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Article

Thoracotomy Versus Sternotomy for Left Ventricular Assist Device Placement: A Statewide Multicenter Analysis

Sean W.W. Noona[1], Steven D. Young[1], Emily C. Scheffel[1,*], Matthew P. Weber[1], Alex M. Wisniewski[1], Raymond J. Strobel[1], Daniella Wong[1], Annie Y. Son[2], Mohammed Quader[3], Michael C. Kontos[3], Ramesh Singh[4], Abdulla A. Damluji[4], Mark E. Roeser[5], Leora T. Yarboro[1], Nicholas R. Teman[6], Jared P. Beller[1]

[1]Division of Thoracic and Cardiovascular Surgery, Department of Surgery, University of Virginia, Charlottesville, VA 22903, USA
[2]University of Virginia School of Medicine, Charlottesville, VA 22903, USA
[3]Division of Cardiothoracic Surgery and Cardiology, Virginia Commonwealth University, Richmond, VA 23219, USA
[4]Department of Cardiac Surgery, INOVA Heart and Vascular, Falls Church, VA 22042, USA
[5]Department of General Surgery, Division of Congenital Cardiac Surgery, Atrium Health, Charlotte, NC 28203, USA
[6]Division of Cardiothoracic Surgery, University of Colorado, Aurora, CO 80045, USA
*Correspondence: etc3jf@virginia.edu (Emily C. Scheffel)
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Abstract

Background: This study aimed to evaluate short-term outcomes, trends, and statewide practice patterns for thoracotomy left ventricular assist device (T-LVAD) versus sternotomy left ventricular assist device (S-LVAD) implantation. **Methods:** Adult patients who underwent durable LVAD implantation (7/1/2014–12/31/2024) within a regional collaborative were identified and stratified by surgical approach. Patients who received a planned right ventricular assist device (RVAD) or other intraoperative right-heart support devices were excluded. Univariable and multivariable analyses were performed to compare 30-day outcomes. **Results:** Among 770 patients, 88 (11.4%) underwent T-LVAD. Notably, T-LVAD patients were older (62 vs. 57 years; $p = 0.014$), more likely to be Caucasian (66% vs. 55%; $p = 0.049$), had a higher body mass index (BMI) (30 vs. 28; $p = 0.009$), and had more cerebrovascular disease (32% vs. 21%; $p = 0.019$) but less chronic lung disease (42% vs. 54%; $p = 0.031$) compared with S-LVAD patients. A total of 61.4% of T-LVAD procedures were redo operations. T-LVAD patients underwent fewer concomitant procedures (1.1% vs. 38.9%; $p < 0.001$), experienced less postoperative atrial fibrillation (8.0% vs. 23%; $p = 0.001$), had shorter intensive care unit stays (124 vs. 209 hours; $p < 0.001$) and postoperative lengths of stay (15 vs. 22 days; $p < 0.001$), and incurred lower hospitalization costs (USD 198,978 vs. USD 267,785; $p < 0.001$). Operating room time (343 vs. 361 min; $p = 0.165$), postoperative right heart failure (2.3% vs. 1.2%; $p = 0.32$), readmission (33% vs. 26%; $p = 0.153$), and operative mortality (4.5% vs. 9.5%; $p = 0.123$) were comparable between groups. After risk adjustment, T-LVAD remained associated with lower hospitalization costs (USD –58,415.69, standard error (SE) 20,627.72; $p = 0.005$). **Conclusions:** T-LVAD was associated with lower postoperative morbidity and reduced resource utilization compared with S-LVAD. The use of T-LVAD remains an important option, is noninferior to S-LVAD, and may be associated with a more benign postoperative course.

Keywords: thoracotomy-based left ventricular assist device; cost; left ventricular assist device; heart failure; cardiac surgery outcomes

1. Introduction

Left ventricular assist devices (LVADs) enhance survival and quality of life in patients with advanced heart failure [1]. Traditionally, median sternotomy has been the standard approach [2]. Sternotomy LVAD (S-LVAD) provides excellent exposure to the heart and great vessels, facilitating management of complications and concomitant procedures [3]. However, the advent of centrifugal, magnetically levitated miniaturized LVADs has driven interest in minimally invasive, thoracotomy LVAD (T-LVAD).

Despite growing interest, T-LVAD outcomes remain a topic of debate. Currently, S-LVAD has a Class IIa recommendation and T-LVAD has a Class IIb recommendation in the 2023 International Society for Heart and Lung Transplantation guidelines [2]. The 2018 United Network for Organ Sharing (UNOS) heart transplantation allocation change has shifted practice, with fewer patients being offered LVAD as a bridge to transplant and diverting sicker patients towards LVAD destination therapy [4,5]. Thus, understanding and optimizing outcomes is vital as more LVADs are implanted as destination therapies in an increasingly high-risk population.

Recent studies, including the Left Anterior Thoracotomy with Upper Hemisternotomy or Right Anterior Thoracotomy (LATERAL) trial, a single arm study with retrospective historical comparative cohorts, suggest that T-LVAD is associated with improved outcomes including reduced right heart failure (RHF), lower transfusion requirements, shorter intensive care unit (ICU) and postoperative lengths of stay (LOS), and reduced hospitalization cost

[6,7,8]. However, the Implantation of the HeartMate 3 in Subjects With Heart Failure Using Surgical Techniques Other Than Full Median Sternotomy (HM3 SWIFT) trial, another single-arm study with a retrospective historical comparative cohort, presented conflicting results, reporting a longer LOS for T-LVAD with no significant differences in RHF, aggregate intra- and postoperative transfusion requirements, or survival [9].

