Chapter

The Evolving Concept of Cardiac Conduction System Pacing

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Abstract

Cardiac pacing is an established treatment option for patients with bradycardia and heart failure. In the recent decade, there is an increasing scientific and clinical interest in the topic of direct His bundle pacing (HBP) and left bundle branch pacing (LBBP) as options for cardiac conduction system pacing (CSP). The concept of CSP started evolving from the late 1970s, passing several historical landmarks. HBP and LBBP used in CSP proved to be successful in small cohorts of patients with various clinical conditions, including binodal disease, atrioventricular blocks, and in patients with bundle branch blocks with indications for cardiac resynchronization therapy. The scope of this chapter is synthesis and analysis of works devoted to this subject, as well as representation of the author's experience in this topic. The chapter includes historical background, technical, anatomical, and clinical considerations of CSP, covers evidence base, discusses patient outcomes in line with the pros and cons of the abovementioned methods. The separate part describes practical aspects of different pacing modalities, including stages of the operation and pacemaker programming. The textual content of the chapter is accompanied by illustrations, ECGs, and intracardiac electrograms.

Keywords: His bundle pacing, left bundle branch pacing, cardiac pacing, conduction system pacing, interventricular septum, electrophysiology, cardiac resynchronization therapy

1. Introduction

Cardiac pacing from the right ventricular apical (RVA) site results in non-physiological ventricular activation, which leads to ventricular function impairment in a long-term perspective. Alternative pacing sites include right ventricular septal pacing (RVSP) and right ventricular (RV) outflow tract pacing; they are thought to be more beneficial to patients because of possibly better activation patterns than the RVA pacing. However, studies on pacing sites that are alternative to RVA are still contradictory as activation still relies on myocardial cell-to-cell conduction, thus does not prevent the development of pacing-induced cardiomyopathy [1]. Biventricular pacing (BVP) is a more favorable option than RVA pacing but still produces non-physiological activation patterns. The ideal physiological cardiac pacing requires sustained proximity to the intrinsic cardiac conduction system that preserves normal QRS complexes or even narrows QRS pattern in the bundle branch block (BBB) presence.

Direct conduction system pacing (CSP) becomes a frontier in the field of cardiac pacing, collecting evidence both from follow-up data and clinical case reports resulting in favor of His bundle (HB) pacing (HBP) and left bundle branch pacing (LBBP) as targets for His-Purkinje CSP. Although, it is necessary to mention that randomized clinical trials or meta-analyses that compare conventional pacing techniques to CSP are currently absent.

2. Historical landmarks

2.1 Predispositions for development

Permanent right ventricular pacing was firstly performed in humans on October 8th, 1958 by Swedish Surgeon Ake Senning. It was a breakthrough of that time, allowing to cope with Adams–Stokes syndrome to a 43-year-old man. Overall, this patient required 26 pacemakers to extend his life for 40 years and to live asymptomatically up to the age of 83 [2].

After 10 years from that date, in 1969, Narula, Sherlag proposed HBP using the electrophysiological catheter for HB stimulation. Authors also supposed a possibility of HB longitudinal dissociation.

More than 30 years passed since that time before Deshmukh et al. firstly implied this method in a group of patients of 12 with atrial fibrillation and indications for permanent cardiac pacing, "narrow" QRS complex, decreased left ventricular ejection fraction (LVEF) of 40% or less and NYHA III-IV [3]. For these purposes, the authors used standard electrodes with active fixation and modified stylet.

HBP was technically possible only in 66% of cases. The authors admitted a statistically significant increase in LVEF from 20 ± 9% to 31 ± 11% ($p < 0.01$). They supposed that the development of dedicated delivery systems for His-electrodes may turn an idea of more physiological cardiac pacing into reality, thus improving conventional RV pacing. However, this article reached the public at the time of BVP prosperity. BVP was proposed as a solution to tackle interventricular asynchronicity that progressively developed in scientific and practical aspects while being supported by the manufactures of cardiac pacemakers.

Numerous randomized clinical trials of cardiac resynchronization therapy (CRT) with the use of biventricular pacemakers and left ventricular epicardial pacing left HBP behind for more than 10 years. It was the first historical curiosity in HBP development.

2.2 Modern stage

At the same time, there was a rise in articles that analyzed predominantly retrospective data regarding HBP [4, 5]. The number of publications devoted to the HBP increases significantly since 2015. Among them are publications that analyze HBP in patients with atrioventricular (AV) block and sick sinus syndrome (SSS) [6]. Separate studies were dedicated to the comparison of HBP and RV pacing [7, 8], as well as to the evaluation of short-term and long-term outcomes of HBP [9].

A significant contribution to the topic was added by Vijayaraman et al. [6, 10] from Geisinger Heart Institute, USA, who demonstrated a technical possibility of HBP with the use of the 4.1 Fr Select Secure 3830 (Medtronic, USA) leads, which boosted the technical efficiency of HBP and expanded indications for it. It was the second curiosity in the HBP history because the abovementioned stylet-less pacing lead was initially developed about 20 years ago for permanent pacing in children with AV blocks, but not for the dedicated HBP.

3. His bundle pacing reasoning

3.1 Lead placement sites

Current approaches to the CSP base on the placement of the permanent pacing leads in the sites of the cardiac conduction system other than the RVA. CSP intends to overcome an asynchronous activation during pacing by producing the most physiologic activation pattern close to the one seen in the intrinsic conduction system. For that purpose, CSP leads may be implanted either at the HB or at the region of the left bundle branch (LBB) for different resynchronization strategies (**Figure 1**). The advantages and limitations of different strategies will be discussed later in the chapter.

