

REVIEW

Alternative Techniques for Left Ventricular Pacing in Cardiac Resynchronization Therapy

ATTILA MIHALCZ, M.D.,* IMRE KASSAI, M.D., PH.D.,† LASZLO GELLER, M.D., PH.D.,‡ and TAMAS SZILI-TÖRÖK, M.D., PH.D.§

From the *Landeskrankenhaus Krems, Krems, Austria; †Hungarian National Institute of Cardiology, Budapest, Hungary; ‡Heart Center, Semmelweis University, Budapest, Hungary; and §Department of Clinical Cardiac Electrophysiology, Thorax Centre, Rotterdam, the Netherlands

Cardiac resynchronization therapy (CRT) is an important treatment modality for a well-defined subgroup of heart failure patients. Coronary sinus (CS) lead placement is the first-line clinical approach but the insertion is unsuccessful in about 5–10% of the patients. In recent years, the number of CRT recipients and the considerable need for left ventricular (LV) lead revisions increased enormously. Numerous techniques and technologies have been specifically developed to provide alternatives for the CS LV pacing. Currently, the surgical access is most frequently used as a second choice by either minithoracotomy or especially the video-assisted thoracoscopy. The transeptal or transapical endocardial LV lead implantations are being developed but there are no longer follow-up data in larger patient cohorts. These new techniques should be reserved for patients failing conventional or surgical CRT implants. In the future, randomized studies are needed to assess the potential benefits of some alternative LV pacing techniques and other new technologies for LV lead placement are expected. (PACE 2014; 37:255–261)

cardiac resynchronization, pacing, epicardial, endocardial

Introduction

Cardiac resynchronization therapy (CRT) has evolved as an effective nonpharmacological method of treating patients with heart failure (HF) and left ventricular (LV) dyssynchrony for those who have not responded adequately to medical therapy.^{1,2} CRT requires permanent pacing of the LV wall and restores the synchronicity of the atrioventricular, interventricular, and intraventricular contractions, resulting in improved clinical outcomes and cardiac performance of advanced HF patients with wide QRS complex.³ However, a significant percentage of patients treated with CRT do not show an improvement in clinical symptoms or cardiac function. The suboptimal position of the LV pacing lead, an absence of LV dyssynchrony, myocardial scar abundance, or suboptimal device programming have been related to a nonresponse to CRT.^{4,5} Furthermore, unsuccessful primary implantation

of the LV lead into the coronary venous system has been reported in up to 10% of patients.^{6–8} The optimal placement of a LV lead is one of the most challenging technical aspects of CRT device implantation and it is one of the major determinants of response to CRT. An optimal LV lead position may theoretically be defined by the positioning of the LV pacing lead coincident with the latest activated areas of the LV.^{9,10} In case of optimal pacing parameters, this location can maximize the hemodynamic benefits of CRT and it provides superior long-term outcomes.⁵

In the last decade, the indication for CRT expanded^{11,12} and the improvements in lead and delivery tool technologies made CRT more accessible to patients with HF. The number of CRT recipients and the considerable need for LV lead revisions or alternative techniques increased enormously.¹³

Problems with the Current LV Lead Implantation Methods

Currently, in clinical practice the standard first-line approach is the transvenous epicardial LV lead placement through a side branch of the coronary sinus (CS).^{2,3,5} The final position of the LV pacing lead depends on the anatomy of the CS, on the performance and stability of the pacing lead, and on the absence of phrenic nerve stimulation.¹⁴ Despite all of the available technologies and the placement techniques, in

Conflict of Interest: None.

Address for reprints: Tamas Szili-Torok, M.D., Ph.D., Department of Clinical Cardiac Electrophysiology, Thorax Centre, Erasmus MC, Dr Molewaterplein 40, kamer Ba 577, Postbus 2040, 3000 CA Rotterdam, the Netherlands. Fax: 36-12151220 ext. 413; e-mail: t.szilitorok@erasmusmc.nl

Received May 1, 2013; revised September 26, 2013; accepted October 13, 2013.

doi: 10.1111/pace.12320

the high-volume centers the rate of failed LV lead implantation into the CS side branch or the risk of late lead dislodgement, phrenic nerve stimulation, or increasing threshold remains a substantial complication (5–10%) of transvenous CRT.^{11,15}

Alternative CRT Methods

The alternative approaches can be classified on the basis of the LV pacing site (epicardial or endocardial), and on the basis of access (closed chest/percutaneous or open chest). In the case of the closed chest/percutaneous approach, the lead insertion can be differentiated as transvenous, transapical, or transarterial.

