ILLUSTRATIVE APPROACH

Procedural Aspects of Lead Positioning for Cardiac Resynchronization Therapy

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ABSTRACT. Cardiac resynchronization therapy (CRT) has been shown to provide symptom relief and improve survival in many patients with congestive heart failure. Still, there are technical problems related to the CRT implant procedure, and these range from inadequate venous anatomy leading to difficulties in accessing or advancing catheters in the coronary venous tree, to a variety of left ventricular (LV) lead problems. In addition, implant of the LV pacing lead in areas with phrenic stimulation or myocardial scar may result in less than optimal cardiac resynchronization. The current review focuses on several imaging modalities, implant strategies, techniques, and tools that can help physicians overcome these difficulties and implant the LV lead in an adequate, stable position with good pacing parameters.

KEYWORDS. cardiac resynchronization therapy, left ventricular pacing lead, coronary sinus.

Introduction

Cardiac resynchronization therapy (CRT) has been shown to improve outcomes and the quality of life in a growing subset of patients with congestive heart failure (CHF).1-4 CRT results in improved mechanical function and efficiency, mechanical and electrical remodeling, and a reduction in mitral regurgitation.5-6 Its effects are mediated through the addition of the left ventricular lead to improve the mechanical and electrical synchrony both between the right and left ventricles as well as within the left ventricle (LV). Although the majority of patients who meet the criteria for CRT under current guidelines derive benefit, there remains approximately one-third of patients who do not respond to this pacing modality.7

The reasons for non-response are complex and may include both device-related factors such as suboptimal programming as well as patient-specific factors such as the extent and location of scar tissue or the pattern of mechanical and electrical synchrony.8-10 LV lead location is an important and complex determinant of response. Strategies to optimize lead location must account for variations in coronary venous anatomy, the location of the LV scar, the location of mechanically delayed LV segments, and both the physical distance and electrical delay in relation to the right ventricle (RV) lead. In the hands of experienced operators, successful lead placement can be achieved in 80-90% of cases. The current review presents our step-by-step approach to LV lead implantation.

Step 1: Venous access, right atrial, and RV lead implantation

The access and placement of the right atrial (RA) and RV/defibrillator leads follows the same principles as in non-CRT devices. It is worth noting that a vein of adequate caliber to accommodate the RA lead, a defibrillator lead (CRT-D devices are the most commonly implanted), and the LV lead delivery system must be selected. This can be achieved through a combined approach: cephalic vein cutdown (for the RA and RV leads) and an axillary or subclavian vein puncture for the LV lead delivery system. Alternatively, the axillary or subclavian veins can be used as the only venous conduit for the leads and lead delivery systems. The left-sided approach allows for lower defibrillator thresholds along with a more direct path to the CS. Once access is obtained, the RV lead is placed first in order to provide backup pacing. This is of particular concern in this group of patients who frequently have left bundle branch block and for whom a catheter-induced right
bundle branch block results in complete heart block. The RA lead is placed in the usual fashion. Attention is then turned to cannulation of the CS.

Step 2: CS access

The CS opens into the posterior right atrium and is behind the right atrioventricular (AV) groove. The relationship of the CS with other landmarks such as a calcified right coronary artery or radiolucency from the fat pad running in the AV groove can be useful in determining the location of the ostium. Studies in patients undergoing CRT using rotational venography11,12 (see below) have shown that in the right anterior oblique (RAO) 48° ± 7° projection, the fluoroscope beam is nearly parallel to the CS plane (Figure 1a), the CS ostium is visualized “en face,” and the CS guiding catheter is straight. By progressively rotating the camera to RAO 14° ± 12°, left anterior oblique (LAO) 3° ± 13°, and LAO 19° ± 13°, the CS ostium is projected over the left edge of the spine, middle of the spine, and right edge of the spine, respectively.11 The CS is on average 3 ± 10 mm above (superior to) the inferior border of the T10 vertebral body and is 10 ± 16 mm above the dome of the left hemidiaphragm (Figure 1b).11 The diameter of the ostium as well as its angulation can vary considerably from patient to patient12 and is generally oriented inferiorly in patients with dilated cardiomyopathy. At the ostium itself, the Thebesian valve presents a potential barrier to cannulation and can vary in morphology from a small inferior ridge along the ostium to a fenestrated membrane. There are a number of commercially available CS guiding catheters with different shapes that can aid in cannulation. In general, these have varying degrees of a J-shaped curve designed to rest on the RA floor, which then orients the tip toward the CS ostium. Successful CS cannulation is suggested by the absence of premature ventricular contractions, the catheter crossing the spine in the LAO projection, or a confirmatory contrast injection.