3.2 Activation pattern

HBP has potential advantages in comparison to the CRT with the use of coronary sinus (CS) for left ventricular (LV) pacing [11]. LV pacing through CS cannot provide ideal resynchronization because of asynchronicity from the LV epicardial pre-excitation (**Figure 2**) [12]. Predominantly pacing comes from a lateral wall of the LV. The higher degree of asynchronicity can be seen through LV apical pacing and pacing in the areas with myocardial fibrotic scarring.

Both RV pacing and BVP change QRS pattern to a greater or lesser extent. Complete identically of QRS pattern to an intrinsic one differentiates HBP from the rest of pacing techniques [11]. Moreover, it is possible to completely or partly renew the intrinsic ventricular conduction in patients with BBBs by obtaining the normal width and form of the QRS complex [13, 14].

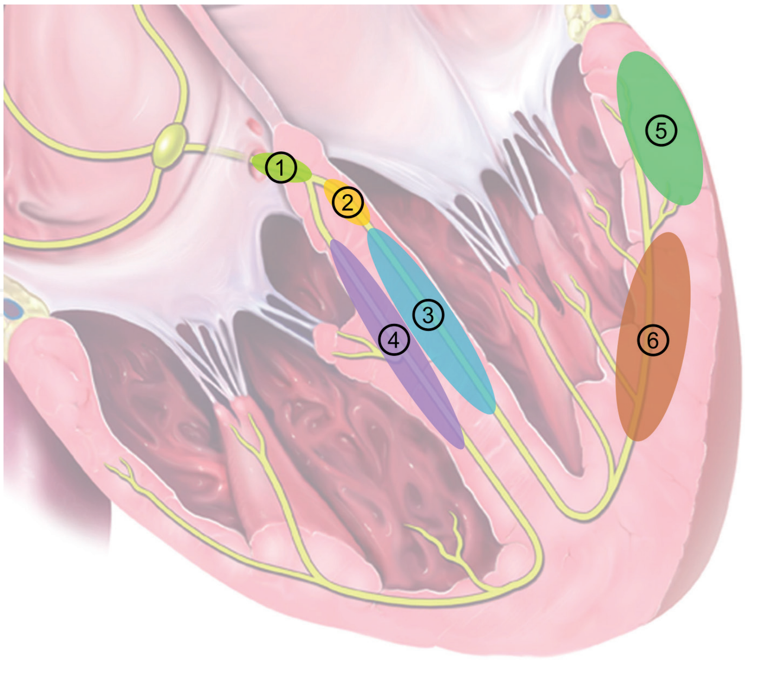

Figure 1.
Locations of the permanent lead placement for ventricular pacing along with strategies for cardiac resynchronization therapy. 1 – His bundle pacing; 2 – Left bundle branch pacing; 3 – Left septal pacing; 4 – Right septal pacing; 5 – Epicardial left ventricular pacing; 6 – Endocardial left ventricular pacing. Cardiac resynchronization therapy strategies: 1 – SINGLE SPOT (1, 2, 3, 4); 2 – CRT (4 + 5); 3 – HOT-CRT (1 + 5); 4. LOT-CRT (2, 3 + 5); 5. CSP-RV (2, 3 + 4). SINGLE SPOT = pacing from a single site, CRT = cardiac resynchronization therapy, HOT-CRT = His-optimized cardiac resynchronization therapy, LOT-CRT = left bundle branch-optimized cardiac resynchronization therapy, CSP-RV = conduction system pacing + right ventricular pacing.

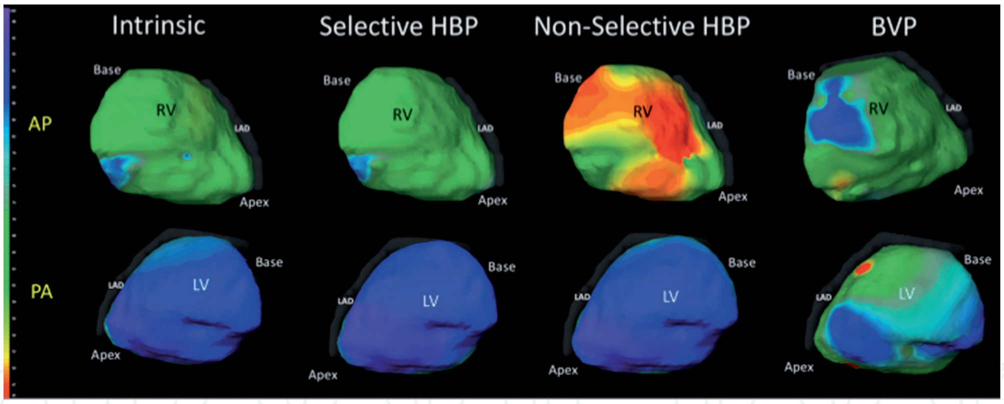

Figure 2.
Comparison of epicardial activation maps for intrinsic QRS, selective HBP, non-selective HBP, and BVP in a patient with normal QRS morphology and duration. The color scale on the left indicates the activation times. Activation from the selective HBP is identical to intrinsic activation. Activation from the non-selective HBP is identical to the intrinsic activation for LV, but evidence of pre-excitation can be seen for RV in the basal and mid areas, which indicates the capture RV myocardium alongside the HB. The activation pattern in the case of BVP is different from an intrinsic one. Differences between selective and non-selective HBP will be discussed later in the chapter. AP – Anterior–posterior projection, PA – Posterior–anterior projection, LAD – Left anterior descending artery.

3.3 Clinical implications

Clinical interest in the HBP significantly increased in the previous 5 years.