Endocardial versus Epicardial LV Lead Placement

LV lead placement in the CS side branch results in epicardial pacing, which is less physiological, reversing the pattern of the normal LV wall activation. In a comparative study by Garrigue et al., endocardial biventricular pacing was associated with better LV filling and systolic performance.¹⁶ Derval et al. tested endocardial and epicardial pacing at identical locations. The maximal rates of LV pressure change (+dP/dTmax), arterial pulse pressure (PP), and end-systolic pressure (ESP) were not significantly different, but endocardial pacing was significantly superior to epicardial pacing on the minimal rates of LV pressure change (–dP/dTmin).¹⁷ The same results were obtained by Spragg et al.¹⁸ In a study in which the acute hemodynamic effects of LV endocardial and epicardial pacing with simultaneous x-ray/cardiac magnetic resonance and noncontact mapping was performed, endocardial stimulation appeared to be superior as compared to conventional CRT.¹⁹ Epicardial pacing may be more proarrhythmic than endocardial LV pacing, since epicardial activation of the LV wall prolongs QT interval and transmural dispersion of repolarization.²⁰ Ventricular tachycardia storms have been clinically observed after the initiation of CRT with epicardial LV pacing²¹ and endocardial pacing reduces the dispersion of ventricular repolarization.²²

Alternative Techniques

Epicardial Pacing Techniques

Currently, the open chest access epicardial lead placement is most frequently used as a second choice by either thoracotomy or video-assisted thoracoscopy (VAT).¹⁴ The advantage of this approach is the direct visual control with the possibility of choosing the lead-tip position (Figs. 1A and B). The risks of lead dislodgement

and phrenic nerve stimulation are low²³ and there is no limitation of the CS anatomy.²⁴ Less fluoroscopy and avoidance of intravenous contrast material are also benefits over conventional CRT.²⁵ Surgical epicardial LV lead placement has several disadvantages such as the need for general anesthesia, the presence of epicardial fat, adhesions, and it is more invasive than the transvenous approaches. The surgical trauma and the recovery time is appreciably higher than the transvenous LV lead implantation.²³ Finally, surgical implanted epicardial leads have a significantly higher failure rate than those of CS and transvenous right heart leads. The surgical implanted epicardial LV lead comparison studies confirmed usually excellent results after 3–6 months follow-up²⁵; however, after a 5-year follow-up period, epicardial leads might have significantly higher failure rate than the CS leads. In a study by Tomaske et al. including 114 juvenile patients with most having congenital heart disease, epicardial ventricular lead survival at 2 years and 5 years was 96% and 85%, respectively.²⁶ On the other hand, a recently published study by Burger et al. demonstrated an excellent long-term (over a period of 48 months) epicardial lead performance and durability after surgical (median sternotomy or lateral minithoracotomy) implantation of epicardial LV lead in 130 consecutive patients.²⁷

Currently, two different technical epicardial lead concepts are available: screw-in and suture-on leads. Both possess theoretical advantages and disadvantages and in this recently published comparison study, neither of the technical epicardial lead concepts was found to be superior.²⁷

There are several surgical approaches to implant the LV pacing lead. *Median sternotomy* is used at planned coronary artery bypass graft surgery and at valve repair or replacement. The *full left thoracotomy* offers the widest accessibility of the lateral LV wall; however, at present it is less applied. The *minimal thoracotomy (minithoracotomy)* offers better survival and a lower incidence of mediastinitis or osteomyelitis.²⁸ Nowadays, the epicardial LV lead is implanted surgically, often through a small left thoracotomy,²³ and two other technologies are increasingly used: VAT techniques and robotic surgery.

Minithoracotomy

LV lead implantation via a lateral minithoracotomy is performed under general anesthesia and on the beating heart. All patients have standard monitoring (electrocardiogram, pulse oximetry, and invasive arterial monitoring). The access to the pericardium is achieved by a 4- to 5-cm left lateral, midaxillary minithoracotomy in the fourth or fifth intercostal space. The pericardium

