly left bundle branch area pacing (LBBAP), has become a popular form of lead implantation for patients with ventricular pacing indications. Success rates are reportedly high, and complication rates are relatively low. However, complications with LBBAP are unique and follow-up and troubleshooting need to be more meticulous. This paper reviews some of the short- and longer-term complications that one may see with LBBAP. Guidance on device programming, follow-up and tips on troubleshooting for LBBAP is also provided.

Keywords

Biventricular pacing, bundle branch block, conduction system, device programming, His bundle, left bundle branch, troubleshooting

Received: 16 March 2024 **Accepted:** 13 June 2024 **Citation:** *Arrhythmia & Electrophysiology Review* 2025;14:e20. **DOI:** https://doi.org/10.15420/aer.2024.12

Disclosures: PSS has received honoraria from and consulted for Medtronic, Biotronik and Abbott. PV has consulted for Abbott and Medtronic, has received honoraria from Medtronic, Biotronik and Boston Scientific, and has received research and fellowship support from Medtronic and holds a patent for a His bundle pacing delivery tool. HB has received institutional research/fellowship grants, speaker and consultant fees from Abbott, Biotronik, Boston Scientific, Medtronic and Microport, and is on the *Arrhythmia & Electrophysiology Review* editorial board; this did not influence peer review.

Correspondence: Parikshit S Sharma, Division of Cardiology, Rush University Medical Center, 1717 West Congress Pkwy, Suite 301 Kellogg, Chicago, IL 60612. E: Parikshit_S_Sharma@rush.edu

Given the potential for adverse clinical outcomes with long-term right ventricular (RV) pacing, conduction system pacing (CSP), which includes His bundle pacing (HBP) and left bundle branch (LBB) area pacing (LBBAP), has become a popular option for ventricular pacing among patients with bradycardia indications.[1–5] Similar to prior data on the benefits of HBP,[1] a recent observational registry comparing LBBAP with RV pacing demonstrated a significant reduction in the primary composite endpoint of heart failure hospitalisation or mortality or the need for upgrade to biventricular-CRT.[2] Data have also emerged on the potential value of CSP, particularly LBBAP, as an option for CRT. An observational international multicentre collaborative group on CSP compared LBBAP with biventricular-CRT in 1,778 CRT-indicated patients and demonstrated that LBBAP resulted in improved composite endpoint of time to death or heart failure hospitalisation compared with traditional biventricular-CRT (20.8% versus 28%; HR 1.495; 95% CI [1.213–1.842]; p<0.001).[6] Given the challenges with HBP, including implant success, sensing issues and potential for rise in His bundle capture thresholds, along with some of the data above, the enthusiasm for LBBAP (as a preferred strategy for CSP) has increased dramatically.[7]

With the increasing adoption of LBBAP, it has become more important that implanters are aware of and monitor for intra- and immediate post-procedural complications. It is also critical to ensure on-going conduction system capture (maybe particularly important in CRT-indicated cases) and to understand options for troubleshooting. This article reviews some important experiences on complications, highlights the importance of ensuring LBB capture – including some guidance on follow-up care – and reviews examples of troubleshooting in challenging cases.

Anatomy of the Conduction System

The bundle of His is the continuation of the compact atrioventricular (AV) node, measuring approximately 20 mm and with a penetrating portion or a branching portion.[8] Anatomical variations exist within the presence of the His bundle within the triangle of Koch; this may impact whether one may be able to implant the lead on the atrial or ventricular aspect of the tricuspid annulus when attempting HBP. The longitudinal structure of the His bundle, as well as presence of disease/delay within the His bundle in some cases, can make HBP technically challenging. Furthermore, if the lead is implanted more proximally along the His bundle, one may encounter challenges such as atrial over-sensing or ventricular under-sensing. Finally, the unpredictable rise in His bundle capture thresholds remains a challenge.

The LBB area offers a more distal target for lead implantation along the conduction system. The LBB takes off over the left interventricular muscular crest from the branching portion of the His bundle and fans out over the left ventricular (LV) endocardium further into Purkinje fibres. Significant anatomical variations exist in the LBB and its branches, although anterior, posterior and septal fascicles may be noted. Given the larger target zone for lead implantation, LBBAP may have perceived technical advantages over HBP. In addition, given the more distal location for lead implantation, it would be more likely to bypass most intra-Hisian or proximal conduction disease. Furthermore, given that the lead is positioned within the muscular inter-ventricular septum (IVS), this location offers better R wave sensing along with low and stable thresholds.[9]

Implant Considerations

The step-by-step approach to performing LBBAP has been previously published.[10–12] Original descriptions of LBBAP were using the Medtronic 3830 lead (lumenless lead with a fixed exposed helix) delivered to the LBBA via a fixed (C315, Medtronic) or deflectable (C304 His, Medtronic) delivery system. Indeed, most of the data on implant successes and performance of LBBAP use this system. Over the past few years, other manufacturers have released dedicated sheaths for delivery of leads targeted on the conduction system.[13] Existing extendable-retractable and stylet-driven leads are now being implanted in this region with good success and promising short–medium term performance results.[14–16] The presence of a stylet might offer these leads better support and success getting into the IVS and with final lead positioning. However, whether these leads may present unique challenges – particularly regarding stability, longer-term performance and extraction ability – remains to be answered.

Acute Intra-procedural Issues and Peri-procedural Complications

Various challenges and complications can arise during the LBBAP lead implantation intra-procedurally and within the first 24–48 hours post procedure.[17] It is important to be mindful of them and follow best practices to avoid some of these issues.

Challenges with Lead Placement

The inability to penetrate at the desired location on the muscular IVS can occur for a variety of reasons, as described in the following sections.

Non-perpendicular Orientation of the Sheath/Lead to Septum or Inadequate Sheath Support

In a lumenless lead, this is the most common reason for being unable to penetrate at the desired location in a structurally normal heart. Looking in the attitudinal left anterior oblique orientation is usually helpful to understand this challenge. Switching to a deflectable sheath (e.g. C304 His sheath, Medtronic) or a stiffer sheath with a longer reach (Selectra 3D, Biotronik) might be an option in such a situation.

Lack of Torque Transfer to the Lead Tip

This may result from angulation of the delivery sheath that is pushed forward up against the IVS, with torque buildup proximally to the curvatures. The sheath can be pinned against the septum by counterclockwise torque and straightened by slight withdrawal, thus facilitating torque transfer to the lead tip.

Proximal Location at a Fibrous Region (Annulus or Membranous septum)

It is beneficial to identify a His bundle potential to gauge the anatomical course of the conduction system and start 1–2 cm more antero-inferior. In cases where the His bundle is not identified prior to LBBAP lead implantation, it may be challenging to find the initial position on the IVS and one may end up more basal. Another clue to this would be small R wave amplitudes in the basal/membranous septal region. Preferably target a location where the R wave amplitude is >5 mV and myocardial injury current (IC) is noted prior to lead fixation. Insistent attempts to deploy the lead with little progression may result in a 'drill' effect, with lead dislodgement.[18]

Tricuspid Leaflet Pinning

Pinning of the septal leaflet (most common) of the tricuspid valve during implantation is a common reason for inability to advance the lead within the IVS. This is more common if the operator tries to advance the lead/sheath system from the annulus to the region of interest. Clues to this would be inability to advance the lead forward along with a poor ventricular IC despite good contact (when using an electrophysiologic system on the unfiltered electrograms or on the pacing system analyser). The best way to avoid this would be to clock the system off the septum, advance deeper into the ventricle and then counter and pull back to the desired site before attempting to advance the lead through the IVS.

