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Surgically Placed Left Ventricular Leads Provide Similar Outcomes to Percutaneous Leads in Patients with Failed Coronary Sinus Lead Placement

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Abstract

Background—Cardiac resynchronization therapy (CRT) using a left ventricular (LV) lead inserted via the coronary sinus (CS) improves symptoms of congestive heart failure (CHF), decreases hospitalizations, and improves survival. An epicardial LV lead is often placed surgically after failed percutaneous attempt, but it is unknown if they offer the same benefits.

Objective—To determine if patients who receive a surgical LV lead after failed CS lead placement for CRT derive the same benefit as patients with a successfully placed CS lead.

Methods—A total of 452 patients underwent attempted CS lead insertion. Forty-five patients who had failed CS lead placement and then had a surgical LV lead placed were matched with 135 patients who had successful CS lead placement.

Results—There were no major differences in preoperative variables between groups. Post-procedure complications of acute kidney injury (26.2% vs. 4.9%, $P < 0.001$) and infection (11.9% vs. 2.4%, $P = 0.03$) were more common in the surgical group. Mean long-term follow-up was 32.4 ± 17.5 months for surgical patients and 39.4 ± 14.8 months for percutaneous patients. At follow-up, all-cause mortality (30.6% vs. 23.8%, $P = 0.22$) and readmission for CHF (26.2% vs. 31.5%, $P = 0.53$) were similar between surgical and percutaneous groups. Improvement in NYHA class (60.1% vs. 49.6%, $P = 0.17$) was similar between surgical and percutaneous groups.

Conclusions—Surgical LV lead placement offers functional benefits similar to percutaneous placement. This comes with the greater risk of perioperative complications including acute renal failure and infection.

Keywords

Heart Failure; Pacing; Complications; Surgery; Cardiac Resynchronization

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INTRODUCTION

Cardiac resynchronization therapy (CRT) improves symptoms of congestive heart failure (CHF), increases exercise tolerance, and decreases hospital readmission. Furthermore, CRT improves ejection fraction and survival.^{1, 2} Most of these data have been derived in large trials using a transvenous approach placing the left ventricular (LV) lead via the coronary sinus (CS). While this approach is least invasive, it can be challenging due to limitations in the coronary sinus anatomy, epicardial scar, and unintended stimulation of the left phrenic nerve.³ Due to these restrictions, success rates of the percutaneous approach are 75–93%.¹

In cases when percutaneous LV lead insertion is unsuccessful, an alternative surgical placement of an epicardial LV lead can be performed via mini-thoracotomy, video-assisted thoracoscopy (VATS), or with robotic assistance.⁴ Surgical LV lead placement is not without risk, as this requires a general anesthetic and often single lung ventilation, adding strain to these already severely compromised patients.

Although one small trial demonstrated that surgical placement of epicardial LV leads improves symptoms as well as CS lead placement at 6 months, it is not known if epicardial LV lead placement after failed transvenous percutaneous approach improves survival or symptoms in the long-term.²⁵ Therefore, the objective of this study was to compare the long-term outcomes of patients undergoing surgical LV lead placement following failed percutaneous lead insertion compared to similar patients who had successful percutaneous LV lead insertion. We hypothesized that patients in whom surgical LV lead placement is performed derive the same benefit from CRT as patients with percutaneously placed leads.

METHODS

Study population

Approval for this investigation was obtained by the Human Investigation Committee of the University of Virginia Health System (IRB # 13619), including a waiver for the need to obtain patient consent. A total of 452 patients underwent attempted insertion of biventricular pacing for CRT from January 2000 to December 2007 at the University of Virginia. All patients met accepted CRT guidelines,⁵ including depressed EF (<35%), advanced heart failure (NYHA functional class III or IV), and wide QRS complex (>120 ms). Percutaneous LV lead insertion was successful in 401 (88.7%) patients. In 51 patients, a CS lead could not be placed due to phrenic capture in 5 patients, inability to capture LV at less than 3V in 21 patients, and inability to find a posterior-lateral branch in 25 patients. A total of 45 of these patients underwent surgical epicardial LV lead insertion via thoracotomy (n=28) or VATS (n=17). Six of the 51 patients did not have surgical lead placement due to patient refusal for surgical intervention or were deemed too high risk to undergo general anesthesia. Patients undergoing concomitant cardiac procedures, undergoing lead insertion for indications other than for symptoms of CHF, and patients with congenital heart disease were excluded.

