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Electrocardiographic characteristics, antiarrhythmic utilization, and outcomes in patients with left ventricular assist devices

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Abstract

Background

Left ventricular assist devices (LVAD) are an increasingly used therapy for patients with advanced heart failure. Arrhythmias are common complications following LVAD implantation requiring admission, initiation, and escalation of medical therapy. Despite their frequent use in the treatment of arrhythmias, little has been reported regarding electrocardiographic changes, antiarrhythmic utilization, and outcomes post-LVAD.

Methods

A total of 309 patients who received a LVAD underwent retrospective chart review pre- and post-LVAD. Kaplan-Meier curves were calculated and compared using the log-rank test. Cox regression model was used for univariate analysis and those with a $p<0.15$ were included in multivariate analysis to evaluate for overall survival.

Results

There was a significant reduction in both the QRS interval ($p=0.0001$) and QTc interval ($p=0.0074$) following LVAD implantation. Ventricular tachycardia is common following LVAD implant at 31.1%. Amiodarone use was frequent prior to LVAD (52.1%) and on discharge (68.6%). Amiodarone use ($p=0.019$, HR 1.7, 95% CI 1.1-2.6), age at implant ($p<0.001$), creatinine ($p=0.004$), albumin ($p=0.02$), red-cell distribution width ($p=0.047$), and prior median sternotomy ($p<0.0001$), were associated with increased mortality. On multivariate analysis, only albumin ($p=0.013$) and prior median sternotomy ($p<0.001$) remained statistically significant. There was no significant difference in post-operative duration of intubation, number of readmissions, or length of stay base on amiodarone utilization.

Conclusions

Amiodarone is a commonly used antiarrhythmic in advanced heart failure and its use prior to LVAD implantation may increase the risk of long-term mortality. The amiodarone efficacy needs to be weighed against its long-term side effects and implant on clinical outcomes.

Keywords: LVAD, antiarrhythmic, amiodarone, electrocardiography

Introduction

While treatments for heart failure have improved over the last two decades, the number of patients with advanced heart failure who are or become refractory to standard medical therapy continues to increase. Heart transplantation alone is not possible for a large proportion of this increasing population of patients, due to an overall plateau in the number of organs available for transplantation worldwide as well as patient-specific factors making them poor candidates for heart transplantation. With the continued development and improvement in left ventricular assist device (LVAD) design, along with decreased morbidity and mortality post-implantation, the incidence of new device implantations not only as bridge to transplantation (BTT), but also as destination therapy (DT) has significantly increased over the last 15 years.[1] Arrhythmias, especially ventricular arrhythmias, are a common post-LVAD complication, with an incidence ranging from 22-59% and are frequently better tolerated in LVAD patients due to their ability to maintain cardiac output when perturbations in heart rate and ventricular synchrony are present.[2, 3]

Appropriate treatment of arrhythmias after LVAD implantation havs not been completely defined and have only been reported in a couple of small, retrospective studies.[4, 5] While antiarrhythmic medications are frequently used to treat both atrial and ventricular arrhythmias in LVAD patients, the use of these agents and the outcomes associated with their used have not been adequately described. The purpose of this study was to determine common rhythms/arrhythmias and electrocardiographic (ECG) changes related to LVAD implantation as well as antiarrhythmic utilization to treat these arrhythmias and how these impact outcomes following implantation.

Methods

Study Population

We conducted a retrospective chart review of 309 patients who underwent LVAD implantation as BTT or DT at The University of Nebraska Medical Center between July 2004 and October 2017. This involved a full review of the patient's electronic health records (EHR), including physician progress notes, nursing notes, telemetry records, and implantable cardioverter defibrillator (ICD) interrogations, evaluating for documented evidence of atrial or ventricular arrhythmias as well as patient's medication administration records to document prescribing of antiarrhythmic

medications. Records were reviewed from the time of first preoperative evaluation by our cardiology or cardiothoracic surgery team and followed postoperatively until death, heart transplant, or completion of data collection on November 27th, 2017. The study was approved by the institutional review board at our institution.

