Anatomical approach to permanent His bundle pacing: Optimizing His bundle capture☆,☆☆,★
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Abstract
Permanent His bundle pacing is a physiological alternative to right ventricular pacing. In this article we describe our approach to His bundle pacing in patients with AV nodal and intra-Hisian conduction disease. It is essential for the implanters to understand the anatomic variations of the His bundle course and its effect on the type of His bundle pacing achieved. We describe several case examples to illustrate our anatomical approach to permanent His bundle pacing in this article. © 2016 Elsevier Inc. All rights reserved.

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Introduction
Permanent His bundle pacing (HBP) is the most physiological form of ventricular pacing. Right ventricular pacing is known to cause ventricular dyssynchrony, heart failure and increased mortality [1–4]. By maintaining conduction through the normal His-Purkinje system, HBP prevents ventricular dyssynchrony and may reduce heart failure. Deshmukh et al., demonstrated the feasibility of permanent HBP in patients undergoing AV node ablation in the year 2000 [5]. Since then, several investigators have reported successful HBP in a significant number of patients [6–10]. Nonetheless, widespread adoption of this technique has remained elusive.

Anatomy of the His bundle
The His bundle begins from the AV nodal tissue and courses along the membranous septum on the right side before penetrating to the left side on the crest of the muscular portion of the inter-ventricular septum. It is essential for the implanters to understand that a significant length of the proximal His bundle rests on the right atrial-left ventricular part of the membranous septum, which is above the tricuspid valve plane. Several anatomical variations of the distal His bundle course have been described. Our experience of permanent His bundle pacing in more than 400 consecutive patients has enabled us to understand these variations and their impact on achieving selective or non-selective His bundle pacing. Kawashima and Sasaki investigated the locational variation of the His bundle in 105 elderly human hearts and described three distinct patterns [11]. In type I (46.7% of 105 cases), the His bundle consistently coursed along the lower border of the membranous part of the interventricular septum but was covered with a thin layer of myocardial fibers spanning from the muscular part of the septum. In type II (32.4%) the His bundle was apart from the lower border of the membranous part of the interventricular septum and ran within the interventricular muscle. In type III (21%), the His bundle was immediately beneath the endocardium and coursed onto the membranous part of the interventricular septum (naked His bundle). These variations in the course of the His bundle help explain the different patterns of His bundle capture.

Definitions
There have been several different descriptions of His bundle capture. In order to provide uniformity, we recommend the following definitions based on the original descriptions published by Williams et al. [12], and Deshmukh et al. [5].

Selective His bundle pacing (S-HBP) is defined by ventricular activation occurring solely over the His-Purkinje system. S-HBP can be recognized by the
following criteria: [1] His-Purkinje mediated cardiac activation and repolarization, as evidenced by electrocardiographic (ECG) concordance of QRS and T wave complexes similar to baseline; [2] the paced-ventricular interval is almost identical to the His-ventricular interval (Fig. 1). S-HBP has been variously described in literature as direct HBP, pure-His pacing and selective-direct HBP. It is important to note that S-HBP may result in normalization of pre-existing right or left bundle branch block with T wave memory changes [13,14].

Non-selective His bundle pacing (NS-HBP) is defined based on capture of basal ventricular septum in addition to His bundle capture as; [1] no isoelectric interval between pacing stimulus and QRS; [2] recording His bundle electrogram on the pacing lead; [3] electrical axis of the paced QRS concordant with the electrical axis of the spontaneous QRS (if known); [4] narrowing of QRS at higher output due to fusion between RV and His bundle capture and widening of QRS at lower output due to loss of His bundle capture or vice-versa (Fig. 2). Paced QRS complexes may be narrower than the baseline rhythm in the setting of pre-existing BBB or infra-nodal AV block [10,15]. NS-HBP has variously been described in literature as paraHisian pacing [5], pure-paraHisian pacing [16], nonselective-direct HBP [17]. Significant confusion still exists regarding paraHisian pacing as several authors do not report actual His bundle capture thresholds (the lowest pacing output at which QRS narrowing occurs) which may or may not be higher than the RV capture threshold [18]. In order to avoid confusion, when His bundle capture is present with fusion, it should be referred to as nonselective HBP (NS-HBP) and both HB and RV capture thresholds should be specified.