Propensity matching was utilized to select 135 of the 401 patients who underwent successful percutaneous CRT insertion. Patients were matched 3:1 (percutaneous: surgical) for the variables: age, ejection fraction (EF), and QRS interval using greedy methodology. These specific variables were chosen as they have been associated with long-term mortality in patients with heart failure.⁵

Patients undergoing attempted lead insertion for biventricular pacing were prospectively entered into a clinical database. A retrospective review of these patients was performed. Patient demographics, preoperative risk factors and perioperative complications were

compared. NYHA class was assessed by a dedicated CHF team led by a single CHF specialist and included assessment through a combination of clinical visits and telephone follow-up. Cardiomegaly was defined as an enlarged heart by radiographic report and impression as read by a certified radiologist. Acute kidney injury was defined by an increase over baseline creatinine of $>1.0\text{mg/dl}$. In patients undergoing surgical LV lead insertion, the most recent creatinine prior to surgical lead insertion was used as the baseline. Patients with biventricular pacemakers are followed at 3-month intervals in a joint device and heart failure clinic where they were maintained on appropriate therapy for their heart failure. Long-term follow-up data included survival, NYHA functional class, and readmission for CHF. In addition, follow-up data on echocardiography and pharmacotherapy were obtained on all patients.

Percutaneous Lead Insertion—Standard techniques for percutaneous lead insertion were utilized. Briefly, after a subcutaneous pocket was made in the left or right prepectoral space, the subclavian, axillary or cephalic vein was cannulated per operator preference. A guiding sheath and guidewire was placed into the coronary sinus using fluoroscopy, and a coronary sinus venogram was obtained using a balloon wedge catheter. An LV lead was placed into a posterior-lateral branch. If the lead appeared stable, it was left in place if the LV sensing was greater than 3mV , threshold less than 2V and there was no phrenic capture at 10V . If any of these parameters were not acceptable, the lead was repositioned in either a posterior or lateral branch. If the lead could not be placed in a posterior or lateral branch, CS lead insertion was abandoned. Once an acceptable position was found, the guiding sheath was removed and the lead retested. Right ventricle (RV) and right atrium (RA) leads were placed using standard techniques. The defibrillator was then attached and tested unless there was a contraindication to testing. A combination of Medtronic, St. Jude and Guidant leads and devices were used. Echocardiographic guidance was not routinely used for CS lead placement. Patients received standard antibiotic prophylaxis with cefazolin (Ancef) 1 gm followed by 1 gm every eight hours for three doses unless they had an allergy in which case they were typically given two doses of Vancomycin.

Surgical Lead Insertion—Surgical LV lead placements following failed percutaneous attempts were performed as elective procedures. None of the cases were performed emergently. Patients received either cefazolin or vancomycin prior to incision.

Mini-thoracotomy: Under general anesthesia, single lumen intubation was performed. Patients were placed in a supine position, rotated 30° to the right. A 4–6 cm anterolateral thoracotomy was made. The pericardium was entered anterior to the phrenic nerve. A bare area of the heart was identified in the posterolateral region of the heart between the diagonal and obtuse marginal arteries. Intraoperative imaging was not routinely used. An epicardial Medtronic unipolar screw-in lead #5071 or bipolar lead #4968 was then secured to the epicardium either with the self screw-in mechanism or with sutures, respectively. Leads were tested to ensure satisfactory function (pacing threshold $<2.0\text{V}$ measured at 0.5ms , sensing $>5\text{ mV}$, impedance $<1500\Omega$). Routine testing for diaphragm stimulation was performed at 10V . If necessary, additional LV leads were inserted until criteria were met for a functional lead. The lead was secured to the generator. The same subcutaneous pocket and generator initially created and placed during failed percutaneous attempts were used in all surgical patients. A small flexible drain was inserted into the pleural space. Patients were generally extubated in the operating room and observed in the cardiac surgery recovery unit.

