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Implant, assessment, and management of conduction system pacing

Kevin Vernooy [1]*, Daniel Keene[2], Weijian Huang[3], and Pugazhendhi Vijayaraman[4]

[1]Cardiovascular Research Institute Maastricht (CARIM), Maastricht University Medical Center, P. Debyelaan 25, 6229 HX, Maastricht, The Netherlands; [2]National Heart and Lung Institute, Imperial College London, UK; [3]The First Affiliated Hospital of Wenzhou Medical University, Wenzhou, China; and [4]Geisinger Wyoming Valley Medical Center, Wilkes-Barre, PA, USA

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His bundle pacing and left bundle branch pacing, together referred to as conduction system pacing, have (re)gained considerable interest over the past years as it has the potential to preserve and/or restore a more physiological ventricular activation when compared with right ventricular pacing and may serve as an alternative for cardiac resynchronization therapy. This review manuscript dives deeper into the implantation techniques and the relevant anatomy of the conduction system for both pacing strategies. Furthermore, the manuscript elaborates on better understanding of conduction system capture with its various capture patterns, its potential complications as well as appropriate follow-up care. Finally, the limitations and its impact on clinical care for both His bundle pacing and left bundle branch pacing are being discussed.

Introduction

Conduction system pacing (CSP) has gained considerable interest over the past 5–10 years. Physiologic pacing of the conduction system has the potential to preserve and/or restore the physiological activation of the ventricles as compared to right ventricular pacing (RVP) and may also serve as an alternative for cardiac resynchronization therapy (CRT). The number of CSP implantation procedures has risen dramatically and is fast becoming part of mainstream practice in many centres across Europe.[1,2]

The initial feasibility of permanent His-bundle pacing (HBP) was demonstrated in a case report in 2000,[3] with improvements in implant success rates only more recently confirmed[4,5] This has provided the basis for the introduction of HBP into the European pacing guidelines.[6]

More recently, left bundle branch area pacing (LBBAP) using a deep septal approach to stimulate the left bundle branch has been described.[7–10] Due to the limitations of HBP, LBBAP has emerged an alternative method of CSP for delivering physiological pacing. Disadvantages of LBBAP are few, and as a result, LBBAP has become the most widely used approach for providing more synchronous ventricular activation. At present, LBBAP is not yet included in either European guideline for pacing therapy given the lack of large, randomized studies to date. Most of the data regarding its safety and efficacy stem from observational studies. Recently, HRS/APHRS/LAHRS have however already provided new guidelines on utilization of both HBP and LBBAP.[11]

The objective of this manuscript is to delve deeper into HBP and LBBAP implant techniques, improving the understanding of conduction system capture during implant, with appropriate follow-up care.

His-bundle pacing

His-bundle pacing aims to activate both right and left ventricles utilizing the entirety of their natural conduction system. This approach implies that completely normal physiological ventricular activation be achieved. The first report of permanent HBP in 2000 demonstrated its

*Corresponding author. Tel: +31 43 3875370, Fax: +31 43 3877081, Email: Kevin.Vernooy@mumc.nl

feasibility,[3] but it is worth noting the lack of dedicated implant tools which led to a very low implant success rate of only 66% which was further discouraged by high thresholds (2.4 ± 1.0 V at 0.5 ms) and very long procedure times. Implant success rates have improved and have been more recently reported to be in the range of 80–93% with the recently published HOPE HF trial demonstrating a 93% implantation success rate.[12-15] Initial reports included patients with proximal conductions system block induced by atrio-ventriuclar (AV) node ablation. In circumstances of more distal disease, however, there were initial concerns about the reliability of capture in HBP. Encouragingly observational studies have demonstrated the feasibility of HBP in many such patients, including those with permanent complete heart block.[12,13]

In a long-term observational study of patients with a bradycardia indication for pacing, 304 patients (92% of those attempted) received HBP and were compared to 433 patients who received RVP. During mean follow-up of 725 ± 423 days, HBP demonstrated stable and parameters with reliable pacing. It was noted that pacing thresholds were higher in the HBP group at 1.30 ± 0.85 V at 0.79 ± 0.26 ms vs. 0.59 ± 0.42 V @ 0.5 ± 0.03 ms; $P < 0.01$, and the sensed R wave was also lower in the HBP. This observational comparison further demonstrated that the HBP group experienced significantly lower death, heart failure hospitalizations, or need for upgrade to biventricular pacing as compared to the RVP group (25% vs. 31.6%, $P = 0.02$). This difference was most pronounced in patients who had a higher burden (>20%) of ventricular pacing (25.3% vs. 35.6% $P = 0.02$).[12]

His-bundle pacing has also shown promise as an alternative method for delivering CRT. In patients with underlying bundle branch block, HBP may overcome the bundle branch block and result in subsequent normalization of ventricular activation time and pattern.[16-18] Although there are several hypotheses for how this occurs, the simplest explanation is that a bundle branch block often occurs as a result of fascicular conduction block or delay within the His bundle. This block or delay can be overcome by positioning the pacing lead distal to the site of block and thus permitting electrical bypass and reversal of the block. Dramatic improvements in QRS duration can be observed, but this is not in all patients; conservative estimates suggesting improvement in 60% of attempted cases and more buoyant reports as high as 90%.[13,14,19]

His-bundle pacing has several procedural advantages over biventricular pacing, which include the absence of contrast required during the procedure, absence of phrenic nerve stimulation, and implantation is not limited by the constraints of the coronary sinus anatomy.

Anatomy of the His bundle

An appreciation of the anatomy of the His Bundle is critical for the implantation procedure and in order to better understand the response to pacing. The His bundle is a cord-like structure, made up of multiple filaments contained within a fibrous sheath. These internal filaments are described to be longitudinally dissociated from one and other. Each filament is predetermined for either the right or left bundle from the point at which they exit the AV node.[20]

The non-branching section of the His bundle extends from the compact AV node within the membranous septum before dividing into its respective bundle branches and crossing the AV junction. This non-branching section is approximately 15–20 mm in length.[21,22] It is typically in this region that is targeted during lead implantation. The lack of surrounding ventricular myocardial tissue present within this region given the vicinity of the membranous septum decreases the likelihood of obtaining non-selective capture than at more distal implant sites. Clearly, this could have important negative implications particularly in patients with underlying atrio-ventricular block.