The largest study regarding the clinical of HBP compared to the RV pacing was published in 2018 [7]. Patients requiring pacemaker implantation were included in the study between 2013 and 2016. HBP was performed in consecutive patients at 1 hospital, while other patients received RV pacing at a sister hospital. A total of 765 people underwent pacemaker implantation: RV pacing in 433 patients and HBP in 332 patients. HBP was technically successful in 304 patients (92%). The mean follow-up duration for the entire cohort was 725 + 423 days.

Implant characteristics, heart failure hospitalization (HFH), upgrades to BVP and all-case mortality were tracked. The primary endpoint of death, HFH, or upgrade to BiVP was significantly reduced in the HBP group (83 of 332 patients [25%]) compared to RVP (137 of 433 patients [32%]; hazard ratio [HR]: 0.71; 95% confidence interval [CI]: 0.534 to 0.944; p = 0.02). The incidence of HFH was significantly reduced in HBP (12.4% vs. 17.6%; HR: 0.63; 95% CI: 0.430 to 0.931; p = 0.02). There was a trend toward reduced mortality in HBP (17.2% vs. 21.4%, respectively; p = 0.06).

From the abovementioned data, it is possible to conclude that HBP can be an alternative to conventional RV pacing in clinical practice while improving patient outcomes, taking into account the technical capabilities of the clinic and accumulated experience. Best candidates for HBP are patients with AV blocks, "narrow" QRS, and impaired LV function [15–17].

4. His bundle pacing in different patient groups

4.1 Patients with indications for CRT

HBP is more frequently used nowadays as an alternative to conventional RV pacing in patients with intraventricular conduction disturbances and indications for CRT. The idea of overcoming distal His-Purkinje system injury with the help of HBP and thus renew normal ventricular conduction seems very appealing [10].

Several groups of patients with intraventricular blocks that were previously treated as distal His-Purkinje injury can successfully restore conduction despite BBB [4, 13, 18–21].

An exact mechanism of QRS complex normalization in these cases is not fully understood. A hypothesis of functional longitudinal dissociation in HB that is the most widespread nowadays for explaining HBP efficiency in BBB was initially proposed by Kaufman R. and Rothberger C in the already distant 1919 [22]. The core of the hypothesis is that there are fibers inside the HB that conduct pacing impulses to the left and right bundle branches, being predominantly isolated from each other. Because of that, damage of these fibers in one of the HBs results in HB branch blocks [23]. It means that His-Purkinje system fibers may be blocked proximally, not distally inside the interventricular septum (IVS), and this block can be corrected with direct HBP.

Basing on the HB anatomy, the current amplitude for pacing specialized HB branch fibers (partially isolated by connective tissue) may be relatively high and involve neighboring myocardial areas [24, 25]. It is necessary to discuss the mechanisms of the non-selective HBP [26, 27]. In non-selective HBP, besides the activation of the HB fibers with block overcoming, additional areas of the adjacent myocardium (mostly septal part of the RV, rarely basal parts of the LV) may be activated.

The main aim of the research conducted by Huang W. et al. was to assess the efficacy of HBP to correct LBB block (LBBB) and long-term clinical outcomes with HBP in patients with heart failure (HF) [13]. Permanent HBP leads were implanted in HB under the guidance of ECG criteria for LBBB correction and pacing threshold <3.5 V / 0.5 ms or 3.0 V / 1 ms. Left ventricular ejection fraction (LVEF), left ventricular end-systolic volume (LVESV), pacing parameters, and NYHA class was assessed during a follow-up. HBP was performed in 74 patients (mean age 69.6 ± 9.2 years and 43 men). LBBB correction was reached in 72 patients (97.3%). 56 patients (75.7%) had adequate pacing thresholds during HB lead implantation. Lead implantation wasn't performed in 18 patients because of a lack of LBBB correction (n = 2) or high pacing threshold for LBBB correction (n = 16). An average follow-up was 37 (range 15.0–48.7) months. Follow-up exceeded 3 years in 30 patients with HBP. Patients had an increase in LVEF from baseline32.4 ± 8.9% to 55.9 ± 10.7% ($p < 0.001$), LVESV decreased from a baseline of 137.9 ± 64.1 mL to 52.4 ± 32.6 mL ($p < 0.001$) and NYHA Class improvement from baseline 2.73 ± 0.58 to 1.03 ± 0.18 ($p < 0.001$). The pacing threshold required for LBBB correction remained the same: 2.13 ± 1.19 V / 0.5 ms during a procedure and 2.29 ± 0.92 V / 0.5 ms at a 3-year follow-up ($p > 0.05$). The conclusions are as follows: HBP with LBBB resolution can be seen in 76% of patients and accompanied by a significant improvement of LV contraction properties. On the other hand, almost a quarter of patients cannot overcome LBBB while performing HBP; the question remains opened which technique should be considered next after HBP failure.

Close results were obtained by Ajijola O. et al. [28]. Selective HBP was successful in 16 patients (76%) out of 21 patients with LBBB. It lead to a significant decrease in the QRS complex duration from 180 ± 23 ms to 129 ± 13 ms ($p < .0001$) and LVEF improvement from 27% ± 10–41% ± 13% ($p < .001$) during a 12-month follow-up.

Sharma et al. performed HBP in candidates for CRT, to whom it was technically impossible to achieve LV epicardial pacing, or to the ones who were non-responders to a conventional CRT. HBP was technically successful in 95 patients out of 106 (90%). The mean follow-up period was 14 months. It was marked a significant decrease of QRS duration from 157 ± 33 ms to 117 ± 18 ms ($p = .0001$), an increase in LVEF from 30 ± 10% to 43 ± 13% ($p = .0001$), and NYHA Class improvement from 2.8 ± 0.5 to 1.8 ± 0.6 ($p = .0001$).

HBP nowadays is considered as an alternative to a conventional BVP in patients with LBBB and broad QRS complexes in addition to chronic ventricular pacing with heart failure and ventricular asynchrony [18, 19, 29–32].