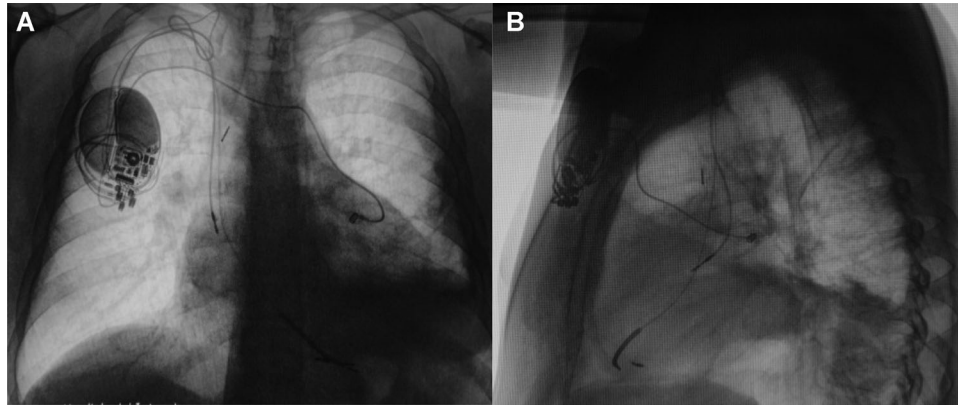


Figure 1. Postoperative chest x-ray from anteroposterior projection (A) and lateral projection (B) after epicardial left ventricular pacing lead implantation via minithoracotomy.

is opened anterior to the phrenic nerve. After mapping the LV for an optimal pacing site, the lead is placed on the target area.²⁹ After testing, the proximal end of the lead is tunneled submuscular to the provisional pocket and connected to the device. A chest tube is required postoperatively and can be discontinued within 48 hours. Recent investigations described this technique safe with a very low complication rate, representing a good alternative as a second-line procedure to transvenous CRT.^{25,27}

VAT

The VAT technique offers less postoperative pain and requires smaller incisions. It does not compromise in visualization.³⁰ Epicardial lead implantation using VAT was initially shown to be feasible in 2001 when a group successfully undertook an LV epicardial lead placement within 40 minutes and without significant blood loss.³¹ In recent years, larger series were reported and surgical leads have also been implanted thoroscopically using two ports.³² Usually two or three incisions are used for these ports within the fourth or fifth intercostal space along the anterior and midaxillary line. The VAT technique should be performed under general anesthesia, single-lung ventilation, standard monitoring, and on the beating heart.³³ The camera and the manipulating instruments are inserted through pre-prepared ports. Under visual control, the pericardium is opened laterally to phrenic nerve, the obtuse marginal artery as landmark help to identify the desired site, and an epicardial lead is screwed into the targeted wall region of the LV. After transesophageal echocardiography (TEE) control and the pacing threshold test, the proximal end of the lead passed through the medial incision and is tunneled subcutaneously to the pocket. The

VAT approach is a feasible and safe alternative, is well tolerated, and it has minimal postoperative recovery. However, a skilled VAT surgeon is necessary for epicardial lead placement.³² It is of importance that using VAT epicardial LV lead fixation on the heart needs special equipment and without this extra support there is an increase in the risk of dislocation.

Robotically Assisted Surgery

Experience with lead implantation using the minimally invasive route is growing rapidly with progression into LV lead implantation using robotics. This technique results in more precise LV lead placement on the ventricular wall and significantly reduces postoperative morbidity and the length of hospitalization.³⁴ This approach also needs general anesthesia, single-lung ventilation, standard monitoring, and TEE control. The robotic camera and instruments are introduced through 5–10-mm port sites. Using the robotic arms (da Vinci® Surgical System, Intuitive Surgical, Inc., Sunnyvale, CA, USA), the pericardium is opened posterior to the phrenic nerve to expose the posterolateral wall of the LV.³⁴ Computer interfacing allows the scaled motion, eliminates tremor, and provides incredibly accurate surgical precision. A screw-in lead is passed into the chest and is secured to the heart using robotic arms. The proximal part is tunneled to the axillar region and is connected to the pacemaker. The previous routine implantation of a second back-up lead is unnecessary.³⁵

The minimally invasive robotic approach to epicardial LV lead placement is associated with 98% acute technical success rate and can be performed with a low complication rate.^{34,35} A recent study by Kamath et al. with the largest cohort of patients who underwent robotic

epicardial LV lead placement report a benefit after 44 months follow-up and an excellent robotic lead performance.³⁵ However, while robotic surgery was shown to be feasible and safe, its use is restricted largely by cost implications.³⁶ The epicardial LV lead fixation on the heart with a robotic arm needs special equipment. Risk of lead dislocation increases without this equipment.

