Practical Approach to Implanting Left Ventricular Pacing Leads for Cardiac Resynchronization

ANGEL R. LEÓN, M.D., DAVID B. DELURGIO, M.D., and FERNANDO MERA, M.D.

From The Carlyle Fraser Heart Center, Division of Cardiology, Emory University School of Medicine, Atlanta, Georgia, USA

Introduction

Our approach to implanting cardiac resynchronization therapy (CRT) devices combines an understanding of the anatomy of the failing heart and the coronary veins, standard pacing lead insertion skills, and techniques common to diagnostic cardiac catheterization and interventional cardiology. The method we have devised over the past 5 years has provided CRT safely and effectively to a large volume of compromised patients with congestive heart failure (CHF) and conduction system disease.

Venous Access

We prefer the left shoulder as the implant site because it provides a more natural curve for the guide catheter to follow from the subclavian vein to the coronary sinus (CS). Right subclavian access forces the guide catheter to make two right-angle turns in opposite directions, one as it goes from the subclavian to the superior vena cava, a second from the right atrium (RA) to the CS ostium. Contrast injection into the peripheral vein opacifies the subclavian vein to help in a difficult puncture and, during a procedure to upgrade an existing system to CRT, detects asymptomatic subclavian vein thrombosis that may be present in up to 10% of patients with chronically implanted pacing leads.

Options to overcome subclavian occlusion include inserting a left ventricular (LV) lead in the contralateral subclavian vein and tunneling the lead across the midline to reach the existing pocket, abandoning the implanted system and inserting an entirely new CRT system in the other shoulder, or sacrificing one of the existing leads implanted in the obstructed vein to provide a rail for a laser sheath to bore through the obstructed subclavian vein and then expanding the bore to accommodate the CRT lead and a replacement for the sacrificed lead. When abandoning an implanted system, one must weigh the benefit of reducing the bulk of abandoned leads against the risk of extraction. We generally prefer to abandon implanted systems requiring multiple leads for upgrade by the tunneling method ICDs or pacing systems requiring only the addition of a single LV lead. We have used the laser boring approach infrequently.

When implanting completely new CRT systems, inserting the right ventricular (RV) lead prior to attempting to enter the CS provides backup RV pacing should instrumentation with a CS guide catheter inadvertently traumatize the right bundle branch in a patient with preexisting left bundle branch block. Attaching the RV lead to the septal surface allows optimal separation between the RV lead and LV electrodes implanted along the lateral LV free wall. Connecting the RV lead to a temporary pacing generator provides rate support in case of atrial-ventricular block. One then can safely proceed with CS catheterization.

Remodeling and CS Access

Understanding the anatomic changes of the failing heart increases the chances of successful CS entry. Chamber enlargement, upward shift of the LV long axis, posterior rotation of the short axis, and mitral annular dilation affect the apparent position of the CS ostium relative to fluoroscopic landmarks normally used to identify cardiac anatomy. Rotation along the long and short axes of the heart moves the CS to a relatively low and posterior position within the enlarged RA. LV enlargement dilates the mitral annulus and changes the angle of approach from the RA into the proximal segments of the CS (Fig. 1).

RA enlargement expands the subeustachian space and distorts the eustachian ridge, creating a barrier to CS entry. Preimplant echocardiography alerts one to unusual RA enlargement or anatomy. Brief fluoroscopic inspection of the cardiac silhouette demonstrates the degree of cardiomegaly, cardiac rotation, the presence of anatomic markers such as right coronary artery calcifications, or the lucent adipose pad overlying the atrial-ventricular groove that marks the course of the CS. Imaging the heart in multiple views provides an understanding of cardiac anatomy and guide the implant procedure. The left anterior oblique (LAO) $30^\circ-45^\circ$ projection best guides CS entry because the CS runs toward the spine toencircle the mitral annulus in that view. However, with experience, one can effectively cannulate the CS guided by the more ergonomically acceptable anteroposterior (AP) or LAO views.

CS Catheterization

Engaging the CS with a guide catheter involves three steps (Fig. 2). (1) Advance the guide catheter to the floor of the RA...
over a guidewire (0.036 J-wire), retract the guidewire completely into the guide catheter, and point the guide catheter at the cardiac apex. (2) “Bounce” the guide catheter off the RA floor to point the tip up while (3) simultaneously applying counterclockwise torque to the guide catheter to direct it posterior and toward the ostium. The guide catheter often enters the RV during attempts to enter the CS from the RA. If so, slowly withdraw the catheter across the tricuspid annulus while applying counterclockwise pressure. When the catheter comes back to the RA, immediate counterclockwise torque followed by slight advancement often will engage the ostium. Probing with the guidewire confirms CS entry when the wire follows the typical contour of the CS. We do not repeatedly inject contrast “puffs” into the RA to find the CS. Once inside the CS, advance the guide over the wire into the CS to reach a stable position for venography and lead insertion. The valve of Vieuxsens found at the junction of the CS and the great cardiac vein occasionally blocks advancement of the guide catheter. Approach the valve carefully, gently crossing it with a guidewire before advancing the guide catheter over the wire and through the valve. Excessive pressure at the valve by a guide catheter often dissects the CS.