However, HBP not always leads to a significant decrease of a ventricular complex. An aim to improve HBP results with the help of additional lead implantation through the coronary sinus to pace LV was set in His-optimized CRT (HOT-CRT) trial to reach a maximum possible resynchronization. This trial demonstrated a possibility of HBP optimization via this additional lead to LV through coronary sinus [33].

HOT-CRT was applied in 27 patients (mean age 72 ± 15 years): 17 with LBBB, 5 with intraventricular blocks, 5 with chronic RV pacing. HOT-CRT protocol was successfully run in 25 patients out of 27. The initial QRS width of 183 ± 27 ms was significantly reduced to 162 ± 17 ms for BVP and 151 ± 24 ms for HBP ($p < .0001$). With HOT-CRT protocol (His pacing lead implantation + LV pacing through coronary sinus), QRS length decreased even more to 120 ± 16 ms ($p < .0001$). Mean follow-up was 14 ± 10 months. LVEF increased from 24 ± 7% to 38 ± 10% ($p < .0001$), and NYHA Class was improved from 3.3 to 2.04. Clinical responders were 21 out of 25 patients (84%), and echocardiographic responders were 23 out of 25 patients (92%).

HOT-CRT trial demonstrated a possibility of electrical resynchronization improvement in patients with indications for CRT and suboptimal HBP by adding LV stimulation site through the coronary sinus.

The most common location for LBBB – is a left part of the HB. HBP eliminates LBBB on this level in 94% of cases. In the case of a more distal location of LBBB, correction is possible in 62% of cases. When the His-Purkinje system is intact on the level of IVS, LBBB correction with HBP does not take place.

In the clinical practice, preferable locations of the LBBB for HBP are left-sided proximal HB fibers blocks with a possibility of activation of the latent distal His-Purkinje system.

4.2 Patients with RBBB

Positive hemodynamical and clinical effects of BVP are limited in patients with right bundle branch block (RBBB). Permanent HBP is proposed as an option for resynchronization therapy in 39 patients with RBBB and low LVEF who had indications for CRT [21]. HBP was an initial strategy for them or a "rescue" strategy in a case of unsuccessful implantation of the epicardial lead for LV pacing.

Selective HBP was successful in 37 patients out of 39 (95%); however, a markable reduction in QRS duration was reached in 78% of cases. HB pacing thresholds for RBBB correction were 1.4 ± 0.7 V / 1 ms. Mean follow-up was 15 ± 23 months. A significant reduction in QRS length from 158 ± 24 ms to 127 ± 17 ms was achieved. LVEF improved from 31 ± 10% to 39 ± 13% ($p = .004$), and NYHA Class was decreased from 2.8 ± 0.6 to 2 ± 0.7 ($p = .0001$). The notable increase in pacing threshold was in 3 cases.

This research concluded that permanent HBS was associated with shortening QRS duration in patients with RBBB and decreased LVEF.

5. His bundle pacing limitations

5.1 Implantation site

The main boundary for the wide adoption of HBP is a relatively small area for pacing lead implantation into the cardiac conduction system with an appropriate pacing threshold. As a result, physicians experience lengthening of the procedure time and an increase in fluoroscopy exposure compared to conventional RV pacing. These problems tend to decrease with an accumulation of physician's experience. Nevertheless, even experienced physicians in high-volume centers perform HBP by 27% longer than RV pacing (70 mins and 55 mins) while increasing fluoroscopy time by 39% (10.3 mins and 7.4 mins) [34, 35].

Further improvements in implantation tools will help overcome technical limitations, but even in this case, procedure and fluoroscopy time will remain lengthier than for RV pacing [7].

5.2 Pacing thresholds

Another disadvantage of HBP – higher pacing thresholds and lesser energy efficiency that leads to the earlier cardiac pacemaker battery discharge. An increase in pacing threshold was observed in post-operational period for HBP compared to RV pacing: 1.30 V + 0.85 V for HBP and 0.59 V + 0.42 V for RV pacing. It resulted in a necessity for early pacemaker replacement in 3 out of 75 patients from the HBP group [7].

5.3 Lead fixation

Lead instability is another problem for HBP, which increases the probability of lead dislocation in the post-operational period despite the active lead fixation type [4, 8, 23, 27]. According to the data from Geisinger Institute, 4.2% of patients required lead correction after performing HBP [7].

5.4 Summary

Summing up data of HBP in patients with indications for CRT, it becomes possible to conclude that HBP leads to adequate cardiac resynchronization in 70–92% of cases, resulting in shortening of QRS complex compared to BVP and decreasing required time for the procedure.

Even though the solid theoretical background and practical applicability among experienced physicians, HBP cannot fully replace conventional BVP nowadays. HBP limitations include higher pacing thresholds, lower R-wave amplitude, and probable difficulties with ventricular signal sensing. On the other hand, there is also a possibility of hypersensitivity to far-field P-waves signals. Lead instability in continuous pacing is another point of concern, along with long-term effects of HBP because of potentially damaging influence on the distal structures of the His–Purkinje system.

Data from upcoming randomized clinical trials may remove the ambiguity in HBP [30, 32]. There is also a need for direct comparison of HBP to RV pacing and conventional multifocal BVP. Additional research may answer further questions regarding HBP complications and mechanisms of non-selective HBP. Could non-selective HBP be treated as an alternative to selective HBP? And what problems may arise during lead extraction?

Much work remains to be done with conducting thoroughly planned randomized clinical trials that will evaluate the potential of HBP in cardiac pacing.