Further studies have suggested benefits from T-LVAD in patients with prior sternotomies, on extracorporeal membrane oxygenation (ECMO), and with obesity. Still, the frequency of these advantages and expansion to other patient populations remains unclear [10,11,12,13].

This study evaluated the rate of T-LVAD in patients undergoing LVAD implantation within a regional collaborative to provide further clarity on real-world safety, potential advantages, and clinical trends. We compared the short-term outcomes and hospitalization costs of T-LVAD and S-LVAD patients. We also aimed to do better. characterize the populations in T- and S-LVAD cohorts. We hypothesized that the T-LVAD patients would have shorter LOS, less RHF, fewer transfusions, and lower hospitalization costs with similar mortality and readmission as S-LVAD.

2. Methods

2.1 Patients

The study was approved by the University of Virginia Institutional Review Board (#23305; 7/14/2021) with a waiver of consent given its retrospective, deidentified nature. We identified patients ≥18 years old who underwent durable LVAD (HeartMate II (Abbott), HeartMate 3 (Abbott), HeartWare Ventricular Assist Device (Medtronic)) implantation between 7/1/2014 and 12/31/2024 within the Virginia Cardiac Services Quality Initiative (VCSQI) collaborative. Patients were stratified by operative approach (Fig. 1). T-LVAD was defined as LVAD implantation via bilateral thoracotomy or left thoracotomy and partial upper sternotomy [3,9].

2.2 Data Collection

Data was sourced from VCSQI, a regional collaboration that pools Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database data from seventeen hospitals in Virginia. Seven VCSQI centers implanted LVADs within the study period. Patient demographics, operative data, and select postoperative outcomes were included. Outcomes were defined via the STS Adult Cardiac Surgery Database. There were no notable definition changes over the study period.

For clinical cost data, charges were captured by revenue codes based on the International Classification of Diseases, 9th and 10th Revisions, and Uniform Billing-04 files were matched to the STS data with a successful matching rate of 99%. Final hospital charges were converted to estimate costs using cost-to-charge ratios submitted to Centers for Medicare and Medicaid Services [14].

2.3 Study Groups and Outcomes Assessed

Patients were stratified into two groups: T-LVAD and S-LVAD. Primary outcomes included severe postoperative RHF and operative mortality. Severe postoperative RHF was defined as patients undergoing LVAD placement who did not receive preoperative ECMO and required unplanned intra- or postoperative venovenous ECMO or right ventricular assist device (RVAD) [15]. Patients who underwent planned total artificial heart, biventricular, temporary percutaneous, RVAD, or unknown device insertion at the time of LVAD were excluded because the technical ease of right heart device insertion via sternotomy decreases likelihood of T-LVAD for reasons outside the focus of this study.

Additional intraoperative and postoperative secondary outcomes included postoperative and ICU LOS, hospitalization cost, concomitant procedures, and transfusion requirements. We chose to include concomitant procedures in the setting of a current landscape of rising feasibility and prevalence of minimally invasive and thoracotomy approaches to valve procedures, patent foramen ovale closures, and left atrial appendage ligations. Overall trends and center-level T-LVAD volumes were explored.

2.4 Statistical Analysis

All available short-term clinical variables were compared via univariable analysis. Continuous variables were reported as median [Q1, Q3] or mean (standard deviation) and categorical variables as n (%), following standard STS definitions. A risk-adjusted analysis was performed to better isolate the effect of operative approach, controlling for variables that differed significantly on univariable analysis. Multivariable linear and logistic regressions were used to risk adjust patients using the *GT* library in R, developed by Posit, PBC in Boston, MA USA and available under the public MIT license. Odds ratios are presented with 95% confidence intervals for logistic regressions. B coefficients with standard errors are presented for linear regressions. R^2 was calculated. Pearson's correlation coefficient (r) was calculated to assess the relationship between the number of T-LVAD and total LVAD cases. Variables with missing data of <10% were imputed using the median value for continuous variables and the most common value for categorical variables. Statistical analysis was performed using R and RStudio (Posit, PBC; Boston, MA USA) [16]. p-values < 0.05 were considered significant.

3. Results

3.1 Baseline Patient Characteristics

770 patients were included. 88 patients (11.4%) underwent T-LVAD and 682 (88.6%) underwent S-LVAD. T-LVAD represented a generally older, more comorbid group with less chronic lung disease. Most T-LVAD patients

