Robotic LV lead placement is an effective and novel technique which can be used for ventricular resynchronization therapy in patients with no other minimally invasive options for biventricular pacing. (J Am Coll Cardiol 2003;41:1414–9) © 2003 by the American College of Cardiology Foundation

Approximately 30% of patients with heart failure exhibit significant ventricular dyssynchrony secondary to alterations in intraventricular conduction as manifested by a widened QRS complex on 12-lead electrocardiogram (1). This ventricular dyssynchrony further impairs the already depressed cardiac contractility of patients with both idiopathic and ischemic cardiomyopathies. The altered contraction pattern may worsen mitral regurgitation and is associated with an increased risk of death (2–4).

Prospective randomized trials have demonstrated improvements in ventricular function, exercise capacity, and quality of life among patients undergoing ventricular resynchronization therapy via biventricular pacing (5–8). However, technical limitations owing to individual coronary sinus (CS) and coronary venous anatomy result in a 10% to 15% failure rate of left ventricular (LV) lead placement and effective biventricular pacing (7,8). Lead dislodgement contributes to an additional 5% to 10% late failure rate of LV lead capture (9). Rescue therapy for these frail patients has typically involved LV epicardial lead placement through a limited anterior thoracotomy.

To provide a minimally invasive option for these patients with LV lead failures, we began a program of endoscopic, epicardial LV lead placement with the use of the da Vinci Robotic Surgical System (Intuitive Surgical Inc., Sunnyvale, California). We report the intermediate results of robotically assisted epicardial lead placement for biventricular pacing in a cohort of patients with previous failure of CS cannulation.

METHODS

Patients. Ten patients were referred to the surgical arrhythmia service for robotic LV lead implantation after initial percutaneous attempts at biventricular lead insertion. The reasons for referral are listed in Table 1. Patient age was 70.5 ± 13 years (range 49 to 87 years), and 80% were male. The etiology of heart failure was idiopathic in six patients and ischemic in the other four patients. Preoperative New York Heart Association (NYHA) heart failure class was 3.4 ± 0.5, and patients had heart failure symptoms for a mean of 5.1 ± 2.0 years. Sixty percent were in the hospital with a heart failure exacerbation, and 40% were electively admitted to the hospital as outpatients. Three patients had a previous cardiac procedure: one patient had a pericardiostomy tube for ventricular perforation six months earlier during insertion of an implantable cardioverter-defibrillator (ICD), and two patients had previous coronary artery bypass grafting (2...
and 20 years previously). Seven patients had a pre-existing right-sided pacemaker or ICD in place upon referral.

**Preoperative assessment.** Written, informed consent was obtained from all patients as part of an approved Institutional Review Board protocol. Preoperative evaluation consisted of a 12-lead electrocardiogram to document a QRS complex $>130$ ms. Dobutamine stress echocardiography was routinely performed to identify areas of viability and recruitable myocardial contractility in the posterolateral and posterobasal segments.

**Robotic system.** The da Vinci Robotic Surgical System (Intuitive Surgical Inc., Sunnyvale, California) was used in all cases. The device is composed of the surgeon control console and the surgical arm unit that positions and directs the micro-instruments (Fig. 1A). Unlike standard thoracoscopic instruments, these specialized “EndoWrist” instruments have a full seven degrees of freedom, simulating the motion of a human wrist at the operative site (Fig. 1B). Insertion of the instruments into the chest cavity is performed through two 8-mm ports. A third 10-mm port is used to insert the endoscope. The instruments are controlled by a surgeon who sits at the operating console away from the operative field. Computer interfacing allows for scaled motion, eliminating tremor and providing for incredibly accurate surgical precision through these small ports. The surgeon views the surgery through the eyepiece in the surgical console, which provides high-definition, magnified, real three-dimensional vision.

<table>
<thead>
<tr>
<th>Reason for Referral for Robotic LV Lead Implantation</th>
<th>Number</th>
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<tbody>
<tr>
<td>Occluded coronary sinus</td>
<td>5</td>
</tr>
<tr>
<td>Atretic venous tributaries</td>
<td>3</td>
</tr>
<tr>
<td>Prior right ventricular perforation</td>
<td>1</td>
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<tr>
<td>Primary implant</td>
<td>1</td>
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</table>

**Abbreviations and Acronyms**
- CS = coronary sinus
- EF = ejection fraction
- ICD = implantable cardioverter defibrillator
- LV = left ventricle/ventricular
- NYHA = New York Heart Association
- OM = obtuse marginal

**Operative technique.** All operations were performed under general anesthesia with selective right lung ventilation. Transesophageal echocardiography was performed routinely, and Swan-Ganz catheter placement was performed selectively in accordance with institutional review board-approved research protocols.