6. Anatomical considerations for His bundle pacing

Knowledge of anatomical and physiological properties of cardiac conduction system, and HB in particular, is required for performing successful lead implantation for further HBP. Significant contribution to this topic was added by Kawashima T., Sasaki H. in 2005, who described relationship of the HB to the membranous part of the IVS based on the autopsy material of 105 subjects [25]. Authors outlined three anatomical variations of HB.

6.1 Normal atrioventricular bundle

The normal variant (type I) was in 49 subjects out of 105 (46.7%). The atrioventricular bundle (the HB) coursed along the lower border of the membranous part of the IVS and was covered by a thin layer of common myocardial fibers spanning from the muscular part to the membranous part of the IVS (**Figure 3**). Fusion phenomenon was seen during HBP in this anatomical variation, or non-selective HBP in higher current amplitude and selective HBP in lower current amplitude during pacing.

6.2 Deep-seated atrioventricular bundle

Deep-seated HB (type II) was found in 34 subjects out of 105 (32.4%). The atrioventricular bundle is clearly distinguished from the membranous part of the IVS and lays within the muscular portion of the IVS (**Figure 4**). In such cases, even in the clear identification of HB signal, it is a rare occurrence of adequate HBP.

6.3 Naked atrioventricular bundle

Naked HB (type III) was found in 22 subjects out of 105 (21%). It is located predominantly beneath the endocardium, and there is no overlay of muscle fibers (**Figure 5**). Possibly, it is the best type for HBP.

6.4 Summary

Thus, HB can be accessible for HBP in at least 68% of cases based on the data from the abovementioned study. Unfortunately, no technology nowadays can define the anatomical variant of HB before the lead implantation.

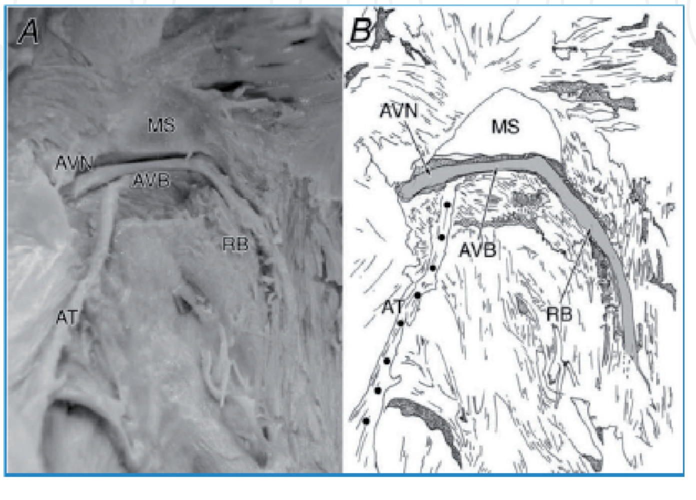

Figure 3.
HB of type I. A – Anatomical substrate; B – Graphical representation; AT - attachment of tricuspid valve; AVB - atrioventricular bundle; AVN - atrioventricular node; RB - right branch; MS - membranous part of the interventricular septum (Kawashima and Sasaki [25]).

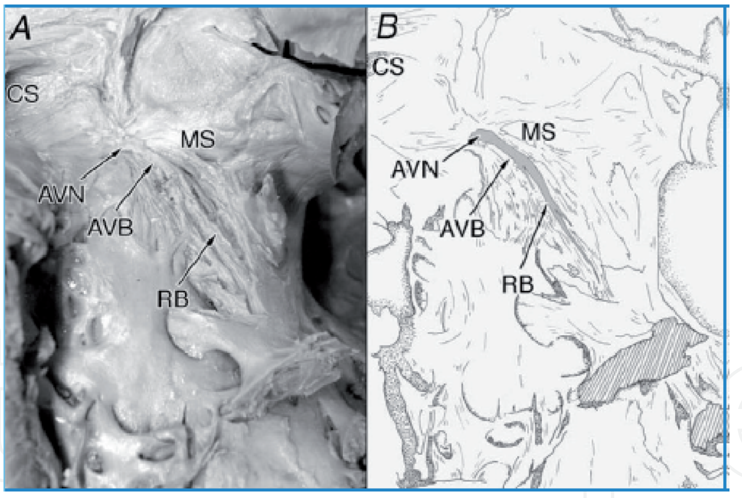

Figure 4.
HB of type II. A – Anatomical substrate; B – Graphical representation; AT - attachment of tricuspid valve; AVB - atrioventricular bundle; AVN - atrioventricular node; RB - right branch; MS - membranous part of the interventricular septum; CS - coronary sinus (Kawashima and Sasaki [25]).

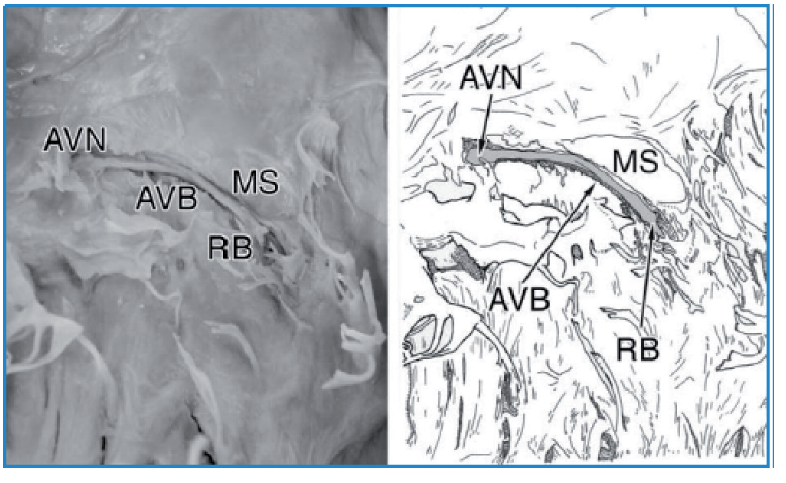

Figure 5.
HB of type III. AVB - atrioventricular bundle; AVN - atrioventricular node; RB - right branch; MS - membranous part of the interventricular septum (Kawashima and Sasaki [25]).