VATS: After general anesthetic, a double lumen endotracheal tube was inserted. With the patient in a right lateral decubitus position using single lung ventilation, three 5–10 mm ports were inserted in the left hemithorax. The pericardium was opened anterior to the

phrenic nerve. A bare area of the heart in the posterolateral region was visualized between the diagonal and obtuse marginal arteries, free from visible scar. A Medtronic unipolar screw-in lead #5071 was inserted through a port and secured in place. The remainder of the procedure was similar to the mini-thoracotomy approach. In surgical patients, intraoperative imaging optimization was not used routinely to place the lead.

Statistical Analysis

Demographic and clinical information as well as outcomes were compared between the two matched groups using Chi-squared analysis or Fisher's exact test, where appropriate for categorical variables, and continuous outcomes were compared using analysis of variance (ANOVA) or the Wilcoxon rank sum nonparametric test for skewed distributions. Categorical variable comparisons are expressed as a percentage of the group of origin. Continuous variables are reported as either means $\pm$ standard deviation (SD) or median [interquartile range]. Long-term survival was compared between the two groups using Kaplan-Meier analysis and the log-rank test.

RESULTS

Demographics

The baseline demographics for surgical and percutaneous patients are listed in Table 1. Mean duration between failed percutaneous attempt and surgical LV lead placement was 25.6 ± 42.6 days. Preoperative variables including age, EF, NYHA class, and QRS duration were similar. The etiology of heart failure (ischemic versus nonischemic) was also similar. The proportion of patients with prior cardiac operation including CABG was no different. Peripheral vascular disease was more common in the percutaneous group (29.3% vs. 9.5% $P=0.01$) while cardiomegaly was more common in surgical patients (56.1% vs. 73.0% $P=0.04$). There was no difference in the proportion of patients on ASA, β -blockers, or spironolactone.

Perioperative complications

Perioperative outcomes are noted in Table 2. All attempts to place an epicardial lead were successful. Occurrence of stroke and myocardial infarction were similar between surgical lead and percutaneous lead placement. Total hospital length of stay, including therapy for CHF, was also similar. However, surgical patients were more likely to develop acute renal injury and infections.

Eleven surgical patients (26.2%) developed acute kidney injury (defined by increase in baseline creatinine of 1.0mg/dL) compared to only six patients (4.9%) in the percutaneous group ($P=0.004$). In nine patients, this renal dysfunction was acute and reversible. Only two surgical patients had a permanent change in their creatinine, one of whom required long-term dialysis (2.2%). In the percutaneous group, three patients (2.2%) had a permanent increase in their creatinine, all of whom required long-term dialysis. An average of 11.0 ± 4.0 ml of dye was used per patient in the percutaneous group compared to 17.0 ± 7.0 ml of dye used in the surgical group during the antecedent percutaneous procedure ($P<0.001$).

Postoperative infection was more common in surgical patients (11.9% vs. 2.4%, $P=0.03$) mostly because of urinary tract infections (UTI). Infections among surgical patients included urinary tract infections ($n=3$), sepsis ($n=1$), lead infection ($n=1$) and pneumonia ($n=1$) while the percutaneous group included sepsis ($n=2$) and one pacer pocket infection.

The 30-day mortality was similar between percutaneous and surgical patients (2.5% vs. 4.8%, $P=0.46$). Two deaths occurred within 30 days in surgical patients. One patient

suffered from intraoperative hypotension requiring vasopressors with subsequent development of multisystem organ failure (MSOF). The other death occurred three weeks after discharge from presumed arrhythmia (without shock from the patient's implantable cardioverter defibrillator) following uncomplicated lead insertion. Three patients died in the percutaneous group, two of refractory CHF and one of a combination of CHF and prostate cancer. At 30 days, EF improvement by at least 5 percent by echocardiography was more common in the surgical group than in the percutaneous group (96.4% vs. 77.0%, $P=0.02$).

Long Term Follow-up

Mean follow-up was 32.4 ± 17.5 months for surgical patients and 39.4 ± 14.8 months for percutaneous patients. Patients were maintained on standard medical regimen for heart failure including beta-blockade (73.0% surgical patients vs. 79.0% percutaneous patients, $P=0.41$) and diuretics (93.0% surgical patients vs. 88.0% percutaneous patients, $P=0.57$).

