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# Interventional and Minimally Invasive Surgical Techniques Facilitating Cardiac Resynchronization Therapy

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Additional information is available at the end of the chapter

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## 1. Introduction

Cardiac resynchronization therapy (CRT) with atriobiventricular pacing has been utilized for more than a decade for severe congestive heart failure associated with intraventricular dyssynchrony. The primary objective of CRT is to coordinate myocardial contraction with stimulation via right atrial (RA), right ventricular (RV) and left ventricular (LV) leads, using a biventricular pacemaker (CRT-P) or defibrillator (CRT-D). Although it provides both morbidity and mortality benefits in addition to medical therapy and implantable cardioverter-defibrillator, several issues remain unresolved, most importantly the high number of non-responder patients (up to 30%) and the technically challenging implantation. These are linked, as optimal lead position is essential for successful resynchronization.

Atriobiventricular pacing is most commonly accomplished with transvenous placement of the system. Endocardial right atrial and right ventricular leads are conventional. The left ventricle is stimulated via a branch of the coronary sinus, performing epicardial stimulation. Unfavorable coronary sinus or vein anatomy, such as valves, tortuosity or focal stenosis may render left ventricular lead implantation very difficult. Even in the absence of these, there may be no appropriate vein in the area which would provide effective resynchronization. The average implantation time of CRT in high volume centers is under 2 hours, with a procedural success rate of 87%-96% (Alonso, 2009). Perioperative complications are seen in 10% and the rate of late complications is 5.5% (Khan, 2009).

Recent evidence suggests that LV lead position is crucial to ensure effective CRT. This chapter will review the indications for CRT, use of imaging modalities to facilitate targeted lead placement, perioperative issues and techniques shown to be useful in challenging cases.

## 2. Indications for CRT

Most clinical CRT trials were performed in patients with advanced heart failure: LVEF ≤35%, wide QRS, sinus rhythm, NYHA III-IV functional stage despite optimal medical treatment (COMPANION, CARE-HF, MIRACLE, MUSTIC SR etc.). Few studies included patients with less severe symptoms (MADIT CRT, REVERSE, RAFT) or who were in atrial fibrillation (MUSTIC-AF and partially RAFT). The guidelines for implantation were recently updated by the HFA and ESC (McMurray, 2012). (Figure 1)
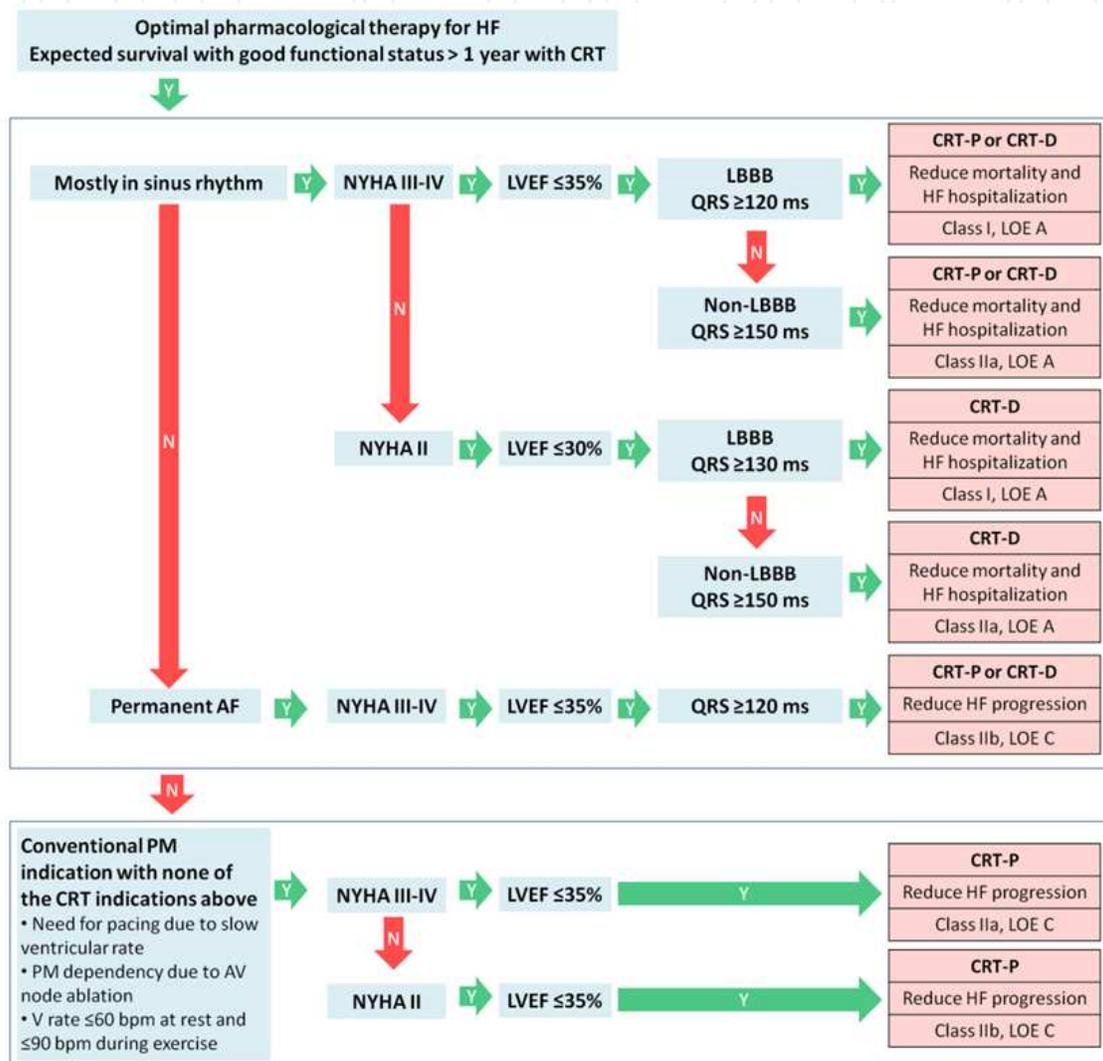