7. Practical recommendations for His bundle pacing

7.1 First stage. Venous access

For venous access, we preferably puncture left axillary vein. Usually, we enter with a short peel-away regular 7F sheath as it is congruent with advanced further C315 His catheter. While having a C315 catheter in RA, we try to place a guiding wire in RV. It advantages smooth guiding of C315 catheter to RV and avoids tip damaging during tricuspidal valve crossing. Afterward, the system withdrawing to the basal septal region is easier than penetrating forward.

7.2 Second stage. His bundle mapping

After the lead introducer system is positioned in a supposed projection of HB, signal mapping of HB starts from the distal tip of the lead to register unipolar or bipolar signal. For this purpose, a standard electrophysiological system can be used and/or PSA 3 signal analyzer and Medtronic programmer. It is advised to apply atrial channel for HB mapping as it is more sensitive. The cathode is

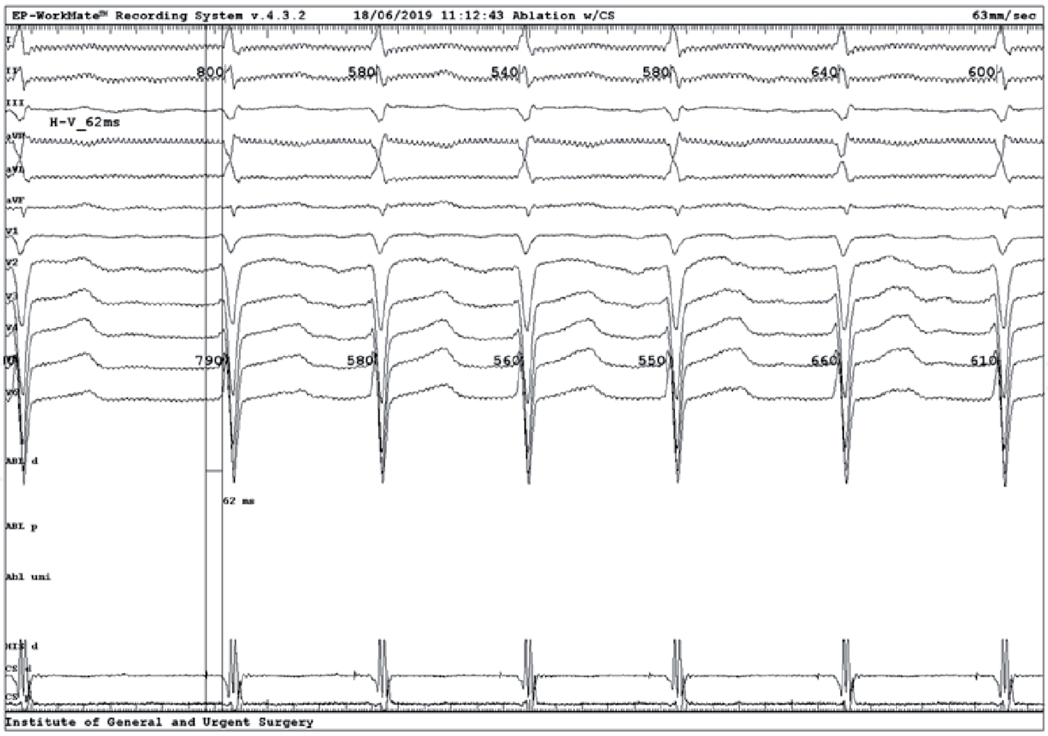

Figure 6.
HB mapping (total gain – 5000, filtration rate – 500 Hz).

connected to the distal tip and anode to the skin. After that, an accurate search of HB potentials starts. It is necessary to point out that the distal electrode (Helix) is in an active position what complicates the overall system manipulation; however, it is possible to map with Helix placed slightly inside the lumen of the delivery system (**Figures 6** and 7).

After HB mapping, it is necessary to know the main maneuvers with C 315 His introducer. For fluoroscopic visualization, RAO 15–30 position is used. Clockwise