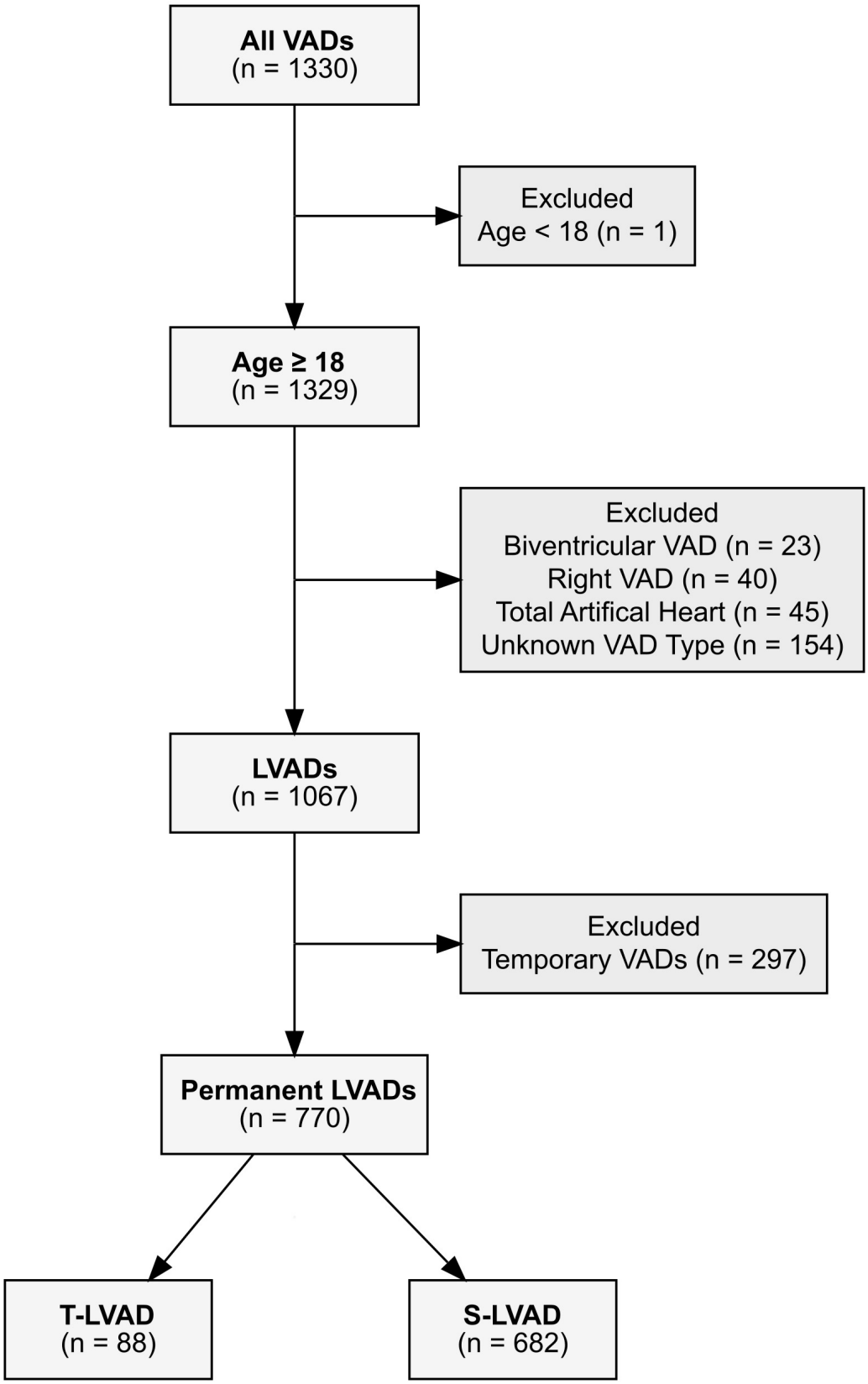

Fig. 1. CONSORT diagram. VADs, ventricular assist devices; LVADs, left ventricular assist devices; T-LVAD, thoracotomy left ventricular assist device; S-LVAD, sternotomy left ventricular assist device.

(61.4%) were redo operations. T-LVADs were more likely due to device failure (11% vs. 1.5%, $p < 0.001$). There were no significant differences between cohorts receiving an LVAD as a bridge to transplant (47% vs. 51%, $p = 0.418$) or destination therapy (40% vs. 45%, $p = 0.338$). T-LVAD patients received more HeartMate II (HMII) (50% vs. 33%, $p = 0.002$) and fewer HM3 devices (9.1% vs. 26%, $p < 0.001$) (Table 1).

Table 1. LVAD patient demographics (2014–2024) stratified by operative approach.

Characteristic	S-LVAD n (%) = 682[1]	T-LVAD n (%) = 88[1]	*p*-value[2]
Patient age	57 (49, 65)	62 (52, 68)	0.014
Gender (male)	514 (75%)	68 (77%)	0.695
Race			
White	374 (55%)	58 (66%)	0.049
African American	281 (41%)	28 (32%)	0.091
Asian	10 (1.5%)	0 (0%)	0.614
BMI	28 (24, 33)	30 (26, 35)	0.009
Hypertension	490 (72%)	63 (72%)	0.960
Smoking history	421 (62%)	54 (61%)	0.947
Chronic lung disease	370 (54%)	37 (42%)	0.031
Home oxygen	16 (2.3%)	4 (4.5%)	0.272
History of pneumonia	128 (19%)	18 (20%)	0.704
Peripheral arterial disease	82 (12%)	6 (6.8%)	0.149
Cerebrovascular disease	142 (21%)	28 (32%)	0.019
Prior cerebrovascular accident	104 (15%)	19 (22%)	0.126
Diabetes	340 (50%)	40 (45%)	0.437
Dialysis dependent	22 (3.2%)	3 (3.4%)	0.758
LVAD indication			
Bridge to transplant	349 (51%)	41 (47%)	0.418
Destination therapy	308 (45%)	35 (40%)	0.338
Device failure	10 (1.5%)	10 (11%)	<0.001
Bridge to recovery	11 (1.6%)	2 (2.3%)	0.652
Salvage	3 (0.4%)	0 (0%)	>0.999
End of device life	1 (0.1%)	0 (0%)	>0.999
LVAD Type			
HVAD	278 (41%)	36 (41%)	0.979
HMII	228 (33%)	44 (50%)	0.002
HM3	176 (26%)	8 (9.1%)	<0.001

[1]Continuous values are expressed as Median (IQR); categorical variables are expressed as n (%).