Autopsy studies in 105 Japanese men have identified three anatomical variants of the His bundle, each giving a differing response to pacing.[22] Varying responses to pacing may even be present within the same patient. The majority of patients (~50%) will have a *type 1* anatomy where the HB has just a thin layer of myocardial cells covering it. In contrast, *type 2* patients (~30%) are more likely have a higher riding muscular septum within which their HB is located. The implication of this structure is that there is a thicker muscular layer separating the pacing lead from the His Purkinje fibres. Finally, *type 3* patients (~20%) have no muscular layer surrounding the HB, and it is frequently described as the *naked* type. In the latter case, the pacing lead may therefore more easily engage the His-bundle fibres. These anatomical variations are shown in *Figure 1*.

Implantation

The pacing lead most often used for permanent HBP pacing is the Medtronic SelectSecure 3830 lead (Medtronic, MN, USA). This lead is a non-stylet-driven, lumenless 4.1-Fr lead which requires a delivery sheath for its deployment. The lead is an active fixation lead with an exposed helix screw mechanism.

The standard lead delivery sheath is a non-deflectable fixed dual curve catheter (C315His sheath 43 cm, Medtronic). The first curve aims to bring the delivery system forward across the tricuspid valve and the second curve then points the delivery system in a septal direction arriving at the septum in a perpendicular fashion. Unlike traditional pacing where lead placement uses fluoroscopic guidance predominantly, His bundle lead placement primarily relies on electrical mapping (less frequently pace mapping) to identify the appropriate target site. If required, the sheath can be manually reshaped with the dilator within the sheath to offer longer reach and a more septal curve.

Mapping of His bundle electrograms is performed in a unipolar fashion wherein only the very tip of the pacing lead needs to be exposed beyond the end of the delivery sheath. This has two advantages:

(1) should it be exposed further it may catch on surrounding cardiac structures or trap myocardial tissue, both may impair the leads' ability to deploy adequately.
(2) When deploying the lead, it is important to have the delivery catheter as close as possible to the lead-myocardial interface to provide support for deploying the lead.

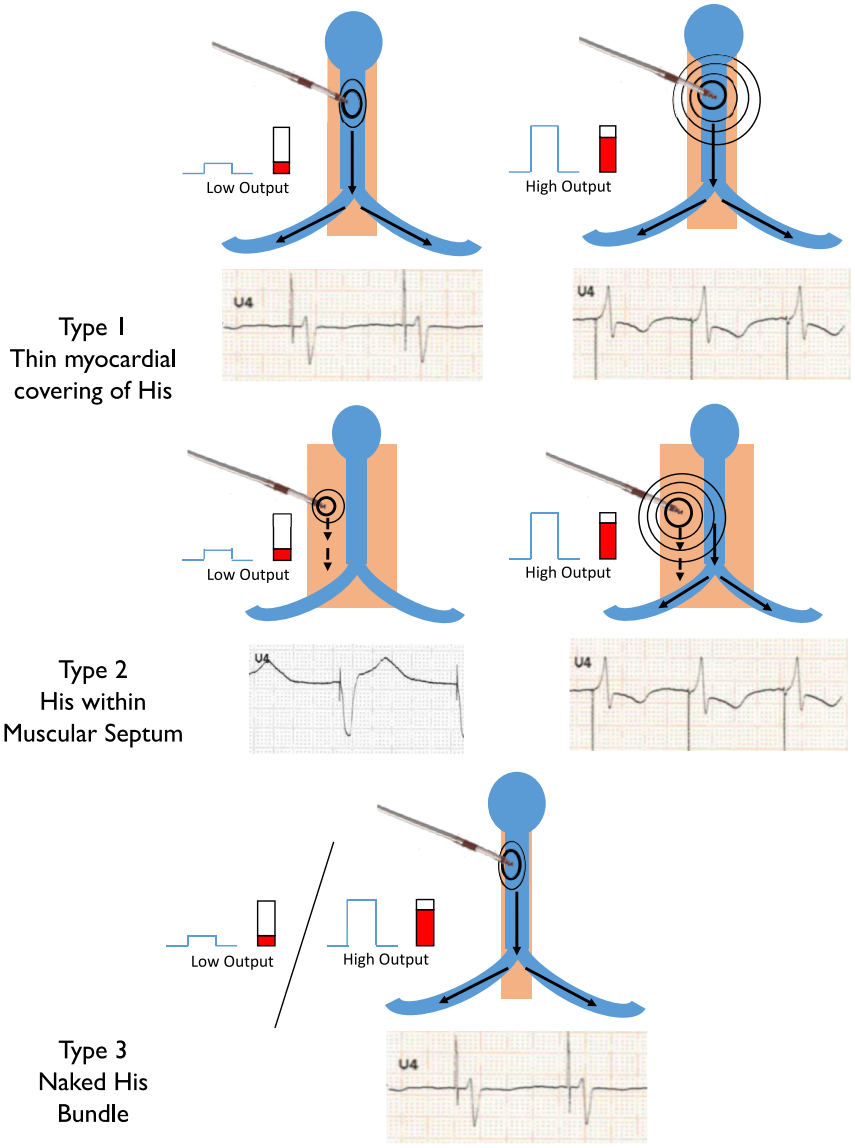


Figure 1 His anatomical variations and the effect on pacing response of His bundle pacing with varying pacing outputs. See text for further explanation.

Should mapping be performed in bipolar fashion the lead would need to be exposed at least 1 cm outside the delivery catheter.

An electrogram detected by the lead tip is displayed during mapping either via a Pacing System Analyser or via a dedicated electrophysiology system. This second approach of mapping via a dedicated electrophysiology system is preferred for HBP as it allows mapping of the signal with real-time alignment with a full 12-lead ECG recording. This is of particular utility for HBP when assessing the response to pacing to enable confirmation of His bundle capture.

A His electrogram is targeted, which is usually surrounded by a preceding atrial component and followed by a ventricular electrogram. The more distal the site along the His Bundle the smaller the atrial component and the larger the ventricular component. More distal sites are often favoured due to improved ventricular sensing and less risk of inadvertent atrial tissue capture. More distal sites may allow the pacing lead to potentially be distal to localized conduction system block that may be present in the proximal His bundle location. The optimal ratio of atrial signal amplitude to ventricular amplitude is at least 1:3 with a His electrogram between the two as shown *Figure 2*.