The technique used most often for CS intubation is to advance the sheath with a 0.035-mm guidewire or an electrophysiologic recording catheter into the RV and withdraw it with counterclockwise rotation. Contrast dye may be used to visualize the floor of the RA and the ostium of the CS in difficult cases. It may reveal unusually high ostium, an overriding Thebesian valve, an early bifurcation, or separate ostium of the middle cardiac vein.13 A deflectable electrophysiologic recording catheter adds maneuverability to this system. The electrograms recorded by the distal poles of the catheter also assist in the definition of the ostium location. The CS has a very typical electrical appearance with a large atrial electrogram and a smaller ventricular electrogram.13

Step 3: Defining the venous anatomy and selecting a target vein

Although methods such as computed tomography (CT) venography and other imaging modalities may be useful in preprocedural planning for certain cases, balloon occlusive retrograde coronary venous angiography remains essential for LV lead implantation. A balloon-tipped catheter is inserted into the CS via the CS guide. Adequate inflation is necessary to prevent the brisk flow of

Figure 1: Balloon occlusive coronary venograms in the right anterior oblique (RAO) 47° angulation (a) illustrating the coronary sinus ostium en face (green circle), with a straight coronary sinus guide (green arrows) and RAO 14° angulation (b). In this view, the coronary sinus ostium is often located at the left end of the spine. The black circles illustrate the location of the coronary sinus ostium in a cohort of patients undergoing cardiac resynchronization therapy in this view. The green arrows point to the inferior aspect of the T10 vertebra and the superior aspect of the left hemidiaphragm, which are useful as superior-inferior axis landmarks.
back into the right atrium from immediately washing out contrast, as well as to achieve stable balloon positioning during contrast injection and imaging. Stable balloon positioning may require advancement of the catheter more distally in a dilated CS. A small contrast puff prior to balloon inflation is useful to make sure that a side branch will not be occluded by balloon inflation. As in arterial angiography, multiple angulations may be necessary to adequately define the venous anatomy, which varies widely from patient to patient. In some cases, high-speed rotational angiography, a technique which acquires images over an arc from RAO 55° to LAO 55°, can be useful to better define the location and orientation of target vessels.

The selection of an appropriate target vein involves a number of variables to improve the chances of response to CRT as mentioned above; the optimal site may vary considerably for an individual patient. However, in the majority of patients, a lateral or posterolateral, non-apical position is preferred. It is useful then to consider the target site anatomy segmentally rather than in terms of CS venous tributaries. A desirable pacing site may effectively be reached most often by a posterior or lateral vein; however, in the absence of an adequate target, or in the presence of a technical barrier such as tortuosity, the same LV segment may be reached via a second- or third-order tributary of the middle cardiac vein or the anterior interventricular vein.

Step 4: Advancing the LV lead delivery system in the CS

Once the CS is cannulated with a guide, the pacing lead is advanced. There are a number of potential obstacles encountered as the guide and lead delivery system advance through the CS body.

- The ostial angle (between the CS ostium and the main CS body; Figure 3) can be acute, hampering advancement of catheters. In a rotational angiography study of 79 patients undergoing CRT, the angle was best visualized in LAO 51 ± 4° and was quite variable (65–151°, mean 119 ± 19°). The angle was acute (<90°) in 10% of patients.
- As the CS continues along the AV groove, it becomes the great cardiac vein (Figure 4). Here, the vein of Marshall is present in 70–80% of cases. It is not uncommon for the wire or lead to be unintentionally advanced into this vein. The valve of Vieussens is present in 70% of cases, and there is often a step-down in diameter at this point, both of which might make advancing the delivery system difficult.
- In some patients, the CS-great cardiac vein body is posteriorly displaced from the left AV plane (Figure 5). This posterior displacement, if pronounced, as it often is in patients with prior coronary artery bypass graft (CABG), can hamper advancement of the lead delivery system in the CS.