[2]Wilcoxon rank sum test; Pearson's Chi-squared test; Fisher's exact test.

BMI, body mass index; HVAD, HeartWare HVAD system; HMII, HeartMate II; HM3, HeartMate 3; IQR, Interquartile Range.

3.2 Unadjusted Outcomes

Intraoperative and short-term (30-day or length of index hospitalization) outcomes were compared (Table 2). T-LVAD patients were less likely to undergo cross-clamp (2.3% vs. 18.5%, $p < 0.001$) and had shorter cross-clamp (19 vs. 48 min, $p = 0.02$) and cardiopulmonary bypass times (73 vs. 100 min, $p < 0.001$). T-LVAD was associated with decreased ICU LOS (124 vs. 209 hr, $p < 0.001$) and postoperative LOS (15 vs. 22 days, $p < 0.001$). T-LVAD patients had less postoperative atrial fibrillation (8.0% vs. 23%, $p = 0.001$), pneumonia (6.8% vs. 15%, $p = 0.044$), and prolonged ventilation (>24 hours) (26% vs. 56%, $p < 0.001$). The T-LVAD cohort was associated with fewer concomitant procedures including tricuspid valve (0% vs. 11%, $p = 0.001$) or aortic valve repair or replacement (1.1% vs. 7.5%, $p = 0.022$), patent foramen ovale closure (0% vs. 8.4%, $p = 0.005$), and left atrial appendage ligation (0% vs. 11%, $p = 0.001$). T-LVAD hospitalization cost ($198,978 vs. $267,785, $p < 0.001$) was lower, based on cost data from 98.1% (755/770) of the cohort. There were no significant differences in operative mortality (4.5% vs. 9.5%, $p = 0.123$), severe postoperative RHF (2.3% vs. 1.2%, $p = 0.320$), stroke (6.8% vs. 5.7%, $p = 0.679$), or postoperative blood products (80% vs. 73%, $p = 0.190$). Thirty-day readmission rates (33% vs. 26%, $p = 0.153$) were similar.

3.3 Risk Adjusted Outcomes

Our risk-adjusted total cost model demonstrated significantly decreased hospitalization cost for T-LVAD (–$58,415.69, SE 20,627.72, $p = 0.005$) when adjusted for operating room (OR) time and patient comorbidities (age, BMI, cerebrovascular disease, chronic lung disease) (Table 3). OR time was also significantly associated with hospitalization cost ($460.32, SE 54.63, $p < 0.001$).

After adjustment, T-LVAD remained significantly associated with reduced ICU hours (–130.67 hrs, SE 48.33, $p = 0.007$), shorter postoperative LOS (–6.99 days, SE 2.49, $p = 0.005$), and lower odds of prolonged ventilation (0.39, 95% CI [0.19, 0.78], $p = 0.007$) (**Supplementary Tables 1,2,3**).

3.4 Trends in T-LVAD Rates and Institutional Volume

Total LVAD volume declined by 65.96% (–10.9 cases/year) from 2018–2024. T-LVAD cases remained low, with a marginal decline (–1.7 cases/year vs. –9.2 cases/year, $p < 0.05$) (Fig. 2). Three high-volume VCSQI centers accounted for 86.4% of T-LVAD cases, while two centers performed no T-LVAD cases (Fig. 3). T-LVAD volume varied directly with total center LVAD volume ($r = 0.849$, $p = 0.016$). Over the study period, T-LVAD case volume trended downward across all three centers throughout the study period.

4. Discussion

In this cohort, T-LVAD did not decrease short-term severe RHF or operative mortality. T-LVAD patients had lower hospitalization costs, despite containing a majority of redo cases. T-LVAD and concomitant procedure rates were negatively correlated. Finally, T-LVAD was performed mostly at high-volume LVAD centers (Fig. 3).

Table 2. LVAD patient outcomes (2014–2024) stratified by operative approach.