**Figure 1.** Indications for cardiac resynchronization therapy, Heart Failure Association and European Society of Cardiology, 2012 (McMurray, 2012). Stage IV heart failure patients should be "ambulatory" – pressor-dependent or acutely decompensated patients are generally not good candidates for CRT. *HF: heart failure. CRT: cardiac resynchronization therapy. NYHA: New York Heart Association functional class. LVEF: left ventricular ejection fraction. LBBB: left bundle branch block. CRT-P: cardiac resynchronization with biventricular pacemaker. CRT-D: cardiac resynchronization with biventricular implantable cardioverter defibrillator. PM: pacemaker. AV: atrioventricular. Class: strength of indication (class I – implantation recommended, class IIa – implantation should be considered, class IIb – implantation may be considered). LOE: level of evidence (A: multiple randomized trials or meta-analysis, C: expert opinion)*

## 3. Pre-implantation evaluation

Patient evaluation prior to implantation should include assessment of functional stage, left ventricular ejection fraction and 12-lead ECG to determine whether the patient is a candidate for CRT. Potentially reversible factors contributing to heart failure and cardiomyopathy should be looked for and corrected (ischemia, hypertension, suboptimal medical management etc.). Co-morbidities limiting life expectancy or decreasing possible benefits of CRT should be identified (cardiac cachexia, advanced renal disease, frailty etc.) (Theuns, 2011). Advanced age alone is not a contraindication to CRT. History of arrhythmias and eligibility for ICD should be also assessed to guide device and lead selection. The patient should not be in a decompensated condition at the time of implantation. Heart failure medications must be utilized at maximally tolerated doses for at least 3 months prior to considering the patient as a candidate for CRT implantation. In the immediate pre-implantation period, basic laboratory parameters should be checked and corrected as necessary to minimize surgical risks (complete blood cell count, electrolytes and kidney function, coagulation tests) (Epstein, 2008). A standardized evaluation of heart failure may help to assess response to CRT (serum BNP, 6 minute walking test).

Echocardiography is the most common test performed to assess severity of left ventricular dysfunction. Right ventricular dysfunction may affect response to CRT and should also be evaluated (Burri, 2010). Although multiple echocardiographic measurements exist to evaluate intraventricular or interventricular mechanical dyssynchrony, so far these were not proven to be helpful to guide patient selection for CRT. Absence of echocardiographic dyssynchrony should not defer utilization of CRT if the patient would otherwise be a candidate, however, the risk of deterioration is higher in these cases (Mullens, 2009).

Cardiac MRI with delayed enhancement imaging may be considered when the presence and location of myocardial scar is relevant and echocardiography is non-diagnostic (Bleeker, 2006).

## 4. Assessment of coronary vein anatomy

Transvenous endovascular left ventricular lead placement is limited by the anatomic constraints of the coronary veins. Patients with history of thoracic irradiation or cardiac surgeries may be at high risk for unsuccessful left ventricular lead implantation. Imaging studies prior to implantation may help to determine if the patient is suitable for transvenous implantation.

Coronary angiography is routinely performed during the workup of heart failure. Delayed images after contrast injection into the coronary arteries may outline the anatomy of the coronary sinus and its main branches. A major advantage of this method is that it does not provide any additional burden to the patient. The position of the orifice, the angle of the proximal CS, tortuousity and diameter of the vein are valuable clues for the selection of target vessel and the implantation approach. Most useful projections are anteroposterior and left anterior oblique, as these are common working views during CRT implantation.

Although the image quality is rarely good enough to assess terminal branches of the CS, the data obtained during coronary angiography may be used to identify fluoroscopic markers for CS cannulation as the ostium is almost always visualized. Another limitation is that this approach provides only two dimensional data (Kovacs, 2004) (Figure 2).
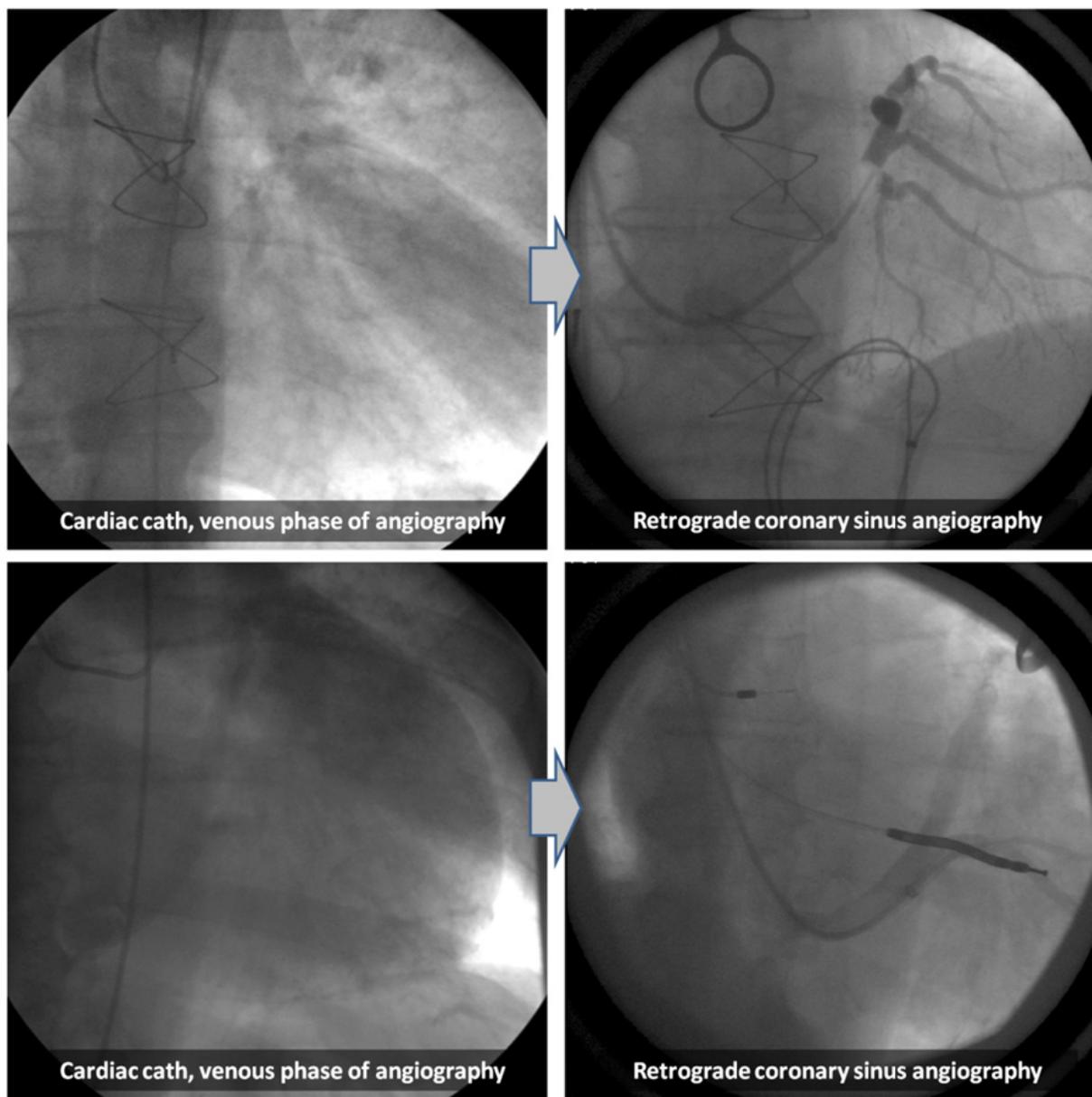