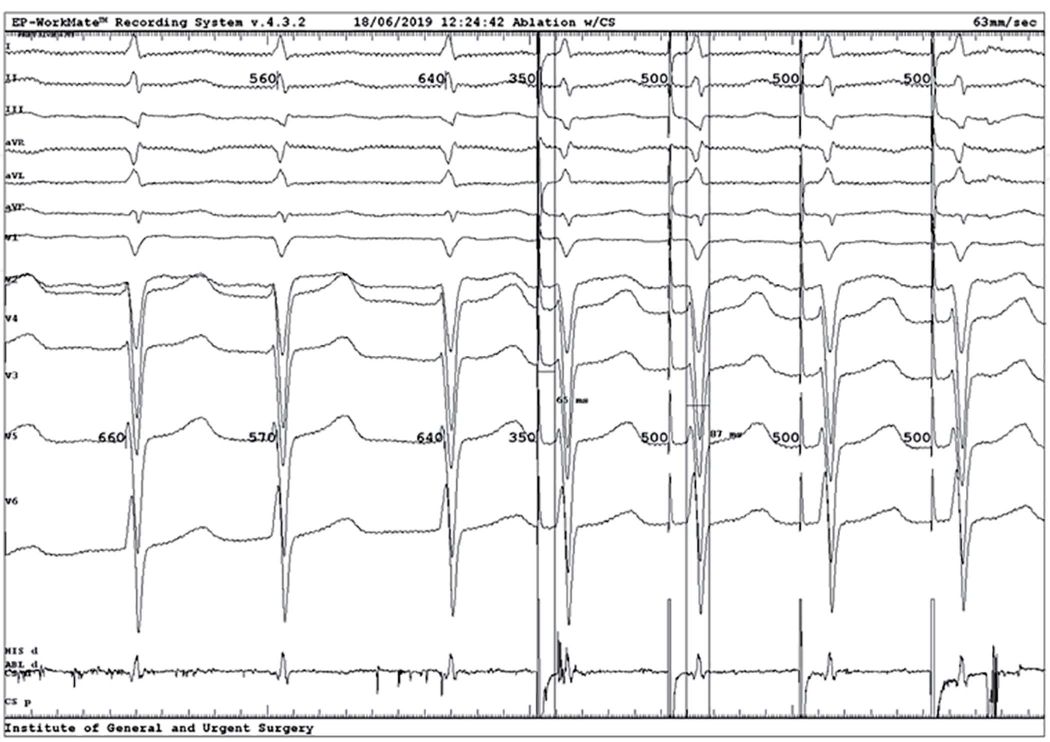

Figure 7.
HB mapping.

introducer rotation with an electrode inside turns its tip forward and upwards relative to the IVS. Counterclockwise introducer rotation directs it backwards, closer to the tricuspid valve.

C 315 His introducer is advanced maximally further through an electrode after identification of the HB signal. It adds additional stability to the system before lead implantation (screwing). His lead implantation is performed after HB signal assessment relative to the atrial and ventricular signals (**Figure 7**).

In a case when it is not possible to register discrete HB potential, the pace-mapping technique may be applied beginning with high amplitudes (5–10 V / 1 ms) with identification of the pacing threshold for RV and HB. This technique is especially useful for conducting HBP in patients with AV blocks.

7.3 Third stage. Lead implantation

Lead implantation starts with both operator's hands for clockwise rotation: 4–5 rotations with slight pressure on lead in a forward direction. Meanwhile assistant supports a delivery system in a necessary position (usually performing anticlockwise movements for pushing introducer and lead perpendicular to the implantation site). Additional rotations may be needed based upon tactic feelings and fluoroscopy. After fixation, the lead is pointed frontward while the introducer is retracted 3–5 cm backward, creating a moderate 'insurance' loop and evaluating lead fixation stability.

In the experimental post-mortem study, M. Jastrzebski et al. distinguished 3 types of lead behavior during deep septal implantation – entanglement, drill-effect, and screwdriver effect [36]. These behaviors depend on endo-myocardial tissue characteristics, positioning angle relative to the cardiac wall, and the way of screwing. Recognition of these behaviors might help to achieve successful penetration without complications and unnecessarily prolong attempts.

7.4 Fourth stage. His bundle pacing testing

R-wave amplitude test is performed afterward. Because of the thin myocardial layer in this region, acceptable values for appropriate R-wave sensing are more than 1–2 mV, which usually provides enough safety margin from far-field atrial and His signals oversensing. This makes use of pacemakers with maximum ventricular sensing of 0.5 mV more reasonable.

QRS complex assessment in standard 12-lead ECG with relatively high amplitude and duration of the pacing impulse (5 V / 1 ms) is the next step. A threshold test is conducted with a gradual decrease of the pacing impulse amplitude. It is necessary to define the threshold of selective HBP and RV pacing. The acceptable HBP threshold is less than 2.5 V / 1 ms. HBP threshold may decrease within 10–20 mins after implantation due to a decrease in an acute HB fibers traumatic damage.

An important prognostic factor is a change between selective and non-selective HBP in response to different pacing outputs. If decreasing a pacing output lead to a transition from non-selective to selective HBP, it is a strong predictor of a favorable outcome because the active electrode part is within the conduction system. The opposite sequence points out a more remote position from HB, and further considerations should be taken into account.

7.5 Fifth stage. Introducer extraction

For introducer extraction, a standard set of knives is used. The presence of a "secure" loop is mandatory before the introducer extraction; it provides sustainability to the lead. Extraction is guided by fluoroscopy to control the lead position.

Unfortunately, delivery and extraction systems are not the perfect ones. Because of that, it is necessary to be prepared for accurate delivery system dissection with small scissors.

After introducer extraction, there is an additional check of the ventricular signal amplitude and pacing thresholds for bipolar/monopolar configuration. Monopolar sensing is inadvisable in pacemaker-dependent patients (risk of atrial oversensing).

7.6 Sixth stage. Atrial lead implantation and pacemaker placement

Implantation of the atrial lead is conventionally performed in the right atrial appendage or the interatrial septum (**Figure 8**). Atrial and ventricular sensing should be no less than 0.45 mV.

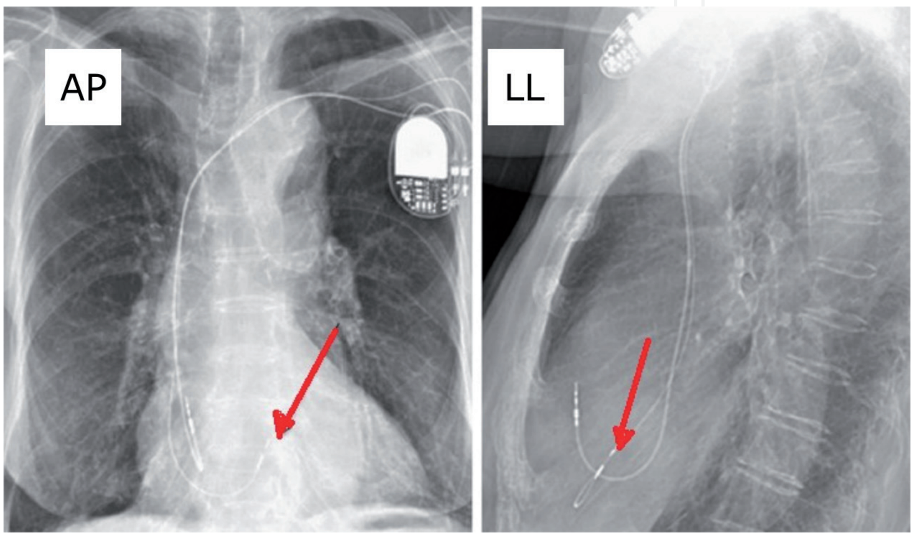

Figure 8.
Final lead and pacemaker positioning in HBP. Red arrow points at the HB pacing lead (AP LL view).