Clockwise rotation of the delivery sheath points the sheath towards the superior atrio-ventricular septum and towards the right ventricle. This movement enables placement more distally along the conduction system. Conversely, anticlockwise rotation will direct the delivery system towards the mid/posterior septum and the atrial region.

Once a suitable site has been found, the lead is deployed with support from the delivery catheter by at least 4–5 complete rotations of the lead. Fixation can be determined by tactile feedback secondary to a build-up of torque within the lead body as it is deployed.

Once the lead is deployed, it is important to initially confirm that the electrograms observed in the unipolar

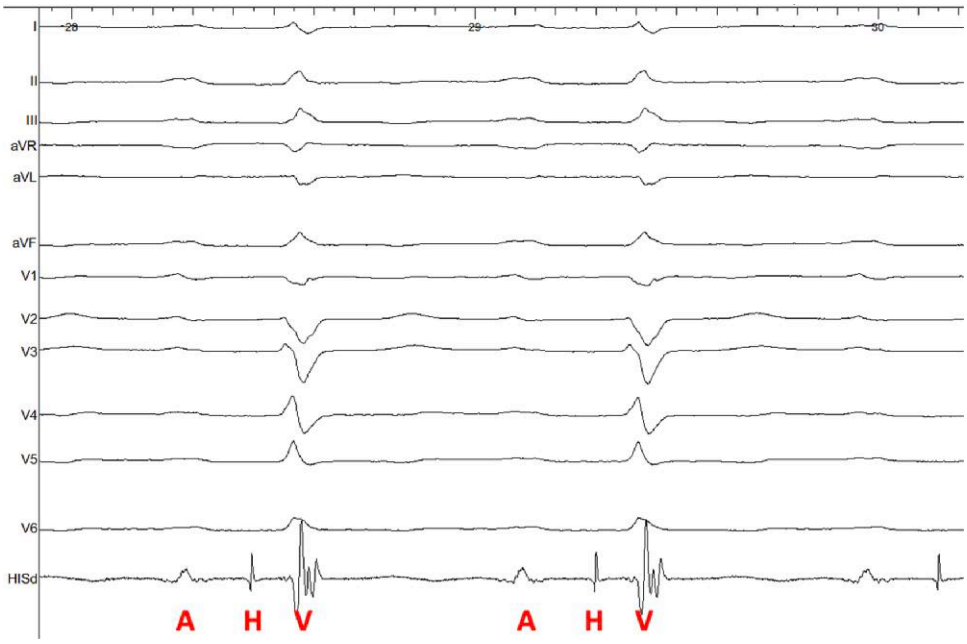


Figure 2 His-bundle electrogram mapping approach with the 12-lead ECG and unipolar electrogram of the tip of the His-bundle lead showing a small atrial signal (A), the His-bundle potential (H) and a large ventricular signal (V).

configuration remain satisfactory and inadvertent displacement has not occurred. Next, the delivery catheter should be pulled back whilst applying forward pressure to the pacing lead in a '*push-pull*' approach to allow slack to be present on the lead and to expose both the anode and the cathode. The delivery catheter is then brought back to the level of the mid or high right atrium. At this point, the response to pace stimulation can be tested. If sensing and pacing responses are satisfactory, the delivery sheath can then be slit in the standard way.

Pacing responses

To confirm successful His bundle capture utilizing the His bundle, a 12-lead ECG and the lead electrogram are required. Assessment is made of the relationship between the pacing stimulus and ventricular signal on the lead electrogram and the paced QRS morphology response on the 12-lead ECG. Assessment of this relationship is easiest with an EP recording system where all the required channels are aligned. These responses are compared with the native QRS and intrinsically observed His signal and relationship with native QRS. A number of responses may be observed.

Selective HBP is defined as ventricular activation occurring solely over the His Purkinje system and is associated with an isoelectric stimulus-ventricular interval that is equal to HV interval, and identical QRS morphology (unless there is correction of underlying bundle branch block). Hallmarks of selective capture are shown in *Figure 3*.

Non-selective capture involves activation of surrounding myocardium in addition to engaging the His bundle. This results in a pseudodelta wave following the pacing artefact and subsequent rapid activation of the QRS. Hallmarks of non-selective capture are shown in *Figure 3*. Locations that permit non-selective capture are likely to be more distal along the conduction system and associated with lower thresholds and greater sensing and also obligatory myocardial capture which may offer reassurance and safety, should His capture thresholds rise.

The RV activation is different between selective and non-selective HBP. The basal and mid RV are activated earlier in non-selective HBP.[23] However, it is important to note LV activation time and pattern remain entirely homogenous and the same as selective HBP, suggesting that this LV activation pattern is not affected by selective or non-selective HBP.

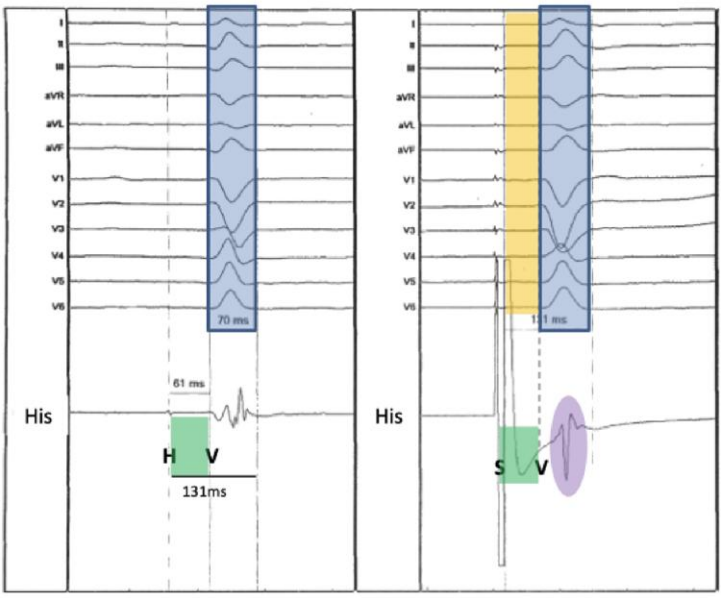
Patients with *type one* anatomy, i.e. those with only a minimal amount of myocardium covering the His bundle, selective capture can commonly be achieved (*Figure 1*, upper row) with non-selective to selective HBP transition occurring during threshold testing. In *type two* anatomy, where the His bundle is deep within the muscular septum, (*Figure 1*, middle row) non-selective HBP to myocardial capture transition is seen during threshold testing. In those patients with a *type three* anatomy, with a *naked* His bundle, His bundle injury current is more often observed on the electrogram and capture thresholds are observed to be low with obligatory selective HBP (*Figure 1*, lower row).