Clinical Variables

We obtained demographic and clinical variables on patients undergoing LVAD implantation via review of the EHR. These variables included age, gender, left ventricular ejection fraction (LVEF), left ventricular internal diameter end diastole (LVIDd), ICD status, routine laboratory values (e.g. potassium, creatinine, albumin, etc.), antiarrhythmic therapy and other drug therapy pre- and post-LVAD implantation, and other pertinent medical history (e.g. presence of arrhythmias, pre-implantation comorbidities, etc.).

Ventricular tachycardia (VT) was defined as sustained or non-sustained VT (NSVT) with symptoms requiring antiarrhythmic therapy. Preoperative VT and atrial fibrillation (afib) were defined as documentation within clinical notes, telemetry records, or ECG of VT or afib prior to LVAD implantation. Postoperative VT or afib were defined as documented VT or afib within clinical notes, telemetry records, or ECG following LVAD implantation.

Pre- and post-LVAD ECG intervals (PR, QRS, QT, and QTc) and rhythms were obtained via review of each ECG documented in the patient's EHR. Both ventricular-paced and non-paced rhythms and intervals were documented for comparison between pre- and post-implantation periods.

Statistical Analysis

Descriptive statistics included counts and percentages for categorical data and means and standard deviations for continuous data. The independent sample t-test was used to compare continuous measures between groups. Overall survival (OAS) was defined as the time from implant to time of death from any cause. Patients who underwent heart transplantation were censored at the time of transplant and patients who underwent LVAD explantation or defunctionalization were censored at the time of this surgery. The OAS curve was calculated using the Kaplan-Meier method and compared using the log-rank test. Confidence interval for estimate of time-to-event distribution was calculated using Greenwood's formula. The Cox regression model for censored data was used to examine patient characteristics of OAS in a univariate analysis. Factors significant on univariate analysis ($p < 0.15$) were included in the multivariate analysis. For secondary outcomes, Fisher's exact test was used to compare intubation at 24 hours between groups and the Mann-Whitney test was used to compare the median LOS and hospital readmissions between groups. A p-value of <0.05 was considered statistically significant.

Results

Our study population included 309 patients, 240 (77.7%) were males and the mean age was 56.7 (12.9) years. Destination therapy was the implant strategy for

187 (60.5%) patients and 163 (52.7%) had ischemic cardiomyopathy. The mean left ventricular ejection fraction (LVEF) was 17.9% (8.9) and mean left ventricular internal dimension in diastole (LVIDd) was 64.7 mm (9.1). Patients on amiodarone prior to LVAD implantation tended to be older (59.2 vs 54 years, p<0.0001), more likely female (25.8% vs 18.7%, p=0.04), have a history of chronic obstructive pulmonary disease (27% vs 16.7%), have a higher creatinine (1.37 vs 1.25, p=0.01), lower albumin (3.27 vs 3.31, p=0.04), and have higher prevalence of ventricular tachycardia (62.9% vs 24.7%, p<0.0001) and atrial fibrillation (71.7% vs 38%, p<0.0001). Full pre-LVAD clinical characteristics are shown in Table 1.