Variable	S-LVAD n (%) = 682[1]	T-LVAD n (%) = 88[1]	*p*-value[2]
Cross-clamp applied	126 (18.5%)	2 (2.3%)	<0.001
Cross-clamp time (minutes)	48 (32, 82)	19 (0, 27)	0.021
Cardiopulmonary bypass time (minutes)	100 (76, 133)	73 (27, 106)	<0.001
Operating room time (minutes)	361 (310, 450)	343 (298, 448)	0.165
Valve repair or replacement			
Aortic	53 (7.8%)	1 (1.1%)	0.022
Mitral	10 (1.5%)	0 (0%)	0.614
Tricuspid	73 (11%)	0 (0%)	0.001
Patent foramen ovale closure	57 (8.4%)	0 (0%)	0.005
Left atrial appendage ligation	72 (11%)	0 (0%)	0.001
ICU length of stay (hours)	209 (142, 403)	124 (79, 212)	<0.001
Length of stay (days)	22 (15, 34)	15 (11, 29)	<0.001
Stroke	39 (5.7%)	6 (6.8%)	0.679
Pulmonary embolism	4 (0.6%)	0 (0%)	>0.999
Postoperative atrial fibrillation	154 (23%)	7 (8.0%)	0.001
Cardiac arrest	30 (4.4%)	2 (2.3%)	0.568
Bleeding due to anticoagulation	30 (4.4%)	1 (1.1%)	0.243
Pneumonia	100 (15%)	6 (6.8%)	0.044
Prolonged ventilation	385 (56%)	23 (26%)	<0.001
Renal failure	110 (16%)	10 (11%)	0.246
Sepsis	51 (7.5%)	3 (3.4%)	0.160
Deep sternal wound infection	4 (0.6%)	0 (0%)	>0.999
Readmission	176 (26%)	29 (33%)	0.153
Operative mortality	65 (9.5%)	4 (4.5%)	0.123
Total cost ($)	267,785 (204,734, 378,123)	198,978 (159,191, 305,076)	<0.001
Severe postoperative right heart failure	8 (1.2%)	2 (2.3%)	0.320
Intraoperative blood products	436 (64%)	52 (59%)	0.375
Packed red blood cell units	0.00 (0.00, 2.00)	0.00 (0.00, 1.00)	0.667
Fresh frozen plasma units	0.00 (0.00, 2.00)	0.00 (0.00, 0.00)	0.006
Cryoprecipitate units	0.00 (0.00, 1.00)	0.00 (0.00, 0.50)	0.198
Platelet units	0.00 (0.00, 2.00)	0.00 (0.00, 1.00)	<0.001
Postoperative blood products	498 (73%)	70 (80%)	0.190
Packed red blood cell units	2 (0, 7)	2 (1, 4)	0.176
Fresh frozen plasma units	0.00 (0.00, 1.00)	0.00 (0.00, 0.00)	0.056
Cryoprecipitate units	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.459
Platelet units	0.0000 (0.0000, 0.0000)	0.0000 (0.0000, 0.0000)	0.499

[1]Continuous values are expressed as Median (IQR); categorical variables are expressed as n (%).

[2]Wilcoxon rank sum test; Pearson's Chi-squared test; Fisher's exact test.

Numerous single- and multicenter studies have assessed the potential benefits of T-LVAD. Though study findings have varied, reports have associated T-LVAD with decreased RHF, fewer transfusions, shorter LOS, and improved mobility and survival [3,6,17,18]. Saeed et al. [7] proposed a multifactorial mechanism for reduced RHF in T-LVAD: by better preserving the right heart's pericardium, T-LVAD promotes right ventricular septal function, reduces right ventricular free-wall tethering, avoids volume overload by decreasing transfusions, and augments ventricular unloading with consistent positioning of the inflow cannula [3,6].

Like the HM3 SWIFT trial, our study found that T-LVAD was not associated with decreased risk of severe RHF, aggregate intra- and postoperative transfusions, or operative mortality. Our T-LVAD postoperative RHF (2.3%) and operative mortality (4.5%) rates were lower than those in the HM3 SWIFT trial (21.6% postoperative RHF, 11% operative mortality) and comparable to the LATERAL trial (0.7% severe postoperative RHF, 9.7% operative mortality). Discrepancies may be explained by our smaller sample size, differing definitions of severe RHF from the Interagency Registry for Mechanically Assisted Circulatory Support database, and exclusion of patients who re-

Table 3. Risk adjusted model for total cost.

Risk-adjusted model for total cost			
Variable	b coefficient	Standard error	*p*-value
Patient age	–727.55	523.06	0.165
BMI	–453.41	952.47	0.634
Cerebrovascular disease	27,143.43	15,623.55	0.083
Chronic lung disease	–5883.80	12,853.92	0.647
Operating room time	460.32	54.63	<0.001
T-LVAD approach	–58,415.69	20,627.72	0.005

Multivariable risk factors associated with total hospital cost in LVAD patients (2014–2024). R^2 suggests that 10.55% of the variation in total cost can be explained by the independent variables in our model. B coefficients (unstandardized) are presented with standard error are presented for linear regressions.