Entrapment

Entrapment/entanglement of the helix is a phenomenon that occurs when the helix does not get grip on the septal tissue but instead becomes trapped in the septal subendocardial tissue. It is an important reason for failure to penetrate/advance the lead into the IVS. This has been reported with all types of leads but is more problematic with stylet-driven leads due to their relatively fragile extendible helix, which is more prone to damage than with lumenless leads.[19,20] Prolonged rotation of the lead body without lead advancement into the septum may eventually result in complete helix entrapment and difficulty in repositioning the lead.[20] If entanglement is suspected, gentle counterclockwise rotation and slight traction on the lead body while maintaining tension on the lead usually untangles the lead.

Tissue Lodged in the Screw

It is important to remember to clean the helix of any tissue that may be caught within it after an attempt has been made to deploy the lead within the IVS as this would hinder the ability to get a bite of the tissue or advance the system forward.[13]

Deformed Screw

This can occur after multiple attempts of deployment, particularly in areas where the system is entrapped or the septum is scarred. It is important to pay close attention to the helix when repeated attempts are made.

Intramyocardial Scar

Although this is commonly thought of by operators as the reason for failure to advance, in patients with a normal LV ejection fraction and structurally normal hearts, this is fairly uncommon.[10] It may be valuable to look at prior imaging such as cardiac echocardiography, nuclear imaging or cardiac MRI, particularly in cases with a cardiomyopathy (examples include ischaemic cardiomyopathy or sarcoid cardiomyopathy) to assess for septal scarring prior to implantation.

Perforation

Acute intra-procedural lead perforation through the IVS is important to recognise to avoid inadvertent placement of the lead in the LV cavity. There are various clues to help recognise this intra-procedurally. These are complimentary to one another and using them in conjunction would help increase the accuracy of identifying a perforation. These clues are described below.

Unipolar Pacing Impedance

One indication of possible perforation is an abrupt decrease in impedance by >150–200 ohms as one advances through the IVS and gets closer to the LV endocardium or an absolute unipolar impedance value <450 ohms. In a clinical series of 219 LBBAP cases, Ponnusamy et al. demonstrated that intra-procedural perforations were noted in 13% cases.[21] An absolute unipolar impedance value <450 ohms had a 100% sensitivity and 96.5% specificity to help diagnose an intra-procedural septal perforation during implantation. Bipolar impedance may be within range as the ring electrode is typically still within the IVS and hence one should consistently assess unipolar-tip impedance values. It is important to note that lead impedance may vary depending upon lab setup (e.g. due to testing cable types and lengths), as well as lead model and hence, an abrupt drop in impedance >200 ohms might be an important change to monitor for rather than the absolute impedance value alone.

Injury Current

When there is a good IC on the unipolar recording as the lead advances through the IVS initially and this IC gets smaller as the helix comes in contact with the LV endocardium and is completely lost with 'QS' morphology of the ventricular electrogram when the helix is completely exposed into the LV cavity (particularly if noted along with an abrupt drop in impedance and rise in threshold), that is a highly specific marker for IVS perforation[21] (*Supplementary Figure 1*). Micro-perforation is more difficult to diagnose due to preserved electrical parameters, but a fall in IC to <3–5 mV may be indicative.[11]

Unipolar/Bipolar and Tip/Ring Pacing

Typically, once the lead has perforated through the IVS, the tip electrode is not in contact with tissue and this would result in no capture at all or capture at a very high output. If the lead perforates and makes contact with the postero-medial papillary muscle, unipolar morphology would be wide (like papillary muscle premature ventricular contractions) with a high capture threshold.[22] Furthermore, one can test unipolar tip pacing (generally no/high output capture) versus unipolar ring pacing (would demonstrate LBBAP morphology with a narrow QRS and possibly qR pattern in V1)

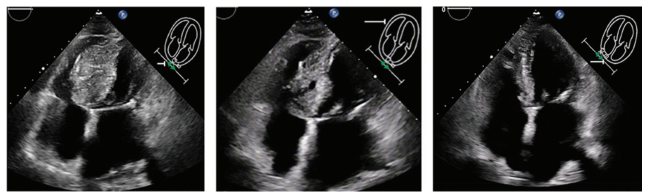
Lead Depth into the Septum on Contrast Injection Being More Than the Inter-ventricular Septum Thickness

This is another way to assess for perforation, but it is the least specific. It is important to know the IVS thickness on echocardiography prior to the case. Each lead used has a certain distance from the tip electrode to the ring electrode. If a RV septogram reveals that the depth of the lead within the IVS is greater than the known IVS thickness, this may be a clue of lead perforation.[10,23] This may be valuable if the lead is traversing in a perpendicular orientation to the IVS. However, if the lead is traversing the septum in an oblique orientation, the lead depth within the IVS would likely be more than the IVS thickness.

Coronary Vessel Injury

During LBBAP lead implantation, the lead permeates the IVS from the RV septum to the LV septum sub-endocardium. This introduces the potential risk of damage to the coronary vessels, such as the septal perforators of the left anterior descending branch (LAD), and less commonly the right posterior descending and posterior branches. Multiple reports of coronary artery injury have been reported, resulting in varying presentations of acute coronary syndrome, ranging from coronary spasm to frank injury and coronary fistulas.[24,25] In the large-scale multicentre European MELOS registry, the incidence of acute coronary syndrome was 0.4%.[26] The mechanisms of coronary injury with LBBAP involve mechanical trauma, altered coronary blood flow dynamics and endothelial damage.[27] The septal perforators of the LAD are the most likely site for injury; this can be minimised by avoiding placement of the lead higher up along the IVS. It is important to be aware and have a low threshold for assessment of this potential complication in the immediate post-procedure period. Injury to coronary vein septal perforators has also been described, but is usually an incidental finding without any clinical consequences.[28]

Figure 1: Intra-septal Haematoma Post Left Bundle Branch Area Pacing



The figure demonstrates the presence of a large intra-septal haematoma noted on POD #1 (trans-thoracic echocardiography with apical four-chamber view). POD #14 and 3-month follow-up echocardiography demonstrates resolution of haematoma (managed conservatively with holding anti-coagulation). POD = post-operative day. Source: Trivedi et al. 2023.[29] Reproduced under a Creative Commons CC BY-NC-ND 4.0 licence.

Intra-septal Haematoma

Another rare complication that has been reported in patients undergoing LBBAP is the formation of an intra-septal haematoma (*Figure 1*). A few case reports have been published on this complication. Injury to large septal perforator arteries in the proximal anterior IVS is the likely explanation for this rare phenomenon. It can be managed conservatively by stopping antiplatelet and anticoagulation therapy with careful monitoring, or may be managed by coil embolisation or covered stent of the septal perforator branch to prevent further bleeding into the muscular septum.[29,30]

Short-term Complications – Typically within 30 Days

Ravi et al. published their early experience with LBB pacing, with a focus on short-term complications and lead performance.[17] It was noted that among a series of 57 successful LBBAP cases, lead-related complications occurred in 12.3% cases. Srinathan et al. also reported their experience with LBBAP in 306 patients with stylet-driven and lumenless leads, demonstrating lead-related complications in about 8.3% patients.[31] However, the MELOS registry on LBBAP including 2,533 patients reported an overall lead-related complication rate of 8.3%.[26] The most common complications in this acute phase are described in the following sections.