**Figure 2.** Evaluation of coronary vein anatomy during cardiac catheterization. The venous phase after contrast injection into the left coronary artery shows the coronary sinus and its major branches. Although the smaller branches are not visualized, the images are helpful to localize the CS ostium, the angle of the CS and origin of its major branches. The images correlate with those obtained during retrograde CS angiography.

Cardiac CT angiography provides detailed assessment of coronary arterial and venous anatomy, but requires x-ray radiation and contrast. Pre-implantation evaluation of the coronary venous anatomy can facilitate CRT, leading to decreased procedure time (Girsky,

2010 and Doganay, 2011). Area of latest mechanical activation may be correlated with echocardiographic images and veins in this region should be targeted for LV lead implantation – this approach correlates with improved acute response to CRT, however, no long term data available yet (Van de Veire, 2008). The phrenic nerve may also be visualized to identify high risk regions for inadvertent diaphragmatic stimulation (Matsumoto, 2007). Fusion of CT and fluoroscopic images may be of even greater benefit (Auricchio, 2009). Contrast allergy and advanced renal disease are contraindications for cardiac CT.

Cardiac MRI can also be used to assess coronary veins. These images may be overlayed with other MRI data, such as scar distribution or area of latest activation (Duckett, 2011a; White, 2010 and Kronborg, 2012). Imaging of scar burden improves prediction of response to CRT: in ischemic cardiomyopathy, less than 15% of total myocardium infarcted and absence of significant posterolateral scar is associated with better response (Bilchick, 2008 and Chalil, 2007). Real time MRI-guided intubation of the coronary sinus is being investigated (Neizel, 2010). Cardiac MRI requires gadolinium-based contrast and is contraindicated in patients with advanced renal dysfunction. Previously implanted non-MRI compatible hardware may also limit its utilization. The scanning times are longer and image acquisition requires some patient cooperation, which may be poorly tolerated in severe heart failure.

Although these advanced imaging modalities have improved both implantation success rate and responder rate in small studies, currently it is not known whether routine application in all patients undergoing CRT would be cost-efficient. In patients undergoing CRT, review of all existing relevant imaging data is recommended for implant strategy planning. Advanced modalities should be reserved for cases where difficult anatomy is anticipated or if the patient had an unsuccessful implantation attempt. If cardiac CT and MRI will be shown to predict and facilitate CRT in a cost-efficient manner, these modalities may potentially be implemented on a more routine basis in the future.

## 5. Perioperative period

The patient should be on a stable heart failure medication regimen for at least 3 months before CRT implantation. Vasopressor-dependent or significantly fluid overloaded/congested patients are not good candidates for the procedure. Following implantation, careful monitoring is required as occasionally significant diuresis is observed with initiation of CRT, leading to electrolyte imbalances. The dose of heart failure medications should be titrated as tolerated after recovery from the implantation procedure. Bradycardia may not be a limiting factor after CRT implantation when considering utilization of higher dose of beta-blockers. Hypotensive side effects of ACE inhibitors and other vasodilators may be less pronounced, however, individual responses vary significantly. The dose of diuretics should be decreased if significant improvement in volume status is observed with CRT, to avoid prerenal azotemia and hypotension.

Almost all patients undergoing CRT implantation are on antiplatelet or anticoagulation therapy, which increases bleeding risks. Compared to untreated patients, the likelihood of bleeding complications is doubled in patients on aspirin and quadrupled with dual

antiplatelet therapy (1.6%, 3.9% and 7.2%, respectively) (Jamula, 2008). Antiplatelet medications for primary prevention can be safely discontinued for a period of 5–7 days prior to the implantation. Dual antiplatelet therapy following PCI should not be discontinued in patients high risk for subacute stent thrombosis (such as early after coronary stent implantation, with timing dependent on stent type) (Tompkins, 2011). Bridging anticoagulation with heparin is associated with higher bleeding risk (up to 20%), where short-term discontinuation of anticoagulation is not an option – in these cases, continuation of coumadin is recommended (Tompkins, 2010). Continuation of coumadin has a risk of postoperative pocket bleeding of 1.9–6.6% (Wiegand, 2004).