Left bundle branch pacing

Left bundle branch pacing (LBBP) is defined as stimulation of the left bundle branch (LBB) and is usually non-selective (i.e. there is in addition local left ventricular septal myocardial capture), whereas the term left ventricular septal pacing (LVSP) is used when only myocardial capture is present without direct capture of the left bundle or its branches. Left fascicular pacing (LFP) is the term used when the left-sided conduction system is captured distal to the division of the main left bundle

Selective His Bundle pacing

1. *Isoelectric interval between stimulus and QRS onset*
2. *HV interval = stimulus – V interval or a shorter stimulus – V interval if QRS narrowing occurs in BBB*
3. *QRS identical to native morphology or narrower QRS (if intrinsic BBB) with concordance of the T wave complexes*
4. *Discrete local ventricular electrogram on HBP lead*
5. *Widening of the QRS at higher outputs as local myocardium is captured (2/3 of cases)*



Non-Selective His Bundle pacing

1. *Interval from stimulus to end of the QRS = His to end of QRS during native conduction*
2. *Shorter stim to end QRS interval in normalisation of BBB.*
3. *Pseudo delta wave after stimulus reflecting basal anteroseptal ventricular capture*
4. *Electrical axis of the paced QRS must be concordant with the electrical axis of the native QRS*
5. *More likely narrowing of QRS with high output*

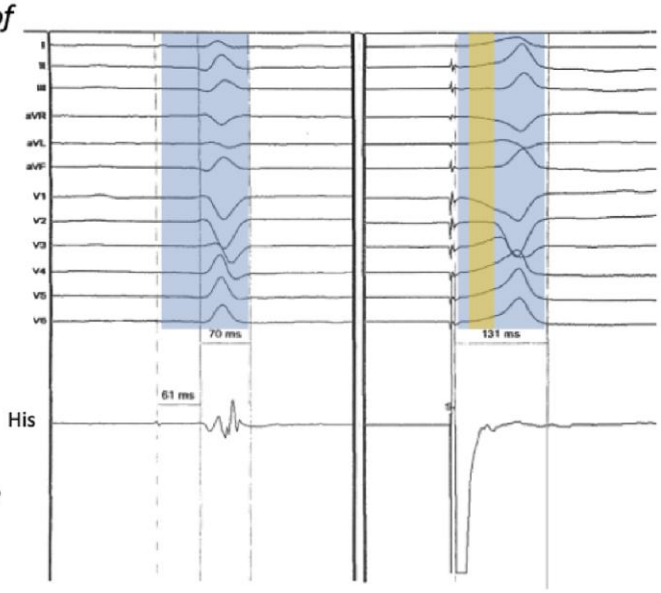


Figure 3 Hallmarks of selective and non-selective His bundle pacing.

branch in the anterior, septal, or posterior fascicules. The term left bundle branch area pacing (LBBAP) is a practical designation intended to reflect the common scenario when differentiation between LBBP, LFP, and LVSP is impossible, uncertain, or not feasible.

Anatomy of left bundle branch

Knowledge of the location of the atrial and penetrating components of the conduction system and their relation with the His bundle location during LBBP are of importance for a successful procedure.[24]

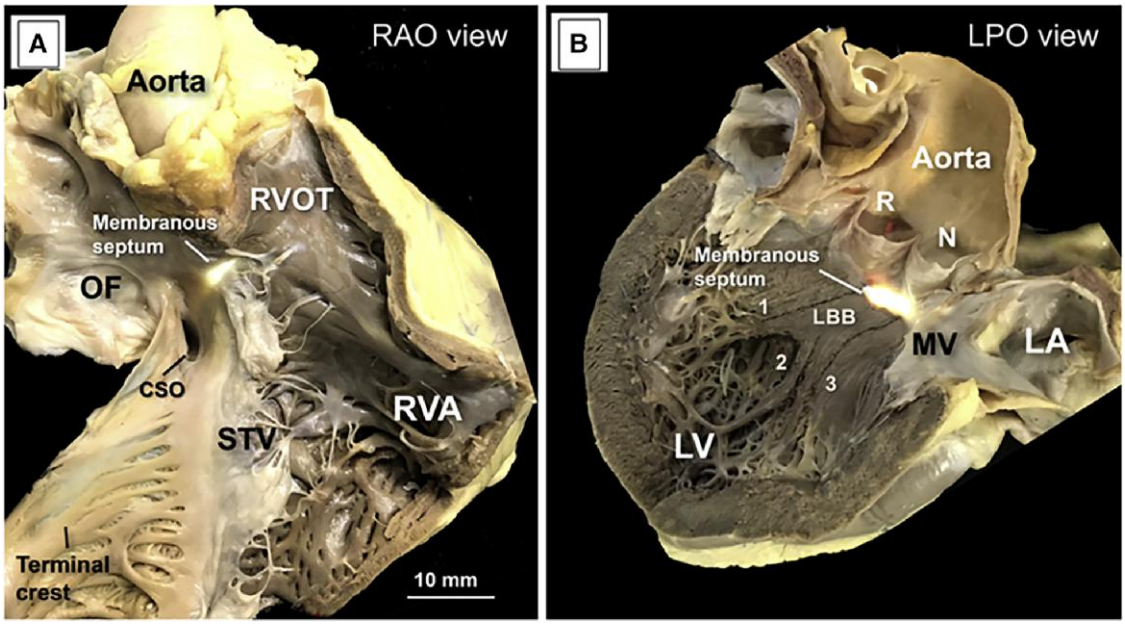


Figure 4 When viewed from the right atrial cavity (*A*), the fibrous membranous septum forms the apex of the triangle of Koch (transillumination). The hinge of the septal leaflet of the tricuspid valve provides the dividing line between the atrio-ventricular and interventricular components of the membranous septum. (*B*) The left posterior oblique view shows the transilluminated membranous septum located inferior to the interleaflet triangle between the right (R) and non-coronary (N) sinus of the aortic valve. Note that we have highlighted in dark colour the limits of the endocardial position of the left bundle branch (LBB) of His and its three fascicles, the left anterior (1), the left septal or middle (2), and the left posterior (3). LPO = left posterior oblique; RAO = right anterior oblique. With permission from Cabrera *et al.*[25]

