Postoperative atrial fibrillation is associated with increased morbidity and resource utilization after left ventricular assist device placement

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ABSTRACT

Background: Postoperative atrial fibrillation (POAF) is a known risk factor for morbidity and mortality after cardiac surgery but has not been investigated in the left ventricular assist device (LVAD) population. We hypothesize that POAF will increase morbidity and resource utilization after LVAD placement.

Methods: Records were extracted for all patients in a regional database who underwent continuous-flow LVAD placement ($n = 1064$, 2009-2017). Patients without a history of atrial fibrillation ($n = 689$) were stratified by POAF for univariate analysis. Multivariable regression models calculated the risk-adjusted association of arrhythmias on outcomes and resource utilization.

Results: The incidence of new-onset POAF was 17.6%, and patients who developed POAF were older and more likely to have moderate/severe mitral regurgitation, a history of stroke, and concomitant tricuspid surgery. After risk adjustment, POAF was not associated with operative mortality or stroke but was associated with major morbidity (odds ratio [OR] 2.5 $P = .0004$), prolonged ventilation (OR 2.7, $P < .0001$), unplanned right ventricular assist device (OR 2.9, $P = .01$), and a trend toward renal failure (OR 2.0, $P = .06$). In addition, POAF was associated with greater risk-adjusted resource utilization, including discharge to a facility (OR 2.2, $P = .007$), an additional 4.9 postoperative days ($P = .02$), and 88 hours in the intensive care unit ($P = .01$).

Conclusions: POAF was associated with increased major morbidity, possibly from worsening right heart failure leading to increased renal failure and unplanned right ventricular assist device placement. This led to patients with POAF having longer intensive care unit and hospital stays and more frequent discharges to a facility. (J Thorac Cardiovasc Surg 2018;156:1543-9)

HeartMate II left ventricular assist device (Images provided by St Jude Medical, Inc).

Central Message

POAF was associated with increased major morbidity, likely due to worsening right heart failure. This led to patients with POAF having longer ICU and hospital stays and more being discharged to facilities.

Perspective

This study clarifies that some known associations of POAF apply to the LVAD population, including increased morbidity and resource utilization. The likely detrimental impact on right heart function should spur further investigation to prevent complications. The impact of these complications represents a great opportunity to translate quality improvement initiatives to the LVAD population.

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This work was supported in part by the National Heart, Lung, and Blood Institute of the National Institutes of Health (T32HL007849).

Read at the 37th Annual Meeting for the International Society for Heart and Lung Transplantation, San Diego, California, April 5-8, 2017.

Received for publication Sept 27, 2017; revisions received March 28, 2018; accepted for publication March 30, 2018; available ahead of print May 22, 2018.

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0022-5223/\$36.00

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<https://doi.org/10.1016/j.jtcvs.2018.03.169>

Postoperative atrial fibrillation (POAF) after cardiac surgery is a common complication, occurring after 10% to 40% of cardiac cases.¹⁻³ The causes of POAF are multifactorial and include preoperative structural changes and perioperative proarrhythmic adrenergic activation, inflammation, and oxidative stress.³ Development of POAF is associated with increased risk of morbidity,

Scanning this QR code will take you to supplemental tables for this article.

Abbreviations and Acronyms

ICU	= intensive care unit
LOS	= length of stay
LVAD	= left ventricular assist device
POAF	= postoperative atrial fibrillation
RVAD	= right ventricular assist device
STS	= Society of Thoracic Surgeons
VCSQI	= Virginia Cardiac Services Quality Initiative

mortality, and resource utilization, including length of stay (LOS), readmission, and hospital cost.⁴ However, the information regarding the impact of POAF after left ventricular assist device (LVAD) implantation is far less well understood. Ventricular arrhythmias garner far more concern than POAF, likely limiting investigation into the clinical and economic impacts of atrial arrhythmias.

Although the complication rate after LVAD surgery is high, at a rate of approximately 30% POAF is one of the most common complications reported.⁵⁻⁸ With the cost of LVAD implantation in the hundreds of thousands of dollars, this therapy warrants scrutiny to identify quality and cost-improvement opportunities.⁹⁻¹¹ The Virginia Cardiac Services Quality Initiative (VCSQI) is a regional consortium of hospitals with the primary goal of improving patient quality, outcomes, and cost. The data available within this cohort represent an ideal opportunity to address quality and cost inefficiencies within a high-cost procedure.

The purpose of this analysis was to identify the potential associations of POAF with complications and resource utilization. We hypothesized that POAF is associated with risk-adjusted morbidity and mortality after LVAD implantation. Furthermore, we believe these differences will be evidenced by increased resource utilization, including postoperative LOS as well as health care–related cost.

PATIENTS AND METHODS**Patient Data**

The VCSQI is a multistate regional collaborative consisting of 19 hospitals and surgical practices. Eight of these hospitals perform LVAD surgeries. Member hospitals submit administrative, demographic, and clinical data via the Society of Thoracic Surgeons (STS) standardized data entry forms to both VCSQI and the STS national adult cardiac surgery database. Early data versions collected mean pulmonary artery pressure, which were converted to estimated pulmonary artery systolic pressure [(mean pulmonary artery pressure – 2)/0.61].

Deidentified records for all continuous-flow LVAD implantations from January 2009 through June of 2017 were extracted from the VCSQI data registry. Continuous-flow LVADs included HeartMate II and III (Thoratec Corp, Pleasanton, Calif) and HVAD (HeartWare, Framingham, Mass). Patients were excluded for missing baseline arrhythmia or POAF data. The primary outcomes of interest were short-term (in-hospital or 30-day) complications and resource utilization. Specifically, the risk-adjusted

associations between POAF and morbidity, mortality, LOS, and cost. Clinical variables used standard STS definitions.¹² Operative mortality is defined as either 30-day or in-hospital mortality. Major morbidity includes permanent stroke, prolonged ventilation, reoperation for any reason, renal failure, and deep sternal wound infection.

The primary objective of VCSQI is quality improvement with implementation of solutions across the collaborative. Business associate agreements are in place between VCSQI, members, and the database vendor (ARMUS Corporation, San Mateo, Calif). This analysis represents a secondary analysis of the VCSQI data registry without Health Insurance Portability and Accountability Act patient identifiers and was exempted from institutional review board review at the University of Virginia (IRB #20321).

Cost Data

The VCSQI cost collection, pairing, and estimation methodologies have been previously described.^{13,14} To summarize in brief, STS clinical data are paired with patient-level hospital financial records using Uniform Billing-04 files, which include all final hospital charges. The matching success rate is 99%. The identified charges are sorted based on *International Classification of Diseases*, Ninth Revision–based revenue codes. Next, the charges are multiplied by a set of cost-to-charge ratios for each hospital that are publicly available and submitted to the Centers for Medicare and Medicaid Services. All costs are presented as 2016 dollars after adjusting for medical inflation using the market basket for the Centers for Medicare and Medicaid Services Inpatient Prospective Payment System.¹⁵

Statistical Analysis

Categorical variables are presented as counts (%) and continuous variables as median [25th, 75th percentile] due to skewedness except for cost data, which was also presented as mean $\pm$ standard deviation. Cost data are presented as both median and mean to more fully understand cost outliers. Patients were stratified by POAF and preoperative atrial fibrillation and compared by univariate analysis. Categorical variables were analyzed by the χ^2 test for and continuous variables by Mann–Whitney *U* test. For univariate analyses, no imputation for missing data was performed.

Multivariable regression modeling assessed the risk-adjusted associations between POAF and morbidity, mortality, and resource-utilization metrics. Predicted associations were adjusted for preoperative and operative risk factors, hospital volume, and operative year with the complete list of covariates listed in Table E1. All risk factors used in previous LVAD risk models were included, except for aspartate aminotransferase, which is not captured in the data set and pulmonary artery pressures due to the high number missing (Table E1).¹⁶ For logistic regression models, a stepwise selection methodology was used to limit the number of covariates to 1 per 10 events, whereas for linear regression models all potential covariates were included.

For univariate analyses, missing data points were excluded from the corresponding analysis. For regression modeling, data imputation was performed based on STS methodology used in the creation of the STS risk models.¹⁷ For missing continuous variables, the median cohort value and for categorical variables the lowest risk definition was applied. Some patients were missing multiple laboratory values; thus, if patients were missing 4 or more values, they were excluded from the regression models ($n = 203$). All statistical analyses were carried out using SAS Version 9.4 (SAS Institute, Cary, NC) with significance determined by a *P* value less than .05.

RESULTS**Patient and Operative Characteristics**

A total of 1064 patients underwent implantation of a continuous-flow LVAD, of whom 375 (35%) had a history of atrial fibrillation. Of the 689 patients without a history of atrial fibrillation, 568 (17.6%) developed POAF. The

baseline descriptive statistics for patients without a history of atrial fibrillation are shown in Table 1 stratified by POAF. At baseline, patients who developed POAF were older with more frequent previous stroke. They had more frequent moderate/severe mitral regurgitation and greater pulmonary artery systolic pressures.

Patients who developed POAF had largely similar operative characteristics, as demonstrated in Table 2, with neither cardiopulmonary bypass time nor application of a complete crossclamp different by development of POAF. The rate of HeartWare HVAD implantation was greater in the POAF cohort (27% vs 18%), with the converse true for HeartMate II (82% vs 72%, $P = .02$). Patients who developed POAF also had a greater rate of concomitant tricuspid surgery.

Postoperative Outcomes and Resource Utilization

By univariate analysis, POAF was associated with greater rates of multiple morbidities, as shown in Table 3. The rate of major morbidity was 16% greater in the POAF cohort ($P = .001$), with many of the component complications similarly elevated. The rate of unplanned right ventricular

assist device (RVAD) was more than double in the POAF group (4% vs 10%, $P = .02$). In addition to complications, resource utilization was greater in patients who developed POAF. POAF was associated with a more than doubling of discharges to a facility ($P < .0001$), although readmission rates were similar. Both intensive care unit (ICU) and post-operative LOS were longer in patients with POAF (both $P < .001$). The unadjusted median total hospital cost was significantly greater for patients who developed POAF (\$300,281 [\$247,120-360,327]) compared with those who did not (\$272,190 [\$213,594-360,327]; $P = .003$). Similarly, the unadjusted median ICU cost for patients with POAF (\$31,926 [\$16,741-50,601]) was significantly greater than for patients without POAF (\$36,506 [\$21,745-64,634]; $P = .025$). Examining average cost, POAF was associated with almost \$30,000 greater mean hospital costs and more than \$4000 greater mean ICU-related costs.

Risk-Adjusted Outcomes and Resource Utilization

POAF continued to be associated with increased morbidity and resource utilization after risk-adjustment,

TABLE 1. Baseline characteristics by POAF status

	No POAF (n = 568)	POAF (n = 121)	P value
Age	54 [42-61]	58 [52-64]	<.0001
Body mass index	28 [24-33]	29 [25-35]	.349
Female	159 (28.0%)	30 (24.8%)	.474
Ventricular arrhythmia	146 (25.7%)	33 (27.3%)	.721
Hypertension	367 (64.7%)	79 (65.3%)	.906
Diabetes	235 (41.5%)	60 (49.6%)	.101
Dialysis-dependent renal failure	13 (2.3%)	2 (1.7%)	.662
Previous stroke	46 (8.3%)	17 (14.2%)	.047
Chronic lung disease (moderate/severe)	88 (15.7%)	21 (17.7%)	.596
Previous myocardial infarction	194 (34.3%)	50 (41.3%)	.142
NYHA class IV	492 (86.9%)	108 (90.0%)	.320
Ejection fraction, %	15 [10-20]	15 [10-20]	.271
Pulmonary artery systolic pressure, mm Hg	47.5 [36-60]	55 [41-62]	.015
Aortic regurgitation (moderate/severe)	19 (4.9%)	4 (4.8%)	.984
Mitral regurgitation (moderate/severe)	243 (49.5%)	62 (61.4%)	.029
Tricuspid regurgitation (moderate/severe)	166 (35.5%)	46 (45.5%)	.058
Preoperative albumin, g/dL	3.6 [3.2-4.0]	3.5 [3.1-3.9]	.066
Preoperative bilirubin, mg/dL	0.8 [0.5-1.4]	0.9 [0.6-1.4]	.259
Preoperative hematocrit, %	35 [31-39]	35 [30-39]	.986
Previous cardiac surgery	153 (26.9%)	23 (19.0%)	.069
Urgent or emergent status	447 (78.7%)	95 (78.5%)	.964
Preoperative inotropes	423 (74.5%)	92 (76.0%)	.720
Preoperative intra-aortic balloon pump	89 (15.7%)	21 (17.4%)	.651
Preoperative ECMO	17 (4.5%)	4 (4.1%)	.862

POAF, Postoperative atrial fibrillation; NYHA, New York Heart Association; ECMO, extracorporeal membrane oxygenation.

TABLE 2. Operative characteristics by POAF status

Operative characteristics	No POAF (n = 586)	POAF (n = 121)	P value
VAD exchange	44 (7.8%)	4 (3.3%)	.084
LVAD device			.023
HeartMate II	463 (81.5%)	87 (71.9%)	
HeartMate III	2 (0.4%)	2 (1.7%)	
HeartWare HVAD	103 (18.1%)	32 (26.5%)	
Tricuspid valve operation	49 (8.7%)	19 (15.7%)	.019
Crossclamp used	108 (19.6%)	30 (24.8%)	.200
Cardiopulmonary bypass time, min	99 [73-131]	103 [77-146]	.076

POAF, Postoperative atrial fibrillation; VAD, ventricular assist device; LVAD, left ventricular assist device.

as demonstrated in Table 4. This included greater risk of major morbidity (OR 2.46, $P = .0004$) with a trend toward increased renal failure (OR 1.96, $P = .060$). POAF was also independently associated with unplanned RVAD placement (OR 2.90, $P = .010$). Resource utilization was greater with POAF, including discharge to a facility (OR 2.23, $P = .007$). Both postoperative and ICU LOS were greater with POAF (80 hours and 4.9 days, both $P < .05$). Estimates for greater hospital (\$19,183) and ICU (\$5488) costs associated with POAF did not reach statistical significance (both $P > .05$).

There was no association between POAF and operative mortality (OR 0.98, $P = .685$) or stroke (1.19, $P = .667$).

Additional risk factors included within each regression model are available in Tables E2-E12. The most widely associated variable was POAF, which was significant in 6 of 11 models. Also widely associated with outcomes were last hematocrit level (4 models) and last total albumin level (6 models). The least useful variables for risk prediction were preoperative inotropes (0 models), last platelet count (1 model), last international normalized ratio (1 model), HeartMate II device (1 model), LVAD volume by center (1 model), and year (1 model). The logistic regression model performance ranged from a c-statistic of 0.66 to 0.74. The linear regression model performance ranged from a r^2 of 0.09 to 0.18.

DISCUSSION

This study analyzes the impact of atrial fibrillation on risk-adjusted morbidity, mortality, and resource utilization, including hospital costs in a large regional cohort of patients with continuous-flow LVAD. Of the 689 patients who underwent LVAD placement and did not have a history of atrial fibrillation, 121 (17.6%) developed POAF. The development of POAF was associated with a risk-adjusted increase in major morbidity (OR 2.5) but not mortality. There was a strong risk-adjusted association between

TABLE 3. Unadjusted outcomes by POAF status

Characteristics	No POAF (n = 568)	POAF (n = 121)	P value
STS operative mortality	78 (13.7%)	15 (12.4%)	.696
STS major morbidity	325 (57.2%)	88 (73.3%)	.001
Permanent stroke	24 (4.2%)	5 (4.2%)	.977
Cardiac arrest	12 (2.1%)	7 (5.8%)	.024
Pneumonia	42 (7.4%)	15 (12.5%)	.065
Prolonged ventilation	300 (52.8%)	87 (72.5%)	<.0001
Unplanned RVAD	25 (4.4%)	12 (9.9%)	.015
Renal failure	54 (9.5%)	18 (15.0%)	.074
Renal failure requiring dialysis	39 (6.9%)	13 (10.8%)	.135
Deep sternal wound infection	1 (0.2%)	0 (0%)	.646
Transfusion, any	390 (68.9%)	90 (74.4%)	.233
Transfusion, PRBC	377 (66.7%)	87 (71.9%)	.270
Reoperation for bleeding	82 (14.4%)	25 (20.8%)	.079
Reoperation for any reason	111 (19.5%)	34 (28.3%)	.032
Discharge to facility	63 (12.5%)	29 (26.9%)	.0002
Readmission	73 (14.7%)	18 (17.1%)	.534
Total cost	\$305,832 ± 160,276	\$334,512 ± 143,733	.003
ICU cost	\$41,984 ± 42,186	\$476,043 ± 34,279	.025
Postoperative LOS (d)	19 [14-28]	24 [17-36]	<.0001
ICU LOS (h)	168 [116-293]	249 [161-447]	<.0001

POAF, Postoperative atrial fibrillation; STS, Society of Thoracic Surgeons; RVAD, right ventricular assist device; PRBC, packed red blood cells; ICU, intensive care unit; LOS, length of stay.

TABLE 4. Risk-adjusted association between POAF and short-term outcomes

	Odds ratio	95% CI	P value	C-statistic
Operative mortality	0.98	0.51-1.87	.944	0.685
Major morbidity*	2.46	1.49-4.06	.0004	0.667
Permanent stroke	1.19	0.42-3.40	.747	0.714
Unplanned RVAD	2.90	1.30-6.49	.010	0.720
Renal failure	1.96	0.97-3.97	.060	0.740
Cardiac arrest	3.42	1.21-9.71	.021	0.713
Prolonged ventilation	2.68	1.64-4.37	<.0001	0.662
Reoperation	1.87	1.10-3.18	.020	0.659
Discharge to facility	2.23	1.25-4.01	.007	0.733
	Estimate	95% CI	P value	R ²
Intensive care unit LOS, h	87.7	22.5-153.0	.009	0.124
Postoperative LOS, d	4.9	0.7-9.2	.022	0.091
Intensive care unit cost	\$5488	−2539 to 13,515	.180	0.184
Total hospital cost	\$19,183	−16,918 to 55,283	.297	0.099

CI, Confidence interval; RVAD, right ventricular assist device; LOS, length of stay. *Major morbidity is permanent stroke, prolonged ventilation, reoperation for any reason, renal failure, and deep sternal wound infection.

POAF and unplanned RVAD (OR 2.9) as well as a trend toward renal failure (OR 2.0). In addition, POAF was broadly associated with increased resource utilization, including discharges to a facility and LOS. This includes a 5-day increase in postoperative LOS, most of which was spent in the ICU (88 additional hours). Although there are contemporary estimates of the impact of POAF in coronary and valve surgery, to our knowledge this represents the first estimates in the LVAD population.

The incidence of POAF after cardiac surgery has been reported to range from 10% to 40%.⁴ However, there are far fewer estimates for rates of atrial fibrillation after LVAD surgery. In this analysis, the overall rate of POAF was 17.6%. This rate is both consistent with the coronary and valve surgery rates, as well as previously reported rates after LVAD implantation of 13% to 32%.^{5,7,8,18} These numbers are somewhat surprising, given that LVAD implantation decreases left atrial pressure and size and has been shown to reduce atrial arrhythmias in the long term, where more than 40% of patients with previous atrial fibrillation will never have a recurrence in long-term follow-up.¹⁸ Although POAF is thought to be brought on by unique perioperative stressors, insight can be gained by noting paroxysmal and permanent atrial fibrillation have drastically different trajectories after LVAD placement, with the former improving and the latter causing increased risk of long-term mortality.^{18,19} Right heart failure is the likely culprit, as permanent atrial fibrillation will continue to compromise right ventricular filling.^{20,21} This is supported by the fact that these patients have greater rates of hospitalization for heart failure and right heart failure as a cause of death.^{19,22}

Although POAF increases the risk of mortality after coronary and valve surgery, this was neither demonstrated in this study, nor was POAF found to increase the risk of short- or long-term mortality after LVAD placement in other studies.^{1,4,5,7} Despite a lack of impact on operative mortality, POAF was highly associated with STS-defined major morbidities. This correlates with the coronary and valve literature but has not been shown previously in the LVAD population.^{4,23} This association appears to be driven by right heart dysfunction and results in a significantly greater risk for unplanned RVAD and a trend of increased renal failure. Although the risk factors for heart failure and atrial fibrillation are similar and the causality cannot be determined from this study, evidence would suggest that POAF is both a cause and symptom of right heart failure. Similar arguments for why permanent atrial fibrillation disrupt right ventricular function apply to POAF. In addition, many patients after LVAD placement have high right-sided pressures increasing the risk of both heart failure and atrial fibrillation, which is borne out by the greater median pulmonary artery pressures in the POAF cohort.²¹ Finally, it is also been shown that treatment of atrial fibrillation with ablation improves right heart symptoms.²⁴

Importantly, the component complication of permanent stroke was not associated with the development of POAF.⁵ This is contrary to other cardiac surgery populations, where POAF increases the risk of stroke, although these patients are not routinely anticoagulated.⁴ In addition, the current literature is mixed with regard to atrial fibrillation and risk of thromboembolic events, with controversy ignited when preoperative atrial fibrillation was found to

increase the risk of late events.²⁵ Recent literature is more consistent with our findings that neither preoperative atrial fibrillation or POAF are associated with increased rate of stroke.^{5,19,26,27}

Resource utilization was found to be increased in patients with LVADs who develop POAF, both in the unadjusted and risk-adjusted analyses. In other cardiac surgery procedures, POAF is associated with increases of 48 hours in the ICU and 3 additional postoperative days.^{4,23} These represent approximately 100% and 50% increases based on respective median LOS for patients without POAF. Similarly, in this study POAF was associated with a risk-adjusted increase in ICU LOS of 88 hours, a 52% increase over the median ICU LOS of 168 hours for patients without POAF. The increase of 5 days postoperatively in the POAF group represents a 26% increase over the median of 19 days in the non-POAF cohort. These results and a lack of association with mortality indicate that POAF has similar effects in LVAD and other cardiac procedures, although the relative effect size is smaller in this population. However, due to the high complication rates and resource utilization, the impact is still decidedly notable and clinically relevant with larger absolute increases in LOS. This is the first time POAF has been identified as predictive of increased LOS after LVAD implantation, as other analyses have not included this as a risk factor in their models.²⁸

This study has limitations, many of which are inherent to any retrospective analysis of a multi-institutional database, such as a risk of selection bias. This design prevents causal determination and in particular the timing and relationship of atrial fibrillation to other complications cannot be determined. Furthermore, we are constrained by the dataset available that includes unique information such as cost but also lacks detailed information present in other databases or common in atrial fibrillation-specific trials as well as INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support). Some patients were missing multiple laboratory values, preventing the entire cohort from being included in the risk-adjustment analysis. The risk-adjustment performed requires regression models be built for each outcome of interest, increasing the risk of a type I error, the false-positive rate. However, compared with other options, this has the advantage of not requiring matching on a postoperative event and using risk models that have been previously validated in large cohorts. Finally, findings were limited by the short-term nature of all STS related databases.

CONCLUSIONS

POAF is an underappreciated complication after LVAD implantation. The development of POAF was associated with a risk-adjusted increase in not only major morbidity but also resource utilization. This is likely driven by right ventricular failure both causing and worsened by the atrial

fibrillation. This correlated with increased renal failure and unplanned RVAD placement. The result is both ICU and postoperative LOS significantly increase with POAF. Contrary to some findings and the coronary/valve literature, POAF was not associated with either mortality or permanent stroke. The significant implications of POAF in the setting of a high-resource utilization surgery make it a prime target for quality improvement measures. Lessons learned in prophylaxis and treatment with other cardiac surgeries may translate to the LVAD population. Further study is warranted to help limit the burden identified by this analysis.

Conflict of Interest Statement

Dr Ailawadi is a consultant for Abbott, Edwards, Medtronic, and Cephea. Dr Speir is a consultant for Medtronic. All other authors have nothing to disclose with regard to commercial support.

References

1. Kalavrouziotis D, Buth KJ, Ali IS. The impact of new-onset atrial fibrillation on in-hospital mortality following cardiac surgery. *Chest*. 2007;131:833-9.
2. Mathew JP, Parks R, Savino JS, Friedman AS, Koch C, Mangano DT, et al. Atrial fibrillation following coronary artery bypass graft surgery: predictors, outcomes, and resource utilization. MultiCenter study of perioperative ischemia research group. *JAMA*. 1996;276:300-6.
3. Maessen B, Nijs J, Maessen J, Alessie M, Schotten U. Post-operative atrial fibrillation: a maze of mechanisms. *Europace*. 2012;14:159-74.
4. LaPar DJ, Speir AM, Crosby IK, Fonner E Jr, Brown M, Rich JB, et al. Postoperative atrial fibrillation significantly increases mortality, hospital readmission, and hospital costs. *Ann Thorac Surg*. 2014;98:527-33; discussion 533.
5. Hickey KT, Garan H, Mancini DM, Colombo PC, Naka Y, Sciacca RR, et al. Atrial fibrillation in patients with left ventricular assist devices. *JACC Clin Electrophysiol*. 2016;2:793-8.
6. Gustafsson F, Rogers JG. Left ventricular assist device therapy in advanced heart failure: patient selection and outcomes. *Eur J Heart Fail*. 2017;19:595-602.
7. Brisco MA, Sundareswaran KS, Milano CA, Feldman D, Testani JM, Ewald GA, et al. Incidence, risk, and consequences of atrial arrhythmias in patients with continuous-flow left ventricular assist devices. *J Card Surg*. 2014;29:572-80.
8. Genovese EA, Dew MA, Teuteberg JJ, Simon MA, Kay J, Siegenthaler MP, et al. Incidence and patterns of adverse event onset during the first 60 days after ventricular assist device implantation. *Ann Thorac Surg*. 2009;88:1162-70.
9. Baras Shreibati J, Goldhaber-Fiebert JD, Banerjee D, Owens DK, Hlatky MA. Cost-effectiveness of left ventricular assist devices in ambulatory patients with advanced heart failure. *JACC Heart Fail*. 2017;5:110-9.
10. Slaughter MS, Bostic R, Tong K, Russo M, Rogers JG. Temporal changes in hospital costs for left ventricular assist device implantation. *J Card Surg*. 2011;26:535-41.
11. Rogers JG, Bostic RR, Tong KB, Adamson R, Russo M, Slaughter MS. Cost-effectiveness analysis of continuous-flow left ventricular assist devices as destination therapy. *Circ Heart Fail*. 2012;5:10-6.
12. Society of Thoracic Surgery. Adult Cardiac Surgery Data Collection. Available at: <http://www.sts.org/sts-national-database/database-managers/adult-cardiac-surgery-database/data-collection>. Accessed October 14, 2016.
13. Osnabrugge RL, Speir AM, Head SJ, Fonner CE, Fonner E Jr, Ailawadi G, et al. Costs for surgical aortic valve replacement according to preoperative risk categories. *Ann Thorac Surg*. 2013;96:500-6.
14. Speir AM, Kasirajan V, Barnett SD, Fonner E Jr. Additive costs of postoperative complications for isolated coronary artery bypass grafting patients in Virginia. *Ann Thorac Surg*. 2009;88:40-5; discussion 45-6.
15. Centers for Medicare and Medicaid Services. Market Basket Data. Available at: <https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/MedicareProgramRatesStats/MarketBasketData.html>. Accessed December 14, 2017.

16. Levy WC. Potential clinical applications of the HeartMate II risk score. *J Am Coll Cardiol*. 2013;61:322-4.
17. Shahian DM, O'Brien SM, Filardo G, Ferraris VA, Haan CK, Rich JB, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 1—coronary artery bypass grafting surgery. *Ann Thorac Surg*. 2009;88:S2-22.
18. Deshmukh A, Kim G, Burke M, Anyanwu E, Jeevanandam V, Uriel N, et al. Atrial arrhythmias and electroanatomical remodeling in patients with left ventricular assist devices. *J Am Heart Assoc*. 2017;6.
19. Enriquez AD, Calenda B, Gandhi PU, Nair AP, Anyanwu AC, Pinney SP. Clinical impact of atrial fibrillation in patients with the HeartMate II left ventricular assist device. *J Am Coll Cardiol*. 2014;64:1883-90.
20. Cerit L. Atrial fibrillation and right ventricular failure. *Eur J Heart Fail*. 2017;20:620.
21. Uriel N, Sayer G, Addetia K, Fedson S, Kim GH, Rodgers D, et al. Hemodynamic ramp tests in patients with left ventricular assist devices. *JACC Heart Fail*. 2016;4:208-17.
22. Oezpeker C, Zittermann A, Puhler T, Ensminger S, Gummert JF, Morshuis M. Permanent atrial fibrillation and 2-year clinical outcomes in patients with a left ventricular assist device implant. *ASAIO J*. 2017;63:419-24.
23. Almassi GH, Schowalter T, Nicolosi AC, Aggarwal A, Moritz TE, Henderson WG, et al. Atrial fibrillation after cardiac surgery: a major morbid event? *Ann Surg*. 1997;226:501-11; discussion 511-3.
24. Hottigoudar RU, Deam AG, Birks EJ, McCants KC, Slaughter MS, Gopinathannair R. Catheter ablation of atrial flutter in patients with left ventricular assist device improves symptoms of right heart failure. *Congest Heart Fail*. 2013;19:165-71.
25. Stulak JM, Deo S, Schirger J, Aaronson KD, Park SJ, Joyce LD, et al. Preoperative atrial fibrillation increases risk of thromboembolic events after left ventricular assist device implantation. *Ann Thorac Surg*. 2013;96:2161-7.
26. Xuereb L, Go PH, Kaur B, Akrawe S, Nemeh HW, Borgi J, et al. Impact of preoperative atrial fibrillation on postoperative thromboembolic events after left ventricular assist device implantation. *Ann Thorac Surg*. 2016;102:1543-9.
27. Xia Y, Stern D, Friedmann P, Goldstein D. Preoperative atrial fibrillation may not increase thromboembolic events in left ventricular assist device recipients on midterm follow-up. *J Heart Lung Transplant*. 2016;35:906-12.
28. Cotts WG, McGee EC Jr, Myers SL, Naftel DC, Young JB, Kirklin JK, et al. Predictors of hospital length of stay after implantation of a left ventricular assist device: an analysis of the INTERMACS registry. *J Heart Lung Transplant*. 2014;33:682-8.

Key Words: atrial fibrillation, ventricular assist device, resource utilization, cost

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TABLE E1. Covariates considered for multivariable regression

Potential covariates	Number of models	Percent missing data
Postoperative atrial fibrillation	6	0%
Preoperative ventricular arrhythmia	3	0%
Age	3	0%
Preoperative inotropes	0	0%
Last creatinine	3	0%
Last hematocrit	4	0.2%
Last platelet count	1	0.2%
Total bilirubin	3	0.8%
Last INR	1	0.6%
Total albumin	4	1.0%
Heart Mate II device	1	0%
LVAD volume by center	1	0%
Year	1	0%

INR, International normalized ratio; LVAD, left ventricular assist device.

TABLE E3. Multivariable logistic regression for major morbidity

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	2.464	1.494-4.063	.0004
Total bilirubin	1.370	1.041-1.802	.0245
Last INR	0.620	0.337-1.142	.1250
Last creatinine	1.311	0.913-1.883	.1428
Preoperative inotropes	1.296	0.844-1.990	.2358
LVAD volume by center	1.003	0.998-1.008	.1821
Last platelet count	0.998	0.995-1.000	.0431
Last hematocrit	0.948	0.918-0.979	.0013

OR, Odds ratio; INR, international normalized ratio; LVAD, left ventricular assist device.

TABLE E2. Multivariable logistic regression for operative mortality

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	0.977	0.510-1.872	.9443
Total bilirubin	1.164	0.934-1.45	.1764
Last creatinine	1.335	0.909-1.961	.1412
Age	1.028	1.005-1.052	.0186
Total albumin	0.643	0.38-1.088	.0996
LVAD volume by center	1.005	0.998-1.013	.1659
Last hematocrit	0.948	0.902-0.996	.0355

OR, Odds ratio; LVAD, left ventricular assist device.

TABLE E4. Multivariable logistic regression for permanent stroke

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	1.189	0.416-3.399	.7471
Last hematocrit	0.886	0.818-0.960	.0032

OR, Odds ratio.

TABLE E5. Multivariable logistic regression for unplanned RVAD

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	2.900	1.296-6.49	.0096
Last creatinine	1.472	0.932-2.326	.0973
Total albumin	2.900	1.296-6.49	.0096

OR, Odds ratio.

TABLE E7. Multivariable logistic regression for cardiac arrest

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	3.423	1.207-9.706	.0207
Last creatinine	0.383	0.098-1.501	.1683

OR, Odds ratio.

TABLE E6. Multivariable logistic regression for renal failure

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	1.963	0.972-3.967	.0602
Total bilirubin	1.868	1.24-2.813	.0028
Last creatinine	1.022	0.995-1.051	.1108
Age	1.573	1.193-2.074	.0013

OR, Odds ratio.

TABLE E8. Multivariable logistic regression for discharge to facility

Covariate	OR	95% Confidence interval	P value
Postoperative atrial fibrillation	2.234	1.246-4.006	.0070
Preoperative ventricular arrhythmia	1.897	1.09-3.301	.0235
Preoperative inotropes	1.818	0.947-3.487	.0723
Age	1.037	1.014-1.061	.0019
LVAD volume by center	1.004	0.997-1.01	.2846
Last hematocrit	0.924	0.882-0.968	.0009

OR, Odds ratio; LVAD, left ventricular assist device.

TABLE E9. Multivariable linear regression for intensive care unit length of stay

Covariate	Estimate	95% Confidence limits	P value
Postoperative atrial fibrillation	87.74839	22.49032-153.00646	.0085
Preoperative ventricular arrhythmia	73.77964	15.00512-132.55417	.014
Total bilirubin	22.92516	0.6107-45.23962	.0441
Last INR	-16.70814	-75.20648 to 41.7902	.5749
Last creatinine level	67.24387	22.36706-112.12068	.0034
Preoperative inotropes	8.38774	-52.15811 to 68.93358	.7856
Age	0.58443	-1.54488 to 2.71375	.5899
Total albumin	-56.79544	-102.88376 to -10.70712	.0158
LVAD volume by center	-0.55471	-1.28446 to 0.17504	.1359
Last platelet	-0.10935	-0.41307 to 0.19437	.4796
Last hematocrit	-0.81524	-5.26905 to 3.63857	.7192
HeartMate II device	-59.93832	-126.05372 to 6.17708	.0755
Year	1.55119	-15.44528 to 18.54767	.8577

INR, International normalized ratio; LVAD, left ventricular assist device.

TABLE E10. Multivariable linear regression for postoperative length of stay

Covariate	Estimate	95% Confidence limits	P value
Postoperative atrial fibrillation	4.9437	0.72892-9.15848	.0216
Preoperative ventricular arrhythmia	1.50535	-2.30008 to 5.31077	.4374
Total bilirubin	0.01504	-1.43069 to 1.46077	.9837
Last INR	-2.48553	-6.2766 to 1.30553	.1983
Last creatinine level	6.29445	3.38812-9.20078	<.0001
Preoperative inotropes	2.40755	-1.47624 to 6.29133	.2238
Age	0.02886	-0.10747 to 0.16519	.6776
Total albumin	-2.87937	-5.85481 to 0.09606	.0578
LVAD volume by center	0.02452	-0.02276 to 0.0718	.3087
Last platelet	-0.01462	-0.03417 to 0.00492	.1422
Last Hematocrit	-0.06158	-0.34999 to 0.22683	.675
HeartMate II device	-2.55351	-6.81143 to 1.70442	.2392
Year	-0.93325	-2.02661 to 0.16011	.0942

INR, International normalized ratio; LVAD, left ventricular assist device.

TABLE E11. Multivariable linear regression for intensive care unit cost

Covariate	Estimate	95% Confidence limits	P value
Postoperative atrial fibrillation	5488.22	−2538.8 to 13,515	.1797
Preoperative ventricular arrhythmia	7664.69	372.8267-14,957	.0394
Total bilirubin	2315.59	−394.608 to 5025.794	.0938
Last INR	−916.897	−9471.28 to 7637.49	.8333
Last creatinine level	11,427	5893.278-16,961	<.0001
Preoperative inotropes	4999.05	−2350 to 12,348	.1819
Age	−49.7071	−307.374 to 207.9594	.7048
Total albumin	−11,123	−16,771 to −5474.16	.0001
LVAD volume by center	−112.678	−205.429 to −19.9274	.0174
Last platelet	−8.95529	−46.2938 to 28.3832	.6376
Last hematocrit	−316.1071	−868.77372 to 236.55953	.2616
HeartMate II device	−12,183	−20,297 to −4069.02	.0033
Year	−4258.5	−6496.73 to −2020.33	.0002

INR, International normalized ratio; LVAD, left ventricular assist device.

TABLE E12. Multivariable linear regression for total hospital cost

Covariate	Estimate	95% Confidence limits	P value
Postoperative atrial fibrillation	19,183	−16,918 to 55,283	.2969
Preoperative ventricular arrhythmia	10,637	−22,158 to 43,431	.5242
Total bilirubin	12,156	−32.3236 to 24,345	.0506
Last INR	−52,569	−91,041 to −14,097	.0075
Last creatinine level	26,023	11,34.969-50,910	.0405
Preoperative inotropes	10,269	−22,783 to 43,320	.5418
Age	557.096	−601.73 to 1715.921	.3453
Total albumin	−32,356	−57,759 to −6952.21	.0127
LVAD volume by center	108.0781	−309.058 to 525.2141	.6109
Last platelet	−56.5075	−224.433 to 111.4181	.5087
Last hematocrit	−2373.61	−4859.16 to 111.946	.0612
HeartMate II device	−31,116	−67,608 to 5375.19	.0945
Year	3151.24	−6914.79 to 13,217	.5387

INR, International normalized ratio; LVAD, left ventricular assist device.