There are other epicardial LV lead implantation techniques that have only been used in either a small number of human cases or experimental animal studies. An alternative method for epicardial lead implantation that did not require classical thoracotomy is the *subxiphoidal video-assisted pericardioscopy*. In an experimental animal study, the access to the epicardium was achieved with subxiphoid video-assisted pericardioscopy, using a device that carries endoscopy with a port through which pacing leads could be introduced.³⁷ This approach requires a special support for LV lead fixation; conversely, the risk of dislocation is higher.

Endocardial Pacing Techniques

Transseptal Endocardial LV Lead Implantation

Transseptal access endocardial LV lead placement was investigated as a means of delivering LV pacing when CRT first emerged as a therapeutic paradigm and currently is used also as a third-line approach. This approach does offer some major advantages: transvenous access, more lead placement sites, endocardial pacing, and there is no need to compromise in LV pacing threshold for positional stability or phrenic nerve stimulation.¹³ Its clinical use has been limited due to several reasons, including the lack of reliable long-term safety data and difficulty of the necessary techniques.¹³ The transseptal technique has been used for over 50 years for hemodynamic measurements, mitral and aortic valve angioplasty, and in electrophysiology for left-sided ablations. The first case report for transseptal LV lead implantation was described by Jaïs et al. using femoral transseptal puncture and a snare technique via the right jugular vein.³⁸ The lead tunneled over the clavicle increases the risk for lead damage and skin erosion. Small modifications were described by Gelder et al. until the recently applied technique was clarified.³⁹

Transseptal endocardial LV placement requires puncture of the interatrial septum (IAS) for passage of a lead from the right atrium (RA) into the left atrium (LA) and the LV cavity (Figs. 2 A and B). The procedure does not require general anesthesia and minimal postoperative recovery is required. The first publication describing the transseptal technique restricted the venous access

to the right internal jugular vein. It requires tunneling of the lead with a relatively sharp curve over the clavicle to a right-sided pectoral device pocket.^{40,41} Later on, when CRT was mostly used as part of CRT-D, the lead had to be tunneled above the sternum in the patient to a left-sided ICD pocket. The medium-term performance of endocardial LV lead placed with this technique appeared satisfactory.⁴² Using a guidewire placed in the LA through an IAS puncture from the right femoral vein as a fluoroscopic marker, Ji et al. in a case presentation repunctured the IAS from the left axillary vein using a manually shaped transseptal needle.⁴³ This modified transseptal approach from the left axillary vein was never tested in a larger cohort. Three years later, two centers published additional case reports describing an alternative technique with a guidewire across the IAS puncture through a Judkins right or internal mammary catheter from the left or right subclavian vein.^{39,44} These techniques allow more flexibility for the upper body venous access used for transseptal endocardial LV lead placement. More recently a transseptal technique using femoral venous access followed by intravascular “pull through” of the lead from the femoral insertion site to a pectoral device pocket was applied in 11 patients.⁴⁵ This latter technique is an alternative for superior transseptal attempts using standard equipment and it is also applicable for pacing sites that are more easily reachable by the femoral approach. During transseptal LV lead implantation, Kutiyifa et al. successfully applied electroanatomical mapping to identify the location of the transseptal puncture and to achieve an optimal LV lead position.⁴⁶

There is a debate about the risk of the procedure without well-experienced operators. However, the major concern is about the long-term risk of thromboembolic complication and mitral valve endocarditis related to permanent presence of the transmitral LV lead from the RA.⁴⁷ Another question is the unknown long-term thromboembolic risk and accordingly the centers accept the risk similar as after mechanical valve implantation.

Transapical Endocardial LV Lead Implantation

This new technique combines the minimal invasive surgical approach and the advantage of endocardial pacing.⁴⁸ The transapical approach was invented for patients who failed the first attempt through the CS approach and with extensive epicardial adhesions. The advantage of this minimally invasive technique is the best accessibility of the all LV endocardial segments without the limitations of the anatomy to reach the most delayed segment of the lateral wall.⁴⁹