After decades of debate, now there is evidence that perioperative antibiotic prophylaxis decreases risk of infectious complications. Although these complications are rare (generally <1%), their consequences are devastating, leading to significant morbidity, mortality and costs (Klug, 2007 and Da Costa, 1998). Iv. cephazolin administered immediately before the procedure reduced the risk of infection from 3.28% to 0.63% in a large randomized trial (de Oliveira, 2009). Although some implant centers continue antibiotic utilization after the implantation, there is no proven benefit for this approach. Data regarding antibiotic prophylaxis for non-transvenous CRT implantation is scarce – generally, cardiothoracic surgical guidelines should apply as the optimal duration and selection of antibiotics may be affected by the given surgical approach (Mertz, 2011; Edwards, 2006 and Engelman, 2006).

Most interventional techniques may be safely utilized in the pacemaker laboratory. It is preferable that the physician attempting a complex implantation or a device upgrade is well trained and current in the appropriate interventional and surgical techniques, or a physician with this training is immediately available. In case lead extraction is planned, a hybrid operating room or prompt access to surgical backup is mandatory. The incidence of unsuccessful implantations is declining, which is partly due to the advances in lead technology and implanting tools, however, interventional cardiology techniques have also been increasingly utilized with excellent efficacy and safety records. Minimally invasive surgical options are rapidly evolving and should be considered in case transvenous implantation is not feasible.

Most common perioperative complications are failure to implant the LV lead, pocket hematoma, hemothorax or pneumothorax, CS dissection, cardiac perforation or tamponade, extracardiac stimulation, complete heart block, LV lead dislodgement, exacerbation of HF, acute renal failure, and death. Overall perioperative complication rates range from 4% in more recent trials to 28% in earlier CRT trials (Leon, 2005 and Linde, 2008).

## 6. Targeting LV lead placement

There is considerable variability in the ventricular activation pattern and distribution of mechanical dyssynchrony even in the LBBB population, and consequently inter-individual variability in the most optimal pacing site (Auricchio, 2004 and Derval, 2010). In addition, a significant number of patients don't even have typical LBBB. Lead placement via endocardial and surgical epicardial approach may have more potential for individualized

targeted pacing. Targeting methods include those assessing electrical, mechanical and anatomic parameters, but there is no consensus yet regarding the best method to improve long term outcomes (Ansalone, 2002; Merchant, 2010; Gold, 2011 and Ypenburg, 2008).

Apically positioned LV lead location is associated with a worse clinical outcome in the REVERSE and MADIT-CRT trials (Thebault, 2012 and Singh, 2011). The COMPANION and MADIT-CRT studies showed a comparable response between lateral, anterior or posterior LV lead locations, while patients in REVERSE benefited from a lateral lead location (Saxon, 2009). Imaging may help to select specific sites for left ventricular pacing based on anticipated optimization of electromechanical effects (Toumoux, 2010). Echocardiography (tissue Doppler or tissue synchronization imaging) may identify LV sites with marked mechanical delay (Cannesson, 2006 and Murphy, 2006). Pacing these sites may result in greater ventricular remodeling and improved clinical outcomes. Currently there is not enough data supporting the role of acute hemodynamic measurements during implantation to target lead implantation (Duckett, 2011b).

Multisite ventricular stimulation (more than one LV lead) may provide even greater benefits with more homogenous ventricular activation. More clinical data will be needed to evaluate whether it is superior to biventricular stimulation.

## 7. Transvenous CRT implantation and reinterventions

The standard approach to CRT is to implant three endovascular leads for cardiac stimulation: endocardial RV and RA leads, and an epicardial LV lead into a coronary vein through the CS. Transvenous implantation should be the preferred way for CRT as most evidence is with this approach. The standard transvenous approach has significant drawbacks as it is dependent on the highly variable venous anatomy. Main reasons of failed LV lead implantations are inability to cannulate the CS due to RA dilatation or prominent Thebesian valve, diminutive CS, severe kinking of the vein or venous valve in the CS. Even with successful lead placement, unstable position, high pacing threshold or phrenic nerve stimulation may hinder effective delivery of LV pacing. Implantation success rate is above 90% in experienced centers, most failures are due to unsuccessful placement of the LV lead. In case of an unsuccessful procedure, repeat transvenous procedure with a more experienced operator or with interventional backup is recommended, if the venous anatomy seems to be suitable for implantation. In unsuitable cases, alternative approaches (surgical epicardial, transseptal endocardial) should be considered.

The EHRA and HRS has recently published guidelines for recommended approach for transvenous CRT implantation (Daubert, 2012). Implantation should be performed from the left subclavian vein system, unless preexisting pathology (venous occlusion, infection) makes this approach unfeasible. The right ventricular lead should be placed first as it is less likely to dislodge during manipulation of other leads and provides information about the position of the tricuspid valve and right atrial size.

New guidelines emphasize the role of cardiac resynchronization therapy in subgroups of patients who already have conventional pacemakers, to avoid pacing-induced dyssynchrony and remodeling. Upgrading an existing device may pose difficulties due to the necessity to operate in a previously scarred area and the presence of previously implanted leads in the venous system. The perioperative risks in these patients are significantly higher: the 6-month major complication rate was 18.7% in the REPLACE registry in patients undergoing upgrade to a CRT device with addition of a new endocardial LV lead to the existing leads (Poole, 2010). The risk of subclavian vein thrombosis is related to the number of leads implanted, among recipients of CRT devices severe obstruction or occlusion can be observed in 30% (Bulur, 2010). Subclavian venography with injection through the upper extremity veins is a simple and effective technique to evaluate venous anatomy prior to an upgrade or lead revision. Venoplasty may be performed if ipsilateral implantation is favored (Worley, 2011).

Extraction of non-used leads during an upgrade or revision has to be considered as the risk of long-term complications from abandoned leads is not negligible and correlates with the number of leads implanted and the number of prior procedures performed (Diemberger, 2011). Implantation via the jugular or contralateral subclavian vein, with subcutaneous tunneling is required if the anatomy does not permit ipsilateral addition of a new lead. Although primary transvenous device implantations are routinely performed using conscious sedation without much patient discomfort, deep sedation or general anesthesia may be required for lead tunneling (Fox, 2007). In case lead extraction has to be performed prior to the upgrade, general anesthesia, invasive monitoring and availability of immediate surgical backup is recommended (Kratz, 2010).