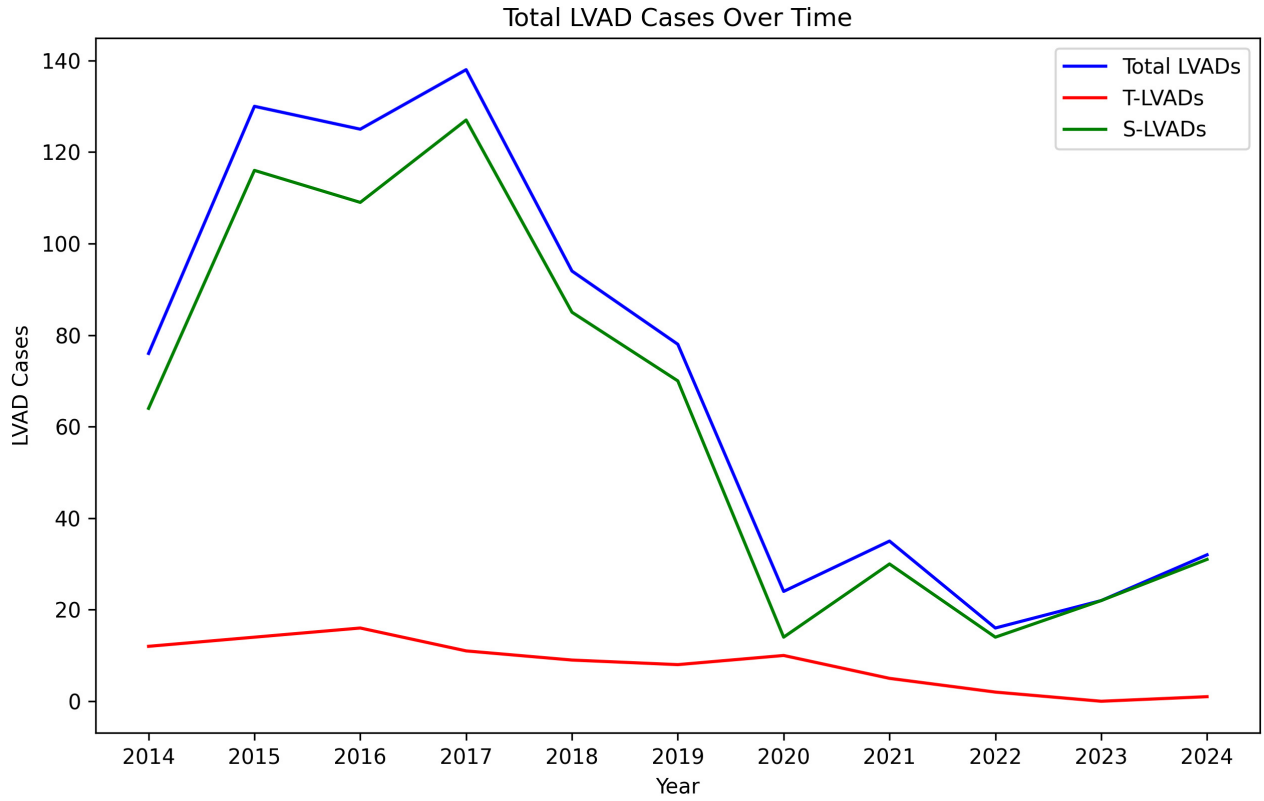

Fig. 2. Overall LVAD rate over time within VCSQI. There is a steady decline in the rate of LVAD implantation (blue), decreasing markedly between 2017–2018 (UNOS allocation change) and again between 2019–2020 (COVID-19 pandemic). T-LVAD cases remained relatively low throughout the study. Between 2018–2024, the rate of T-LVADs (red) declined slower than the rate of S-LVADs (green) (–1.7 cases/year vs. –9.2 cases/year, $p < 0.05$). VCSQI, Virginia Cardiac Services Quality Initiative.

ceived planned RVAD concomitantly with LVAD implantation [15,19,20]. Additionally, our study includes operations from 2014–2024 with inclusion of HMII, HM3 and HVAD devices. The smaller pump size of the HM3 may have facilitated a minimally invasive approach more than HMII and HVAD devices. Moreover, our findings should be interpreted within the context of the contemporary device landscape, in which HM3 implantation has almost universally supplanted the use of earlier-generation models. In this setting of near-exclusive utilization, the HM3's size advantages, higher initial cost, and potential for long-term cost savings may play a complex role in surgeon LVAD approach decisions [21].

Total hospitalization costs differed between T-LVAD and S-LVAD patients likely due to decreased postoperative atrial fibrillation, prolonged ventilation, and ICU and hospital LOS. Our T-LVAD patients had a median hospitalization cost that was $68,807 less than S-LVAD ($58,415 less

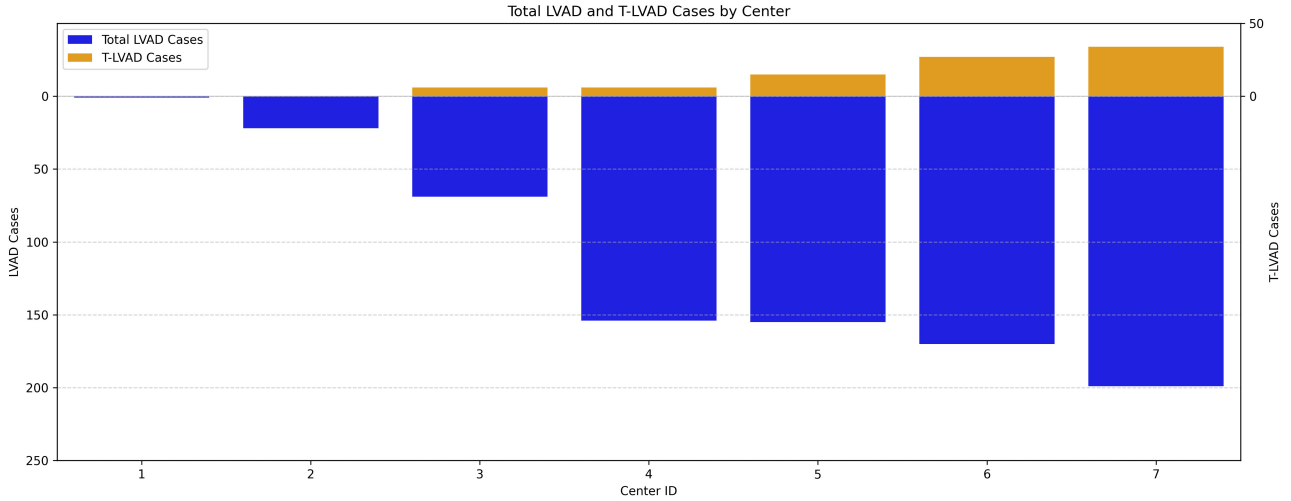

Fig. 3. Center level variation in T-LVAD (orange) vs. total LVAD cases (blue) across VCSQI. T-LVAD case volume was directly related to center LVAD volume. Three centers performed the majority of T-LVAD cases 86.4% (76/88); the remainder performed fewer T-LVAD cases demonstrating variation in institutional practices.