Table 1. Pre-LVAD Implantation Patient Characteristics and Hemodynamics

Characteristic	Total population, N=309	Pre-LVAD Amiodarone, N=159	No Pre-LVAD Amiodarone, N= 150	p-value
Age, y (SD)	56.7 (12.9)	59.2 (11.7)	54.0 (13.7)	<0.0001
Female Sex, N (%)	69 (22.3)	41 (25.8)	28 (18.7)	0.04
BTT Implant Strategy, N (%)	187 (60.5)	92 (57.9)	96 (64)	0.29
Pre-LVAD BMI, kg/m2 (SD)	30.1 (6.6)	29.69 (5.4)	30.40 (7.9)	0.99
Ischemic Cardiomyopathy, N (%)	163 (52.8)	88 (55.3)	74 (49.3)	0.54
Baseline LVEF, % (SD)	17.9 (8.9)	19.5 (10.3)	17 (8.4)	0.034
Baseline LVIDd, mm (SD)	64.7 (9.1)	64.1 (9)	65.1 (9.4)	0.25
INTERMACS Profile at Implantation				
1	63 (20)	31	32	0.69
2	83 (27)	41	42	0.66
3	99 (32)	50	49	0.82
4	62 (20)	36	26	0.24
5-7	2 (1)	0	2	0.14
Comorbidities				
Hypertension, N (%)	186 (60.2)	102 (64.2)	83 (55.3)	0.20
Diabetes Mellitus, N (%)	123 (39.8)	66 (41.5)	58 (38.7)	0.73
Obstructive Sleep Apnea, N (%)	92 (29.8)	52 (32.7)	40 (26.7)	0.27
COPD, N (%)	68 (22)	43 (27)	25 (16.7)	0.039
Chronic Kidney Disease, N (%)	99 (32)	57 (35.8)	42 (28)	0.18
Prior Median Sternotomy, N (%)	100 (32)	53 (33.3)	47 (31.3)	0.72
Ventricular Tachycardia, N (%)	137 (44.3)	100 (62.9)	37 (24.7)	<0.0001
Atrial Fibrillation, N (%)	171 (55.3)	114 (71.7)	57 (38)	<0.0001
Lab Values				
Hemoglobin, g/dL (SD)	11.8 (2.0)	11.7 (2)	12 (2)	0.12
Creatinine, mg/dL (SD)	1.3 (0.4)	1.37 (0.45)	1.25 (0.41)	0.01
Albumin, g/dL (SD)	3.3 (0.6)	3.27 (0.55)	3.41 (0.55)	0.04
RDW, % (SD)	15.9 (2.5)	15.9 (2.4)	15.8 (2.7)	0.39
Pre-LVAD Hemodynamics				
Right Atrial Pressure, mmHg (SD)	12.5 (6.3)	12.8 (6.4)	12.3 (6.2)	0.56
Pulmonary Artery Saturation, % (SD)	53 (10.3)	53.2 (10.7)	52.7 (10)	0.65
Wedge Pressure, mmHg (SD)	24 (8.9)	23.7 (9.1)	24.4 (8.7)	0.32
Fick Cardiac Index, L/min/m2 (SD)	2 (0.5)	2.09 (0.6)	1.97 (0.5)	0.057

Y= year; DT =destination therapy; BMI = body mass index; SD = standard deviation; BSA = body surface area; LVEF = left ventricular ejection fraction; LVIDd= left ventricular internal dimension in diastole; RDW = red blood cell distribution width; TSH= thyroid stimulating hormone; ICD= implantable cardioverter defibrillator; CRT-D= cardiac resynchronization therapy-defibrillator

Of the 290 patients who survived to discharge, 143 (49.3%) patients had CRT-D in place, with no new patients receiving or being upgraded to CRT-D following LVAD implantation. A total of 135 (46.6%) patients had an ICD in place at the time of discharge compared to 83 (28.6%) patients at the time of index admission. Nine patients were discharged from the hospital without an ICD in place. ECGs were evaluated both pre- and post-LVAD implantation. A total of 76 patients had a non-ventricularly paced ECG within 1 month prior to LVAD implantation and a non-ventricularly paced ECG 3 or more months following LVAD implantation for comparison of intervals pre- and post-LVAD (Table 2).

Table 2. Comparison of Non-Ventricular Paced ECG Intervals Pre- and Post-LVAD Implantation

ECG Interval	Average Pre-LVAD Duration, ms (SD)	Average Post-LVAD Duration, ms (SD)	P value (95% CI)
PR	174.3	169.5	0.23 (-3.9-16.0)
QRS	115.2	102.9	0.0001 (6.6-17.4)
QT	393.9	406.4	0.14 (-29.2-4.2)
QTc (Bazett)	485.6	466.8	0.0074 (5.2-32.5)

Of the 309 patients in our study, 137 (44.3%) patients had documented NSVT or sustained VT prior to undergoing LVAD implantation. Thirty-nine (12.6%) patients were admitted to the hospital for their index admission because of VT or had VT during their admission, but prior to undergoing LVAD implantation. The most common pre- and post-LVAD rhythm was a ventricular-paced rhythm (Vpaced) with 118 (38.2%) patients having this as their primary rhythm prior to implantation and 111 (35.9%) having this as their primary rhythm post-implantation (Table 3).