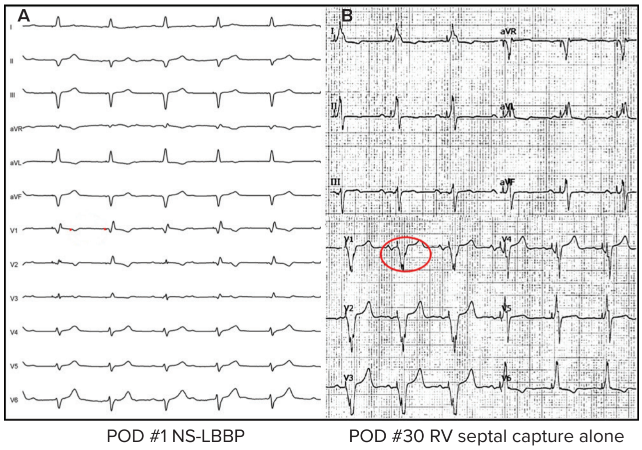
Macro- and Micro-dislodgements

With micro-dislodgment, the LBBAP lead may retract back within the IVS resulting in capture of the RV septum. This change in morphology can only be identified with follow-up ECGs, hence it is critical to perform ECGs during device testing in short-term follow-up (*Figure 2*). Possible causes of dislodgement are improper tissue fixation of the helix due to a 'drill' effect, micro-perforation and inadequate lead slack. Macro-dislodgements would generally result in complete loss of capture unless there is intermittent contact with the RV myocardium post dislodgement. In early experiences, the incidence of micro-dislodgements was reported to be 4.7–7%, while that of macro-dislodgements ranged from 3.5% to 4.3% of patients.[17,31] These rates were higher in stylet-driven leads.[31] The MELOS registry demonstrated that the rates of lead macro-dislodgement were approximately 1.5%.[26] This improvement in outcomes compared with early studies was likely because of the increased operator experience with LBBAP.

Delayed Inter-ventricular Septal Perforation

This is, fortunately, a rare complication. Various case reports of this phenomenon have been identified and published.[22,32] In the MELOS

Figure 2: Micro-dislodgement with Left Bundle Branch Area Pacing



A: POD #1 with evidence of NS-LBBP. B: POD #30 with loss of left bundle branch capture and RV septal capture alone as a result of micro-dislodgement of the left bundle branch area pacing lead. NS-LBBP = non-selective left bundle branch pacing; POD = post-operative day; RV = right ventricular. Source: Ravi et al. 2020.[17] Reproduced with permission from American Heart Association.

registry, the overall incidence of this complication was noted to be 0.1%.[26] The pathogenesis of delayed perforation is unclear. A likely cause is micro-perforation of the helix at implantation, which may go unnoticed owing to lack of symptoms and adequate electrical parameters. Forward forces resulting from myocardial contraction cycles may result in progression of the lead within the septum, ultimately leading to overt perforation.[33] Various degrees of perforation are possible. Generally, with a frank perforation, the tip electrode would be exposed within the LV cavity while the ring electrode may still be within the IVS. This may result in an acceptable morphology in the bipolar pacing configuration but no capture or an LV paced morphology with unipolar pacing. Testing lead parameters (capture threshold, pacing impedances) as well as the assessment of paced ECG morphologies in both unipolar and bipolar configurations for the first 3 months would help identify this complication. Echocardiography can be very useful to assess the tip of the lead if there are any concerns regarding perforation. If a perforation is detected, it would be critical to anti-coagulate the patient (as the lead in within the systemic circulation) and strongly consider explantation of the lead under imaging guidance (transoesophageal echocardiogram or intra-cardiac echocardiography) to avoid the future risk of cardio-embolic phenomena. *Figure 3* shows an example of a patient with LBBAP lead perforation 3 weeks post-implantation, where bipolar morphology on ECG was unchanged from the time of the implant (*Figure 3A*), but unipolar morphology was consistent with papillary muscle capture (*Figure 3B*), along with elevated thresholds but stable impedance trends. Echocardiography confirmed the lead location within the LV cavity (*Figure 3C*) and the lead was successfully explanted without any complications.[22]

Increase in Left Bundle Branch Capture Threshold

A small number of patients may demonstrate a rise in LBBAP capture thresholds in follow-up.[17] In the MELOS registry, the rate of threshold rise was 0.7% (18 of 2,533 patients), of which four cases needed a lead revision.[26] The exact mechanisms for this rise remain to be better elucidated.

Longer-Term Challenges

Left Bundle Branch Capture

Although the long-term threshold performance of LBBAP is reportedly stable, whether existing data accurately reflect on-going capture of the LBB remains unclear. Loss of conduction system capture was observed on 15 of 323 (4.6%) patients undergoing LBBAP during mean follow-up of 19 months.[34] Loss of LBB capture may have an important impact in patients with an underlying cardiomyopathy. Further retraction resulting in RV septal capture would defeat the purpose of LBBAP (*Figure 2*). Larger prospective studies with careful assessment of paced QRS morphologies in follow-up would be necessary to better understand this challenge.