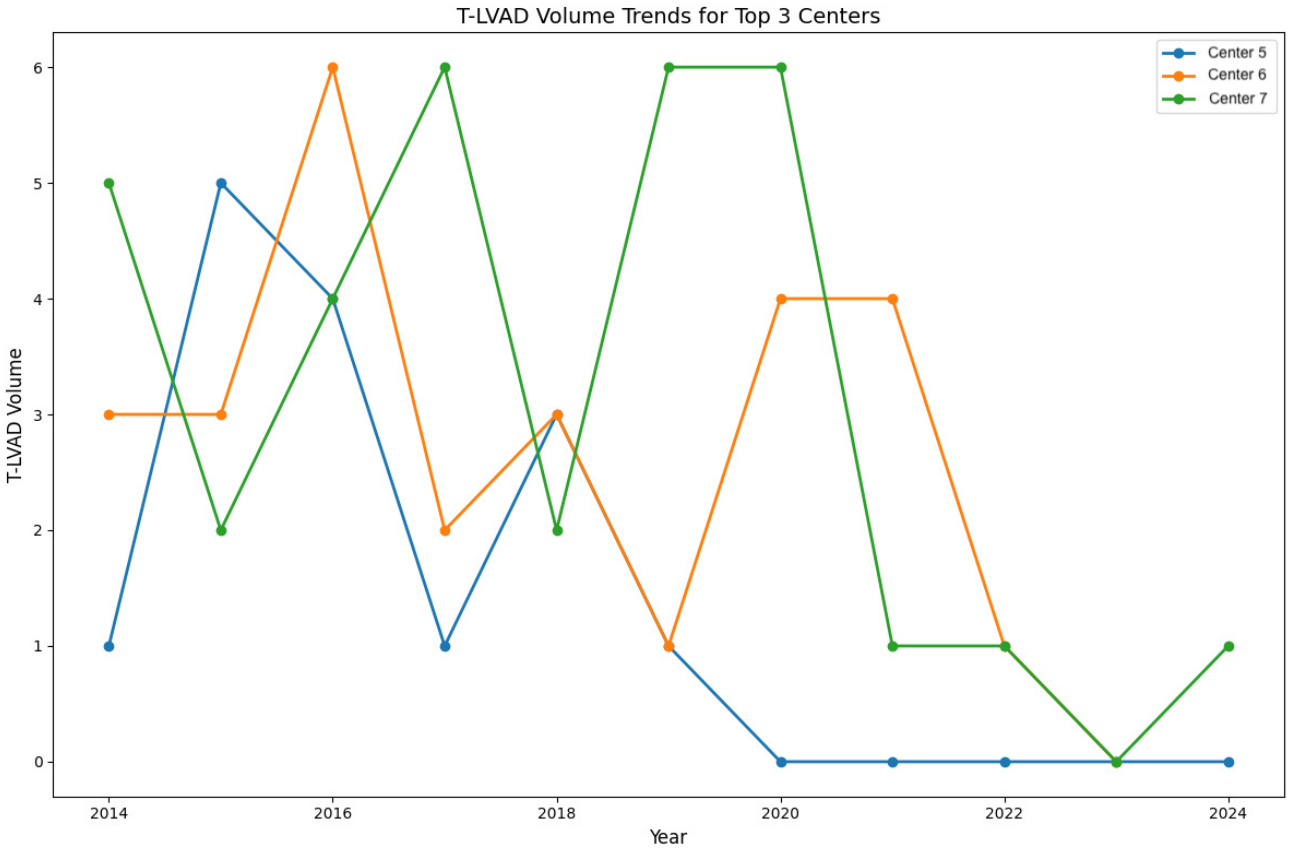

Fig. 4. T-LVAD volume trends from 2014–2024 for the top 3 volume centers in Virginia. T-LVAD case volume trended downward across all three centers throughout the study period.

after risk adjustment). This is congruent with Mokadam et al.'s [8] cost analysis of the LATERAL trial, finding a $56,385 reduction in mean total index hospitalization cost for T-LVAD patients versus a S-LVAD Medicare cohort [6]. This reduction in T-LVAD hospitalization cost persisted in sensitivity analysis when adjusting for concomitant procedures and their associated operative times [8].

Our study demonstrates a significant decrease in both T-LVAD and S-LVAD across a statewide collaborative with T-LVAD rates declining more slowly than those of S-LVAD. Explanation for the slower decline and center-level variation in T-LVAD is likely multifactorial (Fig. 4). First, the lower baseline rates of T-LVAD may have resulted in minimal change over time. Second, T-LVAD may have unique benefits for the high-risk population. As transplant allocation guidelines have shifted since 2018, more LVADs have been used as destination therapy in high-risk patients, potentially resulting in less decline in T-LVAD. While this study cannot assert causality, it highlights T-LVAD patterns and the need for optimized surgical selection in increasingly high-risk LVAD patients [5]. This is especially relevant in complex, redo LVAD patients that are no longer suitable Status 2 candidates for heart transplantation in the new allocation system.

