

Cardiac resynchronization therapy (CRT): the surgeon's perspective

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Kardiologia i Torakochirurgia Polska 2006; 3 (4): 408–411



Congestive heart failure (CHF) is a progressive syndrome marked by structural and electrical changes (remodelling). In approximately 30% of patients with CHF, ventricular dilatation is accompanied by intraventricular conduction delays, most commonly left bundle branch block (LBBB) [1]. Intraventricular conduction defects produce asynchronous ventricular activation characterized by delay in left ventricular (LV) lateral wall contraction [2], and places the failing heart at a further mechanical disadvantage. Ventricular dyssynchrony has been associated with suboptimal filling, paradoxical septal motion, reduced LV contractility and increased mitral regurgitation [3] and has been signified as an independent predictor for cardiac mortality [2].

The clinical and mechanical manifestations of ventricular dyssynchrony can be treated by simultaneously pacing both the right and left ventricles usually in association with right atrial sensing, resulting in atrial-synchronized biventricular pacing or cardiac resynchronization therapy (CRT) [3]. This resynchronization of segmental LV mechanics as well as re-coordination of both atrio-ventricular and inter-ventricular contraction reduces the conduction delay between the two ventricles and restores a normal mechanical relationship between left and right ventricular contraction. Subsequently, there is an increase in cardiac output, decrement in mitral regurgitation [4] and reverse LV remodelling [5].

Patient selection criteria

At present, the subset of patients with moderate to severe drug-refractory CHF with ventricular dyssynchrony, manifested as prolonged QRS duration on the electrocardiogram, are considered candidates for CRT. Subsequently, indications for CRT are New York Heart Association (NYHA) class III or IV despite optimal medical therapy, LV ejection fraction (LVEF) of 35% or less and QRS duration of 120-130 ms or more [6].

Echocardiography, including tissue synchronization imaging (TSI) and myocardial velocities extracted from multiple views, has been advocated to better define mechanical dyssynchrony instead of electrocardiographic me-

asurements [7]. Its role, however, in the decision making and optimization of CRT remains a matter of debate and is currently under investigation [8, 9].

The weight of evidence supporting the clinical benefit of CRT has been corroborated in randomised controlled trials enrolling more than 4000 patients. In comparison to standard pharmacological therapy CRT has been shown to reduce mortality by 36% [10] and reduce the composite end-point of all-cause mortality and hospitalization by 43% [11, 12]. Combining CRT with a defibrillator may further improve survival. CRT has also been associated with marked improvement in NYHA functional class, exercise intolerance and quality of life [12].

Delivery of CRT systems

The main method used today to achieve LV pacing is through transvenous catheter deployment of a pacing lead into a tributary of the coronary sinus, i.e. through coronary vein stimulation [13]. While in this technique the LV pacing lead is introduced percutaneously and advanced transvenously in the catheterization lab, problems still remain, ranging from complicated coronary venous anatomy to LV lead problems.

Data derived from large-scale prospective randomised studies show peri-procedural complication rate of 9% to 14% [13]. The distribution of complications includes coronary sinus dissection, phrenic nerve stimulation, lead dislodgement [13], coronary sinus perforation, ventricular fibrillation, asystole, pulmonary oedema and pneumothorax. The primary causes for early coronary sinus lead revision (re-intervention) are lead dislodgement, phrenic nerve stimulation and infection requiring explantation [13]. The failure rate of transvenous delivery of CRT has been estimated to be 8% [14]. Nevertheless, immediate loss of LV pacing has been reported to be as high as 32%, secondary to LV lead dislodgment or increased threshold levels [15].

The substantial total implant time and the time-fraction of radiation exposure associated with transvenous CRT implantation remain a matter of concern. Implantation time in experienced centres ranges from two to three

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hours [13] and the fraction-time of fluoroscopic exposure, and hence the radiation burden, is apparently significant [16]. In a recent study focusing on this issue, fluoroscopic exposure averaged 35 minutes, which may be associated with increased risk values for fatal cancer and hereditary disorders [16].