When numerous attempts to locate the CS with standard guide catheters fail, consider using alternative equipment to find the ostium. Inserting standard angiographic catheters within the guide catheter creates a telescoping catheter system with increased reach and rotational capability to locate the CS ostium (Fig. 3). The MP-A2 extends the reach of the delivery system with less angle and with the versatility to point up or down at the end of the guide catheter. In the greatly enlarged RA, an AL-3 catheter inside a conventional guide catheter extends the reach of the system and directs a guidewire or contrast injection superiorly toward an upwardly angulated CS. Inserting the left internal mammary (LIMA) into a guide catheter facilitates entry into a CS ostium directed down or into a posterior intraventricular vein. Once in the CS, the diagnostic catheter can track over a guidewire to provide a stiffer path over which the guide catheter can advance into a stable CS position. Pulling the guidewire or diagnostic catheter back while simultaneously advancing the guide catheter facilitates the tracking of the guide catheter. Use of a deflectable electrophysiology catheter provides a less versatile option to the telescoping catheter technique at a greater expense. The limitations of deflectable EP catheters include stiffness that may traumatize the CS, cost, and the lack of a lumen for introducing a guidewire or contrast. We relegate the deflectable EP catheter to a last choice for finding the CS.

Cardiac Venography

We strongly advocate use of venography to facilitate CRT lead implantation. Retrograde injection of contrast material opacifies all potential target veins, valves, strictures, collateral connections, and specific anatomic details that facilitate or impede optimal placement of LV pacing leads. Occluding the CS with a single-lumen balloon-tip catheter allows contrast injection into the entire venous tree either directly by retrograde filling or indirectly by antegrade filling of other vessels through collateral venous channels. Low-pressure injection of diluted (50% saline) nonionic contrast material reduces the chance of vascular trauma, contrast nephropathy, and volume load to the CHF patient. Storing digitally acquired images in two radiographic (AP/LAO or right anterior oblique [RAO]/LAO) planes provides an adequate anatomic reference for advancing guidewires and pacing leads into the targeted LV site. Good venographic technique demonstrates the primary and secondary venous targets and delineates the site of venous entry into the CS to guide steering of the guidewire and lead into the selected vein. Choosing to not use venography can fortuitously result in a successful implant. We feel the advantage of venography greatly outweighs its risk.

The venogram may sometimes demonstrate apparent absence of veins draining the LV free wall, or it may find only small-caliber veins that cannot accept even a 4-French diameter pacing lead. Careful inspection of the venogram often shows a large posterior interventricular vein with a large tributary that parallels the CS and drains the LV lateral wall (Fig. 4A). Occlusive venography deep in the CS demonstrates collateral flow from the anterior/great cardiac vein to the lateral and posterior veins and back to the CS. Identifying the point where the posterior vein enters the CS facilitates selective advancement of the guide catheter into the large vein for passage of the pacing lead to a desirable lateral location. Pointing the LIMA or MP-A2 within the guide catheter down to the posterior vein offers the best chance to
Figure 2. (A) Advance the guide catheter to the lower right atrium and point the tip toward the cardiac apex. Pull the guidewire into the guide. (B) Bounce the guide catheter off the right atrial floor to point the tip up. (C) Counterclockwise torque sends the tip posterior to find the coronary sinus ostium. Advance the guidewire to probe for the coronary sinus.

enter a vein that often can salvage an otherwise unsuccessful implant.

Target Vein Selection

The venogram illustrates the primary target vein and potential alternatives. LV pacing from within the lateral, posterolateral, or anterolateral cardiac vein provides optimal CRT. Pacing from within the anterior cardiac vein or the posterior interventricular vein stimulates primarily the septum and does not resynchronize the LV. Suggested criteria to identify the ideal free-wall pacing site include anatomic position, maximal RV to LV electrode separation during fluoroscopy (Fig. 5), stimulation at the LV site with latest local activation, and imaging tools that identify the area of latest mechanical activation.