For CS cannulation, a wide array of sheaths are available. The ostium may be probed with a standard angiographic soft-tip wire, an angiographic catheter (such as Amplatz) may be inserted into the sheath to adjust its distal curve. Alternatively, a steerable CS EP catheter may also be used for mapping, individual practices vary significantly. Mapping with stiff catheters should be performed very cautiously as after overcoming any resistance from the Thebesian valve, the catheter may advance to the CS at an oblique angle, dissecting it, rendering continuation of the implantation procedure extremely difficult. This is most commonly encountered during insertion or advancement of the occlusion balloon catheter, as it has a relatively stiff distal portion. Transesophageal echocardiography may facilitate CS cannulation when traditional methods have proven ineffective (Bashir, 2003). In difficult cases intracardiac echocardiography may be more tolerable in patients under conscious sedation (Shalaby, 2005).

Cannulation of the CS is followed by coronary sinus angiography using an occluder balloon. Fluoroscopic acquisition should allow time to image late filling terminal branches, due to collateral flow. Some centers perform a single venography image, however, two orthogonal views (RAO and LAO) are preferred for better visualization of 3 dimensional anatomy. A minority of centers perform rotational venography, which may provide more detailed information (Blendea, 2007). The location and takeoff of the ostium may vary considerably, can be distorted by right atrial enlargement or prior surgery. Distally in the CS, the valve of

Vieussens (typically 3-5 cm from the ostium) may hinder cannulation of the distal vessel (Ho, 2004).

LV pacing leads may be implanted over a guidewire or directly. The guidewire may help to achieve more distal position by providing a rail when advancing the lead in a tortuous vein. Care should be taken to place the preformed fixation mechanism (curves, spiral or tags) with adequate distal penetration, to have a large area of contact with the vein wall (Hansky, 2002). Most current leads are at least bipolar with size and flexibility similar to previous unipolar leads. The advantage of multiple electrodes is the possibility of electrical "repositioning" when high pacing threshold or phrenic nerve stimulation is encountered (Gurevitz, 2005 and Forleo, 2011). (Figure 3)



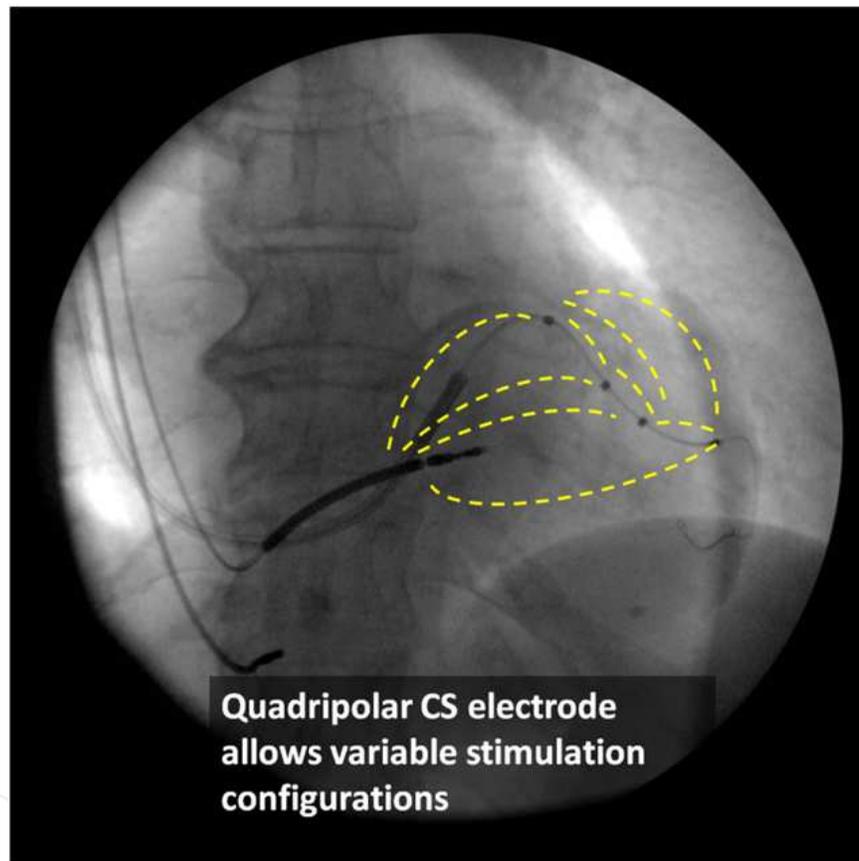Quadripolar CS electrode allows variable stimulation configurations

**Figure 3.** A quadripolar CS lead allows multiple pacing configurations, providing options to avoid phrenic nerve stimulation or sites with high threshold. It also enables a more stable distal lead position, while still allowing pacing on the proximal electrodes if desired.

If the vein is tortuous, a stiffer wire or buddy wire may be used with caution, as the wall thickness and tear resistance of coronary veins is much less compared to coronary arteries. In case severe tortuosity or kinking of the vein does not allow adequate force transition to advance the lead, use of telescopic guides may be considered (Russo, 2009). Inflated venogram (occluder) and coronary balloons can also be used as anchors to facilitate CS cannulation and left ventricular lead placement and help to recover lost CS and target vein access (Worley, 2009).