Lead Extraction Challenges

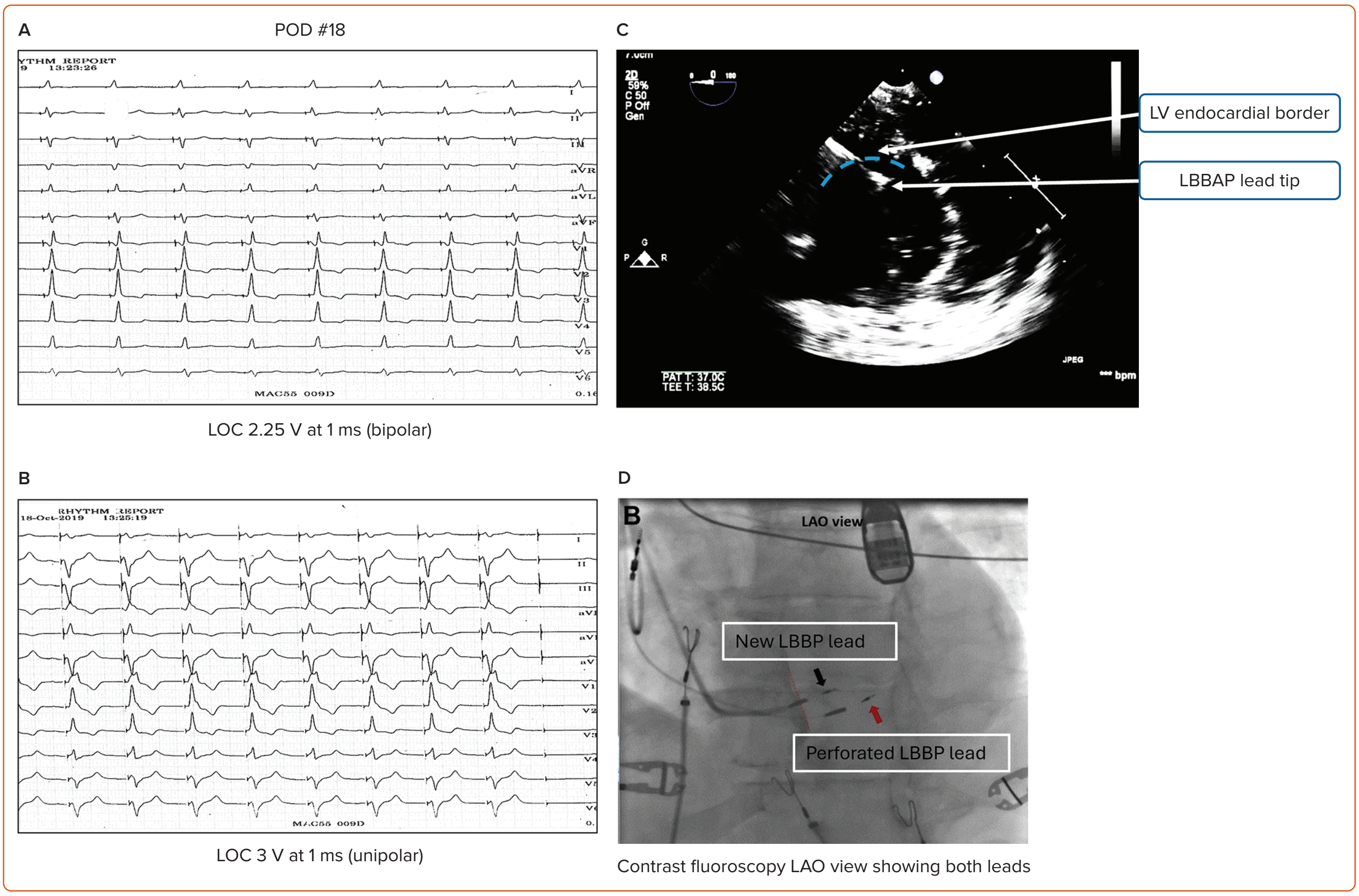
Extraction of lumenless leads implanted in the region of the LBBA is generally feasible without any challenges or need for extraction tools, especially within the first few months after implantation. Vijayaraman et al. reported the first case of extraction of a LBBAP lead (model # 3830, Medtronic), 1-year post implantation with gentle traction (without need for any extraction tools) without any challenges or residual ventricular septal defect.[35] Ponnusamy et al. reported a similar case of a LBBAP lead extraction without issues 2 years post implantation for a lead displacement.[36] Extraction of extendable retractable helix leads has also been reported with success; however, there are reported cases of helix fractures during extraction, requiring snaring of this from the groin.[37] Migliore et al. reported a small series of CSP lead extraction of which three were LBBAP leads, all of which required extraction tools and one lead was incompletely extracted with the helix of the lead (lead # 3830) left behind within the IVS.[38] So far, our initial experience in extracting the LBBAP leads (<3 years) has been encouraging without major unexpected challenges, but whether this is also the case for longer dwell times remains to be evaluated. Results of a large, multicentre observational study of CSP lead extractions are expected to be presented in the forthcoming Heart Rhythm Society scientific sessions.

Device Programming and Follow-Up

It is important to document the criteria that were used to confirm true LBB capture at the time of the original implantation. These have been previously published.[3,11] Changes in morphology with a decrement in pacing outputs are reported in 50–60% cases. Possible morphology changes would depend on the pacing polarity. In the unipolar configuration, a change from non-selective to selective left bundle branch pacing (LBBP) or LV septal capture may be noted (*Supplementary Figure 2*). In bipolar, with high output pacing, one may note anodal capture with a change to non-selective at lower outputs and selective LBBP or LV septal at the lowest outputs (*Supplementary Figure 3*). It is important to note these changes in morphology with changes in pacing output and the threshold for each of these changes. The presence of the lead in the LBBA can be labelled in the ID section of the generator and some details regarding types of morphology may be stored in the notes section of the generator (for future troubleshooting). In rare cases, such as patients with permanent AF, if the LBBAP lead is plugged into the RA port, this should also be specified.

Follow-up frequency is generally recommended with two in-person device check visits within the first 3 months, then every 6–12 months, depending on the indication for pacing (ventricular pacing-dependent patients and those with CRT devices every 6 months is recommended). During the acute phase (first 3 months post implant), outputs are usually programmed to 3.5 V at 0.4 ms. Sensing and pacing polarity are both programmed to bipolar. For patients with sinus node dysfunction, avoidance of ventricular pacing algorithms or long AV delays (after adjusting for intrinsic PR interval) are recommended, while for patients with AV block or bundle branch block (BBB), appropriate shortening of AV

Figure 3: Delayed Perforation into the Left Ventricular Cavity



A: Bipolar LBBAP morphology on ECG (unchanged from the time of the implant) suggesting left bundle branch capture; B: Unipolar paced morphology was wider and more consistent with papillary muscle capture along with elevated threshold of 3 V at 1 ms; C: Echocardiographic short axis view confirming the lead tip location within the LV cavity; D: LAO fluoroscopic image with a septogram demonstrating depth of perforated lead in comparison to new LBBAP lead depth. LAO = left-anterior oblique; LBBAP = left bundle branch area pacing; LBBP = left bundle branch pacing; LOC = loss of capture; LV = left ventricular; POD = post-operative day. D: Source: Ravi et al. 2020.[22] Reproduced with permission from Elsevier.

delays is recommended (usually PR interval −30 ms) to ensure LBB capture. If the LBBAP lead is plugged in the RA port, AV delays are programmed>LBBP to RV sensed interval. If LBB capture thresholds remain low and stable at the 3-month check, the output is lowered to twice the safety margin. Capture management is usually turned to 'off' or 'monitor' and generally would not function at all if the lead is connected to the atrial port of the device. It may be programmed 'on' if they have been shown to provide accurate measurements in a given patient.

It is essential to perform 12-lead ECGs during threshold testing (preferably in both unipolar and bipolar configurations) to ensure that there are no significant changes in the paced QRS morphologies from implantation. Changes in unipolar or bipolar morphologies along with a change in capture threshold may help identify cases of perforation into the LV cavity (*Figure 3*)[17,22] (an increase in threshold with a marked discrepancy in unipolar and bipolar thresholds should trigger prompt evaluation with transthoracic echocardiography, which can then confirm IVS perforation) or micro-dislodgements resulting in RV septal capture (*Figure 2*).[17]