Anatomical approach to His bundle pacing

We have previously described our His bundle pacing technique utilizing unipolar mapping from the pacing electrode without using an electrophysiology mapping catheter [8,9]. In patients with normal His-Purkinje conduction, our approach is to achieve selective His bundle pacing. In our experience, we are able to achieve S-HBP in about 50% of these patients. Our ability to achieve S-HBP is limited by atrial capture, atrial oversensing and/or ventricular undersensing in the proximal His bundle region. If any of the above issues are noted at the time of implant, the lead is positioned slightly more distally. Often the distal His bundle is covered by a thin layer of myocardial fibers spanning from the muscular part of the interventricular septum (Kawashima Type I His bundle) [11]. In these patients we see minimal ventricular fusion and the paced QRS duration is usually less than 120 ms. In a third of patients, the His bundle lies within the muscular interventricular septum (type II), where selective HBP is not feasible. In this situation, NS-HBP is achieved with RV capture threshold lower than the His capture threshold. In patients with the naked His bundle (type III), significant His bundle injury current can be observed with S-HBP and very low His capture thresholds (<0.5 V). In patients with His-Purkinje conduction disease (bundle branch blocks or intra-Hisian AV block) our preference is to achieve NS-HBP. We do not routinely use a RV backup pacing lead in most of our pacemaker implants. By achieving NS-HBP, the right ventricular basal myocardial capture can provide a safety back-up pacing should there be progression of distal Purkinje conduction disease [10]. The following case examples illustrate our anatomic approach to permanent HBP in specific scenarios.

Case 1: A 74-year-old man with recurrent persistent atrial fibrillation, nonischemic cardiomyopathy, severe LV systolic dysfunction, EF <20% and class III NYHA symptoms was referred for AV node ablation and biventricular ICD implantation. He had previously failed multiple antiarrhythmic drugs and atrial fibrillation ablation. EKG at baseline showed normal PR interval...
and narrow QRS width of 110 ms. During His bundle mapping, HV interval was noted to be 60 ms (Fig. 3). Initial attempts to achieve a stable proximal His position using Medtronic C315His sheath and SelectSecure™ pacing lead (Medtronic 3830) was abandoned due to atrial capture at low output. Subsequently, Medtronic C304 deflectable sheath was utilized to map the His bundle region. Despite mapping extensively, selective His bundle pacing (S-HBP) could not be achieved in a more distal location. The paced QRS duration during nonselective HBP was about 170 ms with a 60 ms delta wave (RV fusion) due to slightly prolonged HV interval. RV capture threshold was lower than the His capture thresholds at these locations. Once again the proximal His region was mapped and the lead implanted successfully. Pacing at this site resulted in atrial, ventricular and His bundle capture (Fig. 3). Atrial, right ventricular myocardial and His bundle capture was lost at 2.75 V, 2.2 V and 0.7 V @ 1.0 ms pulse width, respectively (Fig. 4). HBP lead was connected to the LV port of BiV ICD and output programmed to 2 V @ 1 ms to achieve S-HBP. Maximal sensed/paced AV delay was programmed to 100/
120 ms to accommodate the HV interval of 60 ms. NS-HBP is generally acceptable in most situations with minimal fusion (≤40 ms). A proximal placement of the HBP lead can lead to significant challenge during AV node ablation. In patients undergoing AV node ablation, we prefer that a small or no atrial electrogram is seen in the HBP lead. AV node ablation was performed in this patient using a deflectable sheath ensuring that the ablation electrode does not cross the level of the ring electrode (Fig. 5). When ablating very close to the HBP lead, as in this case, we generally pace from the HBP lead at approximately 0.5 V above the HBP threshold (1.5 V @ 1 ms in this patient). Ablation should be terminated if His capture is lost at anytime during the ablation. This case illustrates the various challenges associated with HBP and the need to modify the approach based on clinical needs and the patient’s anatomy.

Case 2: An 84-year-old man with a recent onset persistent atrial fibrillation, slow ventricular response (average HR of 42 bpm), QRS width of 114 ms, LVEF of 40% and NYHA class III symptoms was referred for permanent pacemaker implantation. A dual chamber pacemaker with an HBP lead (ventricular) was planned. In patients with high grade AV block, we routinely place the atrial lead in the RV apex during His bundle mapping to provide temporary ventricular pacing. During initial mapping we identified a site (A) with a small His electrogram (no atrial signal) where S-HBP was obtained (Fig. 6). However, the capture threshold was 2.5 V @ 1 ms at this site. Because of the difficulty in achieving this location, we decided to further map the His bundle region using a second pacing lead without sacrificing the original lead. At a slightly distal location (site B), NS-HBP with minimal fusion was achieved (Fig. 7). His capture threshold was 3 V @ 1 ms at this site. At a slightly more proximal location (approximately 15 mm from site B), small atrial electro-
gram and a large His electrogram (site C) with injury current could be achieved (Fig. 8). HBP threshold at this site was 0.7 V @ 0.5 ms. Minimal or no ventricular capture at the two distal sites with His bundle capture (sites A and B), suggest that the His bundle was mainly at the membranous ventricular septum. High capture threshold at these sites despite adequate fixation at implant suggest an anatomical variant of His bundle with early deep penetration towards the left side of the interventricular septum as previous described in autopsy studies [19]. A more proximal location provided excellent S-HBP in this patient (Fig. 9). Antiarrhythmic therapy with amiodarone was initiated with a plan for DC cardioversion. This case illustrates the value of additional mapping before accepting high His bundle capture threshold. If high HBP threshold at sites A and B were to be accepted, a biventricular pacemaker with an additional RV or LV lead would have been acceptable but at the cost of a significantly shorter pacemaker battery longevity. We prefer a dual chamber pacemaker to achieve longer battery life.