LV Lead Insertion

Implanters have a choice of large diameter, stylet-driven leads, and smaller diameter over-the-wire leads for LV venous pacing. We use over-the-wire leads in >90% of cases, reserving stylet-driven leads for very large LV veins in which we cannot stabilize the smaller, over-the-wire lead. Advance stylet-driven leads by bending the distal 1 to 2 cm of the stylet at an angle corresponding to the angle of entry of the target LV vein into the CS. The bend allows one to steer the lead tip into the desired vein. Once in the tributary vein, placing a soft, straight stylet then allows advancement of the lead to the desired position inside the vein.

The over-the-wire technique provides the ability to target multiple target veins and manipulate the lead into small tributaries to achieve optimal lead stability and avoid stimulation of the left phrenic nerve. Load a guidewire (0.014 inch, intermediate or middle weight) into the lead and shape the distal 3 mm of the wire (40°–60°). Insert the lead and wire into the guide catheter and advance the combined system out of the guide catheter, leading with the wire into the venous system. Once the guidewire enters the targeted vein, advance the wire deep into the distal segment of the vein to provide a track for the lead to enter into the vein and reach the desired final position. Advancing the lead while retracting the wire (the “push-pull” technique) wedges the lead tip into narrow venous segments and stabilizes the lead. The over-the-wire technique permits easy movement of the pacing electrode to multiple sites within one vein or to alternate veins when one encounters unacceptably high stimulation thresholds or extracardiac stimulation during LV pacing.

Valves inside the CS, severe angles at which veins enter the CS, tortuous segments within the veins, and the small caliber of the veins interfere with successful advancement of guidewires and leads. When a vein enters the CS at a very acute angle (>120°), the guidewire may not advance to a distal site or the lead may not track across the angle and actually dislodge the wire. If so, insert a 6-French LIMA into the guide catheter positioned in the CS beyond the target vein and engage the vein by rotating and moving the hook of the LIMA (Fig. 4B). Once the LIMA engages the vein (confirmed by contrast injection), pass a heavy weight (0.014–0.016) guidewire through the LIMA into the most distal segment of the vein. Remove the LIMA and leave the guidewire in place. The heavy weight wire straightens the
A successful implant strategy should include recognition of when to abandon a difficult implant. Early in our implant experience, we established a time limit of 4 hours for any implant session. We brought some patients back for a second session and achieved success. As our experience increased, we learned to identify difficult implants early in the procedure, and the time to aborting such implants decreased. The most common reasons for aborting an implant include difficult CS anatomy and lack of adequate veins draining the LV free wall. We have observed no consistent difference in the degree of difficulty with respect to CHF etiology. The patient with prior heart surgery may have pericardial fibrosis that complicates coronary vein anatomy; severe RA and RV enlargement often presents the greatest challenge to CS cannulation. Patients with previously implanted devices may have distorted subclavian and innominate vein anatomy that makes CS delivery system insertion somewhat difficult.

One can overcome difficult coronary vein anatomy with some of the methods described earlier. Some implanters with adequate interventional cardiology experience advocate coronary venoplasty to treat strictures and other anatomic

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**Figure 3.** (A) The MP-A2 points up to reach the coronary sinus (CS) in a large right atrium (RA). (B) The MP-A2 points down to selectively engage a posterior vein. (C) The AL-3 helps reach the CS in the largest RA.
barriers to LV lead entry. We rarely perform venoplasty but recognize its potential role in CRT device implant. Situations where venoplasty may help include the presence of fibrotic strictures in patients with prior heart surgery or severe angles in coronary veins amenable to straightening by venoplasty or stenting. Venoplasty to increase the diameter of veins too small to otherwise accept a pacing lead rarely works, as recoil of the vessel may prevent lead insertion.

Each implanter should develop a backup plan for thoracoscopic- or thoracotomy-directed lead implant to provide the patient the benefit of CRT. One also should recognize that thoracotomy or thoracoscopy introduces significant risk to the patient with LV dysfunction and moderate to severe CHF.

LV Lead Testing

One may readily accept thresholds up to 3.5 V at 0.5-msec pulse duration in order to deliver CRT to patients with CHF. When encountering high stimulation threshold at a desirable anatomic LV lead position, measure threshold at a variety of pulse duration settings (0.5–1.5 msec). Often, LV pacing at higher pulse width lowers voltage threshold to within an acceptable range of pulse generator energy output. The tradeoff between successful LV pacing and decreased pulse generator duration should favor delivery of therapy over concerns for pulse generator longevity.