Careful advancement of the cannulating guide over a guidewire or a diagnostic catheter positioned in the CS and being aware of the anatomical variability of this region is usually sufficient to overcome the potential...
obstacles related to this step. It is important to use more than one fluoroscopic view to visualize catheter advancement. RAO views are particularly useful to delineate the posterior curvature of the CS and the takeoff of the vein of Marshall. Especially when the advancement is difficult it is important to deep seat the CS guide, usually beyond the CS-great cardiac vein junction, in order to prevent the guide from falling back into the RA and to ensure an unobstructed passage of the LV lead.

One of the potential complications at this stage in the procedure is CS dissection. Potential mechanisms associated with CS dissections include: overinflation of the balloon used for CS angiography, inappropriate cannulation of a side branch, and vigorous advancement of the guiding catheter in the CS when encountering resistance (e.g. valves or stenoses). Finally, an unusual CS anatomy or extensive manipulation to reach a distal lead position in a tortuous target vessel may be responsible for CS dissections. Trying to avoid these potential causes, especially overinflation of the occlusive balloon during angiography and forceful advancement of catheters against resistance in the CS, will significantly reduce the risk of dissection. CS dissections are usually well tolerated, probably because the coronary venous tree is a low-pressure system, with extensive collateral anastomoses between the cardiac veins. If the dissection is large, however (major dissection defined as a dissection equal to or exceeding the luminal diameter of the dissected vessel), the procedure should be terminated and echocardiography performed immediately after the procedure and 24 h later to detect pericardial effusion.

Step 5: Cannulating a first-degree tributary of the CS

The next step in the CRT implant procedure is to cannulate a first-degree tributary of the CS that can accommodate the LV lead.

The choice of LV lead depends on anatomy. In general, if the first-degree CS tributary is large, a lead with a larger diameter is chosen. However, if the target vein is very large and there is a risk of dislodgement, then a lead with an S-shape or sigmoid shape may allow for better lead stability. Bipolar leads are used most frequently because of the ability to program different configurations to overcome phrenic nerve stimulation or elevated pacing thresholds. A thinner unipolar lead may allow for an easier navigation through a tortuous vein and also fixation in a smaller target tributary. In spite of all these available bipolar and unipolar leads with different shapes and diameters, LV lead dislodgement rates are still approximately 5–10%, and the instability of thresholds over time remains a challenge at times. Active-fixation leads were developed as a potential solution for these problems. These leads have lobes at the distal end of the lead that can be deployed and compress gently against the vein wall, and thereby provide enhanced fixation of the LV lead. This fixation mechanism seems to ensure stable LV lead positioning in the target position, even in anatomically challenging veins, and appears to be superior to passive fixation in terms of lead.
stability. There are concerns, however, in regards to the possibility of extracting or replacing an active-fixation lead utilizing deployable lobes. There have been other solutions proposed to solve the problem of lead stability, such as leaving a guidewire in place for CS lead stabilization. Another solution was the placement of coronary stents besides the lead body. However, this method may also be very problematic when extraction becomes necessary. There are several procedural issues related to this step:

- When implanting the LV lead, the angle of takeoff of the first-degree tributary of the CS is important. Acute takeoff angles of the CS tributaries (angles of <90° between the first-degree CS tributary and the main CS) can impede cannulation. The takeoff angles can be misclassified by standard two-view angiography. Rotational angiography, by offering a multidimensional view of the coronary venous tree, allows better definition of this angle. Acute angulation was found to be present in 30% of the lateral veins and 17% of the posterior veins in a population of patients undergoing CRT. One solution for navigating the acute angled takeoff is to use a subselection guide to allow for more support in negotiating the turn from the CS to the first-degree tributary. Another technique is to use the preformed tip of the LV lead to engage the ostium and then advance the guidewire once the branch is engaged.

- Increased tortuosity of the CS branch is another potential obstacle to implanting the LV lead (Figure 6). When defined as a complete “U-turn” along the course of the vein, tortuosity was present in 18% of the posterior veins and 31% of the lateral veins. Placing the guide sheath close to the target vessel to offer more support in advancing the guidewire/lead, using stiffer guidewires, an internal mammary artery catheter, and the buddy wire technique for straightening the vessel are some procedural techniques that may be used to overcome tortuosity.