Case 3: An 80-year-old man with chronic LBBB presented with complete heart block and a RBBB escape rhythm at 28 bpm. The patient was urgently brought to the electrophysiology laboratory for permanent pacemaker implantation. The atrial lead was placed in the right ventricular apex to provide temporary ventricular pacing during His bundle mapping. His bundle region was quickly identified and the electrograms confirmed HV block. On fixing the lead to this site, large His electrograms with injury current was recorded (Fig. 10). However pacing at 5 V @ 1 ms at this site did not result in His capture. The HBP lead repositioned slightly more distally (Figs. 11 and 12) resulted in excellent NS-HBP with a His capture threshold of 1 V @ 1 ms. His electrogram recorded at this site was much smaller in amplitude and likely represented the far-field signal from the proximal His bundle. Near field His electrogram was not recorded at this site, as there was no distal conduction. Selective His bundle capture achieved at a low output with a short stimulus to ventricular interval of 35 ms confirm that the lead was at the His bundle distal to the
Fig. 8. His bundle mapping. Site C: Large His bundle electrogram is obtained from a more proximal location with excellent selective His bundle capture threshold.

Fig. 9. Fluoroscopic images of His bundle mapping. Left panel shows the HBP leads in site A and site B. Schematic representation of AV node and the course of His bundle is superimposed on the fluoroscopic image. The right panel shows site A and the final successful site C.

Fig. 10. Intra-Hisian AV block. Twelve lead ECG and intracardiac electrogram from proximal His bundle in a patient with complete HV block. Pacing at this site resulted in distal His bundle capture only at high output (10 V @ 1 ms). Sweep speed of 100 mm/s. Note the injury current in the His bundle at the time of lead fixation.
site of block (Figs. 13 and 14). Split His or distal His potentials suggestive of intra-His AV block was recorded only in a small number of patients in our experience [10]. The level of HV block in this patient was very discrete (<5 mm) and by mapping the distal His bundle it was possible to achieve excellent His capture.

**Location of the His bundle pacing lead**

In patients with S-HBP, the entire lead and the tip electrode is in the right atrium and the lead does not cross the tricuspid valve plane and has been demonstrated by echocardiography, cardiac CT [20] and in autopsy study [21]. In most patients with NS-HBP, we have noticed that the HBP lead does not cross the tricuspid annulus [22]. It is our observation that in some patients with NS-HBP, the HBP lead tip just passes between the septal and anterior tricuspid leaflets.

**Summary**

Selective HBP can be achieved in the majority of patients with normal His-Purkinje conduction. Even in patients with NS-HBP, the His capture threshold is often lower than the RV capture threshold. This can be explained by the presence of thin layer of ventricular myocardium spanning the His bundle at the membranous septum. Understanding the His bundle anatomy is essential to achieving successful permanent HBP. In majority of patients with HV block, the block is at the level of the proximal His bundle and HBP can be achieved by mapping the distal His bundle.

![Proximal His Bundle](image1.png)  ![Distal His Bundle](image2.png)

Fig. 12. Fluoroscopic images of HBP lead. The left panel shows the HBP lead in a proximal location. Schematic representation of AV node and the course of the His bundle superimposed on the fluoroscopic image with proposed site of discrete intra-His AV block (*). The right panel shows the HBP lead in the final location slightly distal to the proposed site of His block.

![Fig. 11](image3.png)

Fig. 11. Intra-Hisian AV block. The left panel demonstrates the electrograms obtained from a slightly distal location at a sweep speed of 100 mm/s. Note the far-field His electrograms on the HBP lead. The right panel shows NS-HBP from this site with a narrow QRS at sweep speed of 50 mm/s.
References


Fig. 13. Output dependent capture of right ventricle and distal His bundle. Twelve lead ECG and intracardiac electrograms from the HBP lead are shown at a sweep speed of 100 mm/s. Pacing at 1.4 V results in NS-HBP with minimal RV fusion. As the output is decreased to 1.2 V there is selective His bundle capture and loss of the initial delta waves in V1 (circle). At a pacing output of 1 V there is selective left bundle capture with resultant RBBB morphology of the QRS complex.

Fig. 14. Selective His bundle and left bundle capture. RBBB escape rhythm and output dependent variations in QRS morphologies are shown at a sweep speed of 150 mm/s. During selective HBP (S-HBP), the stimulus-QRS is only 35 ms suggesting the location of the lead to be at the distal His bundle. The baseline QRS morphology during escape rhythm is identical to the selective left bundle (S-LBP) captured QRS morphology with the RBBB and QRS duration of 150 ms.


Vijayaraman P, Ellenbogen KA, Dandamudi G. Longitudinal dissociation in the His bundle: persistent bundle branch block can be corrected by permanent His bundle pacing. Circulation 2014;130:A17180 [abstract].