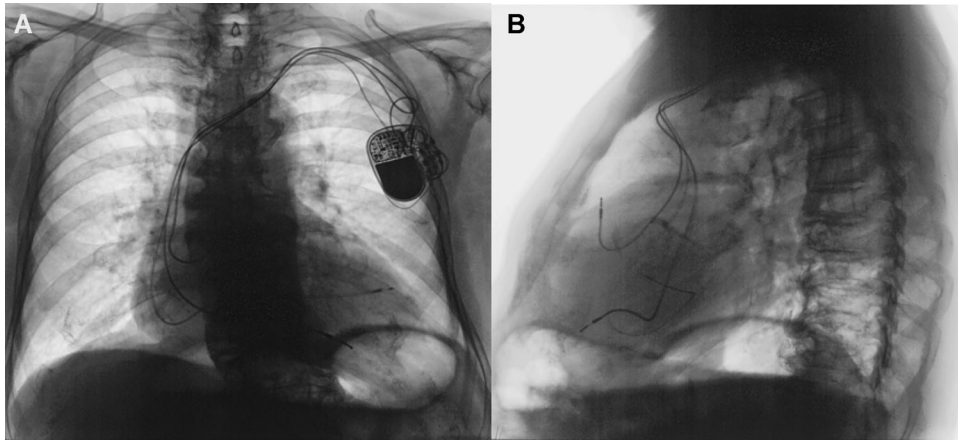


Figure 2. Postoperative chest x-ray from anteroposterior projection (A) and lateral projection (B) after transseptal left ventricular pacing lead implantation.

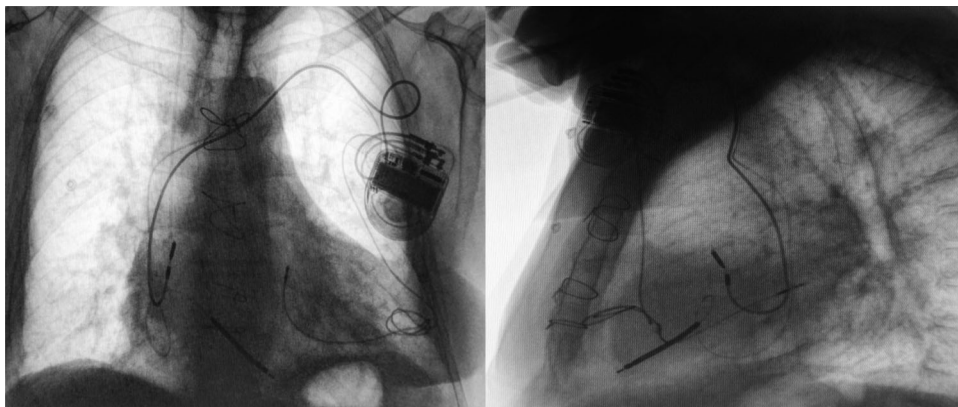


Figure 3. Postoperative chest x-ray from anteroposterior projection (A) and lateral projection (B) after transapical left ventricular pacing lead implantation.

A small pericardiectomy is performed above the LV apex and a standard active fixation endocardial pacing lead is positioned in the LV cavity through the apex (Figs. 3 A and B). Thin commercially available bipolar pacing electrodes are used (Medtronic CapSureFix Novus 5076–52 cm 6Fr [Medtronic Inc., Minneapolis, MN, USA], Medtronic CapSureFix Novus 5076–58 cm 6Fr, St. Jude Tendril ST 1888TC-58 cm [St. Jude Medical, St. Paul, MN, USA]). The leads are inserted using a Seldinger technique with a peel-way sheath through the apex of the heart. Fluoroscopy is necessary for the intracavitary navigation and endocardial fixation of the electrode at the optimal pacing site for CRT. To reach the target area a “J”-shaped electrode guidewire is used.⁴⁸ Although this technique is minimally invasive, the need of general anesthesia is necessary. A potential disadvantage is the theoretically long-term risk of thromboembolic complication. In order to prevent this, all patients are orally anticoagulated

with a target international normalized ratio level at 2–3.

A recently published study confirms that the transapical technique for endocardial CRT is a feasible approach and has potential advantages such as shorter procedure times and a decreased postoperative burden.⁴⁹ Lead longevity and long-term outcome requires a lengthy follow-up and large-scale evaluation. The idea of using this method as a second and not as third-line therapy also requires further investigation.

Transarterial Endocardial LV Lead Implantation

Transarterial access for endocardial LV lead implantation is possible through the subclavian or axillary artery and through the aortic valve. In recent years, this occurred in insignificant numbers and mostly inadvertently.¹⁴ Only one animal experiment reported the direct transaortic placement of an LV lead as feasible.⁵⁰ In this

study, after 6 months, there was no significant aortic regurgitation and no evidence of thromboembolism reported despite the lack of anticoagulation.⁵⁰

Conclusions

In recent years, the indication for CRT has expanded and there have been continuous improvements in LV lead and delivery tool technologies that have made the CRT more accessible for patients with HF and LV dyssynchrony. The first-line approach remains the transvenous epicardial CS lead implantation. Alternative

techniques remain second-line options; however, the increasing CS lead failure rate along with the increasing number of surgical epicardial lead failures together will result in further increasing the CRT population. In the near future, more and more patients will require urgent LV lead revision. Currently, surgical access is commonly used, especially the video-assisted minimal surgery, while transapical or transseptal endocardial LV lead implantations are being developed. In the future, randomized studies are needed to assess the potential benefits of some alternative LV pacing techniques.