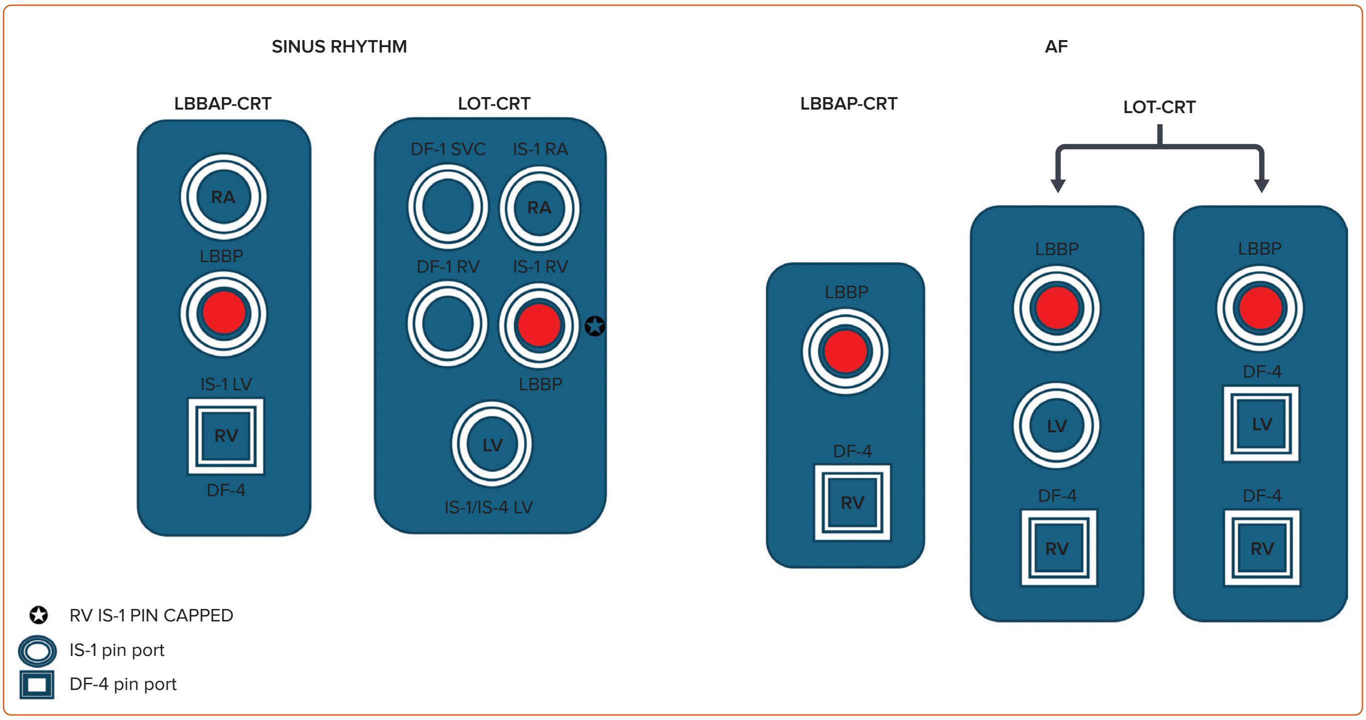
Left Bundle Branch Area Pacing-CRT and Left Bundle-optimised-CRT Programming

When LBBAP is used for CRT along with a CRT generator, it is usually plugged into the LV port of the generator. In cases of left bundle-optimised-CRT (LOT-CRT), this may be plugged into either the atrial port in patients with permanent AF, or the RV pace/sense port of the CRT generator by using a DF-1 RV defibrillator lead (the RV pace/sense portion of the lead is capped) and the LBBAP lead would be used for sensing ventricular tachycardia and ventricular fibrillation (*Figure 4*).

Special programming considerations need to be taken into account when using LBBAP in such cases. If LBBAP morphology alone results in acceptable ECG re-synchronisation, the LV-RV offsets need to be programmed to 80 ms. This would result in pseudo-fusion of RV lead pacing. In the chronic phase, the RV lead outputs can be programmed sub-threshold values to conserve battery in non-dependent patients (backup RV pulses during LV channel threshold tests may be delivered at programmed output, resulting in asystole in dependent patients). In patients with a left BBB (LBBB) and LBBAP-CRT, AV delays can be adjusted to create fusion between LBBAP and conduction over the right bundle branch to allow for simultaneous bi-ventricular activation (*Supplementary Material Figure 4*). For patients with LOT-CRT, AV and VV delays should be optimised on a case-by-case basis to optimise biventricular activation on surface ECG. Unipolar LBBAP (tip) to RV defibrillator (coil) programming may be an option for patients with LBBAP-CRT defibrillator devices and might provide another (unipolar) programming option, particularly in devices that do not offer a unipolar pacing configuration.

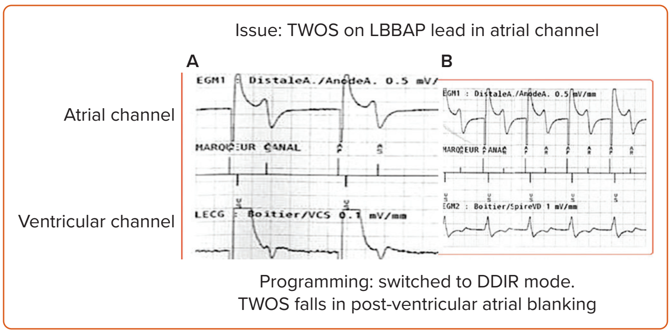
Automatic AV and VV optimisation algorithms should be inactivated, as they have not been designed for CSP.[39] Triggered ventricular pacing algorithms should generally be inactivated (nominally activated in most CRT-devices) as they may result in pseudo fusion and unnecessary battery drain.[39]

Figure 4: Left Bundle Branch Area Pacing Lead Connections in a CRT Generator: Left Bundle Branch Area Pacing-CRT and Left Bundle-Optimised-CRT Options



Connections of the LBBAP lead to the header of a CRT defibrillator (CRT-D) generator. In patients with sinus rhythm, when complete correction is achieved with LBBAP, the lead can be plugged into the LV port in the header. When LOT-CRT is performed, one must use a DF-1 RV defibrillator lead and the LBBAP lead is connected to the pace/sense port of the RV channel. In patients with underlying AF, if complete correction is achieved, the LBBAP lead can be plugged into the atrial port of a dual-chamber defibrillator and if LOT-CRT is needed, the atrial port of a CRT-D generator. CRT-D = CRT-defibrillator; LBBAP = left bundle branch area pacing; LBBAP-CRT =LBBAP-CRT; LOT-CRT = left bundle-optimised CRT; LV = left ventricular; RA = right atrial; RV = right ventricular; SVC = superior vena cava.

Figure 5: T Wave Over-sensing on a Left Bundle Branch Area Pacing Lead in the Atrial Port



An example of TWOS in a patient with permanent AF and HFrEF where the left bundle branch area pacing lead is plugged into the atrial port of a dual-chamber defibrillator and programmed to the AAIR mode at 85 BPM. A: Pacing from the LBBAP lead (AP) is followed by a sensed event (AS) that corresponds with the T wave resulting in TWOS. This resulted in a lower base pacing rate; B: Programming to a DDIR mode resulted in the TWOS falling in the post-ventricular atrial blanking period (AR) and corrected the issue. HFrEF = heart failure with reduced ejection fraction; LBBAP = left bundle branch area pacing; TWOS = T wave oversensing. Source: Bakelants et al. 2021.[39] Reproduced from Radcliffe Cardiology under a Creative Commons CC BY-NC 4.0 licence.

Troubleshooting

Sensing Issues

T Wave Over-sensing

T wave oversensing (TWOS) has been reported with LBBAP leads in both bradycardia-indicated and CRT-indicated populations (when the LBBAP lead is the lead used for sensing). TWOS is generally noted when the T waves are large and are sensed as an additional event, effectively doubling the sensed ventricular rate. The device electrogram would show a 'train track' pattern due to the alternating cycle length of RT and TR intervals forming two separate lines.

