ABSTRACT. There has been a recent upsurge of interest in permanent His bundle pacing, given increased understanding and appreciation of the role dyssynchronous ventricular activation plays in congestive heart failure and atrial fibrillation. Permanent His bundle pacing gives implanters the ability to avoid causing ventricular dyssynchrony in patients dependent on ventricular pacing, and can provide an alternative means to implementing cardiac resynchronization therapy in patients with bundle branch disease and congestive heart failure. This paper describes a step-wise approach to implanting permanent His bundle pacing leads, with a clear demonstration of techniques and observations encountered during the course of typical His bundle lead implantations, including consideration of potential pitfalls and workarounds.

KEYWORDS. cardiac resynchronization, His bundle pacing lead implant techniques, non-selective His bundle pacing, permanent His bundle pacing, selective His bundle pacing.
pacing system analyzer to record electrograms, a multi-channel system allows attachment of 12-lead surface electrodes and simultaneous mapping with an octapolar His mapping catheter, and provides better electrogram resolution. The mapping catheter becomes superfluous after the operator becomes familiar with manipulating and mapping from the permanent pacing lead and delivery sheath; the learning curve, in this author’s estimation, is at least 10 cases, but this will vary depending on the operator’s procedural skills, support and so on. While not an absolute necessity, it is very helpful to be able to monitor all 12 surface leads along with high-resolution intracardiac electrograms; the latter allow excellent mapping and target assessment, while the 12-lead monitoring helps clearly define the pacing response for different outputs and/or polarities. This is especially true in the setting of patients with bundle branch disease where complex and subtle morphology shifts can be appreciated, and may be meaningful in terms of anticipated clinical response, as will be described below.

If a mapping catheter is used to assist with localizing and choosing a His target, the operator must decide on either a femoral or a superior approach. If the former is selected, then a femoral set-up is necessary. When using a simultaneous femoral approach, this author recommends a separate sterile set-up and, ideally, the assistance of another operator who can manipulate the catheter as necessary during the implantation process.

Figure 1: Sheath delivery system preferred for permanent His bundle lead implantation. While it is possible to hand-shape stylets, sheath delivery of a non-stylet-driven, exposed-helical-screw design has multiple advantages: 1) easier target site delivery; 2) small flexible lead caliber that minimizes flow stresses and valvular motion effects, thereby increasing stability; and 3) unipolar mapping capabilities from the exposed active screw. The lead is shown on the left side of the figure (SelectSecure model # 3830, Medtronic Inc., Minneapolis, MN). Currently, there are two sheath delivery options available: the sheath on the top right is deflectable in a single plane, allowing control in the height of anterior lead delivery, the downside being that the sheath is larger in caliber (8 French OD) and lacks septal angulation, making it sometimes difficult to catch septal tissue to permit fixation (SelectSite sheath, Medtronic Inc., Minneapolis, MN). The sheath shown lower right is a fixed dual-plane curve (6.5 Fr. OD), designed to deliver the lead to the anteroseptum at the level of the tricuspid annulus (315His, Medtronic Inc., Minneapolis, MN). The septal deflection makes it easier to screw the lead tip, the trade-off being reduced control due to no deflection capabilities.
thereby maximizing the sterility of the set-up, and minimizing the likelihood of compromising sterility in the pectoral field.

There are two basic sheath designs: a fixed-shape sheath that can be delivered through a 7 French safety sheath, and a deflectable sheath that requires a 9 Fr. sheath. Both sheaths are slit-able (Figure 1). The short sheaths provide extra system support during the implantation process. The preshaped sheath is a Medtronic 315His, and the deflectable sheath is a Medtronic SelectSite C304, both of which accommodate the non-stylet-driven, exposed-helical-screw 4.1 Fr. SelectSecure lead (Medtronic Inc., Minneapolis, MN).

While it is possible to perform permanent His bundle pacing using hand-shaped or deflectable stylets, this approach is considerably more challenging. The vast majority of centers performing permanent His bundle pacing prefer using the much simpler and stable system described above, which is to date the only system on the market that has design features more amenable to stable lead fixation in the His bundle region.

In our laboratory we like to use heparinized saline to flush the His delivery sheath to help prevent accrretion of thrombus within the catheter, which can limit the ability to manipulate the lead as the case progresses.