Readmission for CHF was similar for surgical and percutaneous LV leads (26.2% vs. 31.5%, $P=0.53$). Although short-term improvement in EF was more common in the surgical group, long-term EF change ($\Delta\%$) by echocardiography was similar within surgical ($\Delta=1.25\%$ [-2.5% , 6.25%], $P=0.30$) and percutaneous ($\Delta=0.0\%$ [-3.5% , 27.5%], $P=0.15$) groups as well as between treatment groups (Δ surgical = 1.3% [-2.5 – 6.3] vs. Δ percutaneous = 0.0% [-3.5 – 7.5], $P=0.97$). Long-term mortality for surgical patients was 30.6% compared to 25.3% for percutaneous patients ($P=0.22$). Moreover, by Kaplan-Meier analysis, long-term survival was similar between groups ($P=0.07$, Figure 1).

Significant improvement (Δ) in NYHA functional class occurred within both surgical ($\Delta = 1.0$ [0.0 , 2.0], $P<0.001$) and percutaneous ($\Delta = 1.0$ [0.0 , 2.0], $P<0.001$) groups (Figures 2a and 2b). Improvement in NYHA functional class by at least 1 functional class occurred in 60.1% (28/45) of surgical patients and in 49.6% (67/135, $P=0.17$) of percutaneous patients (Table 4). During the follow-up period, one LV lead in the surgical group and four coronary sinus leads in the percutaneous group were not functioning due to pacing thresholds greater than 7V (2.2% vs. 2.8%, $P=0.45$). The mean percentage of time patients had biventricular pacing was no different (95.0 vs. 93.0%, $P=0.48$).

Comparison of Minithoracotomy to VATS

Surgical patients who underwent minithoracotomy to VATS were compared. Baseline demographics and risk factors were similar with the exception of prior cardiac operation. Only 1 patient with prior cardiac operation underwent VATS approach, while 50% of patients who underwent thoracotomy had prior cardiac operation. Three patients who underwent thoracotomy initially had attempted VATS procedure. Reasons for conversion included severe cardiomegaly in one patient, significant intrapleural adhesions in one patient, and refractory ventricular tachycardia requiring open chest cardioversion in one patient. No significant differences in perioperative outcomes were observed between thoracotomy and VATS approaches, including hospital length of stay (6.0 ± 8.4 vs. 3.2 ± 2.4 , $P=0.19$) and 30-day mortality (2.0% vs. 0.0%, $P=0.52$, Table 3). Procedure time was also similar for thoracotomy vs. VATS (149.0 ± 108.0 vs. 128.0 ± 76.0 , $P=0.49$).

DISCUSSION

Cardiac resynchronization therapy (CRT) has been well-documented to improve left ventricular ejection fraction, heart failure symptoms, and survival.^{1, 6–9} Although percutaneous lead placement with a CS lead is first-line approach, it has been limited by failed lead implantation rates of 7–25%,^{1, 10, 11} Under these circumstances, patients are often referred for surgical LV leads, but there is a paucity of long-term data for this

approach. In the present study, we observed an 11.3% failure rate for percutaneous attempts at LV lead placement. Our failure rate may be greater than some centers as we only accepted a posterior or lateral vein for CS lead placement. We documented similar 30-day and long-term mortality rates as well as hospital readmission rates for CHF between matched patients with surgical and percutaneous LV leads. Although patients with surgically placed leads incurred higher perioperative complications compared to those with percutaneously placed leads, they had statistically similar NYHA functional class improvement at 38-month follow-up.

Despite being less invasive, there are several limitations to percutaneous LV lead placement, including lengthy procedure times and prolonged exposure to radiation. Recently, the risk of radiation to the patient with these procedures has been reported to be considerable.¹² The MIRACLE-ICD trial reported mean percutaneous lead placement times of 2.63 ± 1.13 hours, and lead dislodgement rates of 7.3%.¹³ Similar failure rates have been observed in the MIRACLE trial (8.0%) and MUSTIC study (12.0%).^{7, 10} Complications including coronary sinus dissection and/or cardiac vein perforation (6.0%), complete heart block (0.4%), and cardiac arrest (1.2%) have been reported during percutaneous lead placement.¹

