INNOVATIVE TECHNIQUES

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Left Ventricular Lead Placement for Cardiac Resynchronization Therapy

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ABSTRACT. Expanding indications for cardiac resynchronization therapy (CRT) and emerging data on the importance of targeted left ventricular (LV) lead placement have resulted in renewed focus on refining implantation technique. Many implanting physicians use an “over-the-wire” approach to LV lead placement that may not provide enough support for lead advancement into tortuous vessels. New techniques have been described that utilize directional and support catheters to allow direct advancement of the lead into the target branch. These tools have improved the efficiency and success rate of LV lead placement compared to early implants. Additionally, techniques are described which may help in troubleshooting difficult coronary sinus anatomy.

KEYWORDS. cardiac resynchronization therapy, congestive heart failure, guide support, left ventricular lead implantation.

Evolution of biventricular pacing

In the early 1990s, several small case series were published suggesting a benefit for dual-chamber pacing (DDD) in patients with severe cardiomyopathy but without a typical bradycardia indication for device implantation.12 The hypothesis was that global cardiac function could be improved by optimizing left ventricular (LV) filling via adjustment of the pacemaker’s atrioventricular (AV) delay. Additionally, proper AV timing resulted in a reduction in mitral valve regurgitation with a further decrease in pre-load, thereby improving overall cardiac hemodynamics. In the short-term, patients experienced an improvement in LV ejection fraction (EF) and reduction in New York Heart Association (NYHA) class heart failure (HF) symptoms with DDD pacing.

Despite these early successes, subsequent trials of dual-chamber pacing for the treatment of HF failed to prove short- or long-term benefit and did not impact patient survival.3-5 The benefit of AV synchrony on diastolic filling time was likely outweighed by the deleterious effects of right ventricular (RV) apical pacing on overall cardiac performance. RV apical pacing adversely affects myocardial performance due to a reversal of the normal electrical activation pattern from apex to base, resulting in abnormal septal motion. The deleterious consequence of RV pacing in patients with cardiomyopathy was confirmed in the Dual-Chamber and VVI Implantable Defibrillator (DAVID) trial, where RV pacing greater than 40% conferred a more than fivefold increase in death or hospitalization for HF.6 Thus further efforts to treat symptomatic HF with dual-chamber pacing were abandoned.

In 1994, Cazeau and colleagues7 published the first case report of dedicated biventricular pacing for the treatment of congestive HF. Using an epicardial lead placed on the LV free wall via thoracotomy and endocardial leads placed in the right atrium (RA), left atrium (LA) via the coronary sinus (CS) and RV, they demonstrated a decrease in pulmonary capillary wedge pressure and an increase in cardiac output with temporary four-chamber pacing. Based upon these acute hemodynamic results, the investigators implanted a permanent pacing system, using Y adaptors to provide simultaneous RV and LV pacing. After 6 weeks of biventricular pacing, the patient had a profound diuresis...

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and reported symptomatic improvement to NYHA functional class II.

Several years later the same group reported the results of biventricular pacing in their first eight patients. All of the patients had prolonged QRS duration at baseline, although only two of eight patients were noted to have left bundle branch block (LBBB). At follow-up, half of the patients showed remarkable clinical improvement, confirming the results from their first patient. Following these early reports, enthusiasm began to grow for the application of cardiac resynchronization therapy (CRT) as a novel therapy for severe, drug-refractory HF. In 1998, Daubert and colleagues published a series of the first, fully endocardially placed biventricular pacing systems with LV leads inserted via the CS and in doing so helped to usher in the modern era of CRT.9

Anatomy of the coronary sinus

The CS runs in the posterior coronary groove between the LA and left ventricle, and the CS ostium drains into posteroseptal region of the RA near the tricuspid valve. The ostium itself is 5–15 mm in diameter and is partially covered by a Thebesian valve (a remnant of the embryonic right valve) in roughly 60% of patients.10 In a small subset of patients, the ostium is completely enclosed by the valve with only small fenestrations allowing venous drainage, thereby presenting a major impediment to CS access. In addition, RA dilation may lead to an abnormally high insertion of the CS ostium, making intubation with a fixed-shape catheter or wire difficult.

The body of the CS is made up of muscle fibers that are continuous with the LA, thus encircling the CS proper in a muscular sleeve. A second valve (the valve of Vieussens) located at the junction of the great cardiac vein and the vein of Marshall is present in about 8% of patients.11 This valve may divert a wire or catheter into a distinct vein drain the lateral wall of the left ventricle is usually not a suitable target for LV lead placement. Three branches off the anterior interventricular vein (AIV) are variably present. In patients with prior myocardial infarction, first-order branches to the lateral wall off the CS are often diminutive or absent.12 For CRT implantation, where mid-lateral LV wall lead placement is generally preferred, this region was accessible from at least two CS tributaries (posterolateral and AIV) in greater than 85% of patients. In approximately 20% of patients, the mid-lateral LV wall was also accessible from branches of the MCV.