Table 3. Most Common Heart Rhythms Pre- and Post-LVAD Implantation

Rhythm	Pre-LVAD, N (%)	Post-LVAD, N (%)
Ventricular Paced	118 (38.1)	111 (36.0)
Normal Sinus Rhythm	106 (34.3)	103 (33.3)
Sinus Tachycardia	48 (15.5)	33 (10.7)
Afib/Aflutter	17 (5.5)	21 (6.8)
Unknown Rhythm	8 (2.6)	37 (12.0)
Atrial Paced	7 (2.3)	4 (1.3)
Sinus Bradycardia	5 (1.6)	0 (0.0)

Atrial fibrillation or atrial flutter were present in 171 (55.3%) patients prior to LVAD implantation and 120 (38.8%) patients post-LVAD, but these were the primary rhythm in only 17 (5.5%) patients pre-LVAD and 21 (6.8%) patients post-LVAD. A total of 98 (31.7%) patients had a ventricular arrhythmia following LVAD implantation. Ninety-three (94.9%) had VT only, 2 (2%) patients had VF only, and 3 (3%) patients had both VT and VF following implantation. Of the 98 patients who had a ventricular arrhythmia post-LVAD, 48 (49%) patients had a history of ventricular arrhythmia pre-LVAD, while the other 50 (51%) patients had a

ventricular arrhythmia only after LVAD. While 12 (3.9%) patients underwent VT ablation prior to LVAD implantation, only 1 (0.3%) patient had a VT ablation in the post-implantation period. Frequent post-implantation VT and limited VT ablation led to frequent prescribing of antiarrhythmics post-LVAD, with 225 (72.8%) patients being prescribed at least one antiarrhythmic in the post-implantation period. Only 24 (7.8%) patients were on multiple antiarrhythmic concurrently following LVAD implantation. A total of 161 (52.1%) patients were on amiodarone within 2 years prior to LVAD implantation and 158 (51.4%) patients who survived to discharge were continued on amiodarone at the time of their dismissal. Drug utilization frequencies pre- and post-implantation are listed in Table 4.

Table 4. Drug Utilization Pre- and Post-LVAD Implantation

Medication	Utilization
On beta blocker at time of LVAD admission, N (%)	225 (72.8)
On amiodarone within 2 years prior to LVAD, N (%)	159 (51.4)
Discharged on beta blocker post-LVAD, N (%)	76 (27.7)
Discharged on digoxin post-LVAD, N (%)	110 (40.1)
Discharged on amiodarone post-LVAD, N (%)	158 (57.7)
On beta blocker 3 months post-LVAD, N (%)	89 (34.9)
Antiarrhythmic therapy post-LVAD, N (%)	225 (72.8)
Amiodarone use at any point post-LVAD, N (%)	212 (68.6)
Post-LVAD Mexiletine, N (%)	18 (5.8)
Post-LVAD Sotalol, N (%)	12 (3.9)
Post-LVAD Dofetilide, N (%)	5 (1.6)
Post-LVAD Quinidine, N (%)	2 (0.6)

On univariate analysis, amiodarone was associated with increased mortality, with a hazard ratio of 1.699 (P=0.0193, CI 1.090-2.648). The Kaplan-Meier survival curve is displayed in Figure 1. Other variables associated with increased mortality include age at implant (p=0.0006), creatinine (p=0.0042), albumin (p=0.022), RDW (p=0.0469), and prior median sternotomy (p<0.0001) (Table 5).