In contrast, surgical LV lead insertion requires general anesthesia and has greater perioperative risks.^{14–17} Higher rates of postoperative infection (6.3%), pleural effusion (4.2%), in-hospital mortality (4.2%) as well as increased hospital length of stay have been reported during surgical lead placement.¹⁸ In the present study, we demonstrated significantly higher rates of reversible kidney injury and infection rates in patients undergoing surgical lead insertion. It is our routine to check preoperative serum creatinine levels for all patients. Daily postoperative creatinine surveillance is followed throughout every patient's postoperative stay. However, since creatinine may peak 2–4 days after contrast administration, it is possible that percutaneous patients may have had a higher renal injury rate than documented since most were discharged by post-procedure day 2. Moreover, patients with failed percutaneous attempts and subsequent surgical lead placement had higher contrast loads than those treated successfully with percutaneous lead placement alone, which may have resulted in higher rates of kidney injury. In addition, for those patients undergoing surgical lead placement during the same hospital admission, there may have been an element of dehydration that contributed to higher renal injury rates in surgical patients. General anesthesia and single lung ventilation (which can contribute to underlying right heart dysfunction) could have also increased the risk of renal injury.

Higher perioperative infection rates in surgical patients may be a result of these patients undergoing two procedures despite similar periprocedural antibiotic regimens; however, the majority of infections within the surgical group were urinary tract infections and unlikely related to the surgical procedure itself and perhaps due to longer hospital stays.

Proper lead placement and optimal LV stimulation is paramount to the success and functional benefits of CRT. Due to anatomic limitations, percutaneous CS leads are sometimes placed in non-ideal locations like the anterior wall or septum. However, suboptimal responses to CRT following the inappropriate placement of percutaneous leads may occur.^{1, 7, 19, 20} Surgical lead insertion, however, is not limited by the constraints of the coronary venous anatomy and can be placed posterolaterally on the LV. Although routine lead placement on the lateral margin of the LV was performed in this study, various techniques have been utilized to optimize placement of surgical LV leads including guidance by TEE.^{17, 18, 20–23} One recently reported technique, using intraoperative pressure-volume loops obtained from surgical conductance catheters, demonstrated improvements in stroke volume by nearly 40.0% and EF by 30.0%.²⁴ It is possible that TEE optimization of our surgical lead placements could have further improved outcomes.

The few studies that directly compare outcomes in surgical versus percutaneous lead placement are limited by their retrospective nature, short follow-up, or lack of propensity matching. In a retrospective unmatched study, Puglisi and colleagues demonstrated similar electrical parameters and significantly improved functional status in their comparison of 33 patients undergoing epicardial LV lead placement via thoracotomy versus 282 patients undergoing transvenous lead placement at 12 months follow-up.²³ In another study, 16 patients who underwent surgical lead placement were documented to have less dislodgement rates as well as higher rates of proper lead positioning compared to percutaneously placed leads at 18 months.¹⁷ These findings have been corroborated by studies that have demonstrated improvements in echocardiographic parameters, QRS duration and NYHA status in both surgical and percutaneous patient groups.¹⁸ Furthermore, in a recent randomized trial in Europe, Mohr and colleagues found similar functional results with both percutaneous and surgical lead placement but reported increased morbidity associated with a surgical approach at 6 months follow-up.²⁵ Nevertheless, similar mortality rates have been suggested with both approaches.^{17, 18, 23} This study adds to previous data by adding almost 3 years of follow up of NYHA status and mortality data on matched patients.

The benefits of surgical leads do not appear to be dependent on the technique of insertion.^{17, 18, 20–24} Surgical lead insertion via thoracotomy or VATS has demonstrated shorter procedure times and superior lead implantation rates compared to percutaneous lead placement.^{17, 18} In a comparison of 41 patients undergoing LV lead placement by either VATS or minithoracotomy, Navia and colleagues demonstrated the safety and effectiveness of both approaches.²⁰ They reported significantly shorter operative times with minithoracotomy compared to VATS (165 ± 74 min vs. 232 ± 100 min, $P=0.006$). In our experience, however, the operative times are similar despite the approach. Currently, our preferred approach in patients without prior sternotomy, and in particular without prior CABG, is to perform LV lead insertion via a VATS approach while minithoracotomy is reserved for patients with prior CABG or with severe cardiomegaly in whom port access in the left chest is not feasible.