The surgeon's role in CRT

The surgeon may be engaged in two aspects of resynchronization therapy: (1) in alternative delivery of permanent CRT systems by surgically implanting an epicardial LV lead for *chronic* purposes or (2) as part of the *acute* management of dysfunctioning heart during surgery, by initiating temporary biventricular pacing to enhance cardiac performance during weaning from bypass and the postoperative phases.

Chronic CRT

Failure to deploy the LV pacing leads through coronary sinus catheterization (for anatomical or technical reasons) or complications of a previously implantable device may warrant surgical placement of epicardial LV pacing leads. Implantation failure rate has been shown to be lower with surgical implantation than with the transvenous technique [17, 18]. Surgical epicardial stimulation has a number of advantages: it enables direct visualisation of the epicardium, aids in choosing the most suitable surface and helps to avoid epicardial fat and areas of fibrosis that can cause changes in pacing thresholds. The portion of non-responders to CRT after transvenous implantation is substantial; the response rate is limited to 60% of patients, of whom only 55% respond early (within three months after treatment) [6]. Effectiveness of CRT is determined in part by the location of the LV pacing lead, and the mid-upper posterolateral LV wall has been postulated to be the optimal pacing site. Venous anatomy may preclude placement of the transvenous lead in these locations and favour location in the anterior cardiac vein (a non-curved tributary of the distal coronary sinus). In a recent study of transplant patients, in 77% of the patients who did not respond to CRT prior to the transplantation, LV leads were located in a suboptimal position [19].

Permanent LV epicardial leads. Contemporary epicardial electrodes confer advantages in terms of ease of implantation and longevity. Sutureless leads use designated introducers that attach the lead to the epicardial surface by a screw-in mechanism (clockwise rotation). Epicardial fixation sutures are not required. Thus, epicardial implantation can be performed through very limited minithoracotomy as the exposure required is only of the immediate implanted LV area. An area of the LV free of fat, vessels and infarcted tissue should be chosen for placement of the leads.

Prior to permanent implantation, the stimulation threshold and sensing capability should be verified. The following implantation values are recommended: (1) for acute stimulation, threshold is ≤ 1.5 volt, (2) for acute sensing, threshold ≥ 5 mV, and (3) for acute impedance, between 300 mV and 1500 mV.

Contraindications for epicardial lead implantation include patients who may have an adverse reaction to dexamethasone sodium phosphate (steroid-eluting leads) and patients in whom the ventricular myocardium is thin-walled, suffused with fat or is heavily infarcted.

Surgical approach. Surgical approaches for epicardial LV lead placement include (1) left lateral minithoracotomy [20, 21] (2) video-assisted thoracoscopy [22], and (3) robotically-enhanced approach [21, 23, 24].

Left lateral minithoracotomy. Fluoroscopic-guided implantation of the right atrial and right ventricular leads is first completed followed by insertion of the pacemaker-defibrillator device to a left-sided subcutaneous or sub-pectoralis pocket. The ipsilateral lung is deflated and lateral minithoracotomy, 4 to 5 cm in size, performed in the fourth intercostal space to access the mid-upper lateral LV surface. Off-pump implantation of the sutureless lead is achieved by the screw-in mechanism in a matter of seconds. The opposite end of the LV electrode is then tunneled transthoracically towards the device pocket. The procedure is completed following verification of the threshold, impedance and defibrillation indices.

Video-assisted thoracoscopy. In right-lateral decubitus position (the left chest tilted at 60–70°) and under single-lung ventilation a camera port (between the middle and posterior axillary line) and a flexible instrumentation port (anterior axillary line) are inserted in the fourth intercostal space. A T-shaped pericardial incision is made lateral to the phrenic nerve and a screw-in epicardial electrode is placed. The lead is then guided transthoracically to the pacemaker or ICD pocket [22].