The membranous septum is divided into atrio-ventricular and interventricular components at the base of the interleaflet triangle between the right and the non-coronary leaflets of the aortic valve. The length of the membranous septum can however be quite variable between individuals, ranging from 1 to 9 mm.[25] Where the target zone for HBP is very small, the left bundle branch fibres are distributed widely as a subendocardial network within the left ventricle, and therefore can be easily reached during the transseptal lead implantation.

After penetrating the atrio-ventricular membranous septum, the conduction system has a proximal left bundle trunk, that in many patients runs only for a very short distance before giving rise to the fascicles of the left bundle branch on the septal surface as can be clearly seen in *Figure 4*.

The LBB anatomy is remarkably variable between individuals. The LBBB origin is often broad but can be narrow in others ranging from 1 to 14 mm. This seems to be significantly influenced by the anatomical relationship of the His bundle with the interventricular septum. As the left bundle branch courses down over the interventricular septum, the bundle widens in a variety of configurations and distributions of LBB subdivisions.

Left bundle branch pacing lead implantation

Review of echocardiographic images prior to the procedure to assess the interventricular septal thickness and presence of any septal scar might provide information that might help guide the implantation. In patients with left bundle branch block (LBBB) or high-grade AV block, a temporarily placed back-up pacing lead should be placed in the right ventricle to be prepared to pace in the event of asystole. Simultaneous display of 12-lead ECG and intracardiac electrograms (utilizing electrophysiology recording system) during lead placement is essential for successful LBBP lead implantation. Intracardiac electrograms may be displayed at high gain and filter settings of 30–500 Hz to visualize LBB potentials and at low gain and filter settings of (0.5–500 Hz) to visualize myocardial and LBB potential current of injury (COI).

Since the introduction of LBBP[7,24,26] where distal His bundle location was used as the landmark to locate the right ventricular (RV) site about 1.5–2 cm distal towards the RV apex, several investigators have proposed alternative options. Instead of mapping the His bundle, localizing the superior tricuspid annulus using RV angiogram via the delivery sheath vs. using the 9-partition method to divide the RV into nine segments in right anterior oblique fluoroscopy view and targeting the mid-septum have helped shorten the fluoroscopy and procedure times with similar success rates.[27,28] Alternately, no formal identification steps are required, a purely anatomical approach identifying the interventricular septum can be used perhaps coupled with assessment of the RV-paced ECG morphology to target the proximal LBB.[29] In addition to a notch in the nadir of QS complex in V_1, RV-paced morphology of R, Rs in II, Rs or rS in III and aVF with R in V_5, V_6 marks the proximal mid-interventricular septum while monophasic R in II, III, and aVF would suggest an RV outflow region and unlikely to achieve LBB capture [this region should be avoided as it may result in right bundle branch block (RBBB) or injury to larger septal perforator vessels]. QS morphology in II, III, and aVF would suggest a more

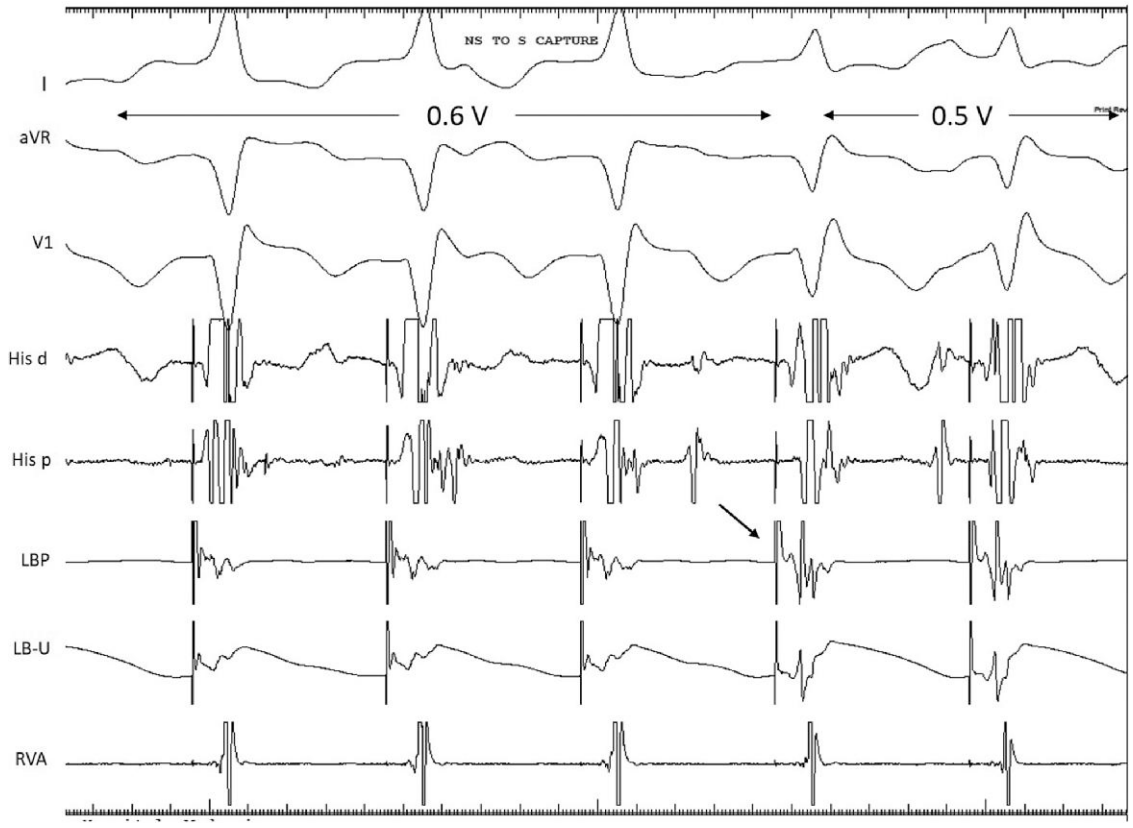


Figure 5 Demonstration of non-selective to selective left bundle branch capture while checking unipolar threshold. Note the distinct local electrogram on the pacing lead after the pacing stimulus with change in QRS morphology from qR to rSR pattern. His d and His p, His bundle electrogram distal and proximal; LBP, LB pacing lead; LB U, LB pacing lead unipolar electrogram; RVA, right ventricle electrogram. With permission from Ponnusamy *et al.*[33]

posterior septal location and likely to achieve more distal posterior left fascicle capture.