Table 5. Univariate Analysis of Pre-LVAD Variables and Their Impact On Survival

Variable	Hazard Ratio	P-Value	95% Confidence Interval
Pre-LVAD amiodarone	1.699	0.019	1.09-2.65
Age at Implant	1.04	0.0006	1.02-1.06
BMI at Implant	0.99	0.68	0.96-1.03
Pre-LVAD Creatinine	1.97	0.004	1.24-3.14
Pre-LVAD Albumin	0.63	0.022	0.43-0.94
Pre-LVAD RDW	1.08	0.047	1.001-1.17
Pre-LVAD COPD	1.13	0.63	0.69-1.84
Prior Pre-LVAD sternotomy	2.30	<0.0001	1.57-3.73

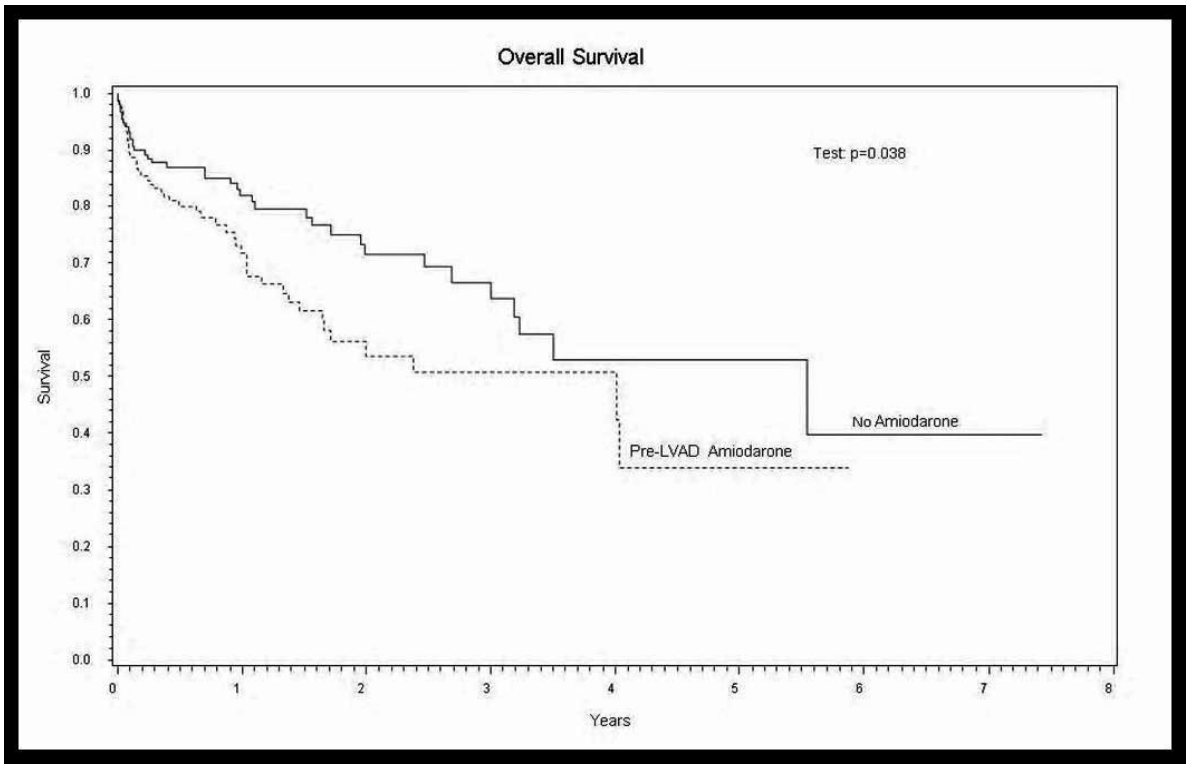

Figure 1. Kaplan-Meier survival curve showing worse post-implantation survival in patients who were on amiodarone prior to LVAD compared to those who were not on Amiodarone

On multivariate analysis, only albumin (p=0.03) and prior median sternotomy (p<0.001) remained independent predictors of survival (Table 6). The use of amiodarone prior to LVAD implantation did not have an impact on duration of intubation following LVAD placement (p=0.43), length of stay following LVAD implantation (p=0.10), or number of readmissions (p=0.57).