Robotically-enhanced approach. The use of the “da Vinci” system (*Intuitive Surgical Inc., USA*) has been reported. This system contributes advantages to standard video-assisted thoracoscopy, such as three-dimensional vision, tremor elimination and the possibility of stitching the lead in place. Considerable costs per intervention and the long operating times, however, are definitive shortcomings [23, 25].

The use of transoesophageal echocardiography to determine the actual position of the lead is not mandatory but has been proposed [22].

Subxyphoid videopericardioscopy has also been described for LV lead placement, but is still considered experimental [26].

LV lead site selection. In general, the electrode should be placed in the area where optimal concordance is achieved between the LV pacing site and the site of the most delayed LV wall [21] – therefore in the postero-lateral LV wall. It has been proposed, however, that intraoperative real-time selection of the implantation site can further optimize CRT [27] and may allow functional improvement up to 40% versus random site selection [28]. Technically, irrespective of the method, minithoracotomy or thoracoscopy, a temporary epicardial electrode is used for biventricular pacing and the best pace site is determined by the resultant pressure-volume loops [27, 28].

Acute CRT

Based on the benefits of chronic CRT, two concepts of resynchronization therapy should be taken into account in patients with cardiac dysfunction undergoing cardiac surgery. The first involves attempting to reproduce acute temporary improvement in cardiac performance and haemodynamics in the post-bypass and early postoperative period. This requires initiation of sequential atrio-biventricular epicardial pacing instead of the standard atrio-right ventricle (RV) pacing. The second is to consider the implantation of a permanent epicardial LV lead for potential future use in subsets of patients at risk.

While the literature on these treatment concepts is currently sparse, sporadic data exist. In a study assessing the effect of epicardial LV pacing on post-bypass haemodynamics in patients with LV dysfunction, an active lead placed on the posterolateral wall, but not on the anterior wall, has been shown to increase cardiac index and mean blood pressure relative to control standard RV epicardial pacing [29]. In another study, postoperative biventricular pacing increased the mean blood pressure by 11%, LV stroke work index by 19%, and reduced MR in the acute postoperative period [30]. Our policy in patients with cardiac dysfunction is to place an additional temporary LV electrode, complementary to the standard right atrial and RV electrodes, during weaning from bypass. Technically, two atrial electrodes are connected to one pacemaker cable in a standard fashion; the RV electrode (placed on the inferior RV wall) and the LV electrode (placed on the posterolateral LV wall) are inserted together to the negative lead of a second pacemaker cable and the positive lead connected to the skin. Temporary sequential atrio-(simultaneous) biventricular pacing can subsequently be initiated.

Implanting a permanent LV epicardial lead during the primary operation in patients with CHF, LV dysfunction and conduction delay for potential future use has been our policy for some time. The permanent LV electrode is placed on the posterolateral LV wall and tunneled to the subclavicular area. Controlled data on this strategy are currently unavailable. Nevertheless, in one report, permanent CRT using a surgically implanted LV electrode was initiated in two of four patients at 1 month and 6 months after surgery [30].

Resynchronization treatment, temporary and/or chronic, may be considered in additional surgical subsets: (1) CHF patients undergoing conventional RV pacing show similar dyssynchrony as patients with intrinsic LBBB. These patients may sustain improved LV function, improvement in dyssynchrony indices and clinical improvement following CRT [31]. (2) Adult patients with systemic RV frequently deteriorate to CHF. It has been estimated that between 4% and 9% of these patients are potential candidates of CRT [32]. (3) CRT has been shown to delay transplantation in heart transplant candidates with dyssynchrony [33]. It should be noted, however, that these are preliminary observations and further validation is required.

To conclude, irrespective of the choice of surgical technique, epicardial LV lead implantation can be performed

readily. Several benefits are conferred over transvenous delivery. While the role of the surgeon in chronic CRT has been established, data on the efficacy of acute resynchronization treatment are lacking. In certain subsets of patients with LV dysfunction undergoing cardiac surgery, however, acute CRT may be considered for temporary cardiac augmentation in the perioperative period. Also, implantation of a permanent epicardial LV lead already during the primary surgery may be advisable for potential CRT in the future.

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