Procedure

Standard techniques are used to obtain vascular access, the number of accesses being determined by the type of pacing indicated, and also by the choice of whether to add a back-up ventricular pacing lead or not. At a minimum, a single access is required for the His lead. If an octapolar mapping catheter is used, the operator must choose between the femoral or axillary/subclavian venous approaches mentioned above. The femoral approach generally provides better mapping along the length of the His bundle, the trade-off being the introduction of femoral access to an otherwise standard pacemaker implant. Mapping from above obviates the need for a distinct sterile set-up, the trade-off being that it is a bit more difficult to map the His bundle.

After venous access is obtained and the generator pocket created, a 0.35 soft-tipped J-wire is advanced through a safety sheath to the level of the inferior vena cava. Generally, this author starts with the preshaped dual-plane, fixed-curved sheath, which is advanced with a dilator over the wire, retracting the dilator and wire when the tip of the sheath is at the level of the posterior annulus–Eustachian ridge. At this point, in most normal-sized atria, the tip of the sheath will abut the septum in close proximity to the His bundle. The sheath is then gently flushed with heparinized saline and the Select Secure lead is advanced just proximal to the tip of the sheath. Usually, at this point, I confirm septal orientation with a left anterior oblique (LAO) view. If a mapping catheter is in place, true LAO can be defined by nearer-field V relative to A, and with the mapping catheter freely advanceable, confirming the mapping catheter is not above Todaro’s tendon. It is critically important to keep these relationships in mind throughout the implantation procedure to avoid targeting a fast pathway potential, which would lead to atrioventricular (AV) nodal pacing. The presence of a mapping catheter simplifies matters since, in the right anterior oblique (RAO) view, it will advance smoothly toward the right}

![Figure 2: Use of a mapping catheter to identify the His target. The blue arrows indicate the distal bipolar electrode pair of an octapolar His mapping catheter introduced from a femoral venous sheath, seen fluoroscopically on the left, identifying a discrete His potential as seen in the right panel. The red arrows confirm the presence of the same His potential on the now screwed-in permanent His bundle pacing lead targeting the distal bipolar electrode pair (dotted blue line). Far-field atrial and ventricular electrograms are more apparent on the permanent pacing lead due to the wider interelectrode spacing compared with the octapolar mapping catheter used in this example. HBD: distal His bundle electrode bipoles; HBP: His bundle pacing lead.](image-url)
ventricular (RV) apex as long as the tip is beyond the tendon. If the lead is in the fast pathway region, it will cant leftward in the LAO view.

At this point, the cathodal alligator clip is attached to the pacing lead cathode pin and the anode to the pacemaker pocket, typically via a Weitlaner retractor. Mapping can now take place with the lead inside the sheath and/or by gentle application of counterclockwise or clockwise torque to the sheath. If there is a mapping catheter in position, the electrode bipole pair can be targeted, showing the potential of interest (Figure 2). For example, in the setting of patients with His–Purkinje disease and bundle branch disease, a more distal target may be of interest, whereas the most discrete proximal His potential can be targeted in those patients with normal His–Purkinje function. In most cases, the pacing site is supravalvular where higher outputs might generate non-selective capture of the His bundle, with lower outputs generating selective capture (Video 1 and Figure 3).10,11 The QRS with selective capture will be essentially identical to native conduction, whereas non-selective QRS morphology will have a characteristic pseudo-delta wave akin to pre-excitation associated with an anteroseptal pathway. If the His pacing site is subvalvular, His capture is more likely to be encountered at higher outputs (resulting in non-selective His bundle capture, described elsewhere4,9,12 and below), with lower output resulting in ventricular capture only prior to loss of capture (Video 2 and Figure 4). This pacing site is the one most often chosen when para-Hisian pacing maneuvers are used to characterize the presence or absence of retrograde-conducting accessory pathways.13

Using the preshaped sheath, it should be possible to map and target a discrete His within several minutes. If identifying the His remains a challenge after multiple passes, it would be reasonable to switch to the deflectable sheath, which requires exchanging the short introductory sheath from 7 to 9 Fr. The deflectable sheath is then advanced with a dilator over the 0.35 J-wire, as described above.