References

- Cleland JGF, Daubert JC, Erdmann E, Freemantle N, Gras D, Kaptenberger L, Klein W, et al. The effect of cardiac resynchronization on morbidity and mortality in heart failure. *N Engl J Med* 2005; 352:1539–1549.
- Bristow MR, Saxon LA, Boehmer J, Krueger S, Kass DA, De Marco T, Carson P, et al. Cardiac-resynchronization therapy with or without an implantable defibrillator in advanced chronic heart failure. *N Engl J Med* 2004; 350:2140–2150.
- Abraham WT, Hayes DL. Cardiac resynchronization therapy for heart failure. *Circulation* 2003; 108:2596–2603.
- Ypenburg C, van de Veire N, Westenberg JJ, Bleeker GB, Marsan NA, Henneman MM, van der Wall EE, et al. Noninvasive imaging in cardiac resynchronization therapy, Part 2: Follow-up and optimization of settings. *Pacing Clin Electrophysiol* 2008; 31:1628–1639.
- Exner DV, Auricchio A, Singh JP. Contemporary and future trends in cardiac resynchronization therapy to enhance response. *Heart Rhythm* 2012; 9(8 Suppl.):S27–S35.
- Bisch L, Da Costa A, Dauphinot V, Romeyer-Bouchard C, Khri L, M'baye A, Isaaz K. Predictive factors of difficult implantation procedure in cardiac resynchronization therapy. *Europace* 2010; 12:1141–1148.
- Fatemi M, Etienne Y, Castellat P, Blanc JJ. Primary failure of cardiac resynchronization therapy: What are the causes and is it worth considering a second attempt? A single-centre experience. *Europace* 2008; 10:1308–1312.
- Lin G, Anavekar NS, Webster TL, Rea RF, Hayes DL, Brady PA. Long-term stability of endocardial left ventricular pacing leads placed via the coronary sinus. *Pacing Clin Electrophysiol* 2009; 32:1117–1122.
- Ansalone G, Giannantoni P, Ricci R, Trambaiolo P, Fedele F, Santini M. Doppler myocardial imaging to evaluate the effectiveness of pacing sites in patients receiving biventricular pacing. *J Am Coll Cardiol* 2002; 39:489–499.
- Lambiase PD, Rinaldi A, Hauck J, Mobb M, Elliott D, Mohammad S, Gill JS, et al. Non-contact left ventricular endocardial mapping in cardiac resynchronization therapy. *Heart* 2004; 90:44–51.
- McAlister FA, Ezekowitz J, Hooton N, Vandermeer B, Spooner C, Dryden DM, Page RL, et al. Cardiac resynchronization therapy for patients with left ventricular systolic dysfunction: A systematic review. *J Am Med Assoc* 2007; 297:2502–2514.
- Dickstein K, Vardas PE, Auricchio A, Daubert JC, Linde C, McMurray J, Ponikowski P, et al. Focused update of ESC Guidelines on device therapy in heart failure. *Eur Heart J* 2010; 31:2677–2687.
- Ernest WL. Achieving permanent left ventricular pacing-options and choice. *Pacing Clin Electrophysiol* 2009; 32:1466–1477.
- Morgan JM, Degaldo V. Lead positioning for cardiac resynchronization therapy: Techniques and priorities. *Europace* 2009; 11:22–28.
- Gras D, Bocker D, Lunati M, Wellens HJ, Calvert M, Freemantle N, Gervais R, et al. Implantation of cardiac resynchronization therapy systems in the CARE-HF trial: Procedural success rate and safety. *Europace* 2007; 9:516–522.