While the initial and majority of the published investigations utilized the lumenless lead (Medtronic, SelectSecure^{R}, Model 3830) and delivery sheaths (SelectSite^{R} C315His and C304His), stylet-driven leads delivered through similar sheaths from other manufacturers have also reported high success.[8,30] Once the lead is fixed to the RV septum, the sheath is positioned at a relatively perpendicular orientation to the septal wall, the lead is rapidly rotated to advance deep into the septum, usually in left anterior oblique fluoroscopy view (20°-30°) to monitor the lead progress.

Intermittent or continuous pacing may be utilized to monitor changes in unipolar-tip pacing impedance and QRS morphology to determine if the lead tip has reached the LBB area. Unipolar-tip impedance would progressively increase as the lead traverses the septum and starts to decrease approximately 200 Ω from the peak impedance as the lead approaches the LBB area. Final impedance values of <450 Ω have been associated with high sensitivity and specificity for left ventricular (LV) septal perforation and should be avoided.[31] Unipolar-tip electrogram should demonstrate significant COI. The lead should be advanced (while monitoring the impedance) until a Qr or qR morphology is seen in lead V1, when LV septal stimulation is achieved (exceptions may be observed with very proximal LBB capture).[32] It should however be borne in mind that pacing impedances vary from lab to lab, and depend upon individual setup.

Alternately, the lead may be advanced until RBBB morphology premature ventricular contractions (fixation beats, template beats, or M beats) are generated due to irritation of LV septal myocardium or LBB.[33-36] This approach has a possible advantage in patients with a fibrotic septum where momentum of lead delivery is more likely to be achieved enabling progress through the septum rather than stopping every few lead rotations to check pacing characteristics. Threshold testing and other pacing manoeuvres should be performed to assess LBB capture prior to advancing the lead further if indicated. Also, the COI obtained from the unipolar lead tip could guide lead depth, especially to avoid lead perforations. With absent or low COI on the lead tip, septal perforation should be suspected.[37,38] Additionally, presence of LBB potentials (13–35 ms pre-QRS) or lead-depth assessment using septal angiography through the sheath or demonstration of myocardial COI in the unipolar-ring electrogram may indicate that the LBB area has been reached.

Left bundle branch capture

Once the lead has been advanced to the deep septal region, LBB capture needs to be confirmed. During lead advancement, monitoring the R-wave peak times (RWPT) in leads $V_{5,6}$ is quite helpful. An abrupt decrease in

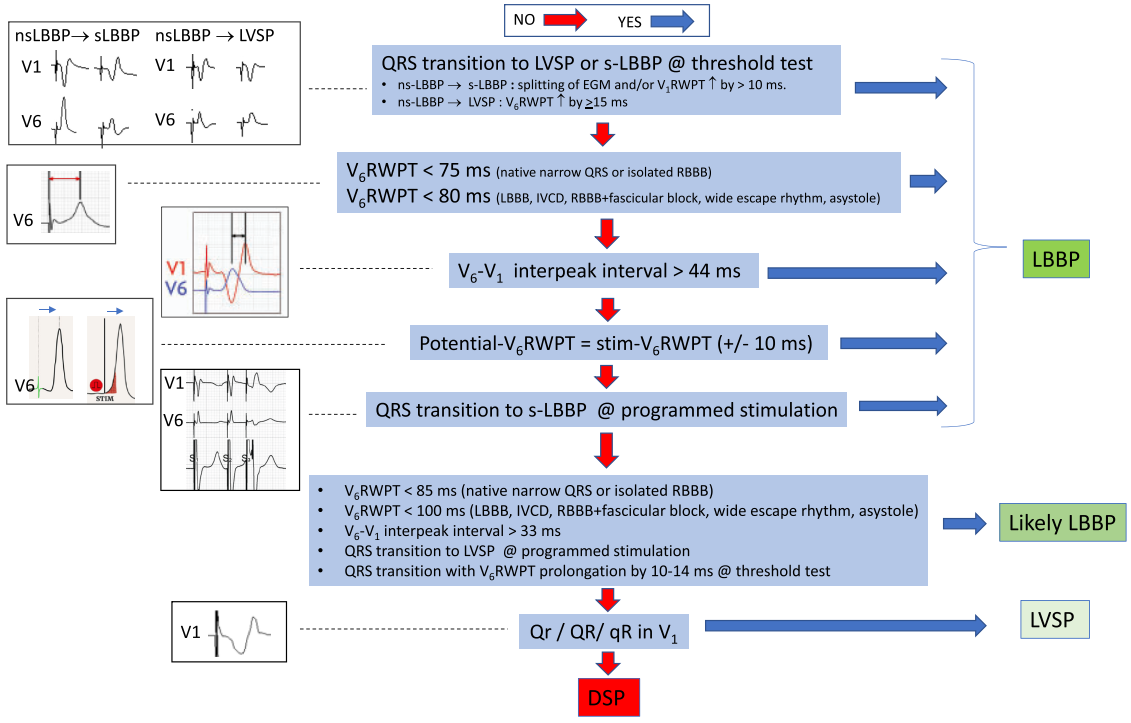


Figure 6 Algorithm for confirming conduction system capture with left bundle branch area pacing. Some of the steps may be skipped according to operator preference, experience or feasibility to perform particular measurements/manoeuvres. DSP, deep septal pacing; IVCD, intra-ventricular conduction delay; LBBAP, left bundle branch area pacing; LBBB, left bundle branch block; ns-LBBP, non-selective left bundle branch pacing; RBBB, right bundle branch block; RBBP, right bundle branch pacing; RWPT, R-wave peak time; s-LBBP, selective left bundle branch pacing. With permission from Burri *et al.*[38]