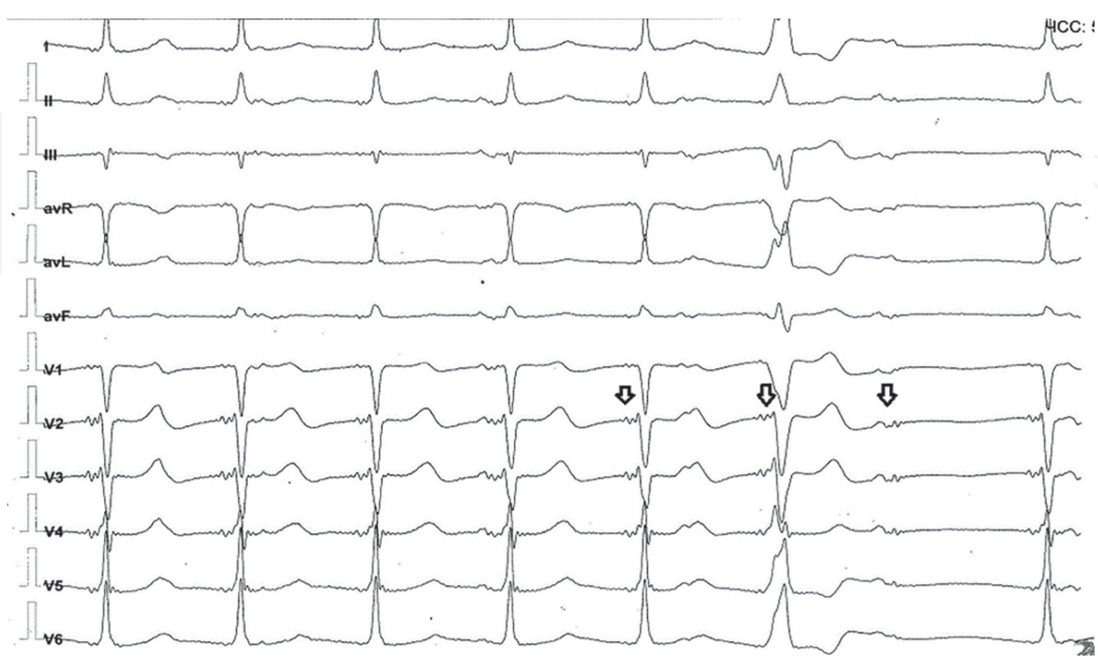

Figure 9.
Detection of the pacing threshold for HB. Asynchronous bipolar stimulation at 90 bpm. The first arrow marks the last QRS complex conducted through HB – Pacing threshold for HB. QRS width is 89 ms. the next QRS complex is a deformed one; its width is 167 ms – Pacing threshold for RV myocardium (second arrow). The third arrow points non-response spike.

In the presence of an initially high pacing threshold for HB, it is recommended to consider pacemakers with prolonged longevity.

7.7 Seventh stage. Programming

While programming a pacing amplitude, it is necessary to consider a probability of a significant rise in pacing threshold in a subacute period in 10% of cases. Non-selective HBP is a predominant pacing type among the patients and, because of probable lower pacing thresholds for myocardium versus HB, adequate pacing amplitude should be programmed 1.5–2 times higher than the HBP threshold (**Figure 9**). Myocardial capture is reserved as a back-up in case of HBP failure.

While programming an AV delay, the time of conducting potential through HB should be considered (H-V interval on electrogram). AV delay is shortened by the duration of this interval (~ 40–70 ms).

Additional attention should be paid to the hypersensitivity for the far-field atrial signal.

8. Conclusion

CSP nowadays becomes even more innovative. HBP and LBB pacing made continuous pacing even more physiologic in certain groups of patients with bradycardias and intraventricular conduction disturbances by restoring conduction close to the native one. A possibility to implant leads in the HB, and LBB creates new options for conducting CRT with such configurations as HOT-CRT or LOT-CRT for patients with corresponding indications. With improvements in HBP tools and accumulation of the individual experience, HBP will become one of the principal methods for bradycardia pacing in patients with intraventricular conduction disturbances and heart failure.

Conflict of interest

Nothing to declare.

Abbreviations

AP	anteroposterior
AV	atrioventricular
BBB	bundle branch block
BVP	biventricular pacing
CRT	cardiac resynchronization therapy
CS	coronary sinus
CSP	conduction system pacing
HB	His bundle
HBP	His bundle pacing
HF	heart failure
HFH	heart failure hospitalization
HOT-CRT	His-optimized CRT
IVS	intervetricular septum
LBB	left bundle branch
LBBB	left bundle branch block

LBBP	left bundle branch pacing
LL	left lateral
LOT-CRT	left bundle branch-optimized CRT
LV	left ventricle
LVEF	left ventricular ejection fraction
LVESV	left ventricular end-systolic volume
RAO	right anterior oblique
RBBB	right bundle branch block
RV	right ventricle
RVA	right ventricular apex
RVSP	right ventricular septal pacing
SSS	sick sinus syndrome

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