Patients were positioned in the full posterolateral thoracotomy position. The da Vinci Robotic Surgical System was used for all portions of the operation. A camera port was placed in the seventh intercostal space in the posterior axillary line. The left and right arms were positioned in the ninth and fifth intercostal space, respectively (Fig. 2). The left chest was insufflated at a pressure of 8 to 10 mm Hg. A 10-mm working port was inserted posterior to the camera port and was used for the introduction of the lead and sutures as necessary. The pericardium was then opened posterior to the phrenic nerve, and the first and second obtuse marginal (OM) vessels were identified (Fig. 3). The pericardium was retracted with one- or two-stay sutures which were brought out of the working port. A temporary pacing wire was used to map the ventricular electrogram and determine the area of latest activation along the posterobasal ventricular surface in relation to the patient’s intrinsic QRS complex. This universally was found to be in the region of the second OM and third OM vessels. The optimal distance from base and apex did show some variability.

A pacing lead was then introduced into the chest through the working port. The robotic arms were used to fix the lead to the LV surface either by screw in fixation or suture technique depending on the lead used. The lead was tested for threshold, resistance, and latency within the native QRS complex. This lead was capped and delivered into the chest. A second lead was then delivered through the working port and was again fixed to the LV surface near the second OM. The second lead was occasionally placed as a screw-in lead by the table surgeon. The pericardium was closed over the leads in all cases with several silk sutures to aid in permanent lead fixation.

The first lead was then retrieved from the chest through the right arm port. Both leads were then tunneled to a counter incision in the axilla. A chest tube was placed through the left arm port for evacuation of air and was removed before leaving the operating room. The port sites were closed and the patient was repositioned in the supine position. The patient was reprepped and drapped. If a prior device had been implanted the pocket was reopened. Both LV leads were retrieved into the pocket and retested for threshold. The LV lead with the best threshold was used as the pacing lead and was connected to the device. The second lead was secured to the fascia and was left capped in the pocket as a backup lead for future use if necessary. If a right-sided pacing or defibrillating lead was required, it was inserted at this time and the leads were connected to either a biventricular pacing generator or an ICD/biventricular pacing device.
Twelve-lead electrocardiograms were obtained in the operating room during right ventricular, LV, and biventricular pacing. All patients were extubated in the operating room and observed in the intensive care unit overnight.

All patients had follow-up at three- and six-month intervals for device interrogation. Interval transthoracic echocardiograms were performed at three and six months and were assessed for ejection fraction and ventricular volumes.

**Statistical analysis.** Changes in preoperative and postoperative measurements were compared among individual patients with a paired, two-tailed Student t test.

**RESULTS**

Nineteen epicardial leads were placed in the 10 patients (one patient received only one lead). Of the active leads, two were epicardial steroid eluting sew-on leads (Medtronic CapSure Epi 4968, 53 cm, Minneapolis, Minnesota) and eight were screw-in leads (Medtronic Sutureless, Unipolar, Myocardial Screw-in, 5069, 53 cm). Mean robotic operative time (time from initial skin incision to patient repositioning) for all cases was $83 \pm 53$ min (range 30 to 180 min). A clear reduction in robotic operative times was detected when the first five cases ($108 \pm 54$ min) were compared with the last.
five cases (50 ± 16 min) (p = 0.05) (Fig. 4). All patients had successful LV lead placement.

There was one intraoperative ventricular injury immediately after lead placement early in our experience. This was the result of inadvertent left arm injury to the LV free wall. Because there is a limited working space in some of these patients, down lung ventilation can cause significant mediastinal shift allowing the LV to move towards the chest wall. This injury was repaired after extending the right arm port 2 cm. Two pledgeted sutures were placed under both direct and videoscopic assistance. After this injury, we adopted a policy of routinely holding ventilation during lead placement. No patient required a blood transfusion and there were no reoperations for bleeding. One patient developed a left lower lobe pneumonia three days after robotic lead placement. This patient had been hospitalized for one week with a congestive heart failure exacerbation before surgery.

All patients are alive and well at a mean follow-up of 25 ± 10 weeks. Eight of ten patients were symptomatically improved at three months follow-up. As a group, NYHA class and LV EF were improved at three months (Table 2). Operative threshold and impedance data are shown in Table 2 and are compared with three-month follow-up lead data. A statistically significant improvement in QRS duration and impedance was found at three months follow-up with no change in lead threshold.

Figure 2. Port placement for totally endoscopic, robotic left ventricular epicardial lead placement. The ports are placed in line with the tip of the scapula allowing for posterior access to the left ventricular surface.

Figure 3. Operative photograph of robotic left ventricular lead placement. The pericardium is divided posterior to the phrenic nerve exposing the obtuse marginal (OM) vessels on the posterolateral wall of the left ventricle. A two-turn, helical screw-in lead is being placed by the console surgeon.
DISCUSSION

The success of ventricular resynchronization therapy relies heavily upon proper LV lead placement. Previous studies have demonstrated that pacing the posterobasal wall of the LV provides more effective hemodynamic augmentation than either lateral or anterior positioned leads (10,11). Despite successful CS cannulation in 85% of percutaneous LV lead insertions, a much smaller percentage of these patients actually receive leads positioned in the posterolateral vertical vein of the CS. Long operative and fluoroscopy times have likewise made percutaneous CS LV lead placement a challenging and meticulous procedure.