Table 6. Multivariate Analysis of Pre-LVAD Variables and Their Impact on Survival

Variable	Hazard Ratio	P-Value	95% Confidence Interval
Pre-LVAD amiodarone use	1.5	0.09	0.94-2.38
Age at Implant	1.0	0.16	0.99-1.04
Pre-LVAD Creatinine	1.5	0.11	0.91-2.57
Pre-LVAD Albumin	0.6	0.03	0.42-0.96
Pre-LVAD RDW	1.0	0.35	0.96-1.1
Prior Pre-LVAD sternotomy	2.3	<0.001	1.41-3.62

Discussion

This single center, retrospective study showed that patients with a history of amiodarone use within two years of LVAD implantation were at increased risk of post-operative mortality, as were older patients, those with prior median sternotomies, low albumin, and high creatinine and RDW. On multivariate analysis, only albumin and prior median sternotomy remained independent predictors of mortality. This study also showed that mechanical unloading of the heart leads to a significant reduction in the QRS and QTc intervals. We found that ventricular tachycardia is common in end-stage heart failure, both pre- and post-LVAD implantation and amiodarone is the most commonly used antiarrhythmic used to treat arrhythmias before and after LVAD implantation.

ECGs were evaluated both pre- and post-LVAD implantation for rhythm and interval durations. A total of 76 patients had non-ventricularly paced ECGs both pre- and post-LVAD implantation available for comparison. We found a statistically significant decrease in QRS duration (p=0.0001) as well as a significant decrease in the QTc interval (p=0.0074) from pre- to post-implantation. Harding and colleagues previously looked at changes in ECG intervals pre- and post-LVAD and found a significant decrease in the QRS immediately post-implant (within 6 hours), but this was not sustained more than a week post-LVAD.[6] It has been hypothesized that since changes in conduction velocity after cardiac distension have not been identified, possible decreases in cardiac dimensions post-LVAD lead to an overall decrease in conduction distance and thus a decrease in QRS duration. This same group has also noted a significant increase in QT and QTc intervals in the immediate post-implantation period followed by a significant decrease in these intervals more than 1-week post-implantation.[7, 8] While we did not evaluate ECGs in the immediate post-implantation period, we did identify a significant decrease in the QTc interval when evaluating a more delayed effect of mechanical unloading on ECG characteristics. Action potential prolongation has previously been shown to be a common abnormality in failing hearts and it has been hypothesized that mechanical unloading of failing hearts reverses this characteristic resulting in decreased action potential durations and thus, shorter QTc intervals. [9]

The primary rhythm identified on ECG and telemetry review in our study was V-paced, both in the pre-LVAD (38.1%) and post-LVAD (36%) time periods. Martinez and colleagues have previously shown a similar prevalence of V-paced rhythm in their pre-implantation population at 40%, but the percentage of patients primarily V-paced following implantation increased to 79% in their study. Normal sinus rhythm and sinus tachycardia were the next two most common rhythms both pre- and post-implantation. There was a low number of patients without ECGs obtained in the pre-LVAD period (2.8%) and significantly higher in the post-implantation period (12%). Martinez and colleagues have emphasized the importance of obtaining an ECG in every patient in the post-implantation period to establish a new baseline.[10] While most of the rhythm monitoring in the post-implantation period is done via ICD interrogation, ECGs are still clinically useful for monitoring

of the QT/QTc duration, especially in patients receiving antiarrhythmic therapy and potentially identifying patients at risk for ventricular arrhythmias.