The double-wire technique involves the use of two wires, one softer and one stiffer, which are placed in the sharply angulated vein, a maneuver that opens the vein, reducing tortuosity and providing better support. The second-support wire can be stiffer and heavier (0.018” diameter or larger). This allows tracking of the lead over the first wire. There are several other techniques for placement of the LV lead inside the sharply angulated/tortuous coronary veins. One is to advance the guidewire as far out inside the vein as possible, sometimes even coming back into the CS via anastomoses. This allows extra support when pushing the lead through the acute angle. Second is to initially position the wire in other first-degree tributaries of the CS, like the anterior interventricular vein or middle cardiac vein, which have extensive collaterals with the lateral/posterolateral vein, and then advancing the wire through the collaterals and terminating in the target area.

**Step 6: Advancing the LV lead to a target vessel and achieving lead stability**

The lead is targeted to a second- or third-order branch of the CS situated on the lateral or posterolateral wall. If the first-degree CS tributary has a favorable anatomy, the operator may elect to advance the lead and an inner 0.014” diameter guidewire. An appropriately shaped inner sheath may be used to deliver the wire or the lead. Very difficult branches may require inner catheters that are capable of lead delivery. These inner catheters are shaped to provide as much support from the opposite wall of the CS body, which allows appropriate forward pressure to be applied to the lead. However, too much pressure applied to the inner sheaths positioned at the ostium of the target vessel can result in coronary venous dissection. Thinner LV leads may be required when using inner catheters.

It is common practice for the LV pacing lead to be positioned into a lateral or posterolateral branch as far as possible from the RV pacing lead. However, there is still controversy regarding the best lead positioning strategy and the choice between an optimal anatomical positioning targeting the segment with maximal mechanical dyssynchrony, or targeting a region with maximal electrical delay. There is evidence to suggest that maximal anatomical separation as assessed radiographically and/or electrical separation between the right and left ventricular leads and positioning the LV lead as far out into the electrical activation sequence may have a beneficial impact on clinical outcomes. There are recent data showing that apical LV lead placement is associated with worse CRT outcomes, and preferential...
positioning of LV leads in the basal/midventricle segments may improve outcomes.16

If the lead implant site is acceptable, then the next step is to remove the sheath. This is done usually by mechanical slitting (cutting). Sheaths may have an inner wire braiding.13 This type of construction requires that a razor-bladed device be used to cut the braids. Given that this process may dislodge the lead, removal of the sheath should be performed under fluoroscopic guidance to ensure that the lead is not rotated or retracted during the process.13 Some operators prefer to have a stylet inside the lead that extends into the main CS body. This provides support and can prevent the sheath from pulling upon the existing lead during the removal process. Maintaining a certain difference in diameter between the outer diameter of the LV lead and inner diameter of the guide catheter might also help prevent lead dislodgement by reducing friction between the lead and the guide during the process of guide removal.

Avoiding phrenic nerve stimulation

A limiting factor to LV lead implant is the presence of phrenic nerve stimulation (PS), which is present in 2–10% of cases.29–33 PS usually occurs when the LV lead is placed in a lateral/posterolateral region in an apical or mid-ventricular position. PS can sometimes be avoided by a pacing configuration other than LV tip-ring, thereby increasing the difference between PS and LV thresholds.

Not infrequently the lead needs to be repositioned into a different first-degree CS tributary because of PS. One important issue is that changing the target site because of PS might prevent the achievement of clinical benefit of CRT and may pose a stability issue (dislodgement risk) when the lead is withdrawn to a more basal position. Patients with a unipolar lead seem to have the highest rate of detectable PS, repeated surgery, and CRT turnoff because of PS. A bipolar LV lead and a device with cathode programmability allow more flexibility in managing PS.29

Electronic repositioning is possible with bipolar LV leads and devices with cathode programmability, which allows better management of the PS.29 A more recent solution is the quadrupolar LV lead, which, by allowing more flexibility in programming different pacing configurations, improves the chances in avoiding PS.34

The importance of myocardial scar

The implantation of the LV lead at an area with myocardial scar may reduce the effectiveness of CRT. Myocardial scarring is associated with slow conduction or block.35 Pacing outside regions of slow conduction can decrease LV activation time and improve the hemodynamic parameters significantly. Recent results36 suggest that CRT can improve resynchronization and LV function to a similar degree in infarcted and non-infarcted hearts, but the optimal lead is different in infarcted hearts and depends on scar location. In patients with ischemic cardiomyopathy and a history of previous infarction, assessment of scar tissue should be considered before CRT implantation.37

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