Implantation techniques

Failure rates for placement of LV leads via the CS ranged between 7.5% and 10% in the two most recent large, randomized controlled trials of CRT.16,17 Most of these implant failures are due to difficulty accessing the CS ostium or advancing the pacing lead into an adequate, stable position. In addition, LV lead dislodgement may occur both acutely or in the first few months after implantation. In a systematic review of six large trials of CRT, the overall lead dislodgement rate was 5.7%.18 In the REVERSE trial, which reported complications up to 12 months, the rate of late LV lead dislodgement (between 1 and 12 months post implant) was 3.4%.19

Historically, the first LV pacing leads were placed on the epicardial surface via a subxiphoid or thorascopic approach. Although operative morbidity was low, access to the lateral or posterolateral walls of the left ventricle is difficult when there is only limited exposure. Early attempts at pacing the left ventricle via the CS branches utilized standard, stylet-driven endocardial pacemaker leads with the tines removed. Maneuverability was difficult and dislodgements common. Early CRT implanters understood the need for designing specific implant tools which would allow 1) easier access to the CS, 2) a means of visualizing the CS branches, and 3) maneuverability of the pacemaker lead.20 The development of pre-shaped sheaths that follow the curvature of the lateral wall and floor of the RA allows easier access to the CS.21 In addition, the development of dual, telescoping catheters of various shapes allows improved maneuverability and access to CS side branches.22 Small injections of contrast through these catheters allow direct visualization of the CS ostium and target branches and speeds implant time.

Despite advancements in catheter design, many implanting physicians rely upon an “over-the-wire” technique for LV lead placement. This technique involves probing for the CS ostium with a soft-tipped wire through a preformed sheath followed by advancement of the pacing lead into the target branch over an angioplasty

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However, tortuous anatomy may make advancement of the sheath or LV lead using only a wire for support difficult or impossible. Similar to percutaneous coronary interventions where the interventionalist chooses a specifically shaped catheter to provide target-vessel support, uses contrast to delineate anatomy, and delivers therapy directly through the guide-catheter, electrophysiologists have utilized this “interventional” approach during CRT implantation.

**Interventional approach to lead placement**

As shown in Figure 3, this technique includes the following steps: 1) localization of the CS ostium via contrast puffs through a preformed guide catheter; 2) cannulation of the CS with a sheath advanced over the guide catheter (with or without wire support); 3) cannulation of the target branch with a two-component, telescoping-support delivery system consisting of a) an inner target vein selector connected to the contrast injection system and b) a delivery-guide shaped to fit into the target vein and deliver the LV lead; 4) advancement of the LV lead through the delivery-guide over an 0.014-inch angioplasty wire. All major device manufacturers and independent companies now provide catheters that allow direct LV lead delivery into the target branch (Table 1).

There are multiple advantages to LV lead implantation using this interventional technique. First, the use of

**Figure 1:** Coronary sinus venogram demonstrating a prominent valve of Vieussens and patent vein of Marshall. Inadvertent advancement of a wire into the vein of Marshall resulted in coronary sinus dissection and hemopericardium. Previously implanted left ventricular lead (asterisk) had high capture threshold.
contrast injection allows rapid identification of the CS ostium and target vessel. Secondly, the implanting physician is not reliant upon a wire to support lead advancement. Rather, the telescoping system acts as a stable “rail” to navigate and straighten tortuous anatomy (Figure 4). Finally, this type of system allows adaptability to alternate implant sites should the first target vessel prove inadequate due to instability, poor capture threshold, or unacceptable phrenic nerve stimulation. Systems that utilize this telescoping system of inner directional catheters and guide sheaths to allow direct lead delivery into the target branch allow more efficient, targeted LV lead placement compared to over-the-wire implants. Although these data are non-randomized, CRT implants using this approach result in fewer failed LV leads (1.9% versus 8.1%, p < 0.02), improved targeted lead placement and reduced fluoroscopic times compared to standard over-the-wire techniques.

Troubleshooting difficult lead implantation

The most common reasons for failed LV lead implantation include inability to access the CS ostium, inability to advance the lead into the target branch, and acute lead dislodgement or instability. Several techniques have been reported to overcome these obstacles.

The CS ostium is located in the posteroseptal region of the RA and is accessed by withdrawing the CS guide catheter across the tricuspid valve with counterclockwise torque. With dilated cardiomyopathy and significant right atrial enlargement, however, the ostium may enter more superiorly, making localization or cannulation difficult. Rarely, the CS ostium may enter the atrium in an anomalous fashion. When initial attempts at CS localization fail, a selective coronary angiogram with cine fluoroscopy of the venous phase may help locate a high or unusual ostial insertion.