- Garrigue S, Jais P, Espil G, Labeque JN, Hocini M, Shah DC, Haissaguerre M, et al. Comparison of chronic biventricular pacing between epicardial and endocardial left ventricular stimulation using Doppler tissue imaging in patients with heart failure. *Am J Cardiol* 2001; 88:858–862.
- Derval N, Steendijk P, Gula LJ, Deplagne A, Laborde J, Sacher F, Knecht S, et al. Optimizing hemodynamics in heart failure patients by systematic screening of left ventricular pacing sites. *J Am Coll Cardiol* 2010; 6:566–575.
- Spragg DD, Dong J, Fetis BJ, Helm R, Marine JE, Cheng A, Henrikson CA, et al. Optimal left ventricular endocardial pacing sites for cardiac resynchronization therapy in patients with ischemic cardiomyopathy. *J Am Coll Cardiol* 2010; 10: 774–781.
- Ginks MR, Lambiase PD, Duckett SG, Bostock J, Chinchapatnam P, Rhode K, McPhail MJ, et al. A simultaneous X-Ray/MRI and noncontact mapping study of the acute hemodynamic effect of left ventricular endocardial and epicardial cardiac resynchronization therapy in humans. *Circ Heart Fail* 2011; 4:170–179.
- Fish JM, Di Diego JM, Nesternko V, Antzelevitch C. Epicardial activation of left ventricular wall prolongs QT interval and transmural dispersion of repolarization: Implications for biventricular pacing. *Circulation* 2004; 109:2136–2142.
- Nyak HM, Verdino RJ, Russo AM, Gerstenfeld EP, Hsia HH, Lin D, Dixit S, et al. Ventricular tachycardia storm after initiation of biventricular pacing: Incidence, clinical characteristics, management and outcome. *J Cardiovasc Electrophysiol* 2008; 19:708–705.
- Scott PA, Yue AM, Watts E, Zeb M, Roberts PR, Morgan JM. Transseptal left ventricular endocardial pacing reduces dispersion of ventricular repolarization. *Pacing Clin Electrophysiol* 2011; 34:1258–1266.
- Doll N, Piorkowski C, Czesla M, Kallenbach M, Rastan AJ, Arya A, Mohr FW. Epicardial versus transvenous left ventricular lead placement in patients receiving cardiac resynchronization therapy: Results from a randomized prospective study. *Thorac Cardiovasc Surg* 2008; 56:256–261.
- Noheria A, Desimone CV, Lachman N, Edwards WD, Gami AS, Maleszewski JJ, Friedman PA, et al. Anatomy of the coronary sinus and epicardial coronary venous system in 620 hearts: An electrophysiology perspective. *J Cardiovasc Electrophysiol* 2013; 24:1–6.
- Patwala A, Woods P, Clements R, Albouaini K, Rao A, Goldspink D, Tan LB, et al. A prospective longitudinal evaluation of the benefits of epicardial lead placement for cardiac resynchronization therapy. *Europace* 2009; 11:1323–1329.
- Tomaske M, Gerritse B, Kretzers L, Pretre R, Dodge-Khatami A, Rahn M, Bauersfeld U. A 12-year experience of bipolar steroid eluting epicardial pacing leads in children. *Ann Thorac Surg* 2008; 85:1704–1711.
- Burger H, Kempfert J, van Linden A, Szalay Z, Schoenburg M, Walther T, Ziegelhoeffer T. Endurance and performance of two different concepts for left ventricular stimulation with bipolar epicardial lead sin long-term follow up. *Thorac Cardiovasc Surg* 2012; 60:70–77.
- Sansone F, Punta G, Parisi F, Dato GM, Zingarelli E, Flocco R, Forsennati PG, et al. Right minithoracotomy versus full sternotomy for the aortic valve replacement: Preliminary results. *Heart Lung Circ* 2012; 21:169–173.