In the bradycardia population, this could result in high ventricular rate events (when the patient is not dependent on pacing) or may result in inhibition of pacing (in pacing-dependent patients; *Figure 5*).[39] The true incidence of this phenomenon remains unclear. LBBAP has been used as the pace-sense lead in cardiomyopathy patients undergoing LOT-CRT. In such patients with a CRT-D device, TWOS can result in inappropriate detection of ventricular arrhythmia, inappropriate delivery of therapy, loss of biventricular capture, and pacing at a slower rate in dependent patients.

In a study of 30 patients with LOT-CRT by Ponnusamy et al., the incidence of TWOS was noted to be 3.3% (1/30 cases), resulting in 29 episodes (11%) of inappropriately detected ventricular tachycardia, about half of which were treated with antitachycardia pacing therapy (*Figure 6*).[40] TWOS can be avoided by increasing the post-pacing ventricular refractory period, re-programming to a less sensitive R wave sensing value (at the risk of under sensing ventricular fibrillation in patients with an ICD) or changing the sensing polarity (bipolar to unipolar in non-dependent patients or integrated bipolar in patients with ICDs).

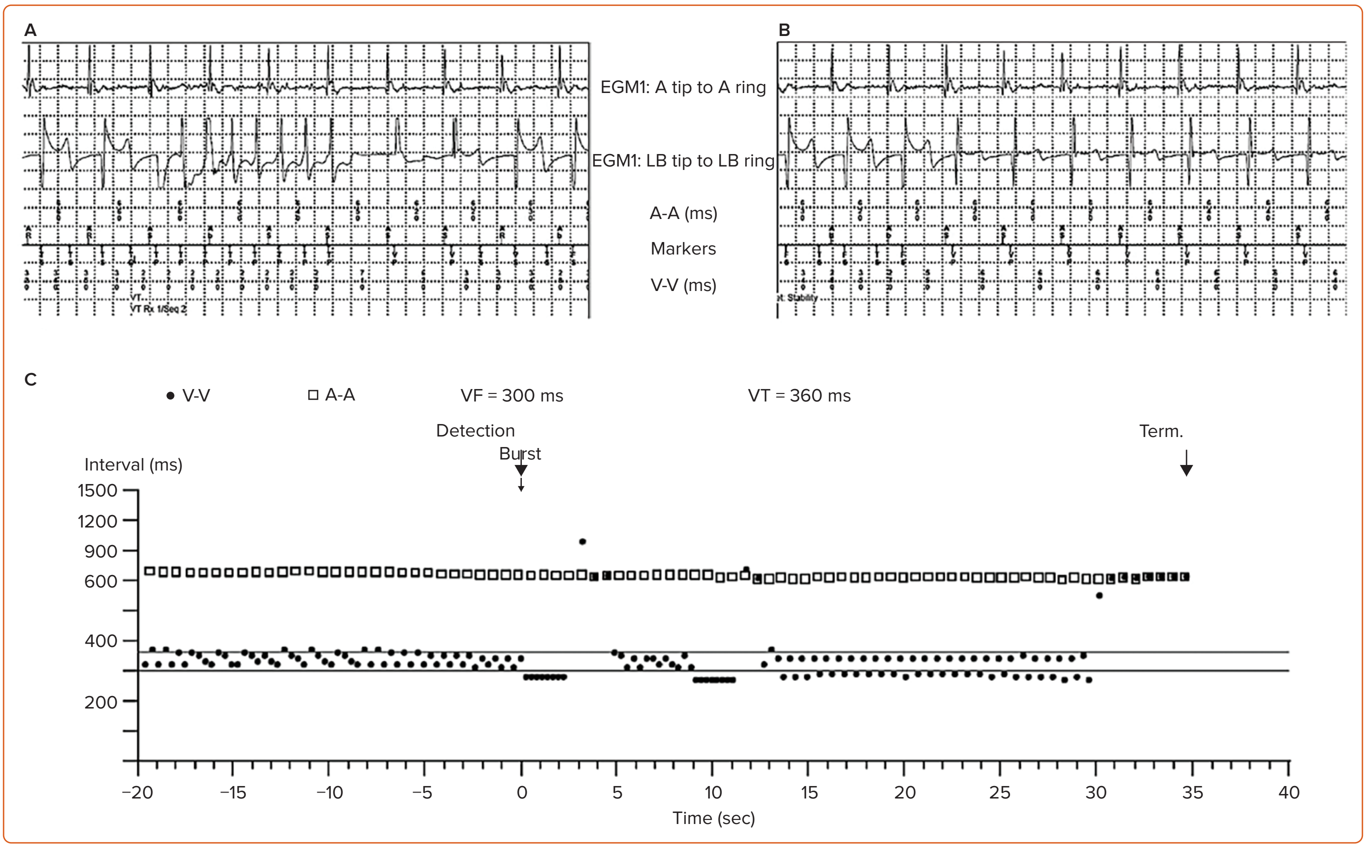
Lead Dislodgements

Micro-dislodgements or frank dislodgements may occur in the region of the LBBA. Micro-dislodgements may result in loss of LBB/LV septal capture, and one may note RV septal capture morphology alone. These are likely under-reported in current literature. Frank dislodgements would result in complete loss of capture if the lead is free floating or RV myocardial capture if the tip is making some contact with the myocardium.

Programming-related Challenges

Individualising programming based on indication for implantation, intrinsic AV conduction, presence or absence of underlying BBB is critical to help realise the true benefits of LBBAP in an individual patient. Some of the

Figure 6: T Wave Over-sensing on a Left Bundle Branch Area Pacing Lead in a CRT-defibrillator Device



TWOS inappropriately detected as VT in a patient with a CRT-D device. A: Inappropriate anti-tachycardia pacing resulted in transient termination of TWOS; B: Spontaneous resolution of inappropriately detected VT due to TWOS. Note the transient loss of conduction system capture during the TWOS episode; C: Typical 'train track pattern' due to the alternating cycle length of RT and TR intervals. CRT-D = CRT-defibrillator; EGM = electrogram; TWOS = T wave oversensing; VT = ventricular tachycardia. Source: Ponnusamy et al. 2023.[40] Reproduced with permission from Elsevier.

challenges encountered with inappropriate programming are described in the following sections.

Inappropriate Atrioventricular Delays

In patients with LBBB, in order to obtain maximal benefit of LBBAP, one must program the AV delay after adjusting for the intrinsic left bundle potential-ventricular interval. If the AV delay is programmed any longer, intrinsic AV conduction will depolarise the ventricles and pacing will result in pseudo-fusion. On the other hand, avoid programming AV delays inappropriately short (sensed AV <50 ms), particularly in patients without AV block because it may result in A wave truncation with pacemaker syndrome, resulting in pacemaker-type syndrome.