Improvement in NYHA functional class occurred in both percutaneous and surgical LV lead placement groups. NYHA improvement by at least 1 class occurred in 60.1% of surgical patients and 49.6% of percutaneous patients. This trend (although not statistically significant) toward higher surgical improvement rates may have resulted from more consistent lead placement in an ideal posterolateral position. Further, the similar improvements observed in both surgical and percutaneous cohorts are consistent with results of other studies;^{18, 25} Importantly, one patient in both the surgical and percutaneous groups had a surprising 3 NYHA class improvement. Although we cannot entirely explain the dramatic improvement achieved in these two patients, these results highlight the potential benefits a small group of patients can achieve from optimized EP and medical management of CHF.

Our patient population may include unique characteristics that may explain some of our results. For example, relatively prolonged QRS durations were noted in both percutaneous and surgical patient groups. As our study cohort included patients who failed percutaneous implantation and their matched controls, our study may include a patient population who is sicker than the typical population who undergoes LV lead placement for CRT.

There are several limitations to note in the present study. First, the study is retrospective with a heterogeneous patient population. We attempted to account for these differences using propensity matching of the critical risk factors (EF, QRS width, and age) known to be associated with mortality. Additionally, although our mean follow-up (38 months) is longer than what is reported in the literature, longer follow-up could show further differences

between percutaneous and surgical leads. The potential for Type II error also exists among group comparisons due to limited sample size. As a result, our ability to detect small differences between the groups was limited. Larger sample sizes may have provided increased statistical power for data analyses. The surgical techniques were not uniform in our study and included both thoracotomy and VATS. This is a reflection of our preferred approach to perform VATS if patients have not had previous cardiac surgery. However, we suspect as VATS becomes more standard, this will become a routine approach at most centers. There is also no control group of patients who failed attempted percutaneous lead insertion and did not receive a surgical lead due to the substantial literature supporting CRT. Furthermore, we do not have a group of patients who received surgical leads as first line therapy since at most institutions percutaneous CRT is standard and is least invasive. Finally, six patients did not receive a surgical LV lead after failed percutaneous lead insertion. These patients were felt to be unable to tolerate surgical therapy or refused surgery. This could introduce bias by making the surgical group less sick, but propensity matching should have corrected for this. Additionally, other factors, including response to anesthesia or left ventricular pacing thresholds were not accounted for and may contribute some unmeasured effects.

CONCLUSION

We demonstrate that in patients with indications for biventricular pacing and failed percutaneous leads, surgical lead placement will likely provide benefit to the patient. Surgical LV lead insertion can be performed with acceptable morbidity and mortality. Importantly, surgical lead placement following failed percutaneous attempt is justified in that surgical leads confer similar functional benefits, short and long-term survival, and readmission rates for CHF compared to primary percutaneous LV lead placement.

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Abbreviations

CHF	Congestive Heart Failure
CRT	Cardiac Resynchronization Therapy
CS	Coronary Sinus
EF	Ejection Fraction
LV	Left Ventricular
NYHA	New York Heart Association
VATS	Video-Assisted Thoracoscopy

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Figure 1.
Long term survival following percutaneous and surgical LV lead placement by Kaplan-Meier analysis

Figure 2. Change in NYHA functional class following surgical (2a) and percutaneous (2b) LV lead placement.

Table 1

Preoperative variables for patients undergoing percutaneous LV versus surgical LV lead placement.

Preoperative Variables	Percutaneous Lead Placement (n= 135)	Surgical Lead Placement (n=45)	P-value
Age	66.2±13.6	64.9±10.1	0.54
Stroke	7 (5.7%)	3 (7.1%)	0.72
NYHA Class			
Class I	0 (0.0%)	0 (0.0%)	>0.99
Class II	3 (2.4%)	1 (2.4%)	
Class III	109 (88.6%)	38 (90.5%)	
Class IV	11 (8.9%)	3 (7.1%)	
Baseline Creatinine	1.5±0.6	1.7±1.5	0.40
PVOD	36 (29.3%)	4 (9.5%)	0.01
COPD	19 (15.5%)	10 (23.8%)	0.22
CAD	85 (69.1%)	29 (69.1%)	0.99
Ventricular Tachycardia	26 (21.1%)	11 (26.2%)	0.50
Atrial Fibrillation	46 (37.4%)	12 (28.6%)	0.30
Prior MI	45 (36.6%)	19 (45.2%)	0.32
Previous Cardiac Operation	51 (41.5%)	14 (33.3%)	0.35
Previous CABG	45 (36.6%)	12 (28.6%)	0.35
Cardiomegaly	69 (56.1%)	31 (73.8%)	0.04
Ischemic Cardiomyopathy	77 (62.6%)	23 (54.8%)	0.37
EF (%)	23.2±6.7	22.8±7.6	0.72
QRS Duration (sec)	0.2±0.02	0.2±0.03	0.79

Key: PVOD: peripheral vascular occlusive disease, COPD: chronic obstructive pulmonary disease, CAD: coronary artery disease, MI: myocardial infarction, CABG: coronary artery bypass grafting, EF: ejection fraction.