Our study showed that 31.3% of patients had VT following LVAD implantation, which is in line with previous studies that have found that VT occurred anywhere from 22-59% following LVAD implantation.[11, 12] We also found that 44.3% of patients had at least one episode of VT prior to undergoing LVAD implantation with 12.6% of patients having an episode of VT leading to index admission or during the in-hospital evaluation prior to implantation. Afib was a problem for 55.3% of patients prior to LVAD, but only 38.8% of patients continued to have issues with afib following implantation. A previous study by Enriquez and colleagues showed a slightly higher incidence of afib post-LVAD at 51.9%.[13] They also found that persistent afib was an independent predictor of death and hospitalization for heart failure. While previous studies have shown that ventricular arrhythmias tend to occur within the first week to month following LVAD-implantation,[4, 14] timing of ventricular arrhythmias was not evaluated in our study.

We found that 49% of patients had CRT in place prior to undergoing LVAD implantation and this did not change following implantation. While only 26.9% of patients had a single-chamber ICD in place prior to LVAD implantation, 52 new devices were implanted in the post-implantation period. In our study, 75.7% of patients had an ICD in place (whether biventricular or single chamber) at the time of LVAD implantation. Previous studies have had significant variability in the number of patients with ICDs in place prior to LVAD implantation, ranging anywhere from 18.8% and 31.1%, up to 75.5%.[15-17] Our study is more in line with data presented by Enriquez and colleagues, with 75.7% having an ICD in place at the time of LVAD, likely indicating that our patients tend to have more chronic heart failure with attempts at optimizing their medical and device therapy prior to proceeding with LVAD and transplant evaluation.[17]

There was a total of nine patients who were discharged without an ICD in place. The reasons for not placing an ICD in these patients varied and included: 1.) prior ICD explantation due to infection, 2.) two with improvement in left ventricular function or decrease in ectopy prior to discharge, 3.) electrophysiology study showing no inducible VT, 4.) receipt of heart transplantation prior to initial discharge, 5.) concern for hypotension with anesthesia and risk for neurologic event, and 6.) three patients with unclear documentation as to why no ICD was placed. To our knowledge, there are no studies investigating the use of intracardiac EP studies in the post-LVAD population to assess low-risk patients for inducible VT to help direct ICD placement. A recent meta-analysis of six observational studies totaling 937 patients showed ICD use in LVAD patients was associated with a significant reduction in mortality, but in a subgroup analysis of 361 patients with continuous flow LVADs, there was not a statistically significant decrease in mortality following LVAD implantation with an ICD in place.[18]

Antiarrhythmic medications are frequently used to treat both atrial and ventricular arrhythmias in advanced heart failure patients both before and after LVAD implantation. We found that 72.8% of patients were on at least one antiarrhythmic medication in the post-implantation period. Amiodarone was the most commonly used antiarrhythmic, with 94% of the patients requiring antiarrhythmic therapy

being on amiodarone. Amiodarone use was equally frequent in the pre-LVAD period (52%) and in the post-LVAD period, with 51% of patients being discharged from the hospital on amiodarone following LVAD implantation. Previous studies have also shown that amiodarone is the most commonly used antiarrhythmic in the post-LVAD setting, with 66.7-75% of antiarrhythmic utilization for VT being done with amiodarone.[11, 14] The utilization of beta-blockers at discharge and 3 months following LVAD implantation is low in our institution (Table 4), historically due to concern for increased risk of right ventricular failure. Wever-Pinzon and colleagues recently showed that patients on a beta-blocker at 12 months following LVAD implantation were more likely to experience cardiac recovery and small, retrospective studies have shown it may improve post-implantation survival and does not appear to increase the number of heart failure readmissions. [19-21]

The side effects of long-term amiodarone use have been documented since the early 1980s and primarily involve the thyroid gland, liver, lungs, skin, and cornea.[22] Given amiodarone's frequent usage in patients undergoing heart transplant evaluation because of increased incidence of ventricular arrhythmias, a few studies over the last 20 years have looked at postoperative outcomes following heart transplantation in patients who received amiodarone in the pre- and post-operative period. Chin et al published a retrospective review in 1999 of 106 consecutive heart transplants and found that patients who had received amiodarone for more than 4 weeks pre-transplant had higher mortality at 1 year.[23] Blomberg and colleagues found that patients who had received amiodarone within 3 months of heart transplant had decreased survival post-transplant, required longer periods of postoperative ventilatory support, and were more likely to experience bleeding complications.[24] More recently, Cooper and colleagues published a retrospective cohort analysis of 14,955 patients from the International Society for Heart and Lung Transplantation registry that again found that patients treated with amiodarone prior to heart transplant had higher 1-year mortality but did not find increased risks of early graft failure, retransplantation, or rehospitalizations.[25] To our knowledge, there have not been prior reports looking at amiodarone utilization prior to LVAD implantation and its impact on post-operative outcomes.

Despite 137 patients having VT prior to LVAD implantation and 96 patients having VT post-implantation, only 12 patients underwent VT ablation pre-LVAD and 1 patient post-LVAD at our institution. Per-LVAD and post-LVAD VT ablation have previously been well described in several studies. Garan and colleagues looked at 224 patients who underwent LVAD placement and identified 7 patients who underwent EP study and VT ablation following LVAD implantation.[26] Multiple VTs were identified and ablated, with 5 of the 7 patients having a significant reduction in their VT following ablation.[26] A larger study evaluated 611 patients who underwent LVAD implantation over almost a 20-year period and identified 21 patients who underwent post-LVAD EP study. Of the 20 patients who had inducible VT, 18 had acute ablative success with 7 patients having recurrent VT and underwent a repeat procedure.[27] Amiodarone use decreased in both studies post-ablation with each study noting very few procedural complications and low post-procedural morbidity and mortality. Intraoperative ablation has been evaluated in a study of 5 patients who underwent peri-LVAD open chest hybrid epicardial mapping and VT ablation with 3 of the 5 patients having acute

procedural success and no arrhythmia related deaths in any of the patients over a mean follow-up period of 363 ± 368 days.[28]

On a univariate analysis, we found that patients on amiodarone within two years prior to LVAD implantation had an increased risk of mortality, with a HR of 1.7 and p=0.019. We also found that pre-implantation albumin, creatinine, and RDW as well as patient's age and history of prior median sternotomy predicted an increased risk of mortality on univariate analysis. Our findings confirm prior studies showing increased risk of mortality with lower albumin, higher RDW, worse renal function, and increasing age at the time of implantation.[29-34] Our findings of increased risk of mortality in patients with a history of a previous sternotomy prior to LVAD implantation conflict with a recent study published by Papathanasiou and colleagues. In their study of 112 patients who underwent implantation with HeartWare (HeartWare International Inc., Framingham, MA), they found no difference in survival rate at 6 months (p=0.37) in patients who had a history of prior median sternotomy at the time of LVAD implantation compared to those without prior sternotomy.[35] In our study, history of prior median sternotomy was the strongest predictor of increased mortality (p<0.0001) and on multivariate analysis remained an independent predictor of mortality (p=0.0007). Pre-LVAD albumin (p=0.0302) was the only other independent predictor of increased mortality on multivariate analysis, similar to findings previously described by Kato and colleagues.

There are several limitations to our study. This is a single-center experience involving both DT and BTT patients. Our analysis is retrospective in nature with a limited patient population. In some cases, pre- and post-LVAD ECGs were not available and prevented full evaluation of the entire patient population. Transition to a new electronic health record during the study period may have created difficulties in transfer of information between the systems as well as documentation early on.

In summary, the present study shows a significant decrease in QRS and QTc intervals post-LVAD implantation. Amiodarone was frequently used in both the pre- and post-LVAD setting to treat both atrial and ventricular arrhythmias. Amiodarone use may increase post-LVAD mortality. Despite the incidence of VT both before and after LVAD implantation, ablation was performed relatively infrequently in our patient population. With numerous studies showing increased mortality following heart transplant in patients who received pre-transplant amiodarone and our study showing pre-LVAD amiodarone potentially being associated with worse survival on univariate analysis, further studies need to be done investigating amiodarone reduction strategies and if ablation for recurrent VT is a superior strategy in patients undergoing transplant evaluation or with LVADs as bridge to transplant.

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