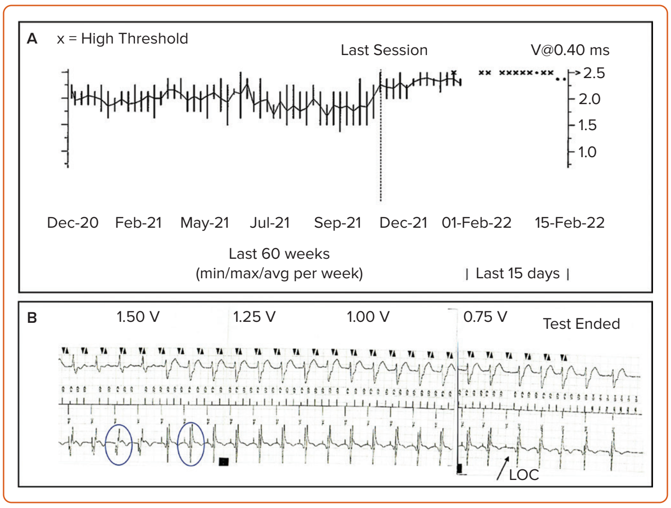
Challenges with Programmed Polarity

As sensing in the LBBA is generally good and thresholds are low, we recommend programming these leads to the bipolar sensing and pacing configuration. Unipolar sensed polarity can result in pectoral myopotential oversensing, which could result in inhibition of pacing and hence should be avoided in pacing dependent patients. Unipolar pacing may be preferable in some patients in whom anodal capture at working output leads to wide non-physiological QRS complexes, and this should be checked for carefully at the time of programming. Unipolar LBBAP (tip) to RV defibrillator (coil) programming may be an option for patients with CRT defibrillator devices and might provide another programming option in patients with LBBAP.

Automatic Capture Algorithms

Most current automatic capture algorithms are designed to assess for myocardial capture using the myocardial evoked potential. As a result, in patients with myocardial capture thresholds lower than LBB capture thresholds, the algorithm may inappropriately program an output lower

Figure 7: Failure of Autocapture Algorithm in Left Bundle Branch Area Pacing



A: Alert received for high capture thresholds on a LBBAP lead noted to be about 2.5 V at 0.4 ms; B: Device EGMs demonstrating the transition from NS-LBBP to S-LBBP (circled) and loss of capture (arrow) are shown. Unusually long stimulus to local EGM and higher thresholds differences between NS-LBBP and S-LBBP resulted in inability of the algorithm to recognise true loss of left bundle branch capture. EGM = electrogram; LBBAP = left bundle branch area pacing; NS-LBBP = non-selective left bundle branch pacing; S-LBBP = selective left bundle branch pacing. Source: Garg et al. 2023.[41] Reproduced with permission from Elsevier.

than the LBB capture threshold resulting in septal capture alone. Also, if the LBB capture threshold is significantly lower than septal myocardial capture threshold, it may result in inappropriately high pacing outputs, resulting in premature battery drain.

An example of this is demonstrated in *Figure 7*, where a significant difference between non-selective (higher threshold of 2.5 V at 0.4ms) and selective LBBAP (lower threshold of 0.75 V at 0.4 ms) results in the automatic capture demonstrating a high capture threshold while the true loss of capture is much lower.[41] However, most patients have LBB and LV septal thresholds that are within 0.5 V of each other and, in these patients, programming automatic capture algorithms may be appropriate.

Conclusion

LBBAP is a form of CSP that may present unique challenges. Understanding the various issues one can encounter during implantation and an in-depth knowledge regarding sensing and capture in this region are critical to troubleshooting and appropriate programming during implant and in follow-up. ❑

Clinical Perspective

- Left bundle branch area pacing (LBBAP) has gained popularity as a pacing therapy for synchronised biventricular activation in patients undergoing cardiac implantable electronic device implantations.
- The nuances of this implant procedure and of pacing in this region create challenges that are unique compared with other forms of cardiac pacing.
- This article reviews the short- and long-term complications, provides guidance on follow-up and troubleshooting examples with LBBAP with the intent of educating and helping providers of implantation.