ALTERNATIVE TECHNIQUES FOR LV PACING IN CRT

29. Mair H, Sachweh J, Meuris B, Nollert G, Schmoeckel M, Schuetz A, Reichart B, et al. Surgical epicardial left ventricular lead versus coronary sinus lead placement in biventricular pacing. *Eur J Cardiothorac Surg* 2005; 27:235–242.
30. Landreneau RJ, Hazelrigg SR, Mack MJ, Dowling RD, Burke D, Gavlick J, Perrino MK, et al. Postoperative pain-related morbidity: Video-assisted thoracic surgery versus thoracotomy. *Ann Thorac Surg* 1993; 56:1285–1289.
31. Antonic J, Crnjac A, Kamenik B. Epicardial electrode insertion by means of video-assisted thoracic surgery technique. *Wien Klin Wochenschr* 2001; 113:65–68.
32. Jutley RS, Waller DA, Loke I, Skehan D, Ng A, Stafford P, Chin D, et al. Video-assisted thoracoscopic implantation of the left ventricular pacing lead for cardiac resynchronization therapy. *Pacing Clin Electrophysiol* 2008; 31:812–818.
33. Gabor S, Prenner G, Wasler A, Schweiger M, Tscheliessnigg KH, Smolle-Jüttner FM. A simplified technique for implantation of left ventricular epicardial leads for biventricular re-synchronization using video-assisted thoracoscopy (VATS). *Eur J Cardiothorac Surg* 2005; 28:797–800.
34. DeRose JJ, Ashton RC, Belsley S, Swistel DG, Vloka M, Ehlert F, Shaw R, et al. Robotically assisted left ventricular epicardial lead implantation for biventricular pacing. *J Am Coll Cardiol* 2003; 41:1414–1419.
35. Kamath GS, Balaram S, Choi A, Kuteyeva O, Garikipati NV, Steinberg JS, Mittal S. Long-term outcome of leads and patients following robotic epicardial left ventricular lead placement for cardiac resynchronization therapy. *Pacing Clin Electrophysiol* 2011; 34:235–240.
36. Turchetti G, Palla I, Pierotti F, Cuschieri A. Economic evaluation of da Vinci-assisted robotic surgery: A systematic review. *Surg Endosc* 2012; 26:598–606.
37. Zenati MA, Bonanomi G, Chin AK, Schwartzman D. Left heart pacing lead implantation using subxiphoid videopericardioscopy. *J Cardiovasc Electrophysiol* 2003; 14:949–953.
38. Jais P, Douard H, Shah DC, Barold S, Barat JL, Clémenty J. Endocardial biventricular pacing. *Pacing Clin Electrophysiol* 1998; 21:2128–2131.
39. van Gelder BM, Scheffer MG, Meijer A, Bracke FA. Transseptal endocardial left ventricular pacing: An alternative technique for coronary sinus lead placement in cardiac resynchronization therapy. *Heart Rhythm* 2007; 4:454–460.
40. Jais P, Takahashi A, Garrigue S, Yamane T, Hocini M, Shah DC, Barold SS, et al. Mid-term follow-up of endocardial biventricular pacing. *Pacing Clin Electrophysiol* 2000; 23:1744–1747.
41. Leclercq F, Hager FX, Macia JC, Mariottini CJ, Pasquié JL, Grolleau R. Left ventricular lead insertion using a modified transseptal catheterization technique: A totally endocardial approach for permanent biventricular pacing in end-stage heart failure. *Pacing Clin Electrophysiol* 1999; 22:1570–1575.
42. Pasquié JL, Massin F, Macia JC, Gervasoni R, Bortone A, Cayla G, Grolleau R, et al. Long-term follow-up of biventricular pacing using a totally endocardial approach in patients with end-stage cardiac failure. *Pacing Clin Electrophysiol* 2007; 30(Suppl 1.):S31–S33.
43. Ji S, Cesario DA, Swerdlow CD, Shivkumar K. Left ventricular endocardial lead placement using a modified transseptal approach. *J Cardiovasc Electrophysiol* 2004; 15:234–236.
44. Nuta B, Lines I, MacIntyre I, Haywood GA. Biventricular ICD implant using endocardial LV lead placement from the left subclavian vein approach and transseptal puncture via the transfemoral route. *Europace* 2007; 11:1038–1040.
45. van Gelder BM, Houthuizen P, Bracke FA. Transseptal left ventricular endocardial pacing: Preliminary experience from a femoral approach with subclavian pull-through. *Europace* 2011; 13:1454–1458.
46. Kutiyifa V, Merkely B, Szilágyi SZ, Zima E, Róka A, Király A, Osztheimer I, et al. Usefulness of electroanatomical mapping during transseptal endocardial left ventricular lead implantation. *Europace* 2012; 4:599–604.
47. Kassai I, Szili-Torok T. Concerns about the long-term outcome of transseptal cardiac resynchronization therapy: What we learned from surgical experience. *Europace* 2008; 10:121–122.
48. Kassai I, Foldesi CS, Szekely A, Szili-Torok T. New method for cardiac resynchronization therapy: Transapical endocardial lead implantation for left ventricular free wall pacing. *Europace* 2008; 10:882–883.
49. Mihalcz A, Kassai I, Kardos A, Foldesi C, Theuns D, Szili-Torok T. Comparison of the efficacy of two surgical alternatives for cardiac resynchronization therapy: Trans-apical versus epicardial left ventricular pacing. *Pacing Clin Electrophysiol* 2012; 35:124–130.
50. Reinig M, White M, Levine M, Cha R, Cinel I, Purnachandra J, Goldfarb R, et al. Left ventricular endocardial pacing: A transarterial approach. *Pacing Clin Electrophysiol* 2007; 30:1464–1468.