Direct access to the LV surface has been described previously as a rescue procedure in patients with failed CS leads. These procedures have included both limited thoracotomy and thoracoscopic techniques. All of these procedures, however, have targeted the anterior and lateral LV wall for LV lead placement and have included limited access to the entire LV surface. The presently described technique of posterolateral thoracotomy position has several advantages. Access to the most posterior and basal portion of the LV is possible as far back as the distal circumflex. Likewise, more lateral and anterolateral regions of the LV can be easily targeted should preoperative studies or intraoperative mapping suggest a more beneficial lead site. The posterobasal surface of the LV is also an area of the LV with a bare myocardial surface, devoid of epicardial fat, allowing for excellent lead thresholds. Furthermore, we believe that the posterior approach is critical for reoperative surgery, as the posterior pericardial well is frequently least involved in the adhesive process.

Application of robotic technology to this operation allows for high-resolution, three-dimensional vision of the ventricular surface. The fine scaling of motion makes opening the pericardium in these very large hearts quite simple. Suturing and accurate lead placement are also significantly enhanced with robotic technology. Despite insufflation, there is frequently little working space and the posterior approach ensures a reliable entry into the chest. Nonetheless, working area remains limited in certain cases and the small articulating robotic instruments can become invaluable. A similar posterior approach might be devised thoracoscopically; however, a camera fixation device is critical. Nonetheless, we believe that application of robotics makes this newly described procedure more accurate, expeditious, and facile when compared with other currently described surgical approaches to epicardial lead placement.

Although the patients in the series described herein all had failed previous percutaneous attempts at epicardial LV lead placement, the presently described procedure can be applied as an initial, primary procedure. Potential advantages might exist when compared with percutaneous approaches. Access to the entire heart gives the surgeon the ability to place the LV lead in the most hemodynamically and electrophysiologically advantageous position based on both preoperative and intraoperative studies. The reproducibility of the procedure allows it to be done with a near 100% immediate success rate in a very expeditious manner. The early functional and hemodynamic improvements demonstrated in this study compare favorably with those re-

Table 2. Comparison of Electrophysiologic and Hemodynamic Variables at Baseline and 3 to 6 Months Follow-Up

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>3–6 Months Postoperative</th>
<th>p Value</th>
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<tr>
<td>LVEF (%)</td>
<td>12 ± 6</td>
<td>19 ± 13</td>
<td>0.04</td>
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<tr>
<td>LVEDD (cm)</td>
<td>7.1 ± 1.3</td>
<td>7.2 ± 1.0</td>
<td>NS</td>
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<tr>
<td>LVESD (cm)</td>
<td>6.4 ± 1.7</td>
<td>6.3 ± 1.4</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA class</td>
<td>3.4 ± 0.5</td>
<td>1.9 ± 1.0</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>QRS duration (ms)</td>
<td>184 ± 31</td>
<td>152 ± 21</td>
<td>0.006</td>
</tr>
<tr>
<td>Impedance (volts at 0.5 ms)</td>
<td>1,143 ± 261</td>
<td>310 ± 59</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Threshold (ohms at 5.0 V)</td>
<td>1.0 ± 0.5</td>
<td>2.1 ± 1.4</td>
<td>NS</td>
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LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic diameter; NYHA = New York Heart Association.

Figure 4. Bar graph demonstrating the operative time associated with robotic left ventricular epicardial lead placement. A statistically significant difference in operative time is demonstrated when early and later experiences are compared.
ported for percutaneous LV lead placement. A larger randomized study will be necessary to determine if robotic LV epicardial lead implantation results in improved functional outcome when compared with CS LV lead placement.

Robotic LV lead placement does have the disadvantage of requiring general anesthesia and selective single-lung ventilation. Surprisingly, we have found no significant hemodynamic consequences to single-lung ventilation or chest cavity insufflation in these frail patients with severe cardiomegaly. We hypothesize that the high intraventricular and intra-atrial pressures of these hearts may be less susceptible to extracavitary insufflation than cardiac chambers that are more compressible. Likewise, the posterior positioning may serve to allow displacement into the right chest, further ameliorating the effects of insufflation. Ongoing studies at our institution hope to delineate the consequences of chest insufflation and single-lung ventilation in this patient population.

Despite requiring general anesthesia, intraoperative hemodynamic control of these patients is improved with the use of transesophageal echocardiography and management by experienced cardiac anesthesiologists. The single episode of pneumonia in our series may have been related to single-lung ventilation and general anesthesia. However, this patient had been hospitalized in heart failure and had been treated for pneumonia preoperatively.

In summary, robotically assisted LV epicardial lead implantation is a safe, reliable, fast, and effective technique for ventricular resynchronization. Presently, it is an important technique to allow for minimally invasive rescue in the setting of failed CS cannulation. Given the success of isolated LV pacing, this procedure could conceivably exist as a simple, stand-alone technique with the addition of an atrial lead. This would avoid the potential deleterious effects of right ventricular pacing while maintaining the beneficial effects of LV pacing. Prospective randomized studies will be necessary to determine the role of robotic LV epicardial lead implantation in primary ventricular resynchronization therapy.

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REFERENCES