LV pacing can stimulate the phrenic nerve anywhere along the lateral wall of the heart as multiple small branches of the nerve course along broad areas of the pericardium. Consider repositioning the LV lead even if pacing at high outputs (5–7 V) stimulates the diaphragm. Check for diaphragmatic pacing during deep inspiration. Often, when the patient sits or stands after the procedure, the diaphragmatic threshold drops and/or the LV threshold rises. Most patients find even intermittent stimulation unacceptable. Moving the lead to different branches of the selected vein or to a different vein can correct the problem. Some LV pacing leads deliver true bipolar stimulation or provide the option to change the pacing sites along the lead (programmable cathode) without moving the lead. A willingness to invest time to eliminate diaphragmatic stimulation at implant can reduce the chance of reoperation later.

Guide Catheter Removal

The available techniques for guide catheter removal include longitudinal slitting of the catheter using a cutting device attached to the lead, removal of the intact catheter over a lead stabilized by insertion of a long “finishing” wire, and the traditional break and peel-away method. Always keep a stylet or stabilizing wire inside the lead during catheter removal. Advancing the lead during removal of the guide catheter by either method introduces redundancy of the lead into the venous system and dislodges the lead. Pushing the slitting tool forward instead of fixing it in space while drawing the guide catheter into the blade pushes excess lead into the vein. Advancing the “finishing” wire within a lead while removing
the guide catheter, or pushing the lead into the subclavian vein while peeling away a guide catheter, produces the same effect. Leaving excessive slack in the lead, particularly in the RA, pushes the lead body into the RV and pulls the tip out of the vein. Secure the sewing collars tightly after removing the stylet or stabilizing wire from the LV lead to prevent dislodgment due to movement of the leads through inadequately tightened anchoring sutures.

**Troubleshooting**

The leading causes of failed LV lead implants in a series of 2,078 patients included failure to locate the CS ostium (38%), inadequate/unstable guide catheter position (33%), and poor LV vein anatomy or phrenic nerve stimulation (29%).

Complications inherent to LV lead implantation include CS dissection, vein perforation, dislodgment, and device-associated complications resulting from integration of additional leads in cardiac chambers not previously sensed or paced. Coronary venous trauma emerged as a procedural complication associated with LV lead implantation, but most perforations produce little, if any, clinical consequence. One should recognize when a catheter tip enters the subintimal space and avoid injecting large amounts of contrast to create a stain. Venous perforation usually does not produce hemodynamic instability because the CS blood circulates rapidly at low pressure and the pericardium contains the perforation. When perforation causes hypotension, immediate echocardiography defines the need for administration of fluids, vaso-pressors, or pericardial drainage. Should injection of contrast stain create a large stain or if dissection occludes the CS, abort the implant procedure and consider another attempt at least 2 weeks later to allow the injury or stain to resolve. Even after a perforation or dissection, one usually can proceed to a successful implant in the absence of hemodynamic instability, large stains, or CS occlusion.

LV lead dislodgment, exit block, or phrenic nerve stimulation rates occur in 7% to 8% of patients within 6 months after implant. When symptoms of CHF recur in a patient who initially responded to CRT, check LV capture thresholds. Chest radiography detects overt LV electrode movement; however, microdislodgment with loss of capture occurs without obvious movement on x-ray film. Attempts to reposition LV leads without the support provided by a guide catheter usually fail. If inserting a guidewire into the lead does not pull the lead completely out of the CS, carefully advance the guide catheter over the guidewire and lead (LV-1 leads only) directly into the CS. If one cannot keep the guidewire within the CS or if an IS-1 lead cannot accommodate a guide catheter around the connector, insert a heavyweight guidewire through the lumen of the dislodged lead to create central venous access without another subclavian puncture. Remove the lead and insert a new guide catheter. Consider what factors contributed to the dislodgment of the original lead when choosing a site for the new lead. Avoid a mismatch in lead–vein diameters, proximal lead positions, excessive slack in the lead, and any phrenic nerve stimulation. Wedge the lead tip into a small-caliber vein and observe the lead in place without a stylet for 10 to 15 minutes to detect early lead instability in the new position. Once the lead appears stable, reinsert the stylet and proceed with guide catheter removal.

**Figure 5.** Top: LAO 45° view demonstrates the separation between the RV and LV electrodes. The RV septal and LV lateral positions appear 180° apart on the circular short axis of the ventricle. Bottom: AP view. Both pacing electrodes appear at the midventricular position between the base and apex of the ventricle.

**Conclusion**

Implant outcomes clearly improve with practice and persistence. The development of new leads, better guide catheter design, and other advancements in delivery systems clearly contribute to greater success. However, understanding the anatomic challenges in the failing heart and adopting a consistent and reliable technique will best allow the implanter to capitalize on the evolution in CRT implant technology and provide the patient with a safe and effective implant.

**References**