The advantage of the deflectable sheath is that it can help provide more anterior reach and the curve can be modified to reach a more distal or proximal target. The disadvantage

![Figure 3: The first QRS shows His bundle pacing with selective His bundle capture above the plane of the tricuspid valve, showing all the characteristics of selective capture including the presence of the local RV anteroseptal activation occurring well after His bundle capture and conduction (Figure 5). Extensions of ventricular myocardium adjacent to the membranous septum above the plane of the tricuspid valve vary between individuals: depending on how close the tip of the pacing lead is to the valve and ventricular extensions, an increase in electrical output may capture local ventricular myocardial extensions, resulting in loss of the local septal ventricular electrogram ("no local V") and a QRS morphology similar to that seen with anteroseptal pre-excitation pattern (pseudo-delta wave). The second complex demonstrates the pseudo-delta wave morphology with local V now coincident with the stimulus artifact.](image-url)
is the absence of a septal plane of deflection, making it more
difficult at times to get the lead screw to catch; often a fair
amount of counterclockwise torque is needed to try to catch
the endocardium. At times, however, the tip of the sheath
will seat well at the nexus between Todaro’s tendon and the
tricuspid valve annulus, where often an excellent His pacing
response and threshold can be obtained. Typically, if there is
no further advantage noted using this sheath within 10–15
minutes, it is reasonable to consider an alternative pacing
strategy.

While His bundle pacing thresholds are commonly higher
than a traditional right ventricular site, they should be
within the 1–3 volt and up to 1 msec pw ranges. The best
thresholds correlate with observation of His injury current
that resolves over several minutes after screwing in the
lead. The latter has been observed 30–40% of the time in
one large series. For thresholds greater than 3.5 volts it
would be reasonable to seek an alternative site, depending,
of course, on the clinical scenario. In select cases it may be
reasonable to accept a very high threshold. In our
experience, 5–6 sites can be safely attempted. It is
conceivable that the more sites are tried, the more likely
it is that the His potential will be obscured and/or heart
block created due to trauma to the His bundle and/or
surrounding tissue. Additionally, it is important to avoid
the tip of the lead becoming wrapped up in chordae
tendineae with ensuing lead tip entrapment. This can occur
if the lead is advanced beyond the plane of the tricuspid
valve attachment plane and screwed in anteriorly near the
outflow tract. When intentionally attempting a distal
subvalvular site, advance a small amount of the lead tip
before screwing and pull back, making sure nothing is
grabbing the helical screw. If the screw catches, seek an
alternative site.

Full active fixation typically occurs with 4–6 full clockwise
rotations (a full rotation can be identified by watching the

Figure 4: Subvalvular lead position. With more distal lead placement, the His bundle lead tip is actively fixed to anterobasal
ventricular myocardium adjacent to the penetrating portion of the His bundle; in contrast to the supravalvular implant site,
higher output will be required to capture the His bundle in the subvalvular position. This position elicits His capture similar to
what is seen during para-Hisian pacing maneuvers in the setting of electrophysiologic studies wherein an attempt is being
made to distinguish retrograde atrial activation between accessory pathways and the AV node. At lower output, therefore,
there will be only para-Hisian ventricular myocardial capture, as seen in the first complex (stimulation (Stim) to QRSend 178
msec), whereas at higher output, non-selective His bundle capture will manifest with the end of the QRS being advanced, as
seen in the second complex (Stim to QRSend 128 msec).
lead sleeve wings rotate), resulting in some torque build-up in the lead. After fixation of the lead, the sheath is pulled back while gently maintaining forward pressure on the lead, allowing a posterior loop to form on the distal lead end. The lead is then tested with either bipolar or unipolar pacing configurations, or both, using either the pacing system analyzer (PSA) or electrogram acquisition system, and paying close attention to defining characteristics of His bundle pacing:

1. During selective capture, there will be i) a local ventricular electrogram on the His pacing lead and/or mapping catheter timing similarly to the H to local V time during native conduction; ii) electrical diastole on the surface electrocardiogram from Stim to onset of QRS; iii) the Stim to QRS onset will be similar to baseline H to QRS onset; iv) the QRS morphology will be essentially identical to native QRS; and v) the T-wave morphology will be unchanged from native T-wave axes (Figure 5).