In case the target vein is stenotic, balloon angioplasty may be attempted. Although the pathophysiological basis for coronary artery stenoses and coronary sinus/vein abnormalities are different, in most cases these obstacles can be overcome with the use of conventional interventional cardiology techniques. The required instrumentation is the same as for coronary artery angioplasties. In the majority of cases with a focal stenosis or valve, balloon angioplasty is a safe method to facilitate passage of the lead. In selected cases coronary atherectomy or stent implantation may be required (Soga, 2007). Angioplasty may also be used as a rescue when dissection of the coronary sinus or the target vein is observed during implantation, which would otherwise prohibit further attempts for lead placement (Bosa, 2008 and Gutleben, 2008). In case of unfavorable coronary vein anatomy in the target area, dilatation and use of collateral veins may be considered (Abben, 2010). Complications from venoplasty are rare, however, venous rupture has been reported (Worley, 2008). With access to these techniques, implantation success rate may be as high as 99%: a retrospective single center analysis showed that 3.5% of patients required venoplasty for LV implantation (of these, 77% coronary vein, 13% subclavian vein, 10% valvular structures within the CS or a Marshall vein). The required inflation pressures for ring-like structures were high (16 ±3 atm), complications were rare. Mostly short balloons with 3 mm diameter were used (Luedorff, 2008). The presence of a persistent left superior vena cava may prohibit successful CRT implantation due to severely dilated CS and distorted anatomy, however, successful use of angioplasty in this case was reported (Cagin, 2010).

High pacing threshold or phrenic nerve stimulation may require repositioning of the lead from a stable to a less optimal position, where its fixation mechanism may not be as effective. In these cases, a coronary stent implanted near the distal end of the lead may stabilize the new position. A large single center study of 312 patients treated with stent implantation showed that the method was safe and effective in long term to prevent lead dislocation. 95% of patients had stenting due to intraoperative lead instability or phrenic nerve stimulation, while 5% required it due to previous lead disclocation. The bare metal stents were implanted 5-35 mm proximal to the most proximal electrode (unipolar and bipolar LV leads). There was no evidence of mechanical damage to the lead or CS perforation. During the follow-up of average 28.4 months, a significant increase in the left ventricular pacing threshold was found in four cases and reoperation was necessary in two patients (0.6%). Phrenic nerve stimulation was observed in 18 instances, and closed repositioning with an ablation catheter was performed in seven cases. In three cases the leads were extracted without complication after 3-49 months (infection, heart transplant) (Geller, 2011). (Figure 4)

Coronary sinus dissection is a rare complication of LV lead placement. It may be recognized as inability to pass instruments though a previously accessible area, and pooling of contrast after angiography. Although complete perforation is even less common and the pressure in the CS is low, cardiac tamponade may occasionally develop. If the dissection is small, it may be possible to finish the implantation, although balloon angioplasty or stenting of the dissected segment may be necessary. In these cases, patients need to be monitored after the implantation, however, the exact duration that is required before a safe discharge is unknown (Figure 5).
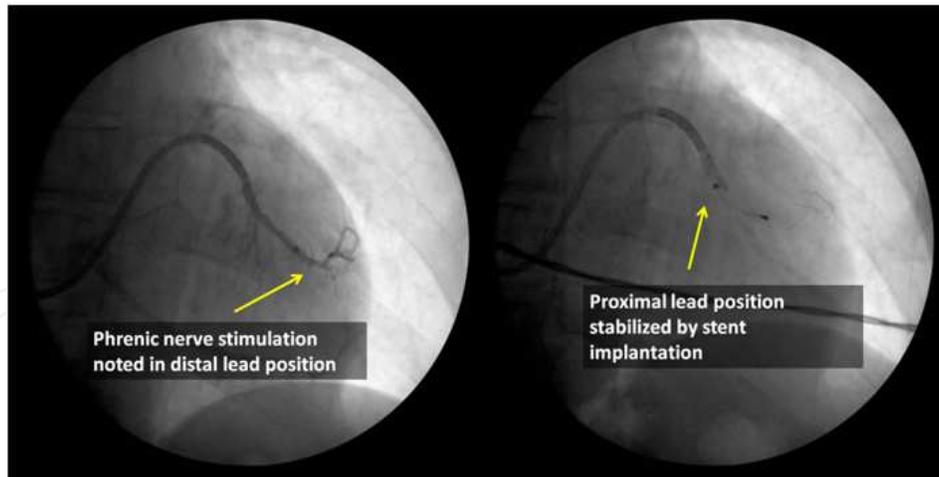
**Figure 4.** Phrenic nerve stimulation was encountered in the distal lateral vein. In a more proximal position, the pacing threshold was acceptable with no diaphragmatic stimulation, however, the lead position was unstable. A bare metal coronary stent was implanted just proximal to the proximal electrode, after which the lead position stabilized.
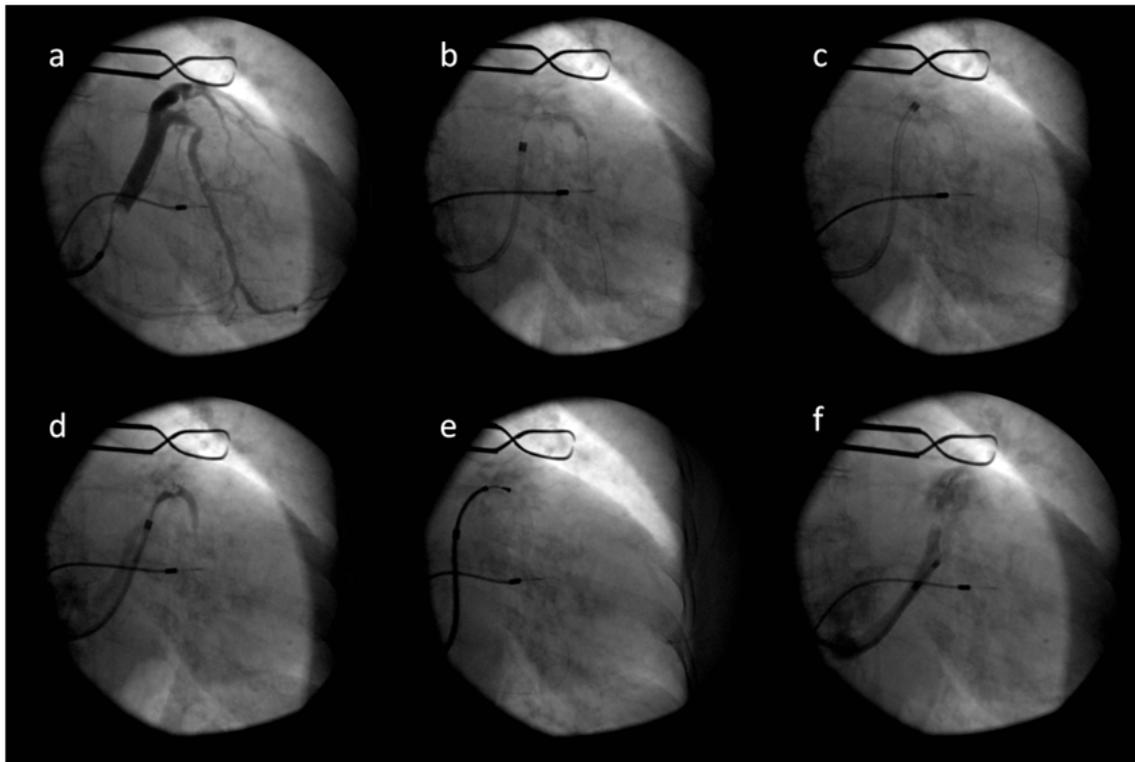