Balloon anchors

Once the ostium is located, a prominent Thebesian valve or a steep takeoff due to atrial enlargement may hinder advancement of the catheter into the main body of the CS. When a wire can be placed into the main CS but there is resistance to sheath advancement, several maneuvers may be attempted. With the wire in place, a small, straight 5-French hydrophilic catheter can be advanced and used as a “rail” to place the larger diameter sheath beyond the tortuous segment. If the small hydrophilic catheter is advanced but there is still impedance to placement of the larger sheath, a rigid 0.035-inch wire (Amplatz Extra-Stiff, Cook Medical, Bloomington, IN) can be exchanged through the small sheath to provide additional support. Finally, if these attempts are unsuccessful, an occlusive balloon can be used as an anchor, allowing sufficient straightening of the ostium for successful catheter placement. With this technique, a compliant venography or small coronary artery balloon is advanced over a wire into the main CS or anterior interventricular vein. Once inflated, backtraction is applied to the balloon to straighten the CS thereby allowing catheter advancement.

Coronary sinus venoplasty

As discussed above, the use of a telescoping system of support and inner catheters is the basis for efficient and successful lead placement into the target branch. However, despite direct catheter access to the target vein, anatomic factors may impede lead delivery. When
a partial occlusion to the target branch is present, invasive angioplasty techniques have been employed with excellent success and minimal complication.\textsuperscript{26} A small-diameter (2.5 or 3.0 mm) coronary balloon can be advanced over a 0.014-inch angioplasty wire across the lesion and inflated to rated burst pressure. This safely allows transient dilation of the vessel to allow lead passage, although CS vein rupture has been reported.\textsuperscript{27} A coronary balloon can also be used to assist lead advancement through a tortuous target branch when no

**Table 1:** Commercially available coronary sinus delivery-guide catheters

<table>
<thead>
<tr>
<th>Company</th>
<th>Product name</th>
<th>No. of shapes</th>
<th>Largest allowable lead size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtronic</td>
<td>Attain Select II</td>
<td>5</td>
<td>5.3 Fr</td>
</tr>
<tr>
<td>St. Jude</td>
<td>CPS Aim SL</td>
<td>3</td>
<td>5.0 Fr</td>
</tr>
<tr>
<td>Boston Scientific</td>
<td>Acuity Break-away</td>
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<td>4.0 Fr</td>
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<tr>
<td>Pressure Products</td>
<td>Worley LVI</td>
<td>4</td>
<td>6.9 Fr</td>
</tr>
</tbody>
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**Figure 3:** Steps in left ventricular lead implantation using telescoping catheters and contrast injection. See text for details.
Figure 4: (a) Coronary sinus venogram demonstrating a tortuous lateral branch. (b) Straightening of tortuosity using a telescoping delivery-guide catheter.

Figure 5: Use of a gooseneck snare to aid left ventricular lead placement. An anterolateral target branch (asterisk) is seen in (a) an anterior–posterior and (b) left anterior oblique view. (c) An 0.014-inch hydrophilic wire is advanced through a collateral branch back into the coronary sinus and the distal tip is grasped with a goose snare (arrow). (d) The lead is advance anterograde into the target branch using traction on both ends of the wire.
stenosis is present. If a second angioplasty wire can be advanced in the vein, the balloon is inflated in the distal portion to “trap” the wire against the vessel wall. Back traction is then applied on the (non-balloon) wire and the LV lead is advanced into the final position.

Snares

If the wire can be advanced into the branch and back into the main CS via a collateral, a gooseneck snare can be used to capture the distal end of the wire to aid lead advancement. The steps in this technique are as follows: 1) a long (300 cm) hydrophilic wire is advanced into the target vein or collateral until the distal end returns to the proximal CS, 2) a gooseneck snare (10–25 mm) is inserted through the same sheath as the wire and the distal end of the wire is snared and retracted, 3) the lead is advanced either anterograde or retrograde into the target location and the wire removed (Figure 5). An assistant or second operator is advised to maintain control of both ends of the wire during lead advancement and wire removal. After the wire is snared, a kink is usually present on the distal tip that can be trimmed to ease lead insertion.

Future advancements

New tools and techniques have greatly improved the efficiency and success rate of LV lead placement compared to early implants. New pacing leads have been developed which allow active fixation into the vessel to prevent dislodgement. Additionally, leads with multiple pacing configurations have been developed which may improve thresholds and prevent phrenic nerve capture. The next great hurdle in CRT is to improve clinical and echocardiographic response rates. In order for this to happen, LV lead implantation likely needs to evolve from a strictly anatomically based procedure to a “targeted” implant strategy. Just as cardiothoracic surgeons use an individual patient’s coronary angiography to plan bypass graft placement, electrophysiologists should arm themselves with the best data before and during the procedure to guide proper lead placement for each patient.

Recently, data have shown that using pre-procedure imaging with speckle-tracking echocardiography to guide LV lead placement to the wall with the latest mechanical contraction results in improved response to CRT compared to “blind” lead placement. However, the mechanical information obtained from echocardiography is not always easily translated to the fluoroscopic appearance on CS venography. During the implant procedure, when there is significant electrical delay (as measured from QRS onset to the LV lead electrogram) at the final implant position, patients experience a greater degree of reverse remodeling. Future studies will need to examine whether targeting the LV lead to the site of greatest electrical delay as measured during the implant procedure results in improved outcomes.

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