Table 2

Perioperative outcomes for patients undergoing percutaneous LV versus surgical LV lead placement.

Outcome	Percutaneous Lead Placement (n= 135)	Surgical Lead Placement (n=45)	P-value
Ventricular Tachycardia	2 (1.6%)	0 (0.0%)	0.56
Cardioversion	1 (0.8%)	2 (4.8%)	0.16
Additional OR Procedure	11 (8.9%)	1 (2.4%)	0.30
PRBC Transfusion	2 (1.6%)	1 (2.4%)	>0.99
Stroke	0 (0.0%)	0 (0.0%)	N/A
MI	1 (0.8%)	0 (0.0%)	>0.99
Acute Kidney Injury	6 (4.9%)	11 (26.2%)	0.0004
Infection	3 (2.4%)	5 (11.9%)	0.03
Hospital LOS (Days)	4.3±19.0	5.0±7.1	0.71
Chest Tube Duration (Days)	N/A	1.9±0.1	N/A
Mortality (30 Day)	3 (2.5%)	2 (4.8%)	0.46

Table 3

Preoperative variables for patients undergoing open thoracotomy versus VATS LV lead placement.

Outcome	Thoracotomy (n=28)	VATS (n= 17)	P-value
PREOPERATIVE VARIABLES			
Age	65.3±9.18	65.0±11.2	0.93
NYHA Class			
Class I	0 (0.0%)	0 (0.0%)	N/A
Class II	1 (3.6%)	0 (0.0%)	>0.99
Class III	27 (96.4%)	14 (82.4%)	0.14
Class IV	0 (0.0%)	3 (17.6%)	0.05
Baseline Creatinine	1.7±1.7	1.7±1.0	>0.99
PVOD	3 (10.7%)	4 (23.5%)	0.40
COPD	11 (39.3%)	2 (11.8%)	0.90
CAD	20 (71.4%)	12 (70.6%)	0.78
Preoperative MI	11 (39.3%)	10 (58.8%)	0.34
Previous Cardiac Operation	14 (50.0%)	1 (5.9%)	0.003
Previous CABG	12 (42.9%)	1 (5.9%)	0.02
Cardiomegaly	19 (67.9%)	13 (76.5%)	0.74
Ischemic Cardiomyopathy	18 (64.3%)	8 (47.1%)	0.41
EF (%)	23.5±7.9	21.6±6.5	0.41
QRS Duration (sec)	0.2±0.02	0.2±0.02	>0.99
Operation Time (min)	149±108	128±76	0.49
PERIOPERATIVE OUTCOMES			
Ventricular Tachycardia	0 (0.0%)	0 (0.0%)	N/A
PRBC Transfusion	1 (3.6%)	0 (0.0%)	>0.99
Postoperative MI	0 (0.0%)	0 (0.0%)	N/A
Acute Kidney Injury	9 (32.1%)	2 (11.8%)	0.16
Infection	5 (17.9%)	0 (0.0%)	0.14
Hospital LOS (Days)	6.0 ± 8.4	3.2 ± 2.4	0.19
Chest Tube Duration (Days)	1.8 ± 1.0	1.8 ± 0.9	>0.99
Mortality (30 Day)	2 (7.1%)	0 (0.0%)	0.52

Change in postoperative NYHA Class for patients undergoing percutaneous LV versus surgical LV lead placement.

Table 4

Procedure Group	3 Class Improvement	2 Class Improvement	1 Class Improvement	No Class Improvement	1 Class Worsening
Surgical Lead Placement	1 (2.2%)	13 (28.9%)	14 (31.1%)	17 (37.8%)	0 (0.0%)
Percutaneous Lead Placement	1 (0.7%)	30 (22.2%)	36 (26.7%)	65 (48.2%)	3 (2.2%)