**Figure 5.** Complicated CS anatomy may prohibit transvenous lead implantation even with extensive use of interventional techniques. The targeted lateral vein has a narrowed proximal segment with a kink, which did not allow lead advancement (a). After passing a coronary guidewire, a bare metal stent was deposited into this region (b). Although the guidewire easily passed through this area, lead advancement was still not feasible, the stent is clearly visible (c). Selective venography shows dissection proximal to the stent (d). Even after multiple attempts with balloon angioplasty in this area, lead advancement was still not possible (e). After multiple attempts with a selective guide and buddy wire, repeat venography shows dissection of CS with distal occlusion and staining, at this point the procedure was aborted (f). No significant pericardial effusion or further sequelae were noted.

Epicardial left ventricular stimulation poses a unique challenge as the electrode position has to be stable to provide effective cardiac resynchronization with low energy output, while avoiding phrenic nerve stimulation. The coronary veins lack trabeculation and the thin wall prohibits the use of conventional screw-in active fixation leads. The majority of coronary sinus leads are passive fixation, which try to maintain stability with pre-shaped tips. Recently, built-in active lead fixation mechanisms became available. Up to 7% of transvenously placed LV leads may require revision (Borleffs, 2008) over long-term follow up (2 years). One third of the interventions are required more than 6 months after the implantation. A dislodged coronary sinus lead can be the source of multiple complications, such as inadvert stimulation of extracardiac structures, arrhythmia or perforation, and loss of effective cardiac resynchronization. Repositioning most of the time requires access to the lead via a device pocket revision. As open revision carries a higher risk of system infection, minimally invasive procedures should be considered when appropriate. In some cases, the dislocation may be resolved by catheter-based techniques. In each case, an attempt has to be made to provide a more stable final lead position. A transfemoral approach was effective for the retraction of the LV lead from distal dislocation in a single center case series, where distal dislocation of the electrode lead to intolerable phrenic nerve stimulation (Szilagyi, 2008). The CS was cannulated with an Amplatz catheter, then a coronary stent was introduced over a guidewire besides the lead into the side branch in 7 patients or in 2 patients, into the CS. A steerable ablation catheter was looped around the LV lead in the atrium with bent tip and was drawn backwards together. The stent was then inflated to stabilize the lead tip in a new position. During follow-up of median 7.7 months, stable pacing thresholds and impedances were measured; transient and avoidable phrenic nerve stimulation was present in only one patient. There were no procedural complications or infections.

Stabilizing the lead position with retained stylets is not recommended due to high risk of late lead failure (Nagele, 2007). With active fixation of the CS leads, lead extraction may be an issue if the device has to be explanted. In the above mentioned case series, the few leads that had to be explanted and were previously stabilized with stent implantation, came out with manual traction most of the time, however, more data will be needed to assess if active anchoring of LV leads into the coronary veins poses any long-term risk.

## 8. Transseptal endocardial left ventricular pacing

Transseptal approach through the interatrial septum has been used for multiple interventional and electrophysiological procedures for decades. It is a relatively safe procedure in experienced hands, however, the facility should be prepared to address potential complications (mainly pericardiocentesis and emergent periocardiotomy). Using the transseptal approach, a conventional endocardial PM lead may be implanted into the LV cavity for endocardial stimulation. The thromboembolic risks are not negligible and these patient require long term anticoagulation. Mitral valve damage and endocarditis are rare, but serious compliations.

The transseptal implantation begins with a standard transseptal puncture via the femoral vein (van Gelder, 2007). After the successful puncture, full anticoagulation with iv. heparin is initiated. A 0.035-inch guidewire is inserted into one of the pulmonary veins and then the dilator and the sheath is removed. The puncture site is dilated with a 6-8 mm balloon. A steerable EP catheter is advanced from the subclavian area towards the interatrial septum, then into the left ventricle after deflating the balloon. A sheath is then advanced into the LA over the EP catheter. The endocardial surface of the LV may be mapped with the EP catheter to localize a site most suitable for lead implantation, then a standard endocardial bipolar pacemaker lead is implanted. Using a modified technique, electroanatomical mapping may be used to precisely identify the area of latest activation in the LV (Kutyifa, 2012).

The main disadvantage of this technique is the unknown long term thromboembolic risk, which may be similar to a mechanical valve, with INR goals in the higher range (3-4). Over an average of 85 month follow up of 6 patients in a case series, one patient had LV lead dislodgment at 3 months requiring reintervention. One patient had a transient ischemic attack, when anticoagulation was accidentally interrupted (Pasquie, 2007). The need to start full dose anticoagulation immediately after the implantation increases the risk of periprocedural bleeding complications.