2. During non-selective capture, there will be evidence of basal anteroseptal ventricular capture with a pseudo-delta wave – mimicking ventricular pre-excitation by an anteroseptal accessory pathway conduction – for the duration of the measured HV time before a normal QRS with preserved axes ensues. The timing of H–QRS end will be nearly identical to Stim to QRSend (Figure 6).

3. His bundle pacing can normalize the QRS in patients with bundle branch disease due to longitudinal dissociation in the proximal His bundle,14,15 In the setting of left bundle branch block, the normalized QRS has a Stim to QRS onset typically 10–20 msec shorter than the HV time, due to earlier ventricular activation from the re-engaged proximal left fascicular system (Figure 7).

4. If the implant site is beyond the plane of the tricuspid valve, the Stim to QRSend will be shorter than with loss of His capture, and His capture will require higher output than local ventricular capture (as described above, this is similar to the case during para-Hisian pacing in the context of an electrophysiologic study). In this case, the lead is its own back-up since V capture is present, the trade-off being that para-Hisian ventricular capture can result in marked QRS widening and associated interventricular dysynchrony (as in Figure 4 where para-Hisian ventricular capture generates a 178 msec QRS, which narrows to 128 msec with simultaneous His capture.

Figure 5: Selective His bundle capture demonstrates all of the following: 1) The local ventricular electrogram can be seen occurring well after His capture, and the timing of local ventricular activation is the same for both the paced and the natively conducted QRS complexes (red arrow, “local V”); 2) HV interval \( \approx \) Stim–V interval; 3) Stim to QRS onset is isoelectric in all 12 surface leads; 4) QRS morphology is identical to the conducted QRS morphology in all 12 leads; and 5) The same QT and T-wave morphology is observed in all 12 leads.
at higher output). This, however, may be a reasonable site when anticipating AV node ablation without the use of a ventricular back-up lead, or when operating on patients with severe proximal disease and/or an unacceptably high threshold at more proximal pacing sites.

Once adequate thresholds are obtained, standard procedure is followed for sheath removal, securing the lead sleeve, and so on. It is very important for follow-up purposes to clearly document the relevant thresholds observed, including non-selective, selective, and para-Hisian ventricular capture, and in the case of performing His bundle pacing correcting bundle branch disease, the threshold output required to elicit QRS normalization.

**Conclusion**

The steps involved in the placement of a permanent His bundle pacing lead in a sense reflect a fusion of basic principles of electrophysiologic studies and standard pacing lead implantation, but in no way do these elements require a dramatic shift in knowledge base or procedural acumen. All of the steps described above can be readily mastered by most electrophysiologically trained implanting physicians, with a learning curve of somewhere between 10 and 20 cases. The level of difficulty of these cases is certainly well within the realm of that encountered during LV lead placement.

The end result is extremely gratifying in that a success rate of more than 90% can be anticipated by an experienced operator. Providing a normal QRS in ventricularly pacer-dependent patients can be expected at a minimum to prevent dyssynchrony-induced ventricular dysfunction, and perhaps in certain settings can lead to marked improvement in ventricular function and functional status.

Pacemaker follow-up in our clinic is standard with respect to the timing of interrogations, including pre-hospital discharge assessment of lead and device function. It is important to clearly define and document the
His lead position and the thresholds present so these parameters can be assessed at subsequent device checks. For example, in Figure 3, the non-selective capture threshold will be between 2.5 and 5 volts at 1 msec, and the selective capture threshold will be ≤ 2.5 volts at 1 msec. This is particularly important with distal lead placement where loss of His capture results in para-Hisian ventricular capture only; the lead output must be left above the non-selective His capture threshold to prevent pacemaker-mediated ventricular dyssynchronous pacing. Consequently, additional training is likely to be needed in many centers where allied health-care providers who may not be familiar with these nuances perform much of the device follow-up.

As of this writing, there is only one commercially available system that allows us to consistently obtain good results; however, it is notable that this system has not been optimized specifically to address the challenges encountered. With increased attention being paid by implanters and device companies, it would take relatively modest resource allocation to greatly improve upon the current choices available for His bundle pacing, including better sheath delivery designs, lead configurations, and device improvements. With adequate proctoring, however, reasonable outcomes can already be obtained using extant systems.

References