1. Abdelrahman M, Subzposh FA, Beer D, 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; PMID: 29535066.
2. Sharma PS, Patel NR, Ravi V, et al. Clinical outcomes of left bundle branch area pacing compared to right ventricular pacing: results from the Geisinger-Rush Conduction System Pacing Registry. *Heart Rhythm* 2022;19:3–11. https://doi.org/10.1016/j.hrthm.2021.08.033; PMID: 34481985.
3. Chung MK, Patton KK, Lau CP, et al. 2023 HRS/APHRS/LAHRS guideline on cardiac physiologic pacing for the avoidance and mitigation of heart failure. *Heart Rhythm* 2023;20:e17–91. https://doi.org/10.1016/j.hrthm.2023.03.1538; PMID: 37283271.
4. Keene D, Anselme F, Burri H, et al. Conduction system pacing, a European survey: insights from clinical practice. *Europace* 2023;25:euad019. https://doi.org/10.1093/europace/euad019; PMID: 36916199.
5. Kircanski B, Boveda S, Prinzen F, et al. Conduction system pacing in everyday clinical practice: EHRA physician survey. *Europace* 2023;25:682–7. https://doi.org/10.1093/europace/euac201; PMID: 36413604.
6. Vijayaraman P, Sharma PS, Cano Ó, et al. Comparison of left bundle branch area pacing and biventricular pacing in candidates for resynchronization therapy. *J Am Coll Cardiol* 2023;82:228–41. https://doi.org/10.1016/j.jacc.2023.05.006; PMID: 37220862.
7. Perino AC, Wang PJ, Lloyd M, et al. Worldwide survey on implantation of and outcomes for conduction system pacing with His bundle and left bundle branch area pacing leads. *J Interv Card Electrophysiol* 2023;66:1589–600. https://doi.org/10.1007/s10840-022-01417-4; PMID: 36607529.
8. Sharma PS, Vijayaraman P, Ellenbogen KA. Permanent His bundle pacing: shaping the future of physiological ventricular pacing. *Nat Rev Cardiol* 2020;17:22–36. https://doi.org/10.1038/s41569-019-0224-z; PMID: 31249403.
9. Raymond-Paquin A, Padala SK, Ellenbogen KA. Left bundle branch pacing: a perfect compromise? *Arrhythm Electrophysiol Rev* 2021;10:241–3. https://doi.org/10.15420/aer.2021.60; PMID: 35106175.
10. Huang W, Chen X, Su L, et al. A beginner's guide to permanent left bundle branch pacing. *Heart Rhythm* 2019;16:1791–6. https://doi.org/10.1016/j.hrthm.2019.06.016; PMID: 31233818.
11. Burri H, Jastrzebski M, Cano Ó, et al. EHRA clinical consensus statement on conduction system pacing implantation: executive summary. Endorsed by the Asia-Pacific Heart Rhythm Society (APHRS), Canadian Heart Rhythm Society (CHRS) and Latin-American Heart Rhythm Society (LAHRS). *Europace* 2023;25:1237–48. https://doi.org/10.1093/europace/euad044; PMID: 37061850.
12. Diaz JC, Duque M, Aristizabal J, et al. The emerging role of left bundle branch area pacing for cardiac resynchronisation therapy. *Arrhythm Electrophysiol Rev* 2023;12:e29. https://doi.org/10.15420/aer.2023.15; PMID: 38173800.
13. Ravi V, El Baba M, Sharma PS. His bundle pacing: tips and tricks. *Pacing Clin Electrophysiol* 2021;44:26–34. https://doi.org/10.1111/pace.14108; PMID: 33174216.
14. De Pooter J, Ozpak E, Calle S, et al. Initial experience of left bundle branch area pacing using stylet-driven pacing leads: a multicenter study. *J Cardiovasc Electrophysiol* 2022;33:1540–9. https://doi.org/10.1111/jce.15558; PMID: 35598298.
15. Cano Ó, Navarrete-Navarro J, Zalavadia D, et al. Acute performance of stylet driven leads for left bundle branch area pacing: a comparison with lumenless leads. *Heart Rhythm* 2023;4:765–76. https://doi.org/10.1016/j.hroo.2023.11.014; PMID: 38204462.
16. Ozpak E, Van Heuverswyn F, Timmermans F, De Pooter J. Lead performance of stylet-driven leads in left bundle branch area pacing: results from a large single-center cohort and insights from in vitro bench testing. *Heart Rhythm* 2024;21:865–73. https://doi.org/10.1016/j.hrthm.2024.01.049; PMID: 38307309.
17. Ravi V, Hanifin JL, Larsen T, et al. Pros and cons of left bundle branch pacing: a single-center experience. *Circ Arrhythm Electrophysiol* 2020;13:e008874. https://doi.org/10.1161/CIRCEP.120.008874; PMID: 33198496.
18. Jastrzebski M, Moskal P, Holda MK, et al. Deep septal deployment of a thin, lumenless pacing lead: a translational cadaver simulation study. *Europace* 2020;22:156–61. https://doi.org/10.1093/europace/euz270; PMID: 31722391.
19. De Pooter J, Wauters A, Van Heuverswyn F, Le Polain de Waroux JB. A guide to left bundle branch area pacing using stylet-driven pacing leads. *Front Cardiovasc Med* 2022;9:844152. https://doi.org/10.3389/fcvm.2022.844152; PMID: 35265691.
20. le Polain de Waroux JB, Wielandts JY, Gillis K, et al. Repositioning and extraction of stylet-driven pacing leads with extendable helix used for left bundle branch area pacing. *J Cardiovasc Electrophysiol* 2021;32:1464–6. https://doi.org/10.1111/jce.15030; PMID: 33825263.
21. Ponnusamy SS, Basil W, Vijayaraman P. Electrophysiological characteristics of septal perforation during left bundle branch pacing. *Heart Rhythm* 2022;19:728–34. https://doi.org/10.1016/j.hrthm.2022.01.018; PMID: 35066178.
22. Ravi V, Larsen T, Ooms S, et al. Late-onset interventricular septal perforation from left bundle branch pacing. *HeartRhythm Case Rep* 2020;6:627–31. https://doi.org/10.1016/j.hrcr.2020.06.008; PMID: 32983881.
23. Ferrari ADL, Pacheco DS, Segat F, Chemello D. Breaching septal veins while attempting left bundle branch area pacing. If necessary, septography contrast should be injected in a stepwise approach. *J Arrhythm* 2023;39:984–7. https://doi.org/10.1002/joa3.12942; PMID: 38045450.
24. Ponnusamy SS, Vijayaraman P. Aborted ST-elevation myocardial infarction – an unusual complication of left bundle branch pacing. *HeartRhythm Case Rep* 2020;6:520–2. https://doi.org/10.1016/j.hrcr.2020.05.010; PMID: 32817832.
25. Ferrari ADL, Klafke LH, Soccol R, et al. Coronary artery complications after left bundle branch area pacing: an increasingly reported issue in the era of physiologic pacing. *Pacing Clin Electrophysiol* 2024;47:101–5. https://doi.org/10.1111/pace.14710; PMID: 37158275.
26. Jastrzebski M, Kielbasa G, Cano O, et al. Left bundle branch area pacing outcomes: the multicentre European MELOS study. *Eur Heart J* 2022;43:4161–73. https://doi.org/10.1093/eurheartj/ehac445; PMID: 35979843.
27. Raza MH, Maqbool MU, Kumar S, et al. Coronary artery complications with left bundle branch area pacing: a review of literature. *Pacing Clin Electrophysiol* 2023;46:1222–9. https://doi.org/10.1111/pace.14822; PMID: 37708313.
28. Molina-Lerma M, Tercedor-Sanchez L, Molina-Jimenez M, Alvarez M. Visualization of a septal perforator branch vein and coronary sinus during left bundle pacing implant. *Eur Heart J Case Rep* 2021;5:ytab049. https://doi.org/10.1093/ehjcr/ytab049; PMID: 33738425.
29. Trivedi R, Rattigan E, Bauch TD, et al. Giant interventricular septal hematoma complicating left bundle branch pacing: a cautionary tale. *JACC Case Rep* 2023;16:101887. https://doi.org/10.1016/j.jaccas.2023.101887; PMID: 37396319.
30. Del Castillo C, Van-Grieken J, Coello M, et al. Interventricular septal hematoma complicating left branch bundle lead implantation: treatment by covered stent. *JACC Case Rep* 2023;28:102087. https://doi.org/10.1016/j.jaccas.2023.102087; PMID: 38204533.
31. Sritharan A, Kozhuharov N, Masson N, et al. Procedural outcome and follow-up of stylet-driven leads compared with lumenless leads for left bundle branch area pacing. *Europace* 2023;25:euad295. https://doi.org/10.1093/europace/euad295; PMID: 37766468.
32. Hsieh JC, Gabriels JK, Epstein LM, Beldner S. Ventricular tachycardia due to delayed septal perforation by a left bundle branch area pacing lead. *HeartRhythm Case Rep* 2024;10:113–6. https://doi.org/10.1016/j.hrcr.2023.12.004; PMID: 38404974.
33. Burri H. Perforation of the interventricular septum with left bundle branch area pacing: diagnosis and management. *HeartRhythm Case Rep* 2024;10:117–8. https://doi.org/10.1016/j.hrcr.2023.12.017; PMID: 38404975.
34. Ponnusamy SS, Ganesan V, Vijayaraman P. Loss of capture during long term follow-up after left-bundle-branch-pacing. *JACC Clin Electrophysiol* 2023;9:418–20. https://doi.org/10.1016/j.jacep.2022.10.006; PMID: 36752483.
35. Vijayaraman P. Extraction of left bundle branch pacing lead. *JACC Clin Electrophysiol* 2020;6:903–4. https://doi.org/10.1016/j.jacep.2020.04.005; PMID: 32703579.
36. 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; PMID: 34245478.
37. Agudo CA, Jaen EGI, Sanchez DJ, et al. Extraction of a fractured pacemaker lead in the left bundle branch area using a snare via a femoral approach. *J Interv Card Electrophysiol* 2023;66:239–40. https://doi.org/10.1007/s10840-022-01325-7; PMID: 35951215.
38. Migliore F, Pittorru R, De Lazzari M, et al. Transvenous lead extraction of lumenless 3830 pacing lead in conduction system pacing: a single-center experience. *J Interv Card Electrophysiol* 2024;67:175–82. https://doi.org/10.1007/s10840-023-01590-0; PMID: 37365481.
39. Bakelants E, Burri H. Troubleshooting programming of conduction system pacing. *Arrhythm Electrophysiol Rev* 2021;10:85–90. https://doi.org/10.15420/aer.2021.16; PMID: 34401180.
40. Ponnusamy SS, Ramalingam V, Mariappan S, et al. Left bundle branch pacing lead for sensing ventricular arrhythmias in implantable cardioverter-defibrillator: a pilot study (LBBP-ICD study). *Heart Rhythm* 2024;21:419–26. https://doi.org/10.1016/j.hrthm.2023.12.009; PMID: 38142831.
41. Garg R, Hussain M, Ponnusamy SS, Vijayaraman P. Automatic capture threshold testing in left bundle branch pacing: a rare failure. *Heart Rhythm* 2023;20:S587–8. https://doi.org/10.1016/j.hrthm.2023.03.1244.