This technique is a feasible and safe second option with a benefit of endocardial pacing site and implantation procedure with no more burden to the patient than conventional transvenous CRT implantation. Main disadvantage is the need for long term anticoagulation. Patients who are ineligible for surgical epicardial implantation and have no contraindications for lifelong oral anticoagulation can be selected for this approach. Biventricular pacing with endocardial stimulation may provide more homogenous intraventricular resynchronization than with epicardial stimulation, and is associated with better LV filling and systolic performance (Garrigue, 2001).

## 9. Surgical epicardial LV lead placement

In early cases of CRT, the LV lead was surgically placed via thoracotomy. This approach was associated with considerable morbidity, requiring general anesthesia and longer recovery time. Long term electrical stability of surgically placed electrodes is inferior when compared to transvenous leads (Lau, 2009). Major advantage of the surgical implantation is that it is not constrained by the venous anatomy and the latest contracting segment may be visually identified. Phrenic nerve stimulation may also be more easily avoided and there is no need for fluoroscopy. As transvenous implantation has a high success rate with excellent long-term stability, surgical implantation should not be considered are first line therapy. The risk of failed transvenous implant is higher in patients with prior cardiac surgeries (however, this also increases the risk of consecutive sternotomy/thoracotomy). In patients eligible for CRT, undergoing cardiothoracic surgical procedure, implantation of epicardial LV lead may be considered, which may be tunneled to the planned PM/ICD generator site. Surgical implantation may also be preferred in patients with complex congenital heart disease, where the venous anatomy may interfere with the transvenous approach.

Usually, there is no need for full left thoracotomy for epicardial LV lead implantation as minimal thoracotomy provides adequate window for the procedure. The surgery is performed using single-lung ventilation on a beating heart. Transeosophageal echocardiography (TEE) control is needed throughout the procedure. A 3 to 5 cm incision is made over the 4th or 5th intercostal space anterior to the midaxillary line. The lung is pushed back and the pericardium is opened anterior to the phrenic nerve. The left ventricle is mapped for optimal pacing site and an epicardial lead placement device is used to attach the electrode (unipolar or bipolar) (Mair, 2005). The leads are tunneled to the PM/ICD generator site, usually in the left infraclavicular region. Short-term chest drainage is required postoperatively. A recent investigation described this technique as a safe and acceptable option, with benefits comparable to transvenous CRT: in 33 patients, functional and echocardiographic parameters showed similar improvement, however, with a delayed onset of peak VO2 improvement (Patwala, 2009).

Instead of minimal thoracotomy, video assisted thoracoscopy may be used for lead placement. It uses two incisions for the ports in the 4th or 5th intercostal space along the anterior and midaxillary line. General anaesthesia and single lung ventilation enables the deflation of the left lung. The camera and the manipulating instruments are inserted through the ports, the pericardium is opened laterally to the phrenic nerve under visual control, then the epicardial lead is screwed into the lateral wall of the LV. The lead is passed through the medial incision and then tunneled subcutaneously to the generator site. The procedure is well tolerated, it has minimal postoperative recovery and very good cosmetic results. In a series of 15 patients, who previously failed transvenous implantation, mean skin-to-skin operating time was 55±16 min, no conversion to thoracotomy was necessary. All patients were extubated in the operating room and remained in the intensive care unit for less than 24h. Chest tubes were removed after a mean of 1.6±0.5 days and the patients were discharged after a mean of 4±1.3 days. Intraoperative and postoperative pacing thresholds at 1 and 7 months were satisfactory in all cases and there was no lead dislocation. All but two patients had an improvement of their NYHA function class. There was neither surgical morbidity nor mortality (Gabor, 2005).

Endoscopic robotic surgery is rapidly evolving and has been investigated for CRT. This technique also needs general anesthesia, single lung intubation and TEE. The left and right arms for the DaVinci system are placed in the 5th and 9th intercostal space. The pericardium is opened posterior to the phrenic nerve and the region of the obtuse marginal is identified to find the latest activating area with a temporary pacing electrode, the procedure is similar to the endoscopic approach. The patient is extubated immediately after the procedure and there is no need for a chest tube. Patients are usually discharged on the first postoperative day. Follow-up results of 42 patients showed a procedure time on the plateau of the learning curve of 45±13 minutes, with a responder rate of 81% and 70% at 3 and 6 month follow up. Three patients experienced loss of LV capture at 1, 9, and 14 months (a second lead, which was simultaneously implanted with the first one and also tunneled to the generator site had to be activated in these patients) (Joshi, 2005). With growing experience and availability of surgical robotic system, this method may gain more widespread utilization.

## 10. Transapical endocardial lead implantation

This technique combines the minimally invasive surgical approach with the advantages of endocardial pacing. This may be the only option for patients with extensive epicardial adhesions prohibiting access to the pericardial space (Kassai, 2008). After induction of general anaesthesia and selective bronchial intubation, the LV apex is localized with transthoracic echocardiography, then a small left thoracotomy is performed. The apex of the left ventricle is punctured and an active fixation lead is inserted into the cavity, using Seldinger technique. The bleeding is controlled with purse-string sutures. The lead is guided into its final position with a guide, using fluoroscopy. As transapical endocardial lead implantation does not involve the mitral valve, the risk of mitral valve endocarditis is reduced. The lead is subcutaneously tunneled to the infraclavicular pocket to be connected to the generator. Long term anticoagulation is required, similar to patients with transseptal endocardial leads. Advantages of this technique are the accessibility of the endocardial segments without limitations of the CS anatomy and absence of phrenic nerve stimulation (Kassai, 2009).

## 11. Conclusion

Transvenous implantation of CRT systems is the preferred way as it poses the least risk for the patient, has excellent long term results and is supported by large amount of evidence from clinical trials. Familiarity with interventional angioplasty methods may facilitate the implant procedure. Although newer left ventricular leads have better maneuverability and improved fixation mechanisms, interventional techniques are useful adjuncts if difficult anatomy is encountered. In case of unsuitable anatomy of failed implantation, minimally invasive surgical procedures should be considered for LV lead placement.

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