V_6RWPT by >10 ms during unipolar-tip pacing from deep septal location to LBB area would confirm LBB capture.[24] Threshold testing at this location would often demonstrate transition from non-selective LBB capture (LBB + LV septal capture) to selective LBB capture or LV septal only capture as shown in *Figure 5*.[24] Left bundle branch capture will be associated with short and constant V_6RWPT and discrete local electrogram while pure LV myocardial septal capture will demonstrate prolongation of V_6RWPT without a change in local electrogram. Additionally, QRS morphology changes (often very subtle) will be observed during this transition. Selective LBBP will be associated with 'rSR' pattern in V_1, more prominent S waves in II, III, aVF, and $V_{5,6}$ compared to LVSP. While QRS morphology changes during threshold testing is the gold standard for confirmation of LBB capture, this feature has been reported to vary between 26 and 75% in different studies.[38]

Several other criteria such as V_6RWPT <75 ms in non-LBBB and <85 ms LBBB, V_6-V_1 interpeak interval >40 ms, QRS transition during programmed stimulation and individualized physiology-based criteria such as stimulus to V_6RWPT = LBB potential to V_6RWPT (±10 ms) with varying sensitivity/specificity have also been utilized to evaluate the presence of LBB capture.[39-41] A recently proposed algorithm to confirm LBB capture is shown in *Figure 6*.[38] In patients with underlying LBBB, LBB potentials may not be visualized unless they can be demonstrated utilizing corrective His bundle pacing, wherein delta-V_6RWPT <10 ms may be used to confirm LBB capture.[42]

In the MELOS registry, different categories of LBBP were described.[8] *Proximal LBB trunk pacing* was characterized by pacing lead position deep in the interventricular septum, approximately 1–2 cm from the distal His bundle potential (or the tricuspid valve summit), LBB potential to QRS interval in the range of 34–25 ms, normal QRS axis, and fulfilled criteria for conduction system capture. However, this was observed only in 9% of the MELOS registry. *Left fascicular pacing* (*LFP*) is defined by capture of one of the LBB fascicles or its distal arborization; this part of the conduction system is demarcated proximally by the ramification of the LBB and distally by the Purkinje fibres to myocardium junction. Left fascicular pacing is characterized by short potential to QRS interval (<25 ms), often with an abnormal paced QRS axis (usually superior and different compared to native QRS axis) with presence of criteria for conduction system capture. Left fascicular pacing may be further defined as being (i) left anterior fascicular pacing (LAFP) with positive QRS in leads II and III, (ii) left mid-septal fascicular pacing (LSFP) with positive/isoelectric QRS polarity in lead II and isoelectric/negative QRS polarity in III, and (iii) left posterior fascicular pacing with negative QRS in II and III (*Figure 7*).

Follow-up

Complications

His-bundle pacing may be associated with higher pacing thresholds at implantation or increasing pacing threshold during follow-up. Sensing issues, like ventricular

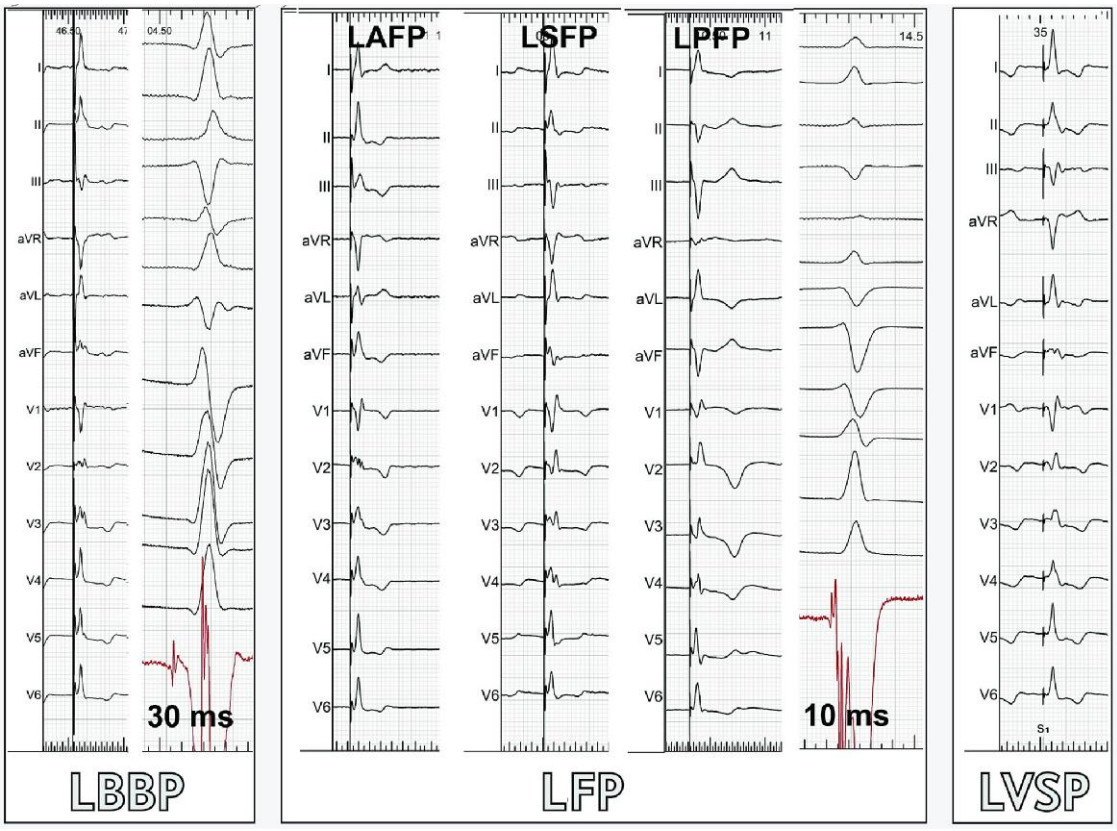


Figure 7 ECGs illustrating left bundle branch pacing (LBBP), left fascicular pacing (LFP) and left ventricular septal pacing (LVSP). QRS axis results both from conduction system capture as well as surrounding myocardial capture. Note the similarity in morphology between left bundle branch pacing and left left anterior fascicular pacing, which may be distinguished by the potential to QRS interval (if present), and anatomic lead position. Potential to QRS intervals recorded in intrinsic rhythm by the pacing lead are also shown for left bundle branch pacing and left fascicular pacing. Sweep speed of 25 mm/s for the paced QRS tracings and 100 mm/s for those in intrinsic rhythm. With permission from Burri *et al.*[38]

undersensing, or oversensing of the His or atrial signal are relatively common in HBP because of the anatomical position and needs attention and subsequent careful programming during implantation and follow-up.

In LBBAP, usually issues related to under- or oversensing such as in HBP are rare. In LBBP, complications are related to the penetration of the lead through the interventricular septum. Cases have been described such as acute and delayed septal perforation, lead (micro)dislodgement, chest pain, tricuspid regurgitation, and trapped or damaged lead helix,[8] septal haematoma,[43] and distal lead damage.[44] Rare cases of coronary artery and vein fistula have also been reported.[38] Although the incidence of complications associated with LBBAP does not seem much higher than routine RV pacemaker implantations, CSP is an evolving field with an expected increasing number of implantations in the near future. The associated learning curve may bring new complications.

Device programming and connections

In LBBAP, the anode is often embedded in the RV septal myocardium. During LBBAP, RV septal myocardium can be captured (anodal capture) in addition to LBB and LV septum resulting in partial or complete correction of the right ventricular conduction delay pattern (rsR or qR pattern replaced by QS). It is recommended during the implantation procedure to evaluate and record the unipolar, bipolar, and anodal capture thresholds and QRS morphologies prior to programming the pulse generator. In addition, the atrio-ventricular delay should be individually programmed based on the underlying rhythm, intrinsic atrio-ventricular conduction, and the presence of left bundle branch block. In LBBAP, pacing can be performed above anodal capture to reduce the delayed RV activation although clinical evidence lacks.

The device of choice and configuration should be individually assessed based on the patient characteristic and clinical needs. The following questions showed are answered to tailor the right therapy. Is the patient in need for pacing for bradycardia or heart failure? Is there a need for a ventricular back-up pacing lead? Is there underlying sinus rhythm or permanent atrial fibrillation? Is the CSP applied together with ICD therapy? Is an additional LV lead for His bundle pacing optimized (HOT-CRT) or left bundle branch pacing optimized CRT (LOT-CRT) considered? All these questions should be considered to decide on the right device and pacing configuration as is presented in the recent consensus document on conduction system pacing.[38]

Follow-up

For the follow-up of patients with CSP, it is advised not to focus primarily on remote follow-up. After the implantation a 4–8 week in-person visit is recommended

with further checks every 6 months. It is important to perform a careful evaluation with pacing threshold and sensing values and to perform a 12-lead ECG. Especially for HBP absence of oversensing and threshold values should be evaluated. A 12-lead ECG is mandatory in CSP during in-person follow-up to evaluate changes QRS morphology as sign of (micro-)dislodgements with loss of conduction system capture as well as the loss of correction of bundle branch block. Especially with LBBAP, it is recommended to evaluate unipolar besides bipolar pacing to check for changes in QRS morphology to identify loss of capture from the tip electrode (e.g. due to perforation) as this is not easy when anodal capture is present with bipolar pacing. Without a 12-lead ECG loss of conduction system capture can be easily missed during routine (remote) device follow-up.

Limitations

His-bundle pacing provides the closest ventricular activation to how nature intended. However, with the current tools, techniques, and devices, HBP cannot always be delivered; either due to failure to engage the conduction system or due to pacing parameters being unacceptable e.g. high capture thresholds, low sensing, atrial oversensing, or an inability to overcome distal sites of block. Moreover, even once a lead has been satisfactorily deployed it is apparent that a significant number of His lead implants will require lead revision or inactivation.[45]

Left bundle branch area pacing on the other hand may offer a more robust alternative to HBP with only minimal compromise on physiological ventricular activation.[46,47] Left bundle branch area pacing, although not necessarily the absolute physiological ideal, is frequently quicker to implant with higher success rates coupled with reduced radiation exposure, lower thresholds and better sensing (far more akin to RV pacing) with a shorter learning curve.[48,49] For these reasons, many physicians appear to have transitioned from utilizing His-bundle approaches to the left bundle approach and many new CSP implanters consciously deciding to only learn the left bundle approach due to its combination of pragmatism with near-normal physiological activation.[1,2]

However, although LBBP is considered to be easier with higher success rate, the MELOS study showed that in a large registry of experienced CSP centres, true proximal LBBP was only achieved in 9% of the patients.[8] In 70% of the patients, conduction capture could be established but at the level of the fascicles, referred to as left fascicular pacing. In 21%, no conduction capture could be obtained (i.e. only LVSP was achieved).[38] Whether the clinical benefit for patients with LV septal pacing as well as left fascicular pacing as compared to proximal true LBBP is the same needs to be investigated in more detail. Also, as many sites are currently starting CSP and especially LBBP without careful training and proctoring, the success of LBBAP might be overestimated with increased number of complications.

That said, many skilled operators still report excellent patient outcomes and satisfactory long-term parameters utilizing the His-pacing approach. Widespread replication of this success though would likely require investment in improvements in implantation techniques, patient selection, lead design, and device technology to improve the feasibility and safety of HBP.[50]

One of the major limitations for the next step of CSP implementation in the pacing guidelines is the lack of clinical studies. There are some initial pilot randomized clinical trials comparing HBP with RV pacing for patients with AV block[51] and with biventricular pacing in patients with heart failure and LBBB.[52,53] For LBBAP, the available data are even more scarce,[54,55] although many larger randomized trials have recently initiated such as the LEAP (NCT04595487), LEFT-HF (NCT05015660), and PROTECT-HF (NCT05815745) that assess the value of CSP strategy over RV pacing for patients with a bradycardia indication.

Despite its limitations, CSP is a very promising new pacing therapy that, after careful training and appropriate application, seem to have good implantation success rate and from which many patients requiring pacing therapy can benefit, both for patients with an indication for pacing because of bradycardia as well as for CRT.

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