As LVAD patients become increasingly high-risk, surgeons must thoughtfully consider their operative approach, balancing the potential reduction in perioperative morbidity, cost, and resource utilization of T-LVAD with the paucity of centers performing high volumes of this specialized technique and the maximum flexibility of S-LVAD to facilitate concomitant procedures.

Concomitant procedures were rare in our T-LVAD group, highlighting that, although in theory these concomitant procedures are possible via T-LVAD, patients are much less likely to receive them, possibly predisposing them to worse long-term outcomes. Still, concomitant procedures via T-LVAD are possible. Bjelic et al. [22] demonstrated the safety and feasibility of left atrial appendage ligation via T-LVAD while Quan et al. [23] occluded an atrial septal defect percutaneously in a T-LVAD patient. While T-LVAD may not permit concomitant or unplanned procedures as readily as S-LVAD, it remains an efficient and cost-effective option for selected patients [17].

5. Limitations

The retrospective and observational nature of our study precludes demonstration of causality and subjects it to selection bias. Our database restricts analysis to 30-days, limiting characterization of severe postoperative RHF, readmission, or additional long-term costs. Unfortunately, our dataset lacks surgeon-specific level data. Since a limited number of institutions performed LVAD insertions, such granularity would potentially reduce biases.

Although we risk-adjusted our groups to control for significant differences in preoperative characteristics, we were unable to control for variables not captured by our dataset, most notably, preoperative right ventricular dysfunction, STS risk scores, and Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) status of the patients. Additionally, many patients (154) were excluded due to a lack of data on ventricular assist device (VAD) type. Unfortunately, this was a limitation of our dataset since it relies on hospital-level reporting. We were unable to reliably identify which procedures were LVAD exchanges versus primary insertions. This potentially confounded the T-LVAD findings as exchange procedures are less invasive and therefore could be disproportionately represented as redo operations in the T-LVAD cohort. Our cost data represents an estimate based on cost-to-charge ratios and may differ from the true costs seen by institutions. Our cohort included only 8 T-LVAD HM3 implantations. As HM3 is the only commercially available LVAD at this time, our results may be less applicable to future patients. Still, overall characterization of T-LVAD usage across many centers illustrates which patients receive this approach and its prevalence across a diverse region. Finally, our results were from surgeons within seven different hospitals in Virginia and may not be widely generalizable.

6. Conclusion

In this multicenter retrospective cohort, T-LVAD did not impact rate of severe postoperative RHF or operative mortality but was associated with shorter ICU and postoperative LOS, and lower total cost. T-LVAD approach was negatively correlated with rates of concomitant procedures, likely reflective of the increased feasibility and ease of many concomitant procedures with an S-LVAD approach. This study investigates T-LVAD use across a statewide cohort of academic and non-academic centers, characterizing real-world implementation of this approach. Our findings highlight that, at this point, T- and S-LVAD patient cohorts represent largely different patient populations with distinct care needs. Further investigation should be undertaken with consideration of a prospective randomized controlled trial.

Abbreviations

ECMO, Extracorporeal membrane oxygenation; HM3 SWIFT, Implantation of the HeartMate 3 in Subjects with Heart Failure Using Surgical Techniques Other Than Full Median Sternotomy; LATERAL, Left anterior thoracotomy with upper hemisternotomy or right anterior thoracotomy; LOS, Length of stay; LVAD, Left ventricular assist device; OR, Operating room; RHF, Right heart failure; RVAD, Right ventricular assist device; S-LVAD, Sternotomy left ventricular assist device; STS, Society of Thoracic Surgeons; T-LVAD, Thoracotomy left ventricular assist device; VCSQI, Virginia Cardiac Services Quality Initiative.

Availability of Data and Materials

We cannot make our data publicly available as VCSQI does not allow that as part of their data use agreement.

Author Contributions

SN: Conceptualization, visualization, methodology, formal analysis, original draft writing, review and revisions,

funding acquisition. SY: Formal analysis, validation, investigation, software, writing, review and revisions. ES: Writing, review, formal analysis and editing. MW: Formal analysis, validation, investigation, review and revisions. AW: Validation, investigation, writing, review and revisions. RStrobel: Validation, investigation, writing, review and revisions. DW: Validation, investigation, writing, review and revisions. AS: Writing, review, formal analysis and editing. MQ: Data curation, resources, review and editing, supervision. MK: Data curation, resources, review and editing, supervision. RSingh: Data curation, resources, review and editing, supervision. AD: Conceptualization, resources, review and editing, supervision. MR: Conceptualization, resources, review and editing, supervision. LY: Conceptualization, resources, review and editing, supervision. NT: Conceptualization, resources, review and editing, supervision. JB: Conceptualization, resources, review and editing, supervision, project administration. All authors contributed to critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the ethical principles for medical research involving human subjects as outlined in the Declaration of Helsinki. The study and its protocol (#23305) received approval from the University of Virginia Institutional Review Board on 7/14/2021. Due to the entirely deidentified nature of the database, VCSQI, individual patient/participant consent is not required by our IRB approval.

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Conflicts of Interest

The authors declare no conflicts of interest. Nicholas R. Teman is serving as one of the Editorial Board members of this journal. We declare that Nicholas R. Teman had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Anton Sabashnikov.

Supplementary Material

Attached please find out **Supplementary Tables 1,2,3**. These tables expand upon the granularity of this study with multivariable logistic regression data for ICU hours (**Supplementary Table 1**), prolonged ventilation (**Supplementary Table 2**), and postoperative length of stay (**Supplementary Table 3